Holtec International
Final Safety Analysis Report for the HI-STORM 100 Cask System*

by

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4.	4	IR	4/24/2012	314945	IR	7/26/2013	734752			
5.	5	KB	4/15/2012	685233	PS	7/26/2013	655200			
6.	6	VG	4/15/2012	547279	TH	7/27/2013	874739			
7.	7	VG	4/15/2012	574727	BK	7/27/2013	199808			
8.	8	VG	4/15/2012	227587	VG	7/27/2013	517656			
9.	9	VG	4/15/2012	951243	VG	7/27/2013	166560			
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11.	11	VG	4/15/2012	577089	IR	7/27/2013	730705			
12.	12	VG	4/24/2012	514303	IR	7/27/2013	419931			
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1.	1	TSM	8/8/08	628639	TSM	1/18/10	261682	TSM	2/13/10	47430
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6.	6	SPA	8/7/08	372258	SPA	1/18/10	809344	SPA	2/13/10	597586
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8.	8	TSM	8/8/08	85811	TSM	1/18/10	604039	TSM	2/13/10	155974
9.	9	TSM	8/6/08	782515	TSM	1/18/10	711656	TSM	2/13/10	132301
10.	10	SPA	8/8/08	218691	TSM	1/18/10	547146	TSM	2/13/10	218054
11.	11	ER	7/10/08	955026	TSM	1/18/10	205144	TSM	2/13/10	518926
12.	12	TSM	8/6/08	841345	TSM	1/18/10	262082	TSM	2/13/10	399215
13.	13	TSM	8/7/08	791174	TSM	1/18/10	664314	TSM	2/13/10	188554

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1.	1	LEH	4/10/06	679018	TSM	6/19/07	254841	TSM	2/7/08	251576
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4.	4	DMM	4/10/06	53264	DMM	6/20/07	839967	DMM	2/7/08	846793
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8.	8	JG	4/10/06	728141	JDG	6/19/07	540392	JDG	2/7/08	121986
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1.	1	BGU	8/22/02	330888	BGU	1/19/04	147902	SPA	5/26/05	921348
2.	2	BGU	9/17/02	181394	BGU	1/12/04	635397	SPA	5/26/05	306544
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7.	7	KC	8/22/02	181406	KC	3/3/04	538268	KC	5/26/05	618709
8.	8	JG	8/22/02	786745	JG	3/5/04	705490	JG	5/26/05	672421
9.	9	BGU	8/22/02	118193	BGU	1/12/04	305051	LEH	5/26/05	896141
10.	10	JG	8/22/02	504833	JG	2/17/04	384984	JG	5/26/05	511173
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Certificate of Compliance (1014) and Final Safety Analysis Report Matrix

HI-STORM 100 Cask Storage System Final Safety Analysis Report (FSAR) Revision	NRC Certificate of Compliance (CoC) 1014 Amendment No.
0	0
1	1
2*	1
3	2
4*	2
5	3
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8	6
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* - These Revisions incorporated changes made via ECO/72.48 process only.

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CHAPTER 1†: GENERAL DESCRIPTION

1.0 GENERAL INFORMATION

This Final Safety Analysis Report (FSAR) for Holtec International's HI-STORM 100 System is a compilation of information and analyses to support a United States Nuclear Regulatory Commission (NRC) licensing review as a spent nuclear fuel (SNF) dry storage cask under requirements specified in 10CFR72 [1.0.1]. This FSAR describes the basis for NRC approval and issuance of a Certificate of Compliance (C of C) for storage under provisions of 10CFR72, Subpart L, for the HI-STORM 100 System to safely store spent nuclear fuel (SNF) at an Independent Spent Fuel Storage Installation (ISFSI). This report has been prepared in the format and content suggested in NRC Regulatory Guide 3.61 [1.0.2] and NUREG-1536 Standard Review Plan for Dry Cask Storage Systems [1.0.3] to facilitate the NRC review process.

The purpose of this chapter is to provide a general description of the design features and storage capabilities of the HI-STORM 100 System, drawings of the structures, systems, and components important to safety, and the qualifications of the certificate holder. This report is also suitable for incorporation into a site-specific Safety Analysis Report, which may be submitted by an applicant for a site-specific 10 CFR 72 license to store SNF at an ISFSI or a facility similar in objective and scope. Table 1.0.1 contains a listing of the terminology and notation used in this FSAR.

To aid NRC review, additional tables and references have been added to facilitate the location of information requested by NUREG-1536. Table 1.0.2 provides a matrix of the topics in NUREG-1536 and Regulatory Guide 3.61, the corresponding 10CFR72 requirements, and a reference to the applicable FSAR section that addresses each topic.

The HI-STORM 100 FSAR is in full compliance with the intent of all regulatory requirements listed in Section III of each chapter of NUREG-1536. However, an exhaustive review of the provisions in NUREG-1536, particularly Section IV (Acceptance Criteria) and Section V (Review Procedures) has identified certain deviations from a verbatim compliance to all guidance. A list of all such items, along with a discussion of their intent and Holtec International's approach for compliance with the underlying intent is presented in Table 1.0.3 herein. Table 1.0.3 also contains the justification for the alternative method for compliance adopted in this FSAR. The justification may be in the form of a supporting analysis, established industry practice, or other NRC guidance documents. Each chapter in this FSAR provides a clear statement with respect to the extent of compliance to the NUREG-1536 provisions. Chapter 1 is in full compliance with NUREG-1536; no exceptions are taken.

† This chapter has been prepared in the format and section organization set forth in Regulatory Guide 3.61. However, the material content of this chapter also fulfills the requirements of NUREG-1536. Pagination and numbering of sections, figures, and tables are consistent with the convention set down in Chapter 1, Section 1.0, herein. Finally, all terms-of-art used in this chapter are consistent with the terminology of the glossary (Table 1.0.1) and component nomenclature of the Bill-of-Materials (Section 1.5).

The generic design basis and the corresponding safety analysis of the HI-STORM 100 System contained in this FSAR are intended to bound the SNF characteristics, design, conditions, and interfaces that exist in the vast majority of domestic power reactor sites and potential away-from-reactor storage sites in the contiguous United States. 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 basis and safety analysis documented herein. In accordance with 10CFR72, Subpart K, site-specific implementation of the generically certified HI-STORM 100 System requires that the licensee perform a site-specific evaluation, as defined in 10CFR72.212. The HI-STORM 100 System FSAR identifies a limited number of conditions that are necessarily 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 pad (including the embedment for anchored cask users) 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, land slides, and lightning protection.

- Determination that the physical and nucleonic characteristics and the condition of the SNF assemblies to be dry 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 8 and 9, and the technical specifications provided in 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.

The generic safety analyses contained in the HI-STORM 100 FSAR may be used as input and for guidance by the licensee in performing a 10CFR72.212 evaluation.

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 sequential number. Thus, for example, Figure 1.2.3 is the third figure in Section 1.2 of Chapter 1.

Revisions to this document are made on a section level basis. Complete sections have been replaced if any material in the section changed. The specific changes are noted with revision bars in the right margin. Figures are revised individually. Drawings are controlled separately within the Holtec QA program and have individual revision numbers. Bills-of-Material (BOMs) are considered separate drawings and are not necessarily at the same revision level as the drawing(s) to which they apply. If a drawing or BOM was revised in support of the current FSAR revision, that drawing/BOM is included in Section 1.5 at its latest revision level. Drawings and BOMs appearing in this FSAR may be revised between formal updates to the FSAR. Therefore, the revisions of drawings/BOMs in Section 1.5 may not be current.

Through revision 3 of this FSAR, discussions and specific analyses were presented that described and evaluated MPC designs called the MPC-24EF, MPC-32F, and MPC-68FF. These designs contained features required to classify them as secondary containments, permitting transportation of fuel debris under the auspices of 10 CFR 71, and were the only MPC designs allowed to be loaded with fuel debris. Recent changes to 10 CFR 71 have eliminated the need for secondary containment of fuel debris, so the non-F type MPCs (i.e., MPC-24E, MPC-32 and MPC-68) can now accept fuel debris. Any contents that used to require loading into an MPC-24EF, MPC-32F or MPC-68FF may therefore now be loaded in an MPC-24E, MPC-32 or MPC-68, respectively.

Supplements identified by a Roman numeral "I" (i.e. Chapter 1 and Supplement 1.I) have been inserted in the FSAR as placeholders for future use.

1.0.1 Engineering Change Orders

The changes authorized by the Holtec ECOs (with corresponding 10CFR72.48 evaluations, if applicable) listed in the following table are reflected in this Revision of the FSAR.

LIST OF ECO'S AND APPLICABLE 10CFR72.48 EVALUATIONS

Affected Item	ECO Number	72.48 Evaluation or Screening Number
MPC-68/68F/68FF/68M Basket	1021-111	N/A
MPC-24/24E/24EF Basket	1022-87	985
MPC-32 Basket	-	-
MPC Enclosure Vessel	1021-111,1022-87,1023-66 1021-112,1022-88,1023-67 1021-115,1022-90,1023-68	N/A 1007 N/A
HI-STORM Overpack	1024-152	984
HI-TRAC 100 and 100D Transfer Cask	1026-45R0, 1026- 45R1, 1026-45R2	1009
HI-TRAC 125 and 125D Transfer Cask	1025-64	983
General FSAR Changes	5014-201 5014-202 5014-203 5014-205 5014-206 5014-207 5014-208 5014-209 5014-210	988 1004 999 N/A 1007 1026 1027 N/A N/A

1.0.2 Design Compatibility of Licensed HI-STORM 100 System Components

Each of the licensed HI-STORM 100 System components (i.e., the MPC, overpack, and transfer cask), if fabricated in accordance with any of the approved CoC Amendments, may be used with one another provided an assessment is performed by the CoC holder that demonstrates design compatibility.

The following certified HI-TRAC transfer casks have been determined to have design compatibility and may be used with the MPCs and overpacks fabricated in accordance with the CoC #1014 amendments as listed in the table below:

HI-TRAC Design Compatibility			
HI-TRAC Model	Program Number	Serial Number	Applicable CoC Amendments
125	1025	001	0,1,2,3,4,5,6,7,8
125	1025	002	0,1,2,3,4,5,6,7,8
125D	1025	003	1,2,3,4,5,6,7,8
125D	1025	004	1,2,3,4,5,6,7,8
125D	1025	005	2,3,4,5,6,7,8
125D	1025	007	1,2,3,4,5,6,7,8
125D	1025	008	1,2,3,4,5,6,7,8
125D	1025	009	2,3,4,5,6,7,8
125D	1025	010	3,4,5,6,7,8
125D	1025	011	5,6,7,8
125D	1025	012	5,6,7,8
125D	1025	013	5,6,7,8
125D	1025	014	3,4,5,6,7,8
125D	1025	015	3,4,5,6,7,8
125D	1025	016	5,6,7,8
125D	1025	017	7,8
125D	1025	019	7,8
100	1026	001	0,1,2,3,4,5,6,7,8
100D	1026	003	2,3,4,5,6,7,8
100D	1026	004	2,3,4,5,6,7,8
100D	1026	005	2,3,4,5,6,7,8
100D	1026	006	2,3,4,5,6,7,8
100D Version IP1	1026	008	4
100D	1026	009	6,7,8

Table 1.0.1

TERMINOLOGY AND NOTATION

ALARA is an acronym for As Low As Reasonably Achievable.

Boral is a generic term to denote an aluminum-boron carbide cermet manufactured in accordance with U.S. Patent No. 4027377. The individual material supplier may use another trade name to refer to the same product.

Boral™ means Boral manufactured by AAR Advanced Structures.

BWR is an acronym for boiling water reactor.

C.G. is an acronym for center of gravity.

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.

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.

Cooling Time (or post-irradiation cooling time) for a spent fuel assembly is the time between reactor shutdown and the time the spent fuel assembly 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.

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) means a specially designed enclosure for damaged fuel or fuel debris which permits gaseous and liquid media to escape while minimizing dispersal of gross particulates.

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 FSAR, if operated and maintained in accordance with this FSAR.

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 FSAR serves as the Design Report for the HI-STORM 100 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 100 System. The FSAR serves as the Design Specification for the HI-STORM 100 System.

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 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.

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

HI-TRAC transfer cask or HI-TRAC means 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 overpack or HI-STAR storage/transportation overpack. The HI-TRAC shields the loaded MPC allowing loading operations to be performed while limiting radiation exposure to personnel. HI-TRAC is an acronym for **H**oltec **I**nternational **Tra**nsfer **C**ask. In this FSAR there are several HI-TRAC transfer casks, the 125-ton standard design HI-TRAC (HI-TRAC-125), the 125-ton dual-purpose lid design (HI-TRAC 125D), the 100-ton HI-TRAC (HI-TRAC-100), the 100-ton dual purpose lid design (HI-TRAC 100D). The 100-ton HI-TRAC is provided for use at sites with a maximum crane capacity of less than 125 tons. The term HI-TRAC is used as a generic term to refer to all HI-TRAC transfer cask designs, unless the discussion requires distinguishing among the designs. The HI-TRAC is equipped with a pair of lifting trunnions and the HI-TRAC 100 and HI-TRAC 125 designs also include pocket trunnions. The trunnions are used to lift and downend/upend the HI-TRAC with a loaded MPC.

HI-STORM overpack or storage overpack means the cask that receives and contains the sealed multi-purpose canisters containing spent nuclear fuel. It provides the gamma and neutron shielding, ventilation passages, missile protection, and protection against natural phenomena and accidents for the MPC. The term "overpack" as used in this FSAR refers to all overpack designs, including the standard design (HI-STORM 100) and two alternate designs (HI-STORM 100S and HI-STORM 100S Version B). The term "overpack" also applies to those overpacks designed for high seismic deployment (HI-STORM 100A or HI-STORM 100SA), unless otherwise clarified.

HI-STORM 100 System consists of any loaded MPC model placed within any design variant of the HI-STORM overpack.

Holtite™ is the trade name for all present and future neutron shielding materials formulated under Holtec International's R&D program dedicated to developing shielding materials for application in dry storage and transport systems. The Holtite development program is an ongoing experimentation effort to identify neutron shielding materials with enhanced shielding and temperature tolerance characteristics. Holtite-A™ is the first and only shielding material qualified under the Holtite R&D program. As such, the terms Holtite and Holtite-A may be used interchangeably throughout this FSAR.

Table 1.0.1 (continued)

TERMINOLOGY AND NOTATION

Holtite™-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).

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

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 (20 years).

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.

METCON™ is a trade name for the HI-STORM overpack. The trademark is derived from the **metal-con**crete 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.

Table 1.0.1 (continued)

TERMINOLOGY AND NOTATION

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 (MPC) means the sealed canister consisting of a honeycombed fuel basket for spent nuclear fuel storage, contained in a cylindrical canister shell (the MPC Enclosure Vessel). There are different MPCs with different fuel basket geometries for storing PWR or BWR fuel, but all MPCs have identical exterior diameters. The MPC is the confinement boundary for storage conditions.

MPC Transfer means transfer of the MPC between the overpack 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 overpack (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 Material is a generic term used in this FSAR to indicate any neutron absorber material qualified for use in the HI-STORM 100 System MPCs.

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), 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 distinct regions each with its own maximum allowable specific heat generation rate. Regionalized fuel loading does not apply to the MPC-68F model.

SAR is an acronym for Safety Analysis Report (10CFR71).

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.

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.

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

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.

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.

Table 1.0.2

HI-STORM 100 SYSTEM FSAR REGULATORY COMPLIANCE CROSS REFERENCE MATRIX

Regulatory Guide 3.61 Section and Content	Associated NUREG-1536 Review Criteria	Applicable 10CFR72 or 10CFR20 Requirement	HI-STORM FSAR
1. General Description			
1.1 Introduction	1.III.1 General Description & Operational Features	10CFR72.24(b)	1.1
1.2 General Description	1.III.1 General Description & Operational Features	10CFR72.24(b)	1.2
1.2.1 Cask Character-istics	1.III.1 General Description & Operational Features	10CFR72.24(b)	1.2.1
1.2.2 Operational Features	1.III.1 General Description & Operational Features	10CFR72.24(b)	1.2.2
1.2.3 Cask Contents	1.III.3 DCSS Contents	10CFR72.2(a)(1) 10CFR72.236(a)	1.2.3
1.3 Identification of Agents & Contractors	1.III.4 Qualification of the Applicant	10CFR72.24(j) 10CFR72.28(a)	1.3
1.4 Generic Cask Arrays	1.III.1 General Description & Operational Features	10CFR72.24(c)(3)	1.4
1.5 Supplemental Data	1.III.2 Drawings	10CFR72.24(c)(3)	1.5
NA	1.III.6 Consideration of Transport Requirements	10CFR72.230(b) 10CFR72.236(m)	1.1
NA	1.III.5 Quality Assurance	10CFR72.24(n)	1.3
2. Principal Design Criteria			
2.1 Spent Fuel To Be Stored	2.III.2.a Spent Fuel Specifications	10CFR72.2(a)(1) 10CFR72.236(a)	2.1
2.2 Design Criteria for Environmental Conditions and Natural Phenomena	2.III.2.b External Conditions, 2.III.3.b Structural, 2.III.3.c Thermal	10CFR72.122(b)	2.2
		10CFR72.122(c)	2.2.3.3, 2.2.3.10
		10CFR72.122(b)(1)	2.2
		10CFR72.122(b)(2)	2.2.3.11
		10CFR72.122(h)(1)	2.0
2.2.1 Tornado and Wind Loading	2.III.2.b External Conditions	10CFR72.122(b)(2)	2.2.3.5

Table 1.0.2 (continued)

HI-STORM 100 SYSTEM FSAR REGULATORY COMPLIANCE
CROSS REFERENCE MATRIX

Regulatory Guide 3.61 Section and Content	Associated NUREG-1536 Review Criteria	Applicable 10CFR72 or 10CFR20 Requirement	HI-STORM FSAR
2.2.2 Water Level (Flood)	2.III.2.b External Conditions 2.III.3.b Structural	10CFR72.122(b)(2)	2.2.3.6
2.2.3 Seismic	2.III.3.b Structural	10CFR72.102(f) 10CFR72.122(b)(2)	2.2.3.7
2.2.4 Snow and Ice	2.III.2.b External Conditions 2.III.3.b Structural	10CFR72.122(b)	2.2.1.6
2.2.5 Combined Load	2.III.3.b Structural	10CFR72.24(d) 10CFR72.122(b)(2)(ii)	2.2.7
NA	2.III.1 Structures, Systems, and Components Important to Safety	10CFR72.122(a) 10CFR72.24(c)(3)	2.2.4
NA	2.III.2 Design Criteria for Safety Protection Systems	10CFR72.236(g) 10CFR72.24(c)(1) 10CFR72.24(c)(2) 10CFR72.24(c)(4) 10CFR72.120(a) 10CFR72.236(b)	2.0, 2.2
NA	2.III.3.c Thermal	10CFR72.128(a)(4)	2.3.2.2, 4.0
NA	2.III.3f Operating Procedures	10CFR72.24(f) 10CFR72.128(a)(5)	10.0, 8.0
		10CFR72.236(h)	8.0
		10CFR72.24(1)(2)	1.2.1, 1.2.2
		10CFR72.236(1)	2.3.2.1
		10CFR72.24(e) 10CFR72.104(b)	10.0, 8.0
	2.III.3.g Acceptance Tests & Maintenance	10CFR72.122(1) 10CFR72.236(g) 10CFR72.122(f) 10CFR72.128(a)(1)	9.0
2.3 Safety Protection Systems	--	--	2.3

Table 1.0.2 (continued)

HI-STORM 100 SYSTEM FSAR REGULATORY COMPLIANCE CROSS REFERENCE MATRIX

Regulatory Guide 3.61 Section and Content	Associated NUREG-1536 Review Criteria	Applicable 10CFR72 or 10CFR20 Requirement	HI-STORM FSAR
2.3.1 General	--	--	2.3
2.3.2 Protection by Multiple Confinement Barriers and Systems	2.III.3.b Structural	10CFR72.236(1)	2.3.2.1
	2.III.3.c Thermal	10CFR72.236(f)	2.3.2.2
	2.III.3.d Shielding/ Confinement/ Radiation Protection	10CFR72.126(a) 10CFR72.128(a)(2)	2.3.5.2
		10CFR72.128(a)(3)	2.3.2.1
		10CFR72.236(d)	2.3.2.1, 2.3.5.2
		10CFR72.236(e)	2.3.2.1
2.3.3 Protection by Equipment & Instrument Selection	2.III.3.d Shielding/ Confinement/ Radiation Protection	10CFR72.122(h)(4) 10CFR72.122(i) 10CFR72.128(a)(1)	2.3.5
2.3.4 Nuclear Criticality Safety	2.III.3.e Criticality	10CFR72.124(a) 10CFR72.236(c) 10CFR72.124(b)	2.3.4, 6.0
2.3.5 Radiological Protection	2.III.3.d Shielding/ Confinement/ Radiation Protection	10CFR72.24(d) 10CFR72.104(a) 10CFR72.236(d)	10.4.1
		10CFR72.24(d) 10CFR72.106(b) 10CFR72.236(d)	10.4.2
		10CFR72.24(m)	2.3.2.1
2.3.6 Fire and Explosion Protection	2.III.3.b Structural	10CFR72.122(c)	2.3.6, 2.2.3.10
2.4 Decommissioning Considerations	2.III.3.h Decommissioning	10CFR72.24(f) 10CFR72.130 10CFR72.236(h)	2.4
	14.III.1 Design	10CFR72.130	2.4
	14.III.2 Cask Decontamination	10CFR72.236(i)	2.4

Table 1.0.2 (continued)

HI-STORM 100 SYSTEM FSAR REGULATORY COMPLIANCE CROSS REFERENCE MATRIX

Regulatory Guide 3.61 Section and Content	Associated NUREG-1536 Review Criteria	Applicable 10CFR72 or 10CFR20 Requirement	HI-STORM FSAR
	14.III.3 Financial Assurance & Record Keeping	10CFR72.30	(1)
	14.III.4 License Termination	10CFR72.54	(1)
3. Structural Evaluation			
3.1 Structural Design	3.III.1 SSC Important to Safety	10CFR72.24(c)(3) 10CFR72.24(c)(4)	3.1
	3.III.6 Concrete Structures	10CFR72.24(c)	3.1
3.2 Weights and Centers of Gravity	3.V.1.b.2 Structural Design Features	--	3.2
3.3 Mechanical Properties of Materials	3.V.1.c Structural Materials 3.V.2.c Structural Materials	10CFR72.24(c)(3)	3.3
NA	3.III.2 Radiation Shielding, Confinement, and Subcriticality	10CFR72.24(d) 10CFR72.124(a) 10CFR72.236(c) 10CFR72.236(d) 10CFR72.236(1)	3.4.4.3 3.4.7.3 3.4.10
NA	3.III.3 Ready Retrieval	10CFR72.122(f) 10CFR72.122(h) 10CFR72.122(l)	3.4.4.3
NA	3.III.4 Design-Basis Earthquake	10CFR72.24(c) 10CFR72.102(f)	3.4.7
NA	3.III.5 20 Year Minimum Design Length	10CFR72.24(c) 10CFR72.236(g)	3.4.11 3.4.12
3.4 General Standards for Casks	--	--	3.4
3.4.1 Chemical and Galvanic Reactions	3.V.1.b.2 Structural Design Features	--	3.4.1
3.4.2 Positive Closure	--	--	3.4.2

Table 1.0.2 (continued)

HI-STORM 100 SYSTEM FSAR REGULATORY COMPLIANCE CROSS REFERENCE MATRIX

Regulatory Guide 3.61 Section and Content	Associated NUREG-1536 Review Criteria	Applicable 10CFR72 or 10CFR20 Requirement	HI-STORM FSAR
3.4.3 Lifting Devices	3.V.1.ii(4)(a) Trunnions --	--	3.4.3
3.4.4 Heat	3.V.1.d Structural Analysis	10CFR72.24(d) 10CFR72.122(b)	3.4.4
3.4.5 Cold	3.V.1.d Structural Analysis	10CFR72.24(d) 10CFR72.122(b)	3.4.5
3.5 Fuel Rods	--	10CFR72.122(h)(1)	3.5
4. Thermal Evaluation			
4.1 Discussion	4.III Regulatory Requirements	10CFR72.24(c)(3) 10CFR72.128(a)(4) 10CFR72.236(f) 10CFR72.236(h)	4.1
4.2 Summary of Thermal Properties of Materials	4.V.4.b Material Properties	--	4.2
4.3 Specifications for Components	4.IV Acceptance Criteria ISG-11, Revision 3	10CFR72.122(h)(1)	4.3
4.4 Thermal Evaluation for Normal Conditions of Storage	4.IV Acceptance Criteria ISG-11, Revision 3	10CFR72.24(d) 10CFR72.236(g)	4.4, 4.5
NA	4.IV Acceptance Criteria	10CFR72.24(d) 10CFR72.122(c)	11.1, 11.2
4.5 Supplemental Data	4.V.6 Supplemental Info.	--	--
5. Shielding Evaluation			
5.1 Discussion and Results	--	10CFR72.104(a) 10CFR72.106(b)	5.1
5.2 Source Specification	5.V.2 Radiation Source Definition	--	5.2
5.2.1 Gamma Source	5.V.2.a Gamma Source	--	5.2.1, 5.2.3

Table 1.0.2 (continued)

HI-STORM 100 SYSTEM FSAR REGULATORY COMPLIANCE
CROSS REFERENCE MATRIX

Regulatory Guide 3.61 Section and Content	Associated NUREG-1536 Review Criteria	Applicable 10CFR72 or 10CFR20 Requirement	HI-STORM FSAR
5.2.2 Neutron Source	5.V.2.b Neutron Source	--	5.2.2, 5.2.3
5.3 Model Specification	5.V.3 Shielding Model Specification	--	5.3
5.3.1 Description of the Radial and Axial Shielding Configura-tions	5.V.3.a Configuration of the Shielding and Source	10CFR72.24(c)(3)	5.3.1
5.3.2 Shield Regional Densities	5.V.3.b Material Properties	10CFR72.24(c)(3)	5.3.2
5.4 Shielding Evaluation	5.V.4 Shielding Analysis	10CFR72.24(d) 10CFR72.104(a) 10CFR72.106(b) 10CFR72.128(a)(2) 10CFR72.236(d)	5.4
5.5 Supplemental Data	5.V.5 Supplemental Info.	--	Appendices 5.A, 5.B, and 5.C
6. Criticality Evaluation			
6.1 Discussion and Results	--	--	6.1
6.2 Spent Fuel Loading	6.V.2 Fuel Specification	--	6.1, 6.2
6.3 Model Specifications	6.V.3 Model Specification	--	6.3
6.3.1 Description of Calcula-tional Model	6.V.3.a Configuration	-- 10CFR72.124(b) 10CFR72.24(c)(3)	6.3.1

Table 1.0.2 (continued)

HI-STORM 100 SYSTEM FSAR REGULATORY COMPLIANCE CROSS REFERENCE MATRIX

Regulatory Guide 3.61 Section and Content	Associated NUREG-1536 Review Criteria	Applicable 10CFR72 or 10CFR20 Requirement	HI-STORM FSAR
6.3.2 Cask Regional Densities	6.V.3.b Material Properties	10CFR72.24(c)(3) 10CFR72.124(b) 10CFR72.236(g)	6.3.2
6.4 Criticality Calculations	6.V.4 Criticality Analysis	10CFR72.124	6.4
6.4.1 Calculational or Experimental Method	6.V.4.a Computer Programs and 6.V.4.b Multiplication Factor	10CFR72.124	6.4.1
6.4.2 Fuel Loading or Other Contents Loading Optimization	6.V.3.a Configuration	--	6.4.2, 6.3.3
6.4.3 Criticality Results	6.IV Acceptance Criteria	10CFR72.24(d) 10CFR72.124 10CFR72.236(c)	6.1, 6.2, 6.3.1, 6.3.2
6.5 Critical Benchmark Experiments	6.V.4.c Benchmark Comparisons	--	6.5, Appendix 6.A, 6.4.3
6.6 Supplemental Data	6.V.5 Supplemental Info.	--	Appendices 6.B,6.C, and 6.D
7. Confinement			
7.1 Confinement Boundary	7.III.1 Description of Structures, Systems and Components Important to Safety ISG-18	10CFR72.24(c)(3) 10CFR72.24(l)	7.0, 7.1
7.1.1 Confinement Vessel	7.III.2 Protection of Spent Fuel Cladding	10CFR72.122(h)(l)	7.1, 7.1.1
7.1.2 Confinement Penetrations	--	--	7.1.2
7.1.3 Seals and Welds	--	--	7.1.3

Table 1.0.2 (continued)

HI-STORM 100 SYSTEM FSAR REGULATORY COMPLIANCE CROSS REFERENCE MATRIX

Regulatory Guide 3.61 Section and Content	Associated NUREG-1536 Review Criteria	Applicable 10CFR72 or 10CFR20 Requirement	HI-STORM FSAR
7.1.4 Closure	7.III.3 Redundant Sealing	10CFR72.236(e)	7.1.1, 7.1.4
7.2 Requirements for Normal Conditions of Storage	7.III.7 Evaluation of Confinement System ISG-18	10CFR72.24(d) 10CFR72.236(1)	7.1
7.2.1 Release of Radioactive Material	7.III.6 Release of Nuclides to the Environment	10CFR72.24(1)(1)	7. 1
	7.III.4 Monitoring of Confinement System	10CFR72.122(h)(4) 10CFR72.128(a)(l)	7.1.4
	7.III.5 Instrumentation	10CFR72.24(l) 10CFR72.122(i)	7.1.4
	7.III.8 Annual Dose ISG-18	10CFR72.104(a)	7.1
7.2.2 Pressurization of Confinement Vessel	--	--	7.1
7.3 Confinement Requirements for Hypothetical Accident Conditions	7.III.7 Evaluation of Confinement System ISG-18	10CFR72.24(d) 10CFR72.122(b) 10CFR72.236(l)	7.1
7.3.1 Fission Gas Products	--	--	7.1
7.3.2 Release of Contents	ISG-18	--	7.1
NA	--	10CFR72.106(b)	7.1
7.4 Supplemental Data	7.V Supplemental Info.	--	--
8. Operating Procedures			
8.1 Procedures for Loading the Cask	8.III.1 Develop Operating Procedures	10CFR72.40(a)(5)	8.1 to 8.5
	8.III.2 Operational Restrictions for ALARA	10CFR72.24(e) 10CFR72.104(b)	8.1.5

Table 1.0.2 (continued)

HI-STORM 100 SYSTEM FSAR REGULATORY COMPLIANCE
CROSS REFERENCE MATRIX

Regulatory Guide 3.61 Section and Content	Associated NUREG-1536 Review Criteria	Applicable 10CFR72 or 10CFR20 Requirement	HI-STORM FSAR
	8.III.3 Radioactive Effluent Control	10CFR72.24(1)(2)	8.1.5, 8.5.2
	8.III.4 Written Procedures	10CFR72.212(b)(9)	8.0
	8.III.5 Establish Written Procedures and Tests	10CFR72.234(f)	8.0 Introduction
	8.III.6 Wet or Dry Loading and Unloading Compatibility	10CFR72.236(h)	8.0 Introduction
	8.III.7 Cask Design to Facilitate Decon	10CFR72.236(i)	8.1, 8.3
8.2 Procedures for Unloading the Cask	8.III.1 Develop Operating Procedures	10CFR72.40(a)(5)	8.3
	8.III.2 Operational Restrictions for ALARA	10CFR72.24(e) 10CFR72.104(b)	8.3
	8.III.3 Radioactive Effluent Control	10CFR72.24(1)(2)	8.3.3
	8.III.4 Written Procedures	10CFR72.212(b)(9)	8.0
	8.III.5 Establish Written Procedures and Tests	10CFR72.234(f)	8.0
	8.III.6 Wet or Dry Loading and Unloading Compatibility	10CFR72.236(h)	8.0
	8.III.8 Ready Retrieval	10CFR72.122(1)	8.3
8.3 Preparation of the Cask	--	--	8.3.2
8.4 Supplemental Data	--	--	Tables 8.1.1 to 8.1.10
NA	8.III.9 Design to Minimize Radwaste	10CFR72.24(f) 10CFR72.128(a)(5)	8.1, 8.3
	8.III.10 SSCs Permit Inspection, Maintenance, and Testing	10CFR72.122(f)	Table 8.1.6
9. Acceptance Criteria and Maintenance Program			
9.1 Acceptance Criteria	9.III.1.a Preoperational Testing & Initial Operations	10CFR72.24(p)	8.1, 9.1

Table 1.0.2 (continued)

HI-STORM 100 SYSTEM FSAR REGULATORY COMPLIANCE CROSS REFERENCE MATRIX

Regulatory Guide 3.61 Section and Content	Associated NUREG-1536 Review Criteria	Applicable 10CFR72 or 10CFR20 Requirement	HI-STORM FSAR
	9.III.1.c SSCs Tested and Maintained to Appropriate Quality Standards	10CFR72.24(c) 10CFR72.122(a)	9.1
	9.III.1.d Test Program	10CFR72.162	9.1
	9.III.1.e Appropriate Tests	10CFR72.236(1)	9.1
	9.III.1.f Inspection for Cracks, Pinholes, Voids and Defects	10CFR72.236(j)	9.1
	9.III.1.g Provisions that Permit Commission Tests	10CFR72.232(b)	9.1(2)
9.2 Maintenance Program	9.III.1.b Maintenance	10CFR72.236(g)	9.2
	9.III.1.c SSCs Tested and Maintained to Appropriate Quality Standards	10CFR72.122(f) 10CFR72.128(a)(1)	9.2
	9.III.1.h Records of Maintenance	10CFR72.212(b)(8)	9.2
NA	9.III.2 Resolution of Issues Concerning Adequacy of Reliability	10CFR72.24(i)	(3)
	9.III.1.d Submit Pre-Op Test Results to NRC	10CFR72.82(e)	(4)
	9.III.1.i Casks Conspicuously and Durably Marked	10CFR72.236(k)	9.1.7, 9.1.1.(12)
	9.III.3 Cask Identification		
10. Radiation Protection			
10.1 Ensuring that Occupational Exposures are as Low as Reasonably Achievable (ALARA)	10.III.4 ALARA	10CFR20.1101 10CFR72.24(e) 10CFR72.104(b) 10CFR72.126(a)	10.1
10.2 Radiation Protection Design Features	10.V.1.b Design Features	10CFR72.126(a)(6)	10.2

Table 1.0.2 (continued)

HI-STORM 100 SYSTEM FSAR REGULATORY COMPLIANCE CROSS REFERENCE MATRIX

Regulatory Guide 3.61 Section and Content	Associated NUREG-1536 Review Criteria	Applicable 10CFR72 or 10CFR20 Requirement	HI-STORM FSAR
10.3 Estimated Onsite Collective Dose Assessment	10.III.2 Occupational Exposures	10CFR20.1201 10CFR20.1207 10CFR20.1208 10CFR20.1301	10.3
N/A	10.III.3 Public Exposure	10CFR72.104 10CFR72.106	10.4
	10.III.1 Effluents and Direct Radiation	10CFR72.104	
11. Accident Analyses			
11.1 Off-Normal Operations	11.III.2 Meet Dose Limits for Anticipated Events	10CFR72.24(d) 10CFR72.104(a) 10CFR72.236(d)	11.1
	11.III.4 Maintain Subcritical Condition	10CFR72.124(a) 10CFR72.236(c)	11.1
	11.III.7 Instrumentation and Control for Off-Normal Condition	10CFR72.122(i)	11.1
11.2 Accidents	11.III.1 SSCs Important to Safety Designed for Accidents	10CFR72.24(d)(2) 10CFR72.122b(2) 10CFR72.122b(3) 10CFR72.122(d) 10CFR72.122(g)	11.2
	11.III.5 Maintain Confinement for Accident	10CFR72.236(1)	11.2
	11.III.4 Maintain Subcritical Condition	10CFR72.124(a) 10CFR72.236(c)	11.2, 6.0
	11.III.3 Meet Dose Limits for Accidents	10CFR72.24(d)(2) 10CFR72.24(m) 10CFR72.106(b)	11.2, 5.1.2, 7.3

Table 1.0.2 (continued)

HI-STORM 100 SYSTEM FSAR REGULATORY COMPLIANCE CROSS REFERENCE MATRIX

Regulatory Guide 3.61 Section and Content	Associated NUREG-1536 Review Criteria	Applicable 10CFR72 or 10CFR20 Requirement	HI-STORM FSAR
	11.III.6 Retrieval	10CFR72.122(l)	8.3
	11.III.7 Instrumentation and Control for Accident Conditions	10CFR72.122(i)	(5)
NA	11.III.8 Confinement Monitoring	10CFR72.122h(4)	7.1.4
12. Operating Controls and Limits			
12.1 Proposed Operating Controls and Limits	--	10CFR72.44(c)	12.0
	12.III.1.e Administrative Controls	10CFR72.44(c)(5)	12.0
12.2 Development of Operating Controls and Limits	12.III.1 General Requirement for Technical Specifications	10CFR72.24(g) 10CFR72.26 10CFR72.44(c) 10CFR72 Subpart E 10CFR72 Subpart F	12.0
12.2.1 Functional and Operating Limits, Monitoring Instruments, and Limiting Control Settings	12.III.1.a Functional/ Operating Units, Monitoring Instruments and Limiting Controls	10CFR72.44(c)(1)	Appendix 12.A
12.2.2 Limiting Conditions for Operation	12.III.1.b Limiting Controls	10CFR72.44(c)(2)	Appendix 12.A
	12.III.2.a Type of Spent Fuel	10CFR72.236(a)	Appendix 12.A
	12.III.2.b Enrichment		
	12.III.2.c Burnup		
	12.III.2.d Minimum Acceptance Cooling Time		
	12.III.2.f Maximum Spent Fuel Loading Limit		
	12.III.2g Weights and Dimensions		
	12.III.2.h Condition of Spent Fuel		
	12.III.2e Maximum Heat Dissipation	10CFR72.236(a)	Appendix 12.A

Table 1.0.2 (continued)

HI-STORM 100 SYSTEM FSAR REGULATORY COMPLIANCE CROSS REFERENCE MATRIX

Regulatory Guide 3.61 Section and Content	Associated NUREG-1536 Review Criteria	Applicable 10CFR72 or 10CFR20 Requirement	HI-STORM FSAR
	12.III.2.i Inerting Atmosphere Requirements	10CFR72.236(a)	Appendix 12.A
12.2.3 Surveillance Specifications	12.III.1.c Surveillance Requirements	10CFR72.44(c)(3)	Chapter 12
12.2.4 Design Features	12.III.1.d Design Features	10CFR72.44(c)(4)	Chapter 12
12.2.4 Suggested Format for Operating Controls and Limits	--	--	Appendix 12.A
NA	12.III.2 SSC Design Bases and Criteria	10CFR72.236(b)	2.0
NA	12.III.2 Criticality Control	10CFR72.236(c)	2.3.4, 6.0
NA	12.III.2 Shielding and Confinement	10CFR20 10CFR72.236(d)	2.3.5, 7.0, 5.0, 10.0
NA	12.III.2 Redundant Sealing	10CFR72.236(e)	7.1, 2.3.2
NA	12.III.2 Passive Heat Removal	10CFR72.236(f)	2.3.2.2, 4.0
NA	12.III.2 20 Year Storage and Maintenance	10CFR72.236(g)	1.2.1.5, 9.0, 3.4.10, 3.4.11
NA	12.III.2 Decontamination	10CFR72.236(i)	8.0, 10.1
NA	12.III.2 Wet or Dry Loading	10CFR72.236(h)	8.0
NA	12.III.2 Confinement Effectiveness	10CFR72.236(j)	9.0
NA	12.III.2 Evaluation for Confinement	10CFR72.236(l)	7.1, 7.2, 9.0
13. Quality Assurance			
13.1 Quality Assurance	13.III Regulatory Requirements	10CFR72.24(n) 10CFR72.140(d)	13.0
	13.IV Acceptance Criteria	10CFR72, Subpart G	

Table 1.0.2 (continued)

HI-STORM 100 SYSTEM FSAR REGULATORY COMPLIANCE CROSS REFERENCE MATRIX

Notes:

(1) The stated requirement is the responsibility of the licensee (i.e., utility) as part of the ISFSI pad and is therefore not addressed in this application.

(2) It is assumed that approval of the FSAR by the NRC is the basis for the Commission's acceptance of the tests defined in Chapter 9.

(3) Not applicable to HI-STORM 100 System. The functional adequacy of all important to safety components is demonstrated by analyses.

(4) The stated requirement is the responsibility of licensee (i.e., utility) as part of the ISFSI and is therefore not addressed in this application.

(5) The stated requirement is not applicable to the HI-STORM 100 System. No monitoring is required for accident conditions.

"—" There is no corresponding NUREG-1536 criteria, no applicable 10CFR72 or 10CFR20 regulatory requirement, or the item is not addressed in the FSAR.

"NA" There is no Regulatory Guide 3.61 section that corresponds to the NUREG-1536, 10CFR72, or 10CFR20 requirement being addressed.

Table 1.0.3

HI-STORM 100 SYSTEM FSAR CLARIFICATIONS AND EXCEPTIONS TO NUREG-1536

NUREG-1536 Guidance	Alternate Method to Meet NUREG-1536 Intent	Justification
2.V.2.(b)(1) "The NRC accepts as the maximum and minimum "normal" temperatures the highest and lowest ambient temperatures recorded in each year, averaged over the years of record."	Exception: Section 2.2.1.4 for environmental temperatures utilizes an upper bounding value of 80°F on the annual average ambient temperatures for the United States.	The 80°F temperature set forth in Table 2.2.2 is greater than the annual average ambient temperature at any location in the continental United States. Inasmuch as the primary effect of the environmental temperature is on the computed fuel cladding temperature to establish long-term fuel cladding integrity, the annual average ambient temperature for each ISFSI site should be below 80°F. The large thermal inertia of the HI-STORM 100 System ensures that the daily fluctuations in temperatures do not affect the temperatures of the system. Additionally, the 80°F ambient temperature is combined with insolation in accordance with 10CFR71.71 averaged over 24 hours.
2.V.2.(b)(3)(f) "10CFR Part 72 identifies several other natural phenomena events (including seiche, tsunami, and hurricane) that should be addressed for spent fuel storage."	Clarification: A site-specific safety analysis of the effects of seiche, tsunami, and hurricane on the HI-STORM 100 System must be performed prior to use if these events are applicable to the site.	In accordance with NUREG-1536, 2.V.(b)(3)(f), if seiche, tsunami, and hurricane are not addressed in the SAR and they prove to be applicable to the site, a safety analysis is required prior to approval for use of the DCSS under either a site specific, or general license.

HI-STORM 100 SYSTEM FSAR CLARIFICATIONS AND EXCEPTIONS TO NUREG-1536

NUREG-1536 Guidance	Alternate Method to Meet NUREG-1536 Intent	Justification
3.V.1.d.i.(2)(a), page 3-11, "Drops with the axis generally vertical should be analyzed for both the conditions of a flush impact and an initial impact at a corner of the cask..."	Clarification: As stated in NUREG-1536, 3.V.(d), page 3-11, "Generally, applicants establish the design basis in terms of the maximum height to which the cask is lifted outside the spent fuel building, or the maximum deceleration that the cask could experience in a drop." The maximum deceleration for a corner drop is specified as 45g's for the HI-STORM overpack. No carry height limit is specified for the corner drop.	In Chapter 3, the MPC and HI-STORM overpack are evaluated under a 45g radial loading. A 45g axial loading on the MPC is bounded by the analysis presented in the HI-STAR FSAR, Docket 72-1008, under a 60g loading, and is not repeated in this FSAR. In Chapter 3, the HI-STORM overpack is evaluated under a 45g axial loading. Therefore, the HI-STORM overpack and MPC are qualified for a 45g loading as a result of a corner drop. Depending on the design of the lifting device, the type of rigging used, the administrative vertical carry height limit, and the stiffness of the impacted surface, site-specific analyses may be required to demonstrate that the deceleration limit of 45g's is not exceeded.
3.V.2.b.i.(1), Page 3-19, Para. 1, "All concrete used in storage cask system ISFSIs, and subject to NRC review, should be reinforced..." 3.V.2.b.i.(2)(b), Page 3-20, Para. 1, "The NRC accepts the use of ACI 349 for the design, material selection and specification, and construction of all reinforced concrete structures that are not addressed within the scope of ACI 359". 3.V.2.c.i, Page 3-22, Para. 3, "Materials and material properties used for the design and construction of reinforced concrete structures important to safety but not within the scope of	Exception: The HI-STORM overpack concrete is not reinforced. However, ACI 349 [1.0.4] is used as guidance for the material selection and specification, and placement of the plain concrete. Appendix 1.D provides the relevant sections of ACI 349 applicable to the plain concrete in the overpack, including clarifications on implementation of this code. ACI 318 [1.0.5] is used for the calculation of the compressive strength of the plain concrete.	Concrete is provided in the HI-STORM overpack primarily for the purpose of radiation shielding during normal operations. During lifting and handling operations and under certain accident conditions, the compressive strength of the concrete (which is not impaired by the absence of reinforcement) is utilized. However, since the structural reliance under loadings which produce section flexure and tension is entirely on the steel structure of the overpack, reinforcement in the concrete will serve no useful purpose. To ensure the quality of the shielding concrete, all relevant provisions of ACI 349 are imposed as clarified in Appendix 1.D. The temperature limits for normal conditions are per Paragraph A.4.3 of Appendix A to ACI 349 and temperature limits for

Table 1.0.3 (continued)

HI-STORM 100 SYSTEM FSAR CLARIFICATIONS AND EXCEPTIONS TO NUREG-1536

NUREG-1536 Guidance	Alternate Method to Meet NUREG-1536 Intent	Justification
ACI 359 should comply with the requirements of ACI 349".		off-normal and accident conditions are per Paragraph A.4.2 of Appendix A to ACI 349. Finally, the Fort St. Vrain ISFSI (Docket No. 72-9) also utilized plain concrete for shielding purposes, which is important to safety.
3.V.3.b.i.(2), Page 3-29, Para. 1, "The NRC accepts the use of ANSI/ANS-57.9 (together with the codes and standards cited therein) as the basic reference for ISFSI structures important to safety that are not designed in accordance with Section III of the ASME B&PV Code."	Clarification: The HI-STORM overpack steel structure is designed in accordance with the ASME B&PV Code, Section III, Subsection NF, Class 3. Any exceptions to the Code are listed in Table 2.2.15.	The overpack structure is a steel weldment consisting of "plate and shell type" members. As such, it is appropriate to design the structure to Section III, Class 3 of Subsection NF. The very same approach has been used in the structural evaluation of the "intermediate shells" in the HI-STAR 100 overpack (Docket Number 72-1008) previously reviewed and approved by the USNRC.
4.IV.5, Page 4-2 "for each fuel type proposed for storage, the DCSS should ensure a very low probability (e.g., 0.5 percent per fuel rod) of cladding breach during long-term storage." 4.IV.1, Page 4-3, Para. 1 "the staff should verify that cladding temperatures for each fuel type proposed for storage will be below the expected damage thresholds for normal conditions of storage." 4.IV.1, Page 4-3, Para. 2 "fuel cladding limits for each fuel type should be defined in the SAR with thermal restrictions in the DCSS technical specifications."	Clarification: As described in Section 4.3, all fuel array types authorized for storage are assigned a single peak fuel cladding temperature limit.	As described in Section 4.3, all fuel array types authorized for storage have been evaluated for the peak normal fuel cladding temperature limit of 400°C.

Table 1.0.3 (continued)

HI-STORM 100 SYSTEM FSAR CLARIFICATIONS AND EXCEPTIONS TO NUREG-1536

NUREG-1536 Guidance	Alternate Method to Meet NUREG-1536 Intent	Justification
4.V.1, Page 4-3, Para. 4 "the applicant should verify that these cladding temperature limits are appropriate for all fuel types proposed for storage, and that the fuel cladding temperatures will remain below the limit for facility operations (e.g., fuel transfer) and the worst-case credible accident."		
4.V.4.a, Page 4-6, Para. 6 "the basket wall temperature of the hottest assembly can then be used to determine the peak rod temperature of the hottest assembly using the Wooten-Epstein correlation."	Clarification: As discussed in Section 4.4, conservative maximum fuel temperatures are obtained directly from the cask thermal analysis. The peak fuel cladding temperatures are then used to determine the corresponding peak basket wall temperatures using a finite-element based model.	The finite-element based thermal conductivity is greater than a Wooten-Epstein based value. This larger thermal conductivity minimizes the fuel-to-basket temperature difference. Since the basket temperature is less than the fuel temperature, minimizing the temperature difference conservatively maximizes the basket wall temperature.
4.V.4.b, Page 4-7, Para. 2 "high burnup effects should also be considered in determining the fuel region effective thermal conductivity."	Exception: All calculations of fuel assembly effective thermal conductivities use nominal fuel design dimensions, neglecting wall thinning associated with high burnup.	The calculated effective thermal conductivities based on nominal design fuel dimensions have been compared with available literature values [1.0.6] and are demonstrated to be conservative.
4.V.4.c, Page 4-7, Para. 5 "a heat balance on the surface of the cask should be given and the results presented."	Clarification: No additional heat balance is performed or provided.	The FLUENT computational fluid dynamics program used to perform evaluations of the HI-STORM Overpack and HI-TRAC transfer cask, which uses a discretized numerical solution algorithm, enforces an energy balance on all discretized volumes throughout the computational domain. This solution method,

Table 1.0.3 (continued)

HI-STORM 100 SYSTEM FSAR CLARIFICATIONS AND EXCEPTIONS TO NUREG-1536

NUREG-1536 Guidance	Alternate Method to Meet NUREG-1536 Intent	Justification
		therefore, ensures a heat balance at the surface of the cask.
4.V.5.a, Page 4-8, Para. 2 "the SAR should include input and output file listings for the thermal evaluations."	Exception: No input or output file listings are provided in Chapter 4.	A complete set of computer program input and output files would be in excess of three hundred pages. All computer files are considered proprietary because they provide details of the design and analysis methods. In order to minimize the amount of proprietary information in the FSAR, computer files are provided in the proprietary calculation packages.
4.V.5.c, Page 4-10, Para. 3 "free volume calculations should account for thermal expansion of the cask internal components and the fuel when subjected to accident temperatures.	Exception: All free volume calculations use nominal confinement boundary dimensions, but the volume occupied by the fuel assemblies is calculated using maximum weights and minimum densities.	Calculating the volume occupied by the fuel assemblies using maximum weights and minimum densities conservatively overpredicts the volume occupied by the fuel and correspondingly underpredicts the remaining free volume.

HI-STORM 100 SYSTEM FSAR CLARIFICATIONS AND EXCEPTIONS TO NUREG-1536

NUREG-1536 Guidance	Alternate Method to Meet NUREG-1536 Intent	Justification
7.V.4 "Confinement Analysis. Review the applicant's confinement analysis and the resulting annual dose at the controlled area boundary."	Exception: No confinement analysis is performed and no effluent dose at the controlled area boundary is calculated.	The MPC uses redundant closures to assure that there is no release of radioactive materials under all credible conditions. Analyses presented in Chapters 3 and 11 demonstrate that the confinement boundary does not degrade under all normal, off-normal, and accident conditions. Multiple inspection methods are used to verify the integrity of the confinement boundary (e.g.,non-destructive examinations and pressure testing). Helium leakage testing of the MPC base metals (shell, baseplate, and MPC lid) and MPC shell to baseplate and shell to shell welds is performed on the unloaded MPC. Pursuant to ISG-18, the Holtec MPC is constructed in a manner that supports leakage from the confinement boundary being non-credible. Therefore, no confinement analysis is required.
9.V.1.a, Page 9-4, Para. 4 "Acceptance criteria should be defined in accordance with NB/NC-5330, "Ultrasonic Acceptance Standards"."	Clarification: Section 9.1.1.1 and the Design Drawings specify that the ASME Code, Section III, Subsection NB, Article NB-5332 will be used for the acceptance criteria for the volumetric examination of the MPC lid-to-shell weld.	In accordance with the first line on page 9-4, the NRC endorses the use of "...appropriate acceptance criteria as defined by either the ASME code, or an alternative approach..." The ASME Code, Section III, Subsection NB, Paragraph NB-5332 is appropriate acceptance criteria for pre-service examination.

Table 1.0.3 (continued)

HI-STORM 100 SYSTEM FSAR CLARIFICATIONS AND EXCEPTIONS TO NUREG-1536

NUREG-1536 Guidance	Alternate Method to Meet NUREG-1536 Intent	Justification
9.V.1.d, Para. 1 "Tests of the effectiveness of both the gamma and neutron shielding may be required if, for example, the cask contains a poured lead shield or a special neutron absorbing material."	Exception: Subsection 9.1.5 describes the control of special processes, such as neutron shield material installation, to be performed in lieu of scanning or probing with neutron sources.	The dimensional compliance of all shielding cavities is verified by inspection to design drawing requirements prior to shield installation. The Holtite-A shield material is installed in accordance with written, approved, and qualified special process procedures. The composition of the Holtite-A is confirmed by inspection and tests prior to first use. Following the first loading for the HI-TRAC transfer cask and each HI-STORM overpack, a shield effectiveness test is performed in accordance with written approved procedures, as specified in Section 9.1.
13.III, " the application must include, at a minimum, a description that satisfies the requirements of 10 CFR Part 72, Subpart G, 'Quality Assurance'..."	Exception: Section 13.0 incorporates the NRC-approved Holtec International Quality Assurance Program Manual by reference rather than describing the Holtec QA program in detail.	The NRC has approved Revision 13 of the Holtec Quality Assurance Program Manual under 10 CFR 71 (NRC QA Program Approval for Radioactive Material Packages No. 0784, Rev. 3). Pursuant to 10 CFR 72.140(d), Holtec will apply this QA program to all important-to-safety dry storage cask activities. Incorporating the Holtec QA Program Manual by reference eliminates duplicate documentation.

1.1 INTRODUCTION

HI-STORM 100 (acronym for Holtec International Storage and Transfer Operation Reinforced Module) is a spent nuclear fuel storage system designed to be in full compliance with the requirements of 10CFR72. The annex "100" is a model number designation which denotes a system weighing over 100 tons. The HI-STORM 100 System consists of a sealed metallic canister, herein abbreviated as the "MPC", contained within an overpack. Its design features are intended to simplify and reduce on-site SNF loading, handling, and monitoring operations, and to provide for radiological protection and maintenance of structural and thermal safety margins.

The HI-STORM 100S and HI-STORM 100S Version B overpack designs are variants of the HI-STORM 100 overpack design and have their own drawings in Section 1.5. The "S" suffix indicates an enhanced overpack design, as described later in this section. "Version B" indicates an enhanced HI-STORM 100S overpack design. The HI-STORM 100S and 100S Version B accept the same MPCs and fuel types as the HI-STORM 100 overpack and the basic structural, shielding, and thermal-hydraulic characteristics remain unchanged. Hereafter in this FSAR reference to HI-STORM 100 System or the HI-STORM overpack is construed to apply to the HI-STORM 100, the HI-STORM 100S, and the HI-STORM 100S Version B. Where necessary, the text distinguishes among the three overpack designs. See Figures 1.1.1A and 1.1.3A for pictorial views of the HI-STORM 100S overpack design. See Figures 1.1.1B and 1.1.3B for pictorial views of the HI-STORM 100S Version B design.

The HI-STORM 100A overpack is a variant of two of the three HI-STORM 100 System overpack designs and is specially outfitted with an extended baseplate and gussets to enable the overpack to be anchored to the ISFSI pad in high seismic applications. In the following, the modified structure of the HI-STORM 100A, in each of four quadrants, is denoted as a "sector lug." The HI-STORM 100A anchor design is applicable to the HI-STORM 100S overpack design, in which case the assembly would be named HI-STORM 100SA. The HI-STORM 100A anchor design is not applicable to the HI-STORM 100S Version B overpack design. Therefore, the HI-STORM 100S Version B overpack cannot be deployed in the anchored configuration at this time. Hereafter in the text, discussion of HI-STORM 100A applies to both the standard (HI-STORM 100A) and HI-STORM 100SA overpacks, unless otherwise clarified.

The HI-STORM 100 System is designed to accommodate a wide variety of spent nuclear fuel assemblies in a single basic overpack design by utilizing different MPCs. The external diameters of all MPCs are identical to allow the use of a single overpack. Each of the MPCs has different internals (baskets) to accommodate distinct fuel characteristics. Each MPC is identified by the maximum quantity of fuel assemblies it is capable of receiving. The MPC-24, MPC-24E, and MPC-24EF contain a maximum of 24 PWR fuel assemblies; the MPC-32 and MPC-32F contain a maximum of 32 PWR fuel assemblies; and the MPC-68, MPC-68F, and MPC-68FF contain a maximum of 68 BWR fuel assemblies.

The HI-STORM overpack is constructed from a combination of steel and concrete, both of which are materials with long, proven histories of usage in nuclear applications. The HI-STORM overpack incorporates and combines many desirable features of previously-approved concrete and metal module designs. In essence, the HI-STORM overpack is a hybrid of metal and concrete systems, with the design objective of emulating the best features and dispensing with the drawbacks of both. The HI-STORM overpack is best referred to as a METCON™ (metal/concrete composite) system.

Figures 1.1.1, 1.1.1A, and 1.1.1B show the HI-STORM 100 System with two of its major constituents, the MPC and the storage overpack, in a cut-away view. The MPC, shown partially withdrawn from the storage overpack, 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 with respect to 10CFR72 requirements and attendant review considerations. The HI-STORM storage overpack provides mechanical protection, cooling, and radiological shielding for the contained MPC.

In essence, the HI-STORM 100 System is the storage-only counterpart of the HI-STAR 100 System (Docket Numbers 72-1008 (Ref. [1.1.2]) and 71-9261 (Ref. [1.1.3])). Both HI-STORM and HI-STAR are engineered to house identical MPCs. Since the MPC is designed to meet the requirements of both 10CFR71 and 10CFR72 for transportation and storage, respectively, the HI-STORM 100 System allows rapid decommissioning of the ISFSI by simply transferring the loaded MPC's directly into HI-STAR 100 overpacks for off-site transport. This alleviates the additional fuel handling steps required by storage-only casks to unload the cask and repackage the fuel into a suitable transportation cask.

In contrast to the HI-STAR 100 overpack, which provides a containment boundary for the SNF during transport, the HI-STORM storage overpack does not constitute a containment or confinement enclosure. The HI-STORM overpack is equipped with large penetrations near its lower and upper extremities to permit natural circulation of air to provide for the passive cooling of the MPC and the contained radioactive material. The HI-STORM overpack is engineered to be an effective barrier against the radiation emitted by the stored materials, and an efficiently configured metal/concrete composite to attenuate the loads transmitted to the MPC during a natural phenomena or hypothetical accident event. Other auxiliary functions of the HI-STORM 100 overpack include isolation of the SNF from abnormal environmental or man-made events, such as impact of a tornado borne missile. As the subsequent chapters of this FSAR demonstrate, the HI-STORM overpack is engineered with large margins of safety with respect to cooling, shielding, and mechanical/structural functions.

The HI-STORM 100 System is autonomous inasmuch as it provides SNF and radioactive material confinement, radiation shielding, criticality control and passive heat removal independent of any other facility, structures, or components. The surveillance and maintenance required by the plant's staff is minimized by the HI-STORM 100 System since it is completely passive and is composed of materials with long proven histories in the nuclear industry. The HI-STORM 100 System can be used either singly or as the basic storage module in an ISFSI. The site for an ISFSI can be located either at a reactor or away from a reactor.

The information presented in this report is intended to demonstrate the acceptability of the HI-STORM 100 System for use under the general license provisions of Subpart K by meeting the criteria set forth in 10CFR72.236.

The modularity of the HI-STORM 100 System accrues several advantages. Different MPCs, identical in external diameter, manufacturing requirements, and handling features, but different in their SNF arrangement details, are designed to fit a common overpack design. Even though the different MPCs have fundamentally identical design and manufacturing attributes, qualification of HI-STORM 100 requires consideration of the variations in the characteristics of the MPCs. In most cases, however, it is possible to identify the most limiting MPC geometry and the specific loading condition for the safety evaluation, and the detailed analyses are then carried out for that bounding condition. In those cases where this is not possible, multiple parallel analyses are performed.

The HI-STORM overpack is not engineered for transport and, therefore, will not be submitted for 10CFR Part 71 certification. HI-STORM 100, however, is designed to possess certain key elements of flexibility.

For example:

- The HI-STORM overpack is stored at the ISFSI pad in a vertical orientation, which helps minimize the size of the ISFSI and leads to an effective natural convection cooling flow around the MPC.

- The HI-STORM overpack can be loaded with a loaded MPC using the HI-TRAC transfer cask inside the 10CFR50 [1.1.4] facility, prepared for storage, transferred to the ISFSI, and stored in a vertical configuration, or directly loaded using the HI-TRAC transfer cask at or nearby the ISFSI storage pad.

The version of the HI-STORM overpack equipped with sector lugs to anchor it to the ISFSI pad is labeled HI-STORM 100A, shown in Figure 1.1.4. Figure 1.1.5 shows the sector lugs and anchors used to fasten the overpack to the pad in closer view. Details on HI-STORM 100A are presented in the drawing and BOM contained in Section 1.5. Users may employ a double nut arrangement as an option. The HI-STORM 100A overpack will be deployed at those ISFSI sites where the postulated seismic event (defined by the three orthogonal ZPAs) exceeds the maximum limit permitted for free-standing installation. The design of the ISFSI pad and the embedment are necessarily site-specific and the responsibility of the ISFSI owner. These designs shall be in accordance with the requirements specified in Appendix 2.A. The jurisdictional boundary between the anchored cask design and the embedment design is defined in Table 2.0.5. Additional description of the HI-STORM 100A configuration is provided in Subsection 1.2.1.2.1. The anchored design is applicable to the HI-STORM 100 and the HI-STORM 100S overpack designs only.

The MPC is a multi-purpose SNF storage device both with respect to the type of fuel assemblies and its versatility of use. The MPC is engineered as a cylindrical prismatic structure with square cross section storage cavities. The number of storage locations depends on the type of fuel. Regardless of the storage cell count, the construction of the MPC is fundamentally the same; it is built as a honeycomb of cellular elements positioned within a circumscribing cylindrical canister shell. The manner of cell-to-cell weld-up and cell-to-canister shell interface employed in the MPC imparts extremely high structural stiffness to the assemblage, which is an important attribute for mechanical accident events. Figure 1.1.2 shows an elevation cross section of an MPC.

The MPC enclosure vessel is identical in external diameter to those presented in References [1.1.2] and [1.1.3]. However, certain fuel basket models may not be certified for storage or transportation in the HI-STAR 100 System. The Part 71 and 72 CoCs for HI-STAR 100 should be consulted for the MPC models that are certified for that system. Referencing these documents, as applicable, avoids repetition of information on the MPCs which is comprehensively set forth in the above-mentioned Holtec International documents docketed with the NRC. However, sufficient information and drawings are presented in this report to maintain clarity of exposition of technical data.

The HI-STORM storage overpack is designed to provide the necessary neutron and gamma shielding to comply with the provisions of 10CFR72 for dry storage of SNF at an ISFSI. Cross sectional views of the HI-STORM storage overpacks are presented in Figures 1.1.3, 1.1.3A, and 1.1.3B. A HI-TRAC transfer cask is required for loading of the MPC and movement of the loaded MPC from the cask loading area of a nuclear plant spent fuel pool to the storage overpack. The HI-TRAC is engineered to be emplaced with an empty MPC into the cask loading area of nuclear plant spent fuel pools for fuel loading (or unloading). The HI-TRAC/MPC assembly is designed to preclude intrusion of pool water into the narrow annular space between the HI-TRAC and the MPC while the assembly is submerged in the pool water. The HI-TRAC transfer cask also allows dry loading (or unloading) of SNF into the MPC.

To summarize, the HI-STORM 100 System has been engineered to:

- minimize handling of the SNF;
- provide shielding and physical protection for the MPC;
- permit rapid and unencumbered decommissioning of the ISFSI;
- require minimal ongoing surveillance and maintenance by plant staff;
- minimize dose to operators during loading and handling;
- allow transfer of the loaded MPC to a HI-STAR overpack for transportation.

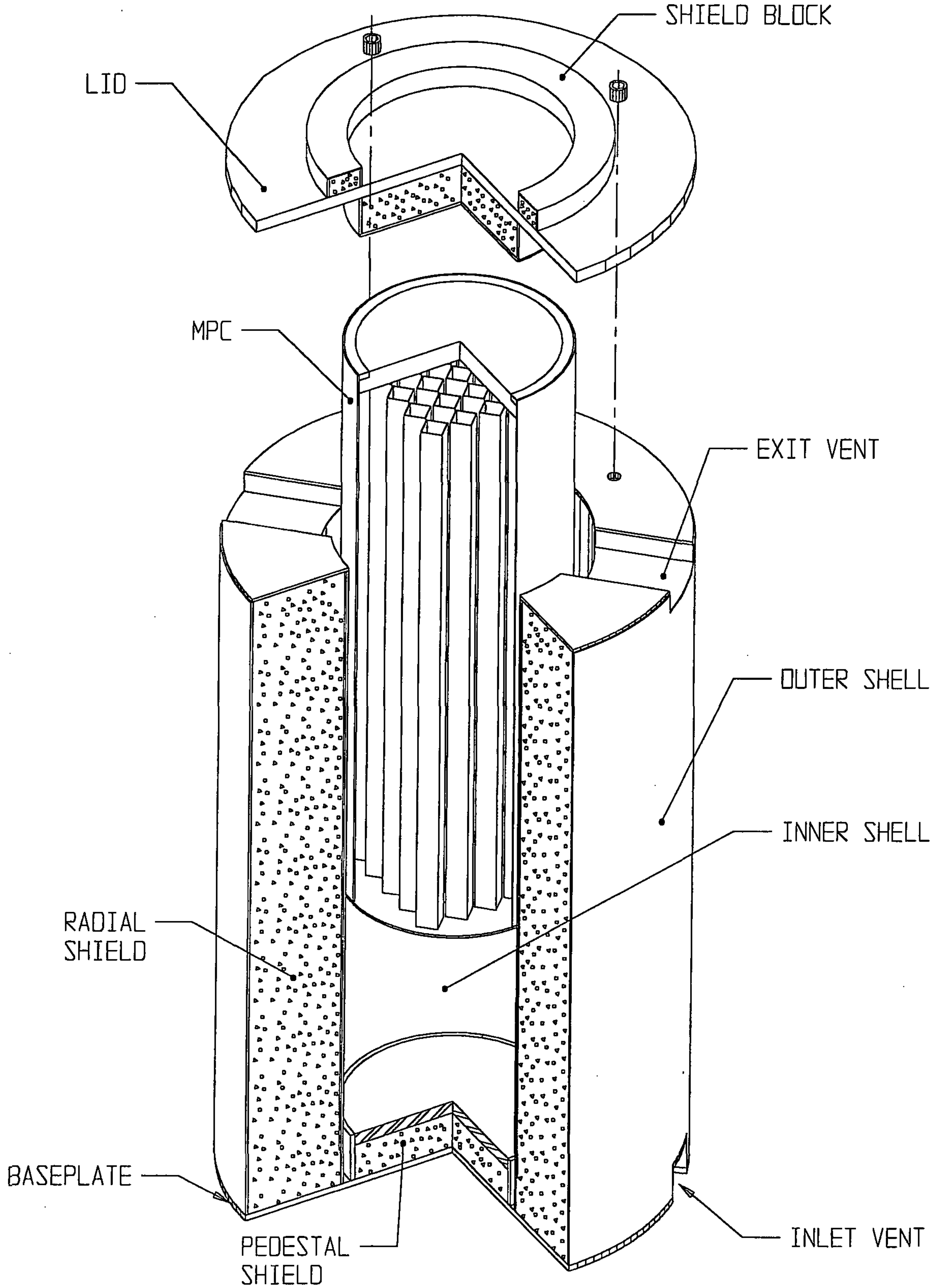

FIGURE 1.1.1; HI-STORM 100 OVERPACK WITH MPC PARTIALLY INSERTED

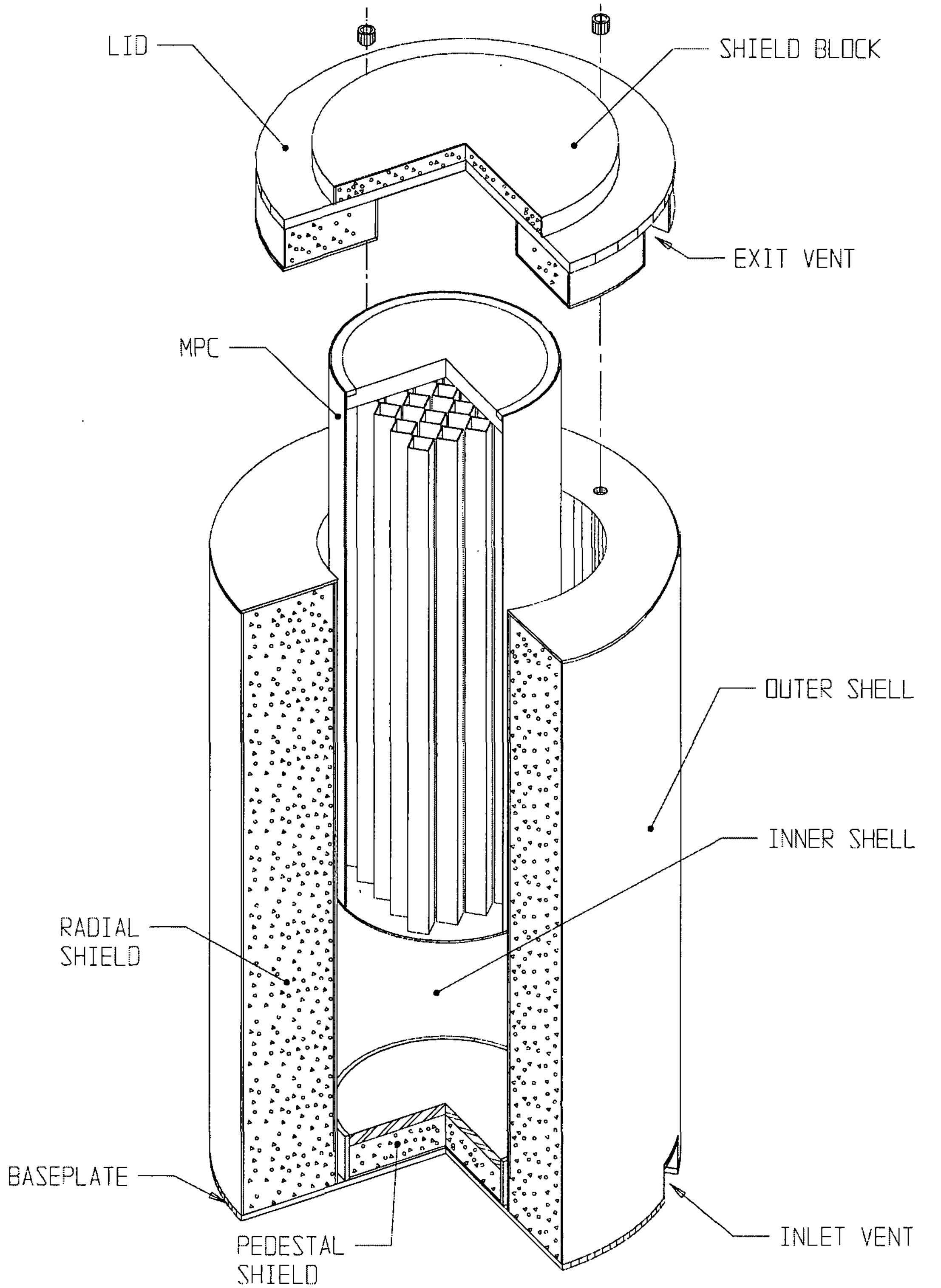

FIGURE 1.1.1A; HI-STORM 100S OVERPACK WITH MPC PARTIALLY INSERTED

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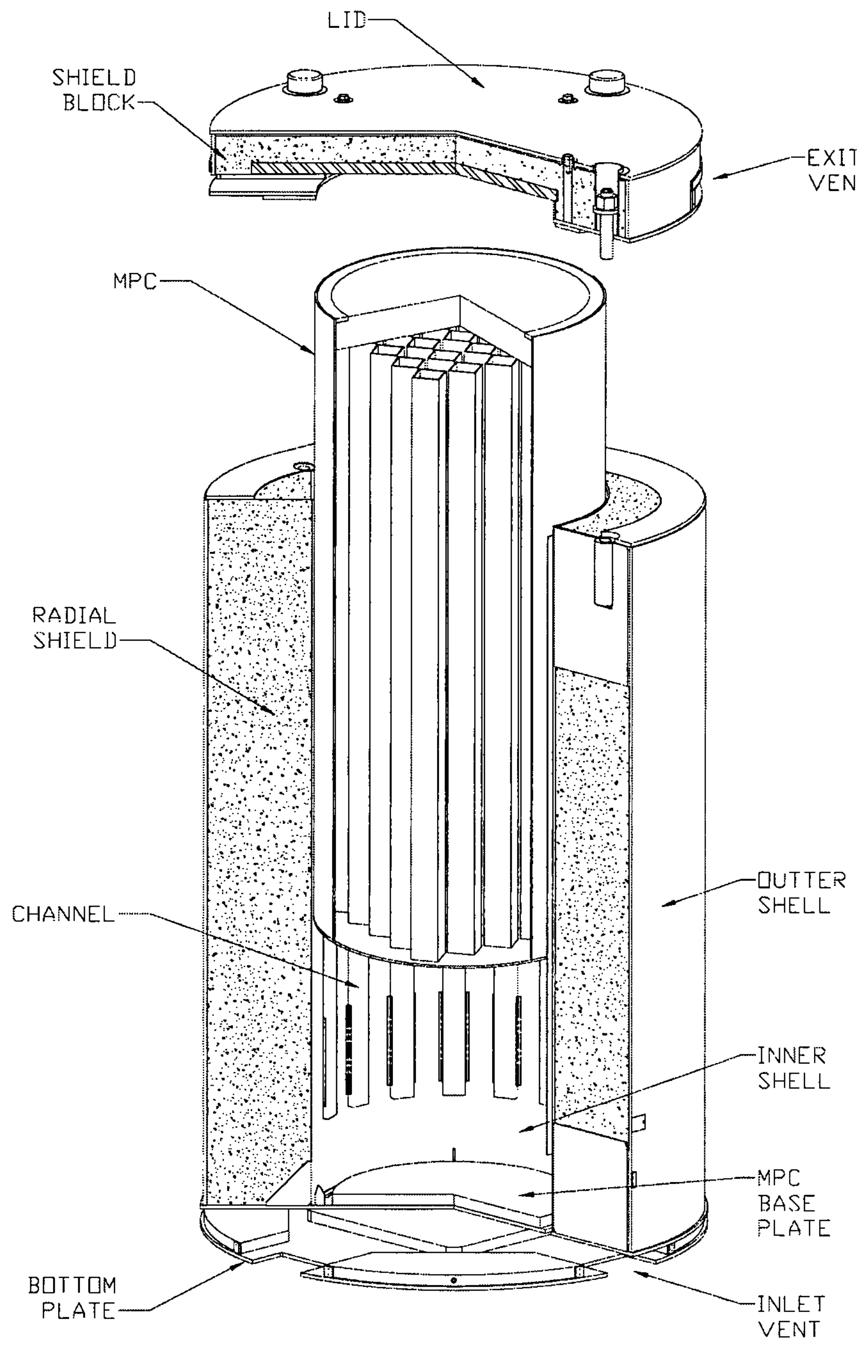

FIGURE 1.1.1B; HI-STORM 100S VERSION B OVERPACK WITH MPC PARTIALLY INSERTED

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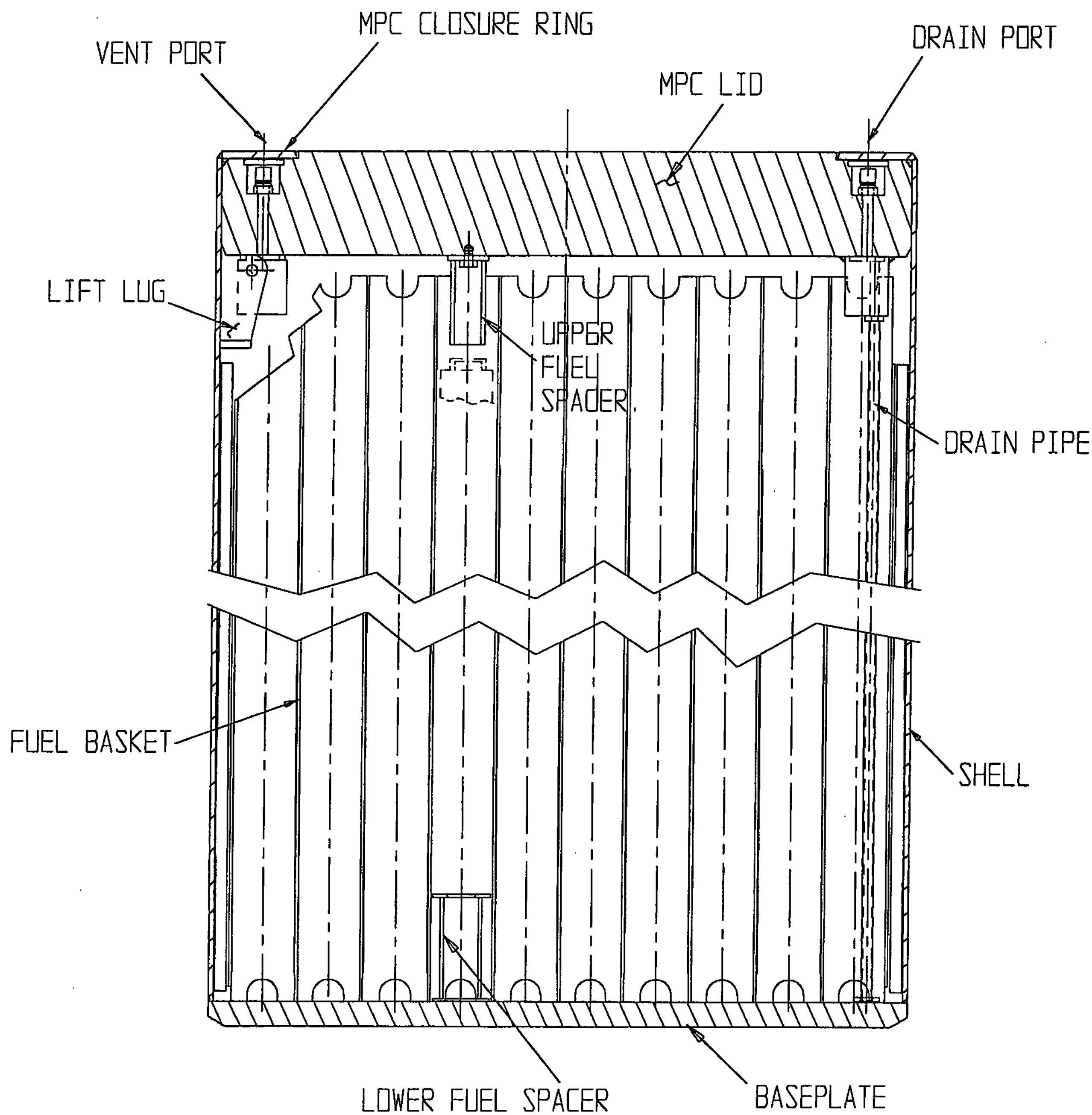

FIGURE 1.1.2; CROSS SECTION ELEVATION VIEW OF MPC

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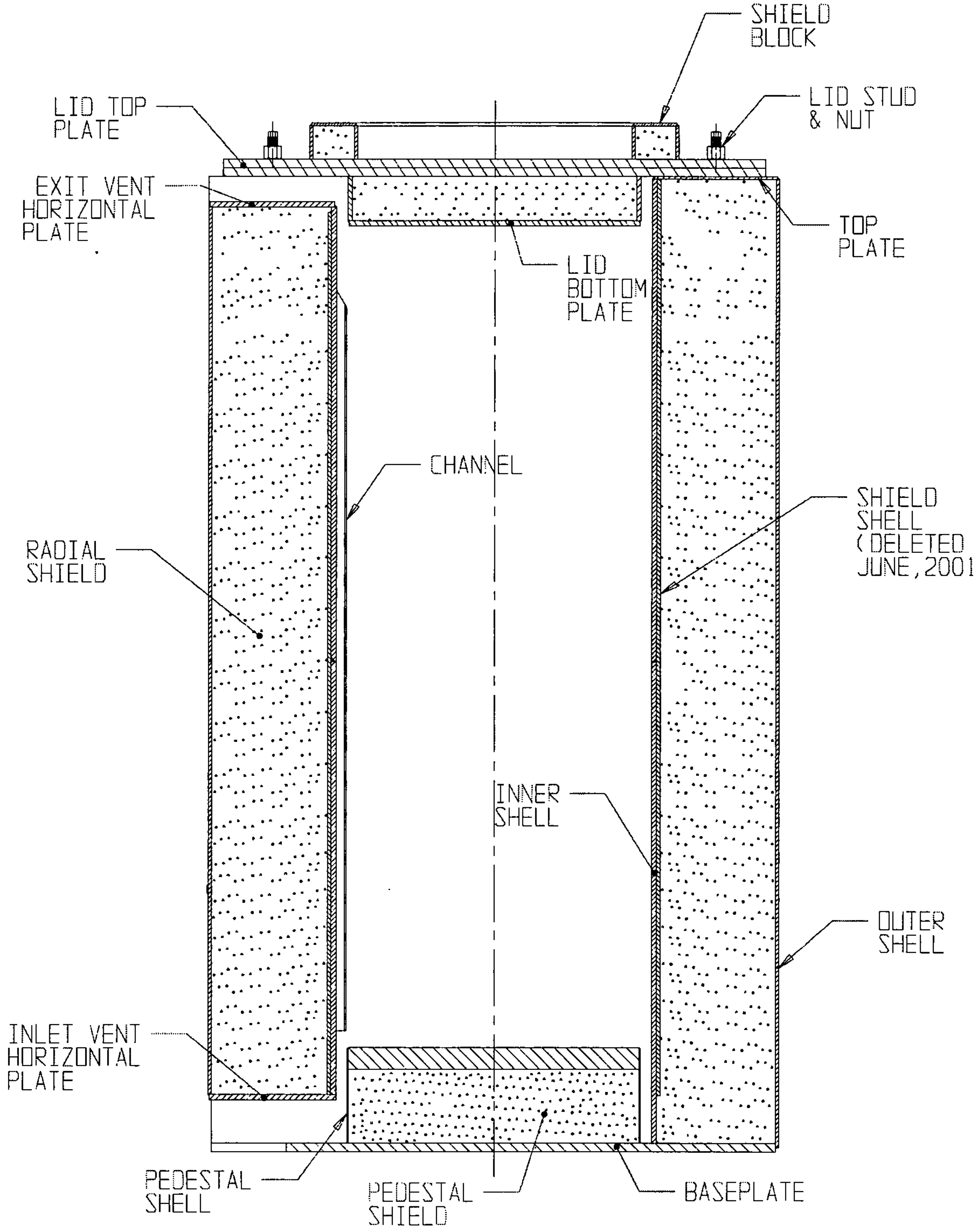

FIGURE 1.1.3; HI-STORM 100 OVERPACK CROSS SECTIONAL ELEVATION VIEW

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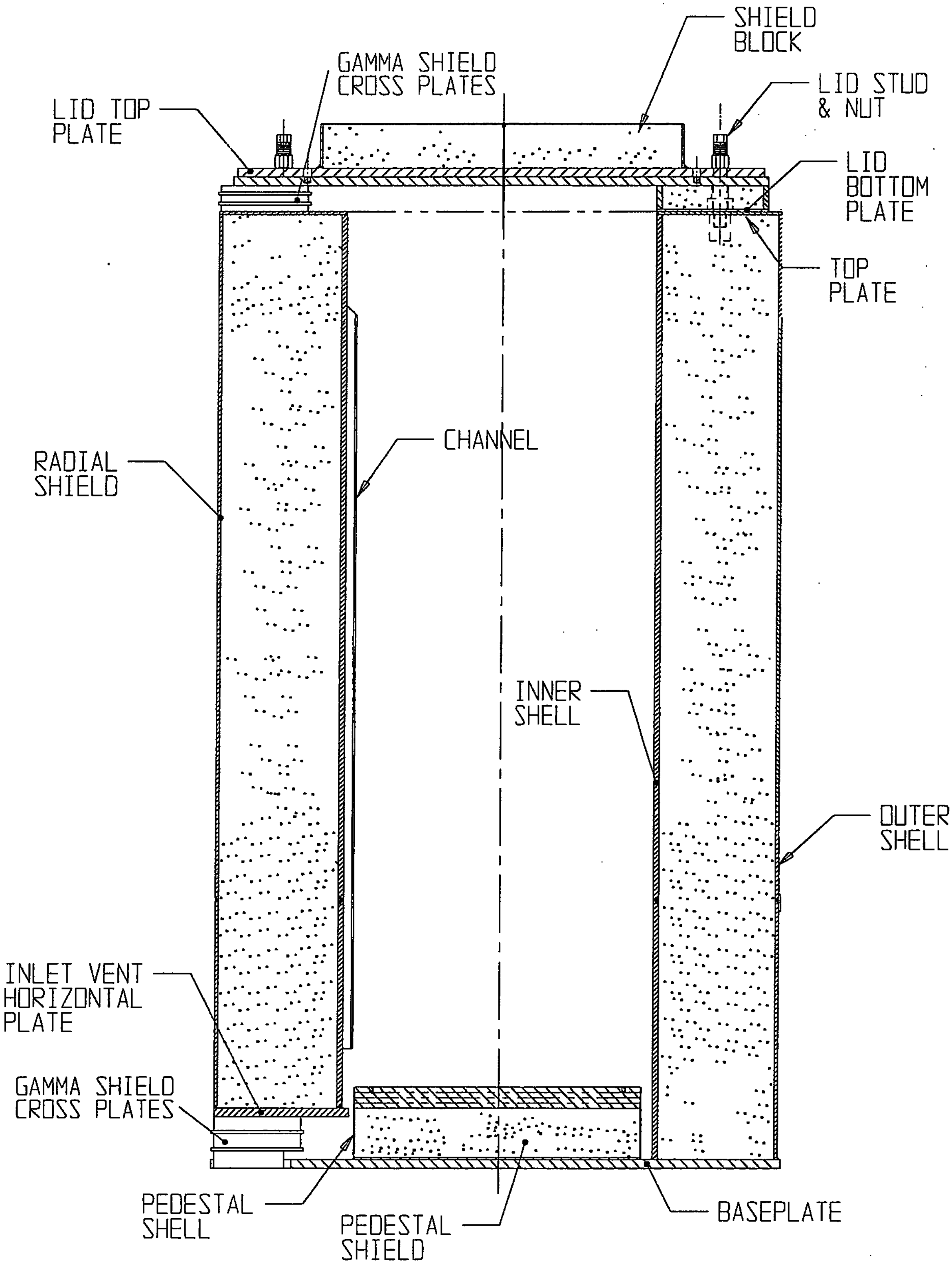

FIGURE 1.1.3A; HI-STORM 100S OVERPACK CROSS SECTIONAL ELEVATION VIEW

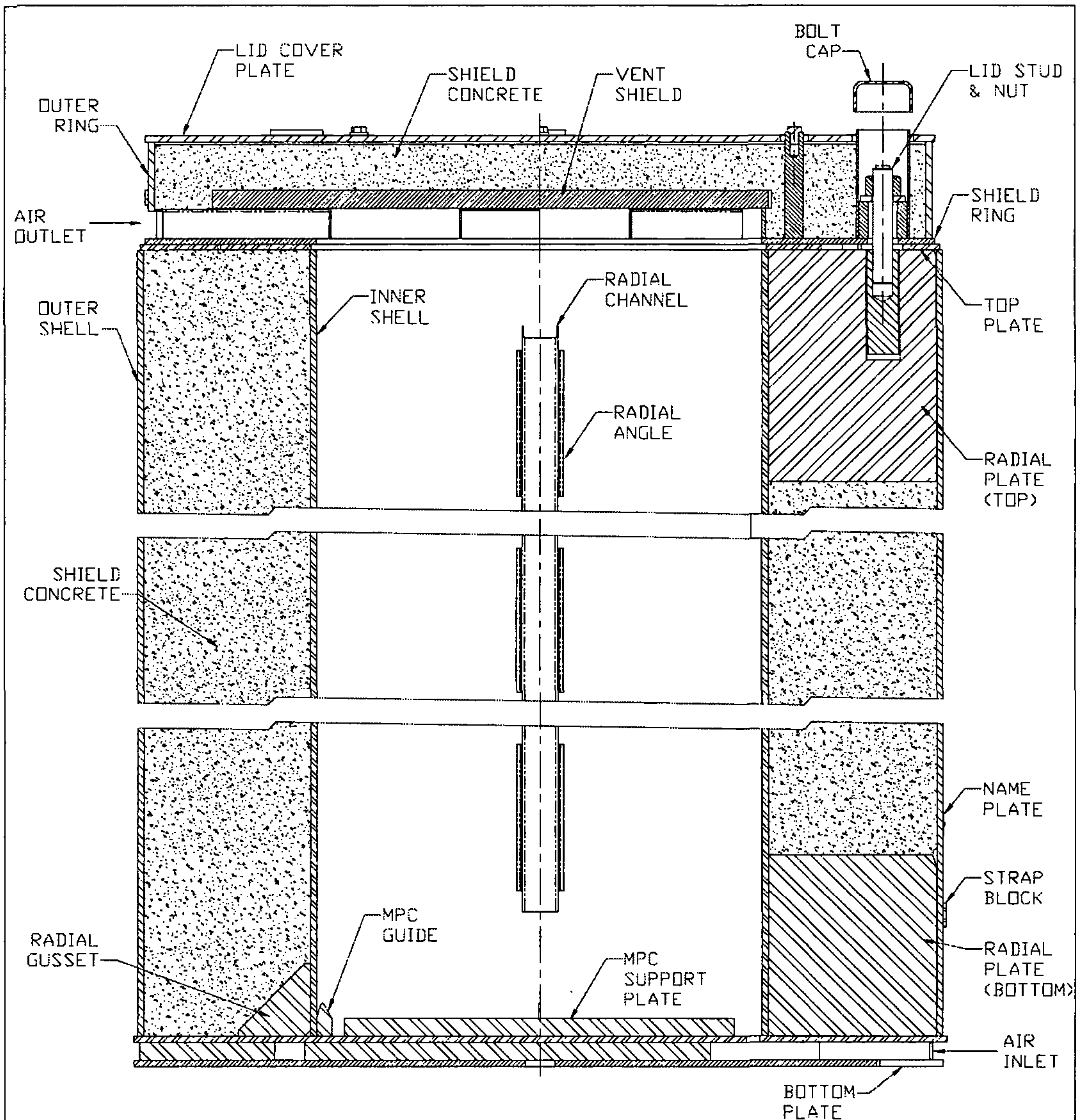

FIGURE 1.1.3B; HI-STORM 100S VERSION B OVERPACK CROSS SECTIONAL ELEVATION VIEW

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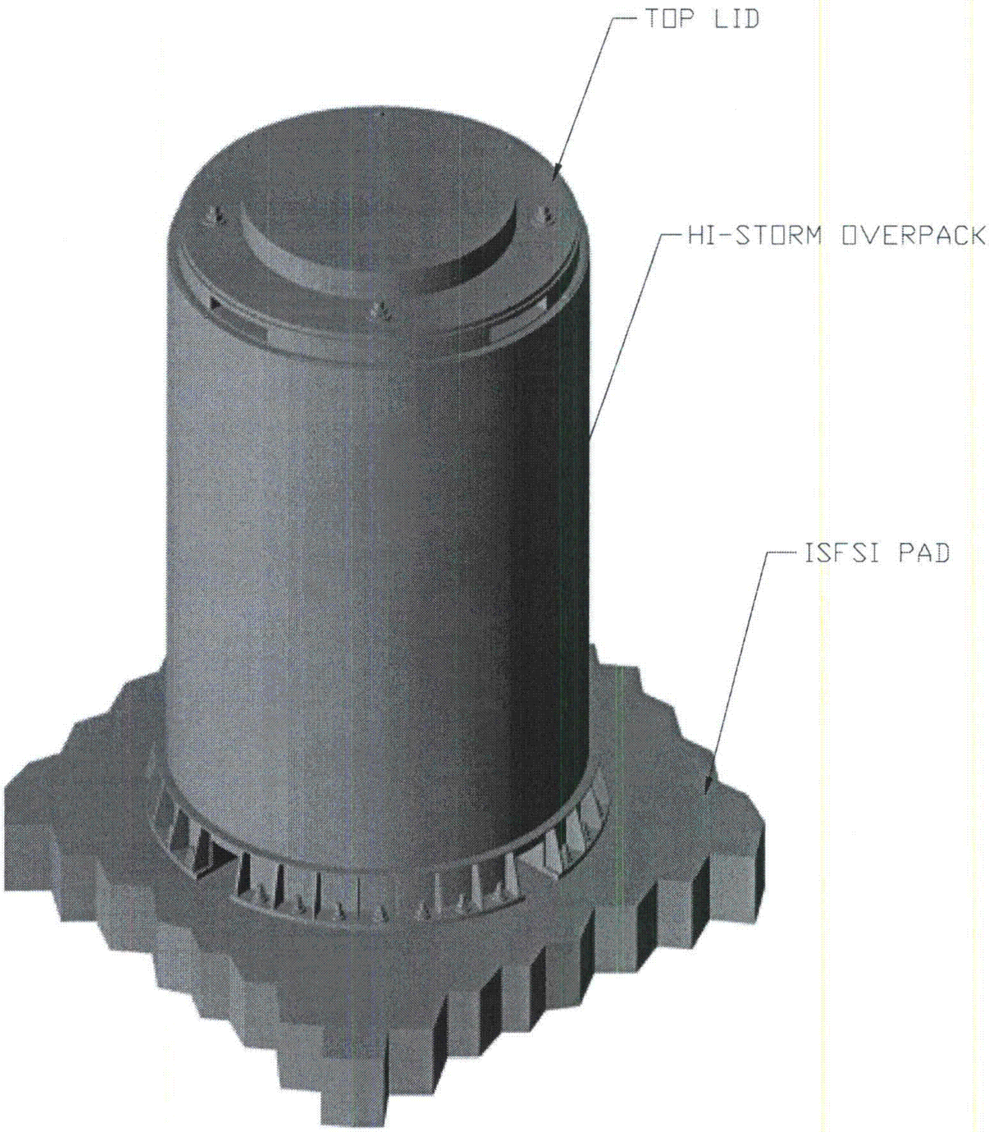

FIGURE 1.1.4; A PICTORAL VIEW OF THE HI-STORM 100A OVERPACK (100SA MODEL SHOWN)

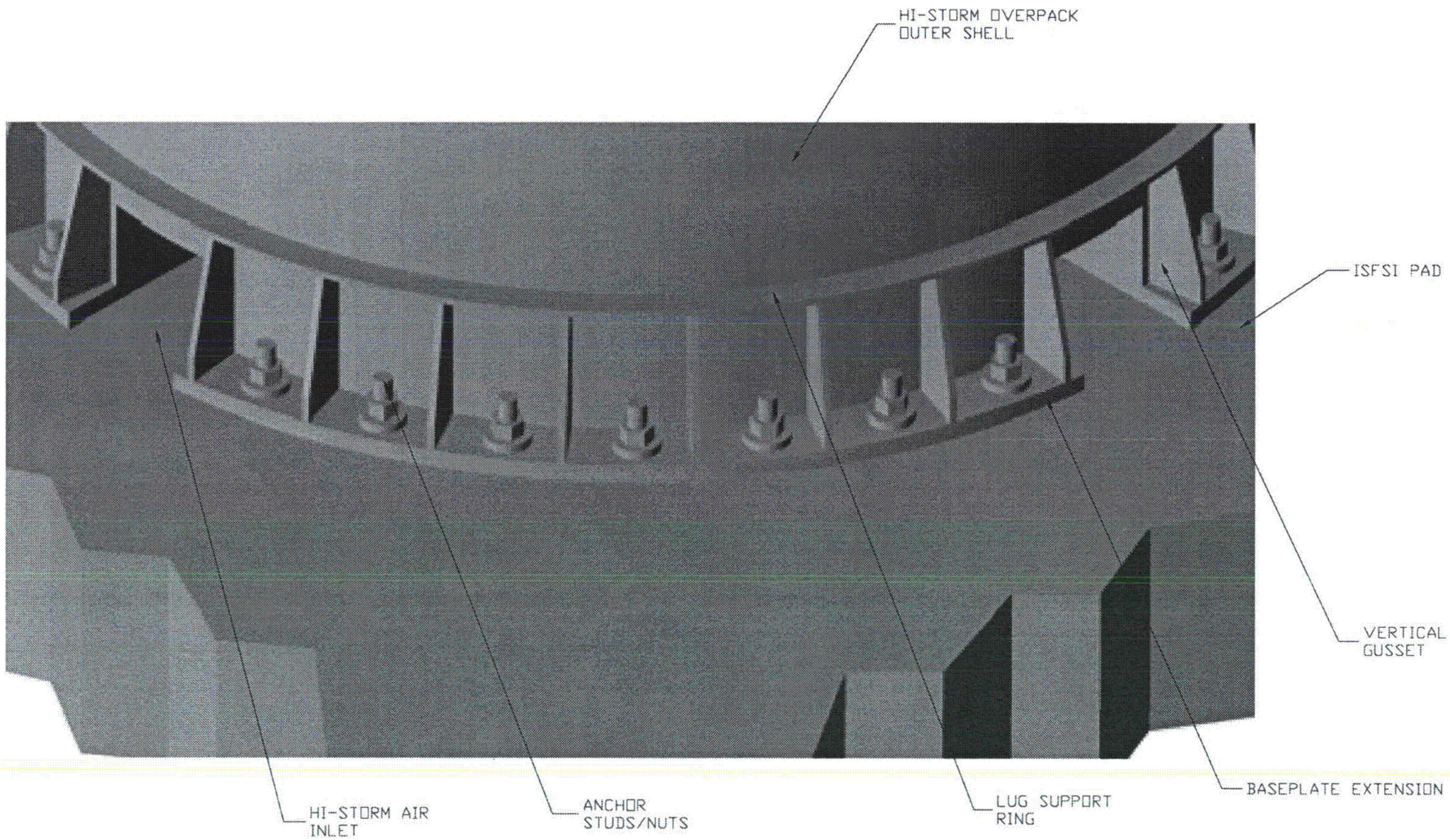

FIGURE 1.1.5; ANCHORING DETAIL FOR THE HI-STORM 100A AND 100SA OVERPACKS

1.2 GENERAL DESCRIPTION OF HI-STORM 100 System

1.2.1 System Characteristics

The basic HI-STORM 100 System consists of interchangeable MPCs providing a confinement boundary for BWR or PWR spent nuclear fuel, a storage overpack providing a structural and radiological boundary for long-term storage of the MPC placed inside it, and a transfer cask providing a structural and radiological boundary for transfer of a loaded MPC from a nuclear plant spent fuel storage pool to the storage overpack. Figures 1.2.1 and 1.2.1A provide example cross sectional views of the HI-STORM 100 System with an MPC inserted into HI-STORM 100 and HI-STORM 100S storage overpacks, respectively. Figure 1.1.1B provides similar information for the HI-STORM 100 System using a HI-STORM 100S Version B overpack. Each of these components is described below, including information with respect to component fabrication techniques and designed safety features. All structures, systems, and components of the HI-STORM 100 System, which are identified as Important to Safety are specified in Table 2.2.6. This discussion is supplemented with a full set of drawings in Section 1.5.

The HI-STORM 100 System is comprised of three discrete components:

i. multi-purpose canister (MPC)
ii. storage overpack (HI-STORM)
iii. transfer cask (HI-TRAC)

Necessary auxiliaries required to deploy the HI-STORM 100 System for storage are:

i. vacuum drying (or other moisture removal) system
ii. helium (He) backfill system with leakage detector (or other system capable of the same backfill condition)
iii. lifting and handling systems
iv welding equipment
v. transfer vehicles/trailer

All MPCs have identical external diameters. The outer diameter of the MPC is 68-3/8 inches† and the maximum overall length is approximately 190-1/2 inches. See Section 1.5 for the MPC drawings. Due to the differing storage contents of each MPC, the maximum loaded weight differs among MPCs. See Table 3.2.1 for each MPC weight. However, the maximum weight of a loaded MPC is approximately 44-1/2 tons. Tables 1.2.1 and 1.2.2 contain the key system data and parameters for the MPCs.

† Dimensions discussed in this section are considered nominal values.

A single, base HI-STORM overpack design is provided which is capable of storing each type of MPC. The overpack inner cavity is sized to accommodate the MPCs. The inner diameter of the overpack inner shell is 73-1/2 inches and the height of the cavity is 191-1/2 inches. The overpack inner shell is provided with channels distributed around the inner cavity to present an inside diameter of 69-1/2 inches. The channels are intended to offer a flexible medium to absorb some of the impact during a non-mechanistic tip-over, while still allowing the cooling air flow through the ventilated overpack. The outer diameter of the overpack is 132-1/2 inches. The overall height of the HI-STORM 100 overpack is 239-1/2 inches.

There are two variants of the HI-STORM 100S overpack, differing from each other only in height and weight. The HI-STORM 100S(232) is 232 inches high, and the HI-STORM 100S(243) is 243 inches high. The HI-STORM 100S(243) is approximately 10,100 lbs heavier assuming standard density concrete. Hereafter in the text, these two versions of the HI-STORM 100S overpack will only be referred to as HI-STORM 100S and will be discussed separately only if the design feature being discussed is different between the two overpacks. See Section 1.5 for drawings.

There are also variants of the HI-STORM 100S Version B overpack, differing from each other only in height and weight. The HI-STORM 100S-218 is 218 inches high, and the HI-STORM 100S-229 is 229 inches high. The HI-STORM 100S-229 is approximately 8,700 lbs heavier, including standard density concrete. Hereafter in the text, the versions of the HI-STORM 100S Version B overpack will only be referred to as HI-STORM 100S Version B and will be discussed separately only if the design feature being discussed is different between the overpacks. See Section 1.5 for drawings.

The weight of the overpack without an MPC varies from approximately 135 tons to 160 tons. See Table 3.2.1 for the detailed weights.

Before proceeding to present detailed physical data on the HI-STORM 100 System, it is of contextual importance to summarize the design attributes which enhance the performance and safety of the system. Some of the principal features of the HI-STORM 100 System which enhance its effectiveness as an SNF storage device and a safe SNF confinement structure are:

- the honeycomb design of the MPC fuel basket;
- the effective distribution of neutron and gamma shielding materials within the system;
- the high heat dissipation capability;
- engineered features to promote convective heat transfer;
- the structural robustness of the steel-concrete-steel overpack construction.

The honeycomb design of the MPC fuel baskets renders the basket into a multi-flange plate weldment where all structural elements (i.e., box walls) are arrayed in two orthogonal sets of plates. Consequently, the walls of the cells are either completely co-planar (i.e., no offset) or orthogonal with each other. There is complete edge-to-edge continuity between the contiguous cells.

Among the many benefits of the honeycomb construction is the uniform distribution of the metal mass of the basket over the entire length of the basket. Physical reasoning suggests that a uniformly distributed mass provides a more effective shielding barrier than can be obtained from a nonuniform basket. In other words, the honeycomb basket is a most effective radiation attenuation device. The complete cell-to-cell connectivity inherent in the honeycomb basket structure provides an uninterrupted heat transmission path, making the MPC an effective heat rejection device.

The composite shell construction in the overpack, steel-concrete-steel, allows ease of fabrication and eliminates the need for the sole reliance on the strength of concrete.

A description of each of the components is provided in the following sections, along with information with respect to its fabrication and safety features. This discussion is supplemented with the full set of drawings in Section 1.5.

1.2.1.1 Multi-Purpose Canisters

The MPCs are welded cylindrical structures as shown in cross sectional views of Figures 1.2.2 through 1.2.4. The outer diameter of each MPC is fixed. Each spent fuel MPC is an assembly consisting of a honeycombed fuel basket, a baseplate, canister shell, a lid, and a closure ring, as depicted in the MPC cross section elevation view, Figure 1.2.5. The number of spent nuclear fuel storage locations in each of the MPCs depends on the fuel assembly characteristics.

There are eight MPC models, distinguished by the type and number of fuel assemblies authorized for loading. Section 1.2.3 and Table 1.2.1 summarize the allowable contents for each MPC model. Section 2.1.9 provides the detailed specifications for the contents authorized for storage in the HI-STORM 100 System. Drawings for the MPCs are provided in Section 1.5.

The MPC provides the confinement boundary for the stored fuel. Figure 1.2.6 provides an elevation view of the MPC confinement boundary. The confinement boundary is defined by the MPC baseplate, shell, lid, port covers, and closure ring. The confinement boundary is a strength-welded enclosure of all stainless steel construction.

The PWR MPC-24, MPC-24E and MPC-24EF differ in construction from the MPC-32 (including the MPC-32F) and the MPC-68 (including the MPC-68F and MPC-68FF) in one important aspect: the fuel storage cells in the MPC-24 series are physically separated from one another by a "flux trap", for criticality control. The PWR MPC-32 and -32F are designed similar to the MPC-68 (without flux traps) and its design includes credit for soluble boron in the MPC water during wet fuel loading and unloading operations for criticality control.

The MPC fuel baskets of non-flux trap construction (namely, MPC-68, MPC-68F, MPC-68FF, MPC-32, and MPC-32F) are formed from an array of plates welded to each other at their intersections. In the flux-trap type fuel baskets (MPC-24, MPC-24E, and MPC-24EF), formed angles are interposed onto the orthogonally configured plate assemblage to create the required flux-trap channels (see MPC-24 and MPC-24E fuel basket drawings in Section 1.5). In both configurations, two key attributes of the basket are preserved:

i. The cross section of the fuel basket simulates a multi-flanged closed section beam, resulting in extremely high bending rigidity.

ii. The principal structural frame of the basket consists of co-planar plate-type members (i.e., no offset).

This structural feature eliminates the source of severe bending stresses in the basket structure by eliminating the offset between the cell walls that must transfer the inertia load of the stored SNF to the basket/MPC interface during the various postulated accident events (e.g., non-mechanistic tipover, uncontrolled lowering of a cask during on-site transfer, or off-site transport events, etc.).

The MPC fuel basket is positioned and supported within the MPC shell by a set of basket supports welded to the inside of the MPC shell. Between the periphery of the basket, the MPC shell, and the basket supports, optional aluminum heat conduction elements (AHCEs) may have been installed in the early vintage MPCs fabricated, certified, and loaded under the original version or Amendment 1 of the HI-STORM 100 System CoC. The presence of these aluminum heat conduction elements is acceptable for MPCs loaded under the original CoC or Amendment 1, since the governing thermal analysis for Amendment 1 conservatively modeled the AHCEs as restrictions to convective flow in the basket, but took no credit for heat transfer through them. The heat loads authorized under Amendment 1 bound those for the original CoC, with the same MPC design. For MPCs loaded under Amendment 2 or a later version of the HI-STORM 100 CoC, the aluminum heat conduction elements shall not be installed. MPCs both with and without aluminum heat conduction elements installed are compatible with all HI-STORM overpacks. If used, these heat conduction elements are fabricated from thin aluminum alloy 1100 in shapes and a design that allows a snug fit in the confined spaces and ease of installation. If used, the heat conduction elements are installed along the full length of the MPC basket except at the drain pipe location to create a nonstructural thermal connection that facilitates heat transfer from the basket to shell. In their operating condition, the heat conduction elements contact the MPC shell and basket walls.

Lifting lugs attached to the inside surface of the MPC canister shell serve to permit placement of the empty MPC into the HI-TRAC transfer cask. The lifting lugs also serve to axially locate the MPC lid prior to welding. These internal lifting lugs are not used to handle a loaded MPC. Since the MPC lid is installed prior to any handling of a loaded MPC, there is no access to the lifting lugs once the MPC is loaded.

The top end of the MPC incorporates a redundant closure system. Figure 1.2.6 shows the MPC closure details. The MPC lid is a circular plate (fabricated from one piece, or two pieces - split top and bottom) edge-welded to the MPC outer shell. If the two-piece lid design is employed, only the top piece is analyzed as part of the enclosure vessel pressure boundary. The bottom piece acts as a radiation shield and is attached to the top piece with a non-structural, non-pressure retaining weld. The lid is equipped with vent and drain ports that are utilized to remove moisture and air from the MPC, and backfill the MPC with a specified amount of inert gas (helium). The vent and drain ports are covered and seal welded before the closure ring is installed. The closure ring is a circular ring edge-welded to the MPC shell and lid. The MPC lid provides sufficient rigidity to allow the entire MPC loaded with SNF to be lifted by threaded holes in the MPC lid.

For fuel assemblies that are shorter than the design basis length, upper and lower fuel spacers (as appropriate) maintain the axial position of the fuel assembly within the MPC basket. The upper fuel spacers are threaded into the underside of the MPC lid as shown in Figure 1.2.5. The lower fuel spacers are placed in the bottom of each fuel basket cell. The upper and lower fuel spacers are designed to withstand normal, off-normal, and accident conditions of storage. An axial clearance of approximately 2 to 2-1/2 inches is provided to account for the irradiation and thermal growth of the fuel assemblies. The suggested values for the upper and lower fuel spacer lengths are listed in Tables 2.1.9 and 2.1.10 for each fuel assembly type. The actual length of fuel spacers will be determined on a site-specific or fuel assembly-specific basis.

The MPC confinement boundary is constructed entirely from stainless steel alloy materials. All MPC components that may come into contact with spent fuel pool water or the ambient environment (with the exception of neutron absorber, aluminum seals on vent and drain port caps, and optional aluminum heat conduction elements) must be constructed from stainless steel alloy materials. Concerns regarding interaction of coated carbon steel materials and various MPC operating environments [1.2.1] are not applicable to the MPC. All structural components in a MPC shall be made of Alloy X, a designation which warrants further explanation.

Alloy X is a material that is expected to be acceptable as a Mined Geological Disposal System (MGDS) waste package and which meets the thermophysical properties set forth in this document.

At this time, there is considerable uncertainty with respect to the material of construction for an MPC that would be acceptable as a waste package for the MGDS. Candidate materials being considered for acceptability by the DOE include:

- Type 316
- Type 316LN
- Type 304
- Type 304LN

The DOE material selection process is primarily driven by corrosion resistance in the potential environment of the MGDS. As the decision regarding a suitable material to meet disposal requirements is not imminent, the MPC design allows the use of any one of the four Alloy X materials.

For the MPC design and analysis, Alloy X (as defined in this FSAR) may be one of the following materials. Any steel part in an MPC may be fabricated from any of the acceptable Alloy X materials listed below, except that the steel pieces comprising the MPC shell (i.e., the 1/2" thick cylinder) must be fabricated from the same Alloy X stainless steel type.

- Type 316
- Type 316LN
- Type 304
- Type 304LN

The Alloy X approach is accomplished by qualifying the MPC for all mechanical, structural, neutronic, radiological, and thermal conditions using material thermophysical properties that are the least favorable for the entire group for the analysis in question. For example, when calculating the rate of heat rejection to the outside environment, the value of thermal conductivity used is the lowest for the candidate material group. Similarly, the stress analysis calculations use the lowest value of the ASME Code allowable stress intensity for the entire group. Stated differently, we have defined a material, which is referred to as Alloy X, whose thermophysical properties, from the MPC design perspective, are the least favorable of the candidate materials.

The evaluation of the Alloy X constituents to determine the least favorable properties is provided in Appendix 1.A.

The Alloy X approach is conservative because no matter which material is ultimately utilized in the MPC construction, the Alloy X approach guarantees that the performance of the MPC will exceed the analytical predictions contained in this document.

1.2.1.2 Overpacks

1.2.1.2.1 HI-STORM Overpack

The HI-STORM overpacks are rugged, heavy-walled cylindrical vessels. Figures 1.1.3B, 1.2.7, 1.2.8, and 1.2.8A provide cross sectional views of the HI-STORM 100 System, showing all of the overpack designs. The HI-STORM 100A overpack design is an anchored variant of the HI-STORM 100 and -100S designs and hereinafter is identified by name only when the discussion specifically applies to the anchored overpack. The HI-STORM 100A differs only in the diameter of the overpack baseplate and the presence of bolt holes and associated anchorage hardware (see Figures 1.1.4 and 1.1.5).The main structural function of the storage overpack is provided by carbon steel, and the main shielding function is provided by plain concrete. The overpack plain concrete is enclosed by cylindrical steel shells, a thick steel baseplate, and a top plate. The overpack lid has appropriate concrete shielding to provide neutron and gamma attenuation in the vertical direction.

The storage overpack provides an internal cylindrical cavity of sufficient height and diameter for housing an MPC. The inner shell of the overpack has channels attached to its inner diameter. The channels provide guidance for MPC insertion and removal and a flexible medium to absorb impact loads during the non-mechanistic tip-over, while still allowing the cooling air flow to circulate through the overpack. Shims may be attached to channels to allow the proper inner diameter dimension to be obtained.

The storage system has air ducts to allow for passive natural convection cooling of the contained MPC. A minimum of four air inlets and four air outlets are located at the lower and upper extremities of the storage system, respectively. The location of the air outlets in the HI-STORM 100 and the HI-STORM 100S (including Version B) design differ in that the outlet ducts for the HI-STORM 100 overpack are located in the overpack body and are aligned vertically with the inlet ducts at the bottom of the overpack body. The air outlet ducts in the HI-STORM 100S and –100S Version B are integral to the lid assembly and are not in vertical alignment with the inlet ducts. See the drawings in Section 1.5 for details of the overpack air inlet and outlet duct designs. The air inlets and outlets are covered by a screen to reduce the potential for blockage. Routine inspection of the screens (or, alternatively, temperature monitoring) ensures that blockage of the screens themselves will be detected and removed in a timely manner. Analysis, described in Chapter 11 of this FSAR, evaluates the effects of partial and complete blockage of the air ducts.

The air inlets and air outlets are penetrations through the thick concrete shielding provided by the HI-STORM 100 overpack. The outlet air ducts for the HI-STORM 100S and –100S Version B overpack designs, integral to the lid, present a similar break in radial shielding. Within the air inlets and outlets, an array of gamma shield cross plates are installed (see Figure 5.3.19 for a pictorial representation of the gamma shield cross plate designs). These gamma shield cross plates are designed to scatter any radiation traveling through the ducts. The result of scattering the radiation in the ducts is a significant decrease in the local dose rates around the air inlets and air outlets. The configuration of the gamma shield cross plates is such that the increase in the resistance to flow in the air inlets and outlets is minimized. For the HI-STORM 100 and –100S overpack designs, the shielding analysis conservatively credits only the mandatory version of the gamma shield cross plate design because they provide less shielding than the optional design. Conversely, the thermal analysis conservatively evaluates the optional gamma shield cross plate design because it conservatively provides greater resistance to flow than the mandatory design. There is only one gamma shield cross plate design employed with the HI-STORM 100S Version B overpack design, which has been appropriately considered in the shielding and thermal analyses.

Four threaded anchor blocks at the top of the overpack are provided for lifting. The anchor blocks are integrally welded to the radial plates, which in turn are full-length welded to the overpack inner shell, outer shell, and baseplate (HI-STORM 100) or the inlet air duct horizontal plates (HI-STORM 100S) (see Figure 1.2.7). The HI-STORM 100S Version B overpack design incorporates partial-length radial plates at the top of the overpack to secure the anchor blocks and uses both gussets and partial-length radial plates at the bottom of the overpack for structural stability. Details of this arrangement are shown in the drawings in Section 1.5.

The four anchor blocks are located on 90° arcs around the circumference of the top of the overpack lid. The overpack may also be lifted from the bottom using specially-designed lifting transport devices, including hydraulic jacks, air pads, Hillman rollers, or other design based on site-specific needs and capabilities. Slings or other suitable devices mate with lifting lugs that are inserted into threaded holes in the top surface of the overpack lid to allow lifting of the overpack lid. After the lid is bolted to the storage overpack main body, these lifting bolts shall be removed and replaced with flush plugs.

The plain concrete between the overpack inner and outer steel shells is specified to provide the necessary shielding properties (dry density) and compressive strength. The concrete shall be in accordance with the requirements specified in Appendix 1.D.

The principal function of the concrete is to provide shielding against gamma and neutron radiation. However, in an implicit manner it helps enhance the performance of the HI-STORM overpack in other respects as well. For example, the massive bulk of concrete imparts a large thermal inertia to the HI-STORM overpack, allowing it to moderate the rise in temperature of the system under hypothetical conditions when all ventilation passages are assumed to be blocked. The case of a postulated fire accident at the ISFSI is another example where the high thermal inertia characteristics of the HI-STORM concrete control the temperature of the MPC. Although the annular concrete mass in the overpack shell is not a structural member, it does act as an elastic/plastic filler of the inter-shell space, such that, while the cracking and crushing under a tip-over accident is not of significant consequence, the deformation characteristics are germane to the analysis of the structural members.

Density and compressive strength are the key parameters that delineate the performance of concrete in the HI-STORM System. The density of concrete used in the inter-shell annulus, pedestal (HI-STORM 100 and –100S overpacks only), and overpack lid has been set as defined in Appendix 1.D. For evaluating the physical properties of concrete for completing the analytical models, conservative formulations of Reference [1.0.5] are used.

To ensure the stability of the concrete at temperature, the concrete composition has been specified in accordance with NUREG-1536, "Standard Review Plan for Dry Cask Storage Systems" [1.0.3]. Thermal analyses, presented in Chapter 4, show that the temperatures during normal storage conditions do not threaten the physical integrity of the HI-STORM overpack concrete.

There are three base HI-STORM overpack designs - HI-STORM 100, HI-STORM 100S, and HI-STORM 100S Version B. The significant differences among the three are overpack height, MPC pedestal height, location of the air outlet ducts, and the vertical alignment of the inlet and outlet air ducts. The HI-STORM 100 overpack is approximately 240 inches high from the bottom of the baseplate to the top of the lid bolts and 227 inches high without the lid installed. There are two variants of the HI-STORM 100S overpack design, differing only in height and weight. The HI-STORM 100S(232) is approximately 232 inches high from the bottom of the baseplate to the top of the lid in its final storage configuration and approximately 211 inches high without the lid installed. The HI-STORM 100S(243) is approximately 243 inches high from the bottom of the baseplate to the top of the lid in its final storage configuration and approximately 222 inches high without the lid installed. There are also variants of the HI-STORM 100S Version B overpack design, differing only in height and weight. The HI-STORM 100S-218 is approximately 218 inches high from the bottom of the baseplate to the top of the lid in its final storage configuration and approximately 199 inches high without the lid installed. The HI-STORM 100S-229 is approximately 229 inches high from the bottom of the baseplate to the top of the lid in its final storage configuration and 210 inches high without the lid installed.

The HI-STORM 100S Version B overpack design does not include a concrete-filled pedestal to support the MPC. Instead, the MPC rests upon a steel plate that maintains the MPC sufficiently above the inlet air ducts to prevent direct radiation shine through the ducts. To facilitate this change, the inlet air ducts for the HI-STORM 100S Version B are shorter in height but larger in width. See the drawings in Section 1.5 for details.

The anchored embodiment of the HI-STORM overpack is referred to as HI-STORM 100A or HI-STORM 100SA. The HI-STORM 100S version B overpack design may not be deployed in the anchored configuration at this time. As explained in the foregoing, the HI-STORM overpack is a steel weldment, which makes it a relatively simple matter to extend the overpack baseplate, form lugs, and then anchor the cask to the reinforced concrete structure of the ISFSI. In HI-STORM terminology, these lugs are referred to as "sector lugs." The sector lugs, as shown in Figure 1.1.5 and the drawing in Section 1.5, are formed by extending the HI-STORM overpack baseplate, welding vertical gussets to the baseplate extension and to the overpack outer shell and, finally, welding a horizontal lug support ring in the form of an annular sector to the vertical gussets and to the outer shell. The baseplate is equipped with regularly spaced clearance holes (round or slotted) through which the anchor studs can pass. The sector lugs are bolted to the ISFSI pad using anchor studs that are made of a creep-resistant, high-ductility, environmentally compatible material. The bolts are pre-loaded to a precise axial stress using a "stud tensioner" rather than a torque wrench. Pre-tensioning the anchors using a stud tensioner eliminates any shear stress in the bolt, which is unavoidable if a torquing device is employed (Chapter 3 of the text "Mechanical Design of Heat Exchangers and Pressure Vessel Components", by Arcturus Publishers, 1984, K.P. Singh and A.I. Soler, provides additional information on stud tensioners). The axial stress in the anchors induced by pre-tensioning is kept below 75% of the material yield stress, such that during the seismic event the maximum bolt axial stress remains below the limit prescribed for bolts in the ASME Code, Section III, Subsection NF (for Level D conditions). Figures 1.1.4 and 1.1.5 provide visual depictions of the anchored HI-STORM 100A configuration. This configuration also applies to the HI-STORM 100SA.

The anchor studs pass through liberal clearance holes (circular or slotted) in the sector lugs (0.75" minimum clearance) such that the fastening of the studs to the ISFSI pad can be carried out without mechanical interference from the body of the sector lug. The two clearance hole configurations give the ISFSI pad designer flexibility in the design of the anchor embedment in the ISFSI concrete. The axial force in the anchors produces a compressive load at the overpack/pad interface. This compressive force, F, imputes a lateral load bearing capacity to the cask/pad interface that is equal to μF ($\mu \leq 0.53$ per Table 2.2.8). As is shown in Chapter 3 of this FSAR, the lateral load-bearing capacity of the HI-STORM/pad interface (μF) is many times greater than the horizontal (sliding) force exerted on the cask under the postulated DBE seismic event. Thus, the potential for lateral sliding of the HI-STORM 100A System during a seismic event is precluded, as is the potential for any bending action on the anchor studs.

The seismic loads, however, will produce an overturning moment on the overpack that would cause a redistribution of the compressive contact pressure between the pad and the overpack. To determine the pulsation in the tensile load in the anchor studs and in the interface contact pressure, bounding static analysis of the preloaded configuration has been performed. The results of the static analysis demonstrate that the initial preloading minimizes pulsations in the stud load. A confirmatory non-linear dynamic analysis has also been performed using the time-history methodology described in Chapter 3, wherein the principal nonlinearities in the cask system are incorporated and addressed. The calculated results from the dynamic analysis confirm the static analysis results and that the presence of pre-stress helps minimize the pulsation in the anchor stud stress levels during the seismic event, thus eliminating any concern with regard to fatigue failure under extended and repetitive seismic excitations.

The sector lugs in HI-STORM 100A are made of the same steel material as the baseplate and the shell (SA516- Gr. 70) which helps ensure high quality fillet welds used to join the lugs to the body of the overpack. The material for the anchor studs can be selected from a family of allowable stud materials listed in the ASME Code (Section II). A representative sampling of permitted materials is listed in Table 1.2.7. The menu of materials will enable the ISFSI owner to select a fastener material that is resistant to corrosion in the local ISFSI environment. For example, for ISFSIs located in marine environments (e.g., coastal reactor sites), carbon steel studs would not be recommended without concomitant periodic inspection and coating maintenance programs. Table 1.2.7 provides the chemical composition of several acceptable fastener materials to help the ISFSI owner select the most appropriate material for his site. The two mechanical properties, ultimate strength σ_u and yield strength σ_y are also listed. For purposes of structural evaluations, the lower bound values of σ_u and σ_y from the menu of materials listed in Table 1.2.7 are used (see Table 3.4.10).

As shown in the drawing, the anchor studs are spaced sufficiently far apart such that a practical reinforced concrete pad with embedded receptacles can be designed to carry the axial pull from the anchor studs without overstressing the enveloping concrete monolith. The design specification and supporting analyses in this FSAR are focused on qualifying the overpack structures, including the sector lugs and the anchor studs. The design of the ISFSI pad, and its anchor receptacle will vary from site to site, depending on the geology and seismological characteristics of the sub-terrain underlying the ISFSI pad region. The data provided in this FSAR, however, provide the complete set of factored loads to which the ISFSI pad, its sub-grade, and the anchor receptacles must be designed within the purview of ACI-349 [1.0.4]. Detailed requirements on the ISFSI pads for anchored casks are provided in Section 2.0.4.

1.2.1.2.2 HI-TRAC (Transfer Cask) - Standard Design

Like the storage overpack, the HI-TRAC transfer cask is a rugged, heavy-walled cylindrical vessel. The main structural function of the transfer cask is provided by carbon steel, and the main neutron and gamma shielding functions are provided by water and lead, respectively. The transfer cask is a steel, lead, steel layered cylinder with a water jacket attached to the exterior. Figure 1.2.9 provides a typical cross section of the standard design HI-TRAC-125 with the pool lid installed. See Section 1.2.1.2.3 for discussion of the optional HI-TRAC 100D and 125D designs.

The transfer cask provides an internal cylindrical cavity of sufficient size for housing an MPC. The top lid of the HI-TRAC 125 has additional neutron shielding to provide neutron attenuation in the vertical direction (from SNF in the MPC below). The MPC access hole through the HI-TRAC top lid is provided to allow the lowering/raising of the MPC between the HI-TRAC transfer cask, and the HI-STORM or HI-STAR overpacks. The standard design HI-TRAC (comprised of HI-TRAC 100 and HI-TRAC 125) is provided with two bottom lids, each used separately. The pool lid is bolted to the bottom flange of the HI-TRAC and is utilized during MPC fuel loading and sealing operations. In addition to providing shielding in the axial direction, the pool lid incorporates a seal that is designed to hold clean demineralized water in the HI-TRAC inner cavity, thereby preventing contamination of the exterior of the MPC by the contaminated fuel pool water. After the MPC has been drained, dried, and sealed, the pool lid is removed and the HI-TRAC transfer lid is attached (standard design only). The transfer lid incorporates two sliding doors that allow the opening of the HI-TRAC bottom for the MPC to be raised/lowered. Figure 1.2.10 provides a cross section of the HI-TRAC with the transfer lid installed.

In the standard design, trunnions are provided for lifting and rotating the transfer cask body between vertical and horizontal positions. The lifting trunnions are located just below the top flange and the pocket trunnions are located above the bottom flange. The two lifting trunnions are provided to lift and vertically handle the HI-TRAC, and the pocket trunnions provide a pivot point for the rotation of the HI-TRAC for downending or upending.

Two standard design HI-TRAC transfer casks of different weights are provided to house the MPCs. The HI-TRAC-125 weight does not exceed 125 tons during any loading or transfer operation. The HI-TRAC-100 weight does not exceed 100 tons during any loading or transfer operation. The internal cylindrical cavities of the two standard design HI-TRACs are identical. However, the external dimensions are different. The HI-TRAC-100 has a reduced thickness of lead and water shielding and consequently, the external dimensions are different. The structural steel thickness is identical in the two HI-TRACs. This allows most structural analyses of the HI-TRAC-125 to bound the HI-TRAC-100 design. Additionally, as the two HI-TRACs are identical except for a reduced thickness of lead and water, the HI-TRAC-125 has a larger thermal resistance than the smaller and lighter HI-TRAC-100. Therefore, for normal conditions the HI-TRAC-125 thermal analysis bounds that of the HI-TRAC-100. Separate shielding analyses are performed for each HI-TRAC since the shielding thicknesses are different between the two.

1.2.1.2.3 HI-TRAC 100D and 125D Transfer Casks

As an option to using either of the standard HI-TRAC transfer cask designs, users may choose to use the optional HI-TRAC 100D or 125D designs. Figure 1.2.9A provides a typical cross section of the HI-TRAC-125D with the pool lid installed. The HI-TRAC 100D (figure not shown) is similar to the HI-TRAC 125D except for the top lid (which contains no Holtite). Like the standard designs, the optional designs are designed and constructed in accordance with ASME III, Subsection NF, with certain NRC-approved alternatives, as discussed in Section 2.2.4. Functionally equivalent, the major differences between the HI-TRAC 100D and 125D designs and the standard designs are as follows:

- No pocket trunnions are provided for downending/upending
- The transfer lid is not required
- A new ancillary, the HI-STORM mating device (Figure 1.2.18) is required during MPC transfer operations
- A wider baseplate with attachment points for the mating device is provided
- The baseplate incorporates gussets for added structural strength
- The number of pool lid bolts is reduce

The interface between the MPC and the transfer cask is the same between the standard designs and the optional designs. The optional designs are capable of withstanding all loads defined in the design basis for the transfer cask during normal, off-normal, and accident modes of operation with adequate safety margins. In lieu of swapping the pool lid for the transfer lid to facilitate MPC transfer, the pool lids remain on the HI-TRAC 100D and 125D until MPC transfer is required. The HI-STORM mating device is located between, and secured with bolting (if required by seismic analysis), to the top of the HI-STORM overpack and the HI-TRAC 100D or 125D transfer cask. The mating device is used to remove the pool lid to provide a pathway for MPC transfer between the overpack and the transfer cask. Section 1.2.2.2 provides additional detail on the differences between the standard transfer cask designs and the optional HI-TRAC 100D or 125D designs during operations.

1.2.1.3 Shielding Materials

The HI-STORM 100 System is provided with shielding to ensure the radiation and exposure requirements in 10CFR72.104 and 10CFR72.106 are met. This shielding is an important factor in minimizing the personnel doses from the gamma and neutron sources in the SNF in the MPC for ALARA considerations during loading, handling, transfer, and storage. The fuel basket structure of edge-welded composite boxes and neutron absorber panels attached to the fuel storage cell vertical surfaces provide the initial attenuation of gamma and neutron radiation emitted by the radioactive spent fuel. The MPC shell, baseplate, lid and closure ring provide additional thicknesses of steel to further reduce the gamma flux at the outer canister surfaces.

In the HI-STORM storage overpack, the primary shielding in the radial direction is provided by concrete and steel. In addition, the storage overpack has a thick circular concrete slab attached to the lid, and the HI-STORM 100 and –100S have a thick circular concrete pedestal upon which the MPC rests. This concrete pedestal is not necessary in the HI-STORM 100S Version B overpack design. These slabs provide gamma and neutron attenuation in the axial direction. The thick overpack lid and concrete shielding integral to the lid provide additional gamma attenuation in the upward direction, reducing both direct radiation and skyshine. Several steel plate and shell elements provide additional gamma shielding as needed in specific areas, as well as incremental improvements in the overall shielding effectiveness. Gamma shield cross plates, as depicted in Figure 5.3.19, provide attenuation of scattered gamma radiation as it exits the inlet and outlet air ducts.

In the HI-TRAC transfer cask radial direction, gamma and neutron shielding consists of steel-lead-steel and water, respectively. In the axial direction, shielding is provided by the top lid, and the pool or transfer lid, as applicable. In the HI-TRAC pool lid, layers of steel-lead-steel provide an additional measure of gamma shielding to supplement the gamma shielding at the bottom of the MPC. In the transfer lid, layers of steel-lead-steel provide gamma attenuation. For the HI-TRAC 125 transfer lid, the neutron shield material, Holtite-A, is also provided. The HI-TRAC 125 and HI-TRAC 125D top lids are composed of steel-neutron shield-steel, with the neutron shield material being Holtite-A. The HI-TRAC 100 and HI-TRAC 100D top lids are composed of steel only providing gamma attenuation.

1.2.1.3.1 Fixed Neutron Absorbers

1.2.1.3.1.1 Boral™

Boral is a thermal neutron poison material composed of boron carbide and aluminum (aluminum powder and plate). Boron carbide is a compound having a high boron content in a physically stable and chemically inert form. The boron carbide contained in Boral is a fine granulated powder that conforms to ASTM C-750-80 nuclear grade Type III. The Boral cladding is made of alloy aluminum, a lightweight metal with high tensile strength which is protected from corrosion by a highly resistant oxide film. The two materials, boron carbide and aluminum, are chemically compatible and ideally suited for long-term use in the radiation, thermal, and chemical environment of a nuclear reactor, spent fuel pool, or dry cask.

The documented historical applications of Boral, in environments comparable to those in spent fuel pools and fuel storage casks, dates to the early 1950s (the U.S. Atomic Energy Commission's AE-6 Water-Boiler Reactor [1.2.2]). Technical data on the material was first printed in 1949, when the report "Boral: A New Thermal Neutron Shield" was published [1.2.3]. In 1956, the first edition of the Reactor Shielding Design Manual [1.2.4] was published and it contained a section on Boral and its properties.

In the research and test reactors built during the 1950s and 1960s, Boral was frequently the material of choice for control blades, thermal-column shutters, and other items requiring very good thermal-neutron absorption properties. It is in these reactors that Boral has seen its longest service in environments comparable to today's applications.

Boral found other uses in the 1960s, one of which was a neutron poison material in baskets used in the shipment of irradiated, enriched fuel rods from Canada's Chalk River laboratories to Savannah River. Use of Boral in shipping containers continues, with Boral serving as the poison in current British Nuclear Fuels Limited casks and the Storable Transport Cask by Nuclear Assurance Corporation [1.2.5].

Boral has been licensed by the NRC for use in numerous BWR and PWR spent fuel storage racks and has been extensively used in international nuclear installations.

Boral has been exclusively used in fuel storage applications in recent years. Its use in spent fuel pools as the neutron absorbing material can be attributed to its proven performance and several unique characteristics, such as:

- The content and placement of boron carbide provides a very high removal cross section for thermal neutrons.
- Boron carbide, in the form of fine particles, is homogeneously dispersed throughout the central layer of the Boral panels.
- The boron carbide and aluminum materials in Boral do not degrade as a result of long-term exposure to radiation.
- The neutron absorbing central layer of Boral is clad with permanently bonded surfaces of aluminum.
- Boral is stable, strong, durable, and corrosion resistant.

Boral absorbs thermal neutrons without physical change or degradation of any sort from the anticipated exposure to gamma radiation and heat. The material does not suffer loss of neutron attenuation capability when exposed to high levels of radiation dose.

Holtec International's QA Program ensures that Boral is manufactured under the control and surveillance of a Quality Assurance/Quality Control Program that conforms to the requirements of 10CFR72, Subpart G. Holtec International has procured over 200,000 panels of Boral from AAR Advanced Structures in over 30 projects. Boral has always been purchased with a minimum ^{10}B loading requirement. Coupons extracted from production runs were tested using the wet chemistry procedure. The actual ^{10}B loading, out of thousands of coupons tested, has never been found to fall below the design specification. The size of this coupon database is sufficient to provide reasonable assurance that all future Boral procurements will continue to yield Boral with full compliance with the stipulated minimum loading. Furthermore, the surveillance, coupon testing, and material tracking processes which have so effectively controlled the quality of Boral are expected to continue to yield Boral of similar quality in the future. Nevertheless, to add another layer of insurance, only 75% ^{10}B credit of the fixed neutron absorber is assumed in the criticality analysis consistent with Chapter 6.0, IV, 4.c of NUREG-1536, Standard Review Plan for Dry Cask Storage Systems.

Operating experience in nuclear plants with fuel loading of Boral equipped MPCs as well as laboratory test data indicate that the aluminium used in the manufacture of the Boral may react with water, resulting in the generation of hydrogen. The numerous variables (i.e., aluminium particle size, pool temperature, pool chemistry, etc.) that influence the extent of the hydrogen produced make it impossible to predict the amount of hydrogen that may be generated during MPC loading or unloading at a particular plant. Therefore, due to the variability in hydrogen generation from the Boral-water reaction, the operating procedures in Chapter 8 require monitoring for combustible gases and purging the space beneath the MPC lid during loading and unloading operations when an ignition event could occur (i.e., when the space beneath the MPC lid is open to the welding or cutting operation).

1.2.1.3.1.2 METAMIC®

METAMIC® is a neutron absorber material developed by the Reynolds Aluminum Company in the mid-1990s for spent fuel reactivity control in dry and wet storage applications. Metallurgically, METAMIC® is a metal matrix composite (MMC) consisting of a matrix of 6061 aluminum alloy reinforced with Type 1 ASTM C-750 boron carbide. METAMIC® is characterized by extremely fine aluminum (325 mesh or better) and boron carbide powder. Typically, the average B_4C particle size is between 10 and 15 microns. As described in the U.S. patents held by METAMIC, Inc.*†, the high performance and reliability of METAMIC® derives from the particle size distribution of its constituents, rendered into a metal matrix composite by the powder metallurgy process. This yields excellent and uniform homogeneity.

The powders are carefully blended without binders or other additives that could potentially adversely influence performance. The maximum percentage of B_4C that can be dispersed in the aluminum alloy 6061 matrix is approximately 40 wt.%, although extensive manufacturing and testing experience is limited to approximately 31 wt.%. The blend of powders is isostatically compacted into a green billet under high pressure and vacuum sintered to near theoretical density.

According to the manufacturer, billets of any size can be produced using this technology. The billet is subsequently extruded into one of a number of product forms, ranging from sheet and plate to angle, channel, round and square tube, and other profiles. For the METAMIC® sheets used in the MPCs, the extruded form is rolled down into the required thickness.

METAMIC® has been subjected to an extensive array of tests sponsored by the Electric Power Research Institute (EPRI) that evaluated the functional performance of the material at elevated temperatures (up to 900°F) and radiation levels (1E+11 rads gamma). The results of the tests documented in an EPRI report (Ref. [1.2.11]) indicate that METAMIC® maintains its physical and neutron absorption properties with little variation in its properties from the unirradiated state. The main conclusions provided in the above-referenced EPRI report are summarized below:

- The metal matrix configuration produced by the powder metallurgy process with a complete absence of open porosity in METAMIC® ensures that its density is essentially equal to the theoretical density.

- The physical and neutronic properties of METAMIC® are essentially unaltered under exposure to elevated temperatures (750° F - 900° F).

- No detectable change in the neutron attenuation characteristics under accelerated corrosion test conditions has been observed.

* U.S. Patent No. 5,965,829, "Radiation Absorbing Refractory Composition".
† U.S. Patent No. 6,042,779, "Extrusion Fabrication Process for Discontinuous Carbide Particulate Metal Matrix Composites and Super, Hypereutectic Al/Si."

In addition, independent measurements of boron carbide particle distribution show extremely small particle-to-particle distance† and near-perfect homogeneity.

An evaluation of the manufacturing technology underlying METAMIC® as disclosed in the above-referenced patents and of the extensive third-party tests carried out under the auspices of EPRI makes METAMIC® an acceptable neutron absorber material for use in the MPCs. Holtec's technical position on METAMIC® is also supported by the evaluation carried out by other organizations (see, for example, USNRC's SER on NUHOMS-61BT, Docket No. 72-1004).

Consistent with its role in reactivity control, all METAMIC® material procured for use in the Holtec MPCs will be qualified as important-to-safety (ITS) Category A item. ITS category A manufactured items, as required by Holtec's NRC-approved Quality Assurance program, must be produced to essentially preclude the potential of an error in the procurement of constituent materials and the manufacturing processes. Accordingly, material and manufacturing control processes must be established to eliminate the incidence of errors, and inspection steps must be implemented to serve as an independent set of barriers to ensure that all critical characteristics defined for the material by the cask designer are met in the manufactured product.

All manufacturing and in-process steps in the production of METAMIC® shall be carried out using written procedures. As required by the company's quality program, the material manufacturer's QA program and its implementation shall be subject to review and ongoing assessment, including audits and surveillances as set forth in the applicable Holtec QA procedures to ensure that all METAMIC® panels procured meet with the requirements appropriate for the quality genre of the MPCs. Additional details pertaining to the qualification and production tests for METAMIC® are summarized in Subsection 9.1.5.3.

Because of the absence of interconnected porosities, the time required to dehydrate a METAMIC®-equipped MPC is expected to be less compared to an MPC containing Boral.

NUREG/CR-5661 (Ref. [1.2.14]) recommends limiting poison material credit to 75% of the minimum ^{10}B loading because of concerns for potential "streaming" of neutrons, and allows for greater percentage credit in criticality analysis "if comprehensive acceptance tests, capable of verifying the presence and uniformity of the neutron absorber, are implemented". The value of 75% is characterized in NUREG/CR-5661 as a very conservative value, based on experiments with neutron poison containing relatively large B_4C particles, such as BORAL with an average particle size in excess of 100 microns. METAMIC®, however, has a much smaller particle size of typically between 10 and 15 microns on average. Any streaming concerns would therefore be drastically reduced.

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† Medium measured neighbor-to-neighbor distance is 10.08 microns according to the article, "METAMIC Neutron Shielding", by K. Anderson, T. Haynes, and R. Kazmier, EPRI Boraflex Conference, November 19-20, 1998.

Analyses performed by Holtec International show that the streaming due to particle size is practically non-existent in METAMIC®. Further, EPRI's neutron attenuation measurements on 31 and 15 B_4C weight percent METAMIC® showed that METAMIC® exhibits very uniform ^{10}B areal density. This makes it easy to reliably establish and verify the presence and microscopic and macroscopic uniformity of the ^{10}B in the material. Therefore, 90% credit is applied to the minimum ^{10}B areal density in the criticality calculations, i.e. a 10% penalty is applied. This 10% penalty is considered conservative since there are no significant remaining uncertainties in the ^{10}B areal density. In Chapter 9 the qualification and on production tests for METAMIC® to support 90% ^{10}B credit are specified. With 90% credit, the target weight percent of boron carbide in METAMIC® is 31 for all MPCs, as summarized in Table 1.2.8, consistent with the test coupons used in the EPRI evaluations [1.2.11]. The maximum permitted value is 33.0 wt% to allow for necessary fabrication flexibility.

Because METAMIC® is a solid material, there is no capillary path through which spent fuel pool water can penetrate METAMIC® panels and chemically react with aluminum in the interior of the material to generate hydrogen. Any chemical reaction of the outer surfaces of the METAMIC® neutron absorber panels with water to produce hydrogen occurs rapidly and reduces to an insignificant amount in a short period of time. Nevertheless, combustible gas monitoring for METAMIC® -equipped MPCs and purging the space under the MPC lid during welding and cutting operations, is required until sufficient field experience is gained that confirms that little or no hydrogen is released by METAMIC® during these operations.

Mechanical properties of 31 wt.% METAMIC® based on coupon tests of the material in the as-fabricated condition and after 48 hours of an elevated temperature state at 900°F are summarized below from the EPRI report [1.2.11].

Mechanical Properties of 31wt.% B_4C METAMIC		
Property	As-Fabricated	After 48 hours of 900°F Temperature Soak
Yield Strength (psi)	32937 ± 3132	28744 ± 3246
Ultimate Strength (psi)	40141 ± 1860	34608 ± 1513
Elongation (%)	1.8 ± 0.8	5.7 ± 3.1

The required flexural strain of the neutron absorber to ensure that it will not fracture when the supporting basket wall flexes due to the worst case lateral loading is 0.2%, which is the flexural strain of the Alloy X basket panel material. The 1% minimum elongation of 31wt.% B_4C METAMIC® indicated by the above table means that a large margin of safety against cracking exists, so there is no need to perform testing of the METAMIC® for mechanical properties.

EPRI's extensive characterization effort [1.2.11], which was focused on 15 and 31 wt.% B_4C METAMIC® served as the principal basis for a recent USNRC SER for 31wt.% B_4C METAMIC for used in wet storage [1.2.12]. Additional studies on METAMIC® [1.2.13], EPRI's and others work provide the confidence that 31wt.% B_4C METAMIC® will perform its intended function in the

MPCs.

1.2.1.3.1.3 Locational Fixity of Neutron Absorbers

Both Boral and METAMIC® neutron absorber panels are completely enclosed in Alloy X (stainless steel) sheathing that is stitch welded to the MPC basket cell walls along their entire periphery. The edges of the sheathing are bent toward the cell wall to make the edge weld. Thus, the neutron absorber is contained in a tight, welded pocket enclosure. The shear strength of the pocket weld joint, which is an order of magnitude greater than the weight of a fuel assembly, guarantees that the neutron absorber and its enveloping sheathing pocket will maintain their as-installed position under all loading, storage, and transient evolutions. Finally, the pocket joint detail ensures that fuel assembly insertion or withdrawal into or out of the MPC basket will not lead to a disconnection of the sheathing from the cell wall.

1.2.1.3.2 Neutron Shielding

The specification of the HI-STORM overpack and HI-TRAC transfer cask neutron shield material is predicated on functional performance criteria. These criteria are:

- Attenuation of neutron radiation to appropriate levels;
- Durability of the shielding material under normal conditions, in terms of thermal, chemical, mechanical, and radiation environments;
- Stability of the homogeneous nature of the shielding material matrix;
- Stability of the shielding material in mechanical or thermal accident conditions to the desired performance levels; and
- Predictability of the manufacturing process under adequate procedural control to yield an in-place neutron shield of desired function and uniformity.

Other aspects of a shielding material, such as ease of handling and prior nuclear industry use, are also considered, within the limitations of the main criteria. Final specification of a shield material is a result of optimizing the material properties with respect to the main criteria, along with the design of the shield system, to achieve the desired shielding results.

Neutron attenuation in the HI-STORM overpack is provided by the thick walls of concrete contained in the steel vessel, lid, and pedestal (only for the HI-STORM 100 and –100S overpack designs). Concrete is a shielding material with a long proven history in the nuclear industry. The concrete composition has been specified to ensure its continued integrity at the long term temperatures required for SNF storage.

The HI-TRAC transfer cask is equipped with a water jacket providing radial neutron shielding.

Demineralized water will be utilized in the water jacket. To ensure operability for low temperature conditions, ethylene glycol (25% in solution) will be added to reduce the freezing point for low temperature operations (e.g., below 32°F) [1.2.7].

Neutron shielding in the HI-TRAC 125 and 125D transfer casks in the axial direction is provided by Holtite-A within the top lid. HI-TRAC 125 also contains Holtite-A in the transfer lid. Holtite-A is a poured-in-place solid borated synthetic neutron-absorbing polymer. Holtite-A is specified with a nominal B_4C loading of 1 weight percent for the HI-STORM 100 System. Appendix 1.B provides the Holtite-A material properties germane to its function as a neutron shield. Holtec has performed confirmatory qualification tests on Holtite-A under the company's QA program.

In the following, a brief summary of the performance characteristics and properties of Holtite-A is provided.

<u>Density</u>

The specific gravity of Holtite-A is 1.68 g/cm^3 as specified in Appendix 1.B. To conservatively bound any potential weight loss at the design temperature and any inability to reach the theoretical density, the density is reduced by 4% to 1.61 g/cm^3. The density used for the shielding analysis is conservatively assumed to be 1.61 g/cm^3 to underestimate the shielding capabilities of the neutron shield.

<u>Hydrogen</u>

The weight concentration of hydrogen is 6.0%. However, all shielding analyses conservatively assume 5.9% hydrogen by weight in the calculations.

<u>Boron Carbide</u>

Boron carbide dispersed within Holtite-A in finely dispersed powder form is present in 1% (nominal) weight concentration. Holtite-A may be specified with a B_4C content of up to 6.5 weight percent. For the HI-STORM 100 System, Holtite-A is specified with a nominal B_4C weight percent of 1%.

<u>Design Temperature</u>

The design temperatures of Holtite-A are provided in Table 1.B.1.. The maximum spatial temperatures of Holtite-A under all normal operating conditions must be demonstrated to be below these design temperatures, as applicable.

<u>Thermal Conductivity</u>

The Holtite-A neutron shielding material is stable below the design temperature for the long term and provides excellent shielding properties for neutrons. A conservative, lower bound conductivity is stipulated for use in the thermal analyses of Chapter 4 (Section 4.2) based on information in the technical literature.

1.2.1.3.3 Gamma Shielding Material

For gamma shielding, the HI-STORM 100 storage overpack primarily relies on massive concrete sections contained in a robust steel vessel. A carbon steel plate, the shield shell, is located adjacent to the overpack inner shell to provide additional gamma shielding (Figure 1.2.7)†. Carbon steel supplements the concrete gamma shielding in most portions of the storage overpack, most notably the pedestal (HI-STORM 100 and –100S overpack designs only) and the lid. To reduce the radiation streaming through the overpack air inlets and outlets, gamma shield cross plates are installed in the ducts (Figures 1.2.8 and 1.2.8A) to scatter the radiation. This scattering acts to significantly reduce the local dose rates adjacent to the overpack air inlets and outlets. See Figure 5.3.19 and the drawings in Section 1.5 for more details of the gamma shield cross plate designs for each overpack design.

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.

1.2.1.4 Lifting Devices

Lifting of the HI-STORM 100 System may be accomplished either by attachment at the top of the storage overpack ("top lift"), as would typically be done with a crane, or by attachment at the bottom ("bottom lift"), as would be effected by a number of lifting/handling devices.

For a top lift, the storage overpack is equipped with four threaded anchor blocks arranged circumferentially around the overpack. These anchor blocks are used for overpack lifting as well as securing the overpack lid to the overpack body. The storage overpack may be lifted with a lifting device that engages the anchor blocks with threaded studs and connects to a crane or similar equipment.

A bottom lift of the HI-STORM 100 storage overpack is affected by the insertion of four hydraulic jacks underneath the inlet vent horizontal plates (Figure 1.2.1). A slot in the overpack baseplate allows the hydraulic jacks to be placed underneath the inlet vent horizontal plate. The hydraulic jacks lift the loaded overpack to provide clearance for inserting or removing a device for transportation.

The standard design HI-TRAC transfer cask is equipped with two lifting trunnions and two pocket trunnions. The HI-TRAC 100D and 125D are equipped with only lifting trunnions. The lifting trunnions are positioned just below the top forging. The two pocket trunnions are located above the bottom forging and attached to the outer shell. The pocket trunnions are designed to allow rotation of the HI-TRAC. All trunnions are built from a high strength alloy with proven corrosion and non-galling characteristics. The lifting trunnions are designed in accordance with NUREG-0612 and ANSI N14.6. The lifting trunnions are installed by threading into tapped holes just below the top forging.

† The shield shell design feature was deleted in June, 2001 after overpack serial number 7 was fabricated.

The top of the MPC lid is equipped with four threaded holes that allow lifting of the loaded MPC. These holes allow the loaded MPC to be raised/lowered through the HI-TRAC transfer cask using lifting cleats. The threaded holes in the MPC lid are designed in accordance with NUREG-0612 and ANSI N14.6.

1.2.1.5 Design Life

The design life of the HI-STORM 100 System is 40 years. This is accomplished by using material of construction with a long proven history in the nuclear industry and specifying materials known to withstand their operating environments with little to no degradation. A maintenance program, as specified in Chapter 9, is also implemented to ensure the HI-STORM 100 System will exceed its design life of 40 years. The design considerations that assure the HI-STORM 100 System performs as designed throughout the service life include the following:

HI-STORM Overpack and HI-TRAC Transfer Cask

- Exposure to Environmental Effects
- Material Degradation
- Maintenance and Inspection Provisions

MPC

- Corrosion
- Structural Fatigue Effects
- Maintenance of Helium Atmosphere
- Allowable Fuel Cladding Temperatures
- Neutron Absorber Boron Depletion

The adequacy of the HI-STORM 100 System for its design life is discussed in Sections 3.4.11 and 3.4.12.

1.2.2 Operational Characteristics

1.2.2.1 Design Features

The HI-STORM 100 System incorporates some unique design improvements. These design innovations have been developed to facilitate the safe long term storage of SNF. Some of the design originality is discussed in Subsection 1.2.1 and below.

The free volume of the MPCs is inerted with 99.995% pure helium gas during the spent nuclear fuel loading operations. Table 1.2.2 specifies the helium fill requirements for the MPC internal cavity.

The HI-STORM overpack has been designed to synergistically combine the benefits of steel and concrete. The steel-concrete-steel construction of the HI-STORM overpack provides ease of fabrication, increased strength, and an optimal radiation shielding arrangement. The concrete is primarily provided for radiation shielding and the steel is primarily provided for structural functions.

The strength of concrete in tension and shear is conservatively neglected. Only the compressive strength of the concrete is accounted for in the analyses.

The criticality control features of the HI-STORM 100 are designed to maintain the neutron multiplication factor k-effective (including uncertainties and calculational bias) at less than 0.95 under all normal, off-normal, and accident conditions of storage as analyzed in Chapter 6. This level of conservatism and safety margins is maintained, while providing the highest storage capacity.

1.2.2.2 Sequence of Operations

Table 1.2.6 provides the basic sequence of operations necessary to defuel a spent fuel pool using the HI-STORM 100 System. The detailed sequence of steps for storage-related loading and handling operations is provided in Chapter 8 and is supported by the drawings in Section 1.5. A summary of the general actions needed for the loading and unloading operations is provided below. Figures 1.2.16 and 1.2.17 provide a pictorial view of typical loading and unloading operations, respectively.

Loading Operations

At the start of loading operations, the HI-TRAC transfer cask is configured with the pool lid installed. The HI-TRAC water jacket is filled with demineralized water or a 25% ethylene glycol solution depending on the ambient temperature conditions. The lift yoke is used to position HI-TRAC in the designated preparation area or setdown area for HI-TRAC inspection and MPC insertion. The annulus is filled with plant demineralized water, and an inflatable annulus seal is installed. The inflatable seal prevents contact between spent fuel pool water and the MPC shell reducing the possibility of contaminating the outer surfaces of the MPC. The MPC is then filled with water (borated if necessary). Based on the MPC model and fuel enrichment, this may be borated water or plant demineralized water (see Section 2.1). HI-TRAC and the MPC are lowered into the spent fuel pool for fuel loading using the lift yoke. Pre-selected assemblies are loaded into the MPC and a visual verification of the assembly identification is performed.

While still underwater, a thick shielding lid (the MPC lid) is installed. The lift yoke is remotely engaged to the HI-TRAC lifting trunnions and is used to lift the HI-TRAC close to the spent fuel pool surface. As an ALARA measure, dose rates are measured on the top of the HI-TRAC and MPC prior to removal from the pool to check for activated debris on the top surface. The MPC lift bolts (securing the MPC lid to the lift yoke) are removed. As HI-TRAC is removed from the spent fuel pool, the lift yoke and HI-TRAC are sprayed with demineralized water to help remove contamination.

HI-TRAC is removed from the pool and placed in the designated preparation area. The top surfaces of the MPC lid and the upper flange of HI-TRAC are decontaminated. The inflatable annulus seal is removed, and an annulus shield is installed. The annulus shield provides additional personnel shielding at the top of the annulus and also prevents small items from being dropped into the annulus. The Automated Welding System baseplate shield (if used) is installed to reduce dose rates around the top of the cask. The MPC water level is lowered slightly and the MPC lid is seal-welded using the Automated Welding System (AWS) or other approved welding process. Liquid penetrant examinations are performed on the root and final passes. A multi-layer liquid penetrant or volumetric examination is also performed on the MPC lid-to-shell weld. The MPC water is displaced from the MPC by blowing pressurized helium or nitrogen gas into the vent port of the MPC, thus displacing the water through the drain line. At the appropriate time in the sequence of activities, based on the type of test performed (hydrostatic or pneumatic), a pressure test of the MPC enclosure vessel is performed.

For MPCs containing all moderate burnup fuel, a Vacuum Drying System (VDS) may be used to remove moisture from the MPC cavity. The VDS is connected to the MPC and is used to remove liquid water from the MPC in a stepped evacuation process. The stepped evacuation process is used to preclude the formation of ice in the MPC and Vacuum Drying System lines. The internal pressure is reduced and held for a duration to ensure that all liquid water has evaporated. This process is continued until the pressure in the MPC meets the technical specification limit and can be held there for the required amount of time.

For storage of high burnup fuel and as an option for storage of moderate burnup fuel, the reduction of residual moisture in the MPC to trace amounts is accomplished using a Forced Helium Dehydration (FHD) system, as described in Appendix 2.B. Relatively warm and dry helium is recirculated through the MPC cavity, which helps maintain the SNF in a cooled condition while moisture is being removed. The warm, dry gas is supplied to the MPC drain port and circulated through the MPC cavity where it absorbs moisture. The humidified gas travels out of the MPC and through appropriate equipment to cool and remove the absorbed water from the gas. The dry gas may be heated prior to its return to the MPC in a closed loop system to accelerate the rate of moisture removal in the MPC. This process is continued until the temperature of the gas exiting the demoisturizing module described in Appendix 2.B meets the specified limit.

Following moisture removal, the MPC is backfilled with a predetermined amount of helium gas. The helium backfill ensures adequate heat transfer during storage and provides an inert atmosphere for long-term fuel integrity. Cover plates are installed and seal-welded over the MPC vent and drain ports with liquid penetrant examinations performed on the root and final passes. The cover plates are helium leakage tested to confirm that they meet the established leakage rate criteria.

The MPC closure ring is then placed on the MPC, aligned, tacked in place, and seal welded, providing redundant closure of the MPC lid and cover plates confinement closure welds. Tack welds are visually examined, and the root and final welds are inspected using the liquid penetrant examination technique to ensure weld integrity. The annulus shield is removed and the remaining water in the annulus is drained. The AWS Baseplate shield is removed. The MPC lid and accessible areas of the top of the MPC shell are smeared for removable contamination and HI-TRAC dose rates are measured. The HI-TRAC top lid is installed and the bolts are torqued. The MPC lift cleats are installed on the MPC lid. The MPC lift cleats are the primary lifting point of the MPC.

Rigging is installed between the MPC lift cleats and the lift yoke. . The rigging supports the MPC within HI-TRAC while the pool lid is replaced with the transfer lid. For the standard design transfer cask, the HI-TRAC is manipulated to replace the pool lid with the transfer lid. The MPC lift cleats and rigging support the MPC during the transfer operations.

MPC transfer from the HI-TRAC transfer cask into the overpack may be performed inside or outside the fuel building. Similarly, HI-TRAC and HI-STORM may be transferred to the ISFSI in several different ways. The loaded HI-TRAC may be handled in the vertical or horizontal orientation. The loaded HI-STORM can only be handled vertically.

For MPC transfers inside the fuel building, the empty HI-STORM overpack is inspected and staged with the lid removed, the alignment device positioned, and, for the HI-STORM 100 overpack, the vent duct shield inserts installed. If using HI-TRAC 100D or 125D, the HI-STORM mating device is placed (bolted if required by generic or site specific seismic evaluation) to the top of the empty overpack (Figure 1.2.18). The loaded HI-TRAC is placed using the fuel building crane on top of HI-STORM, or the mating device, as applicable. After the HI-TRAC is positioned atop the HI-STORM or positioned (bolted if required by generic or site specific seismic evaluation) atop the mating device, as applicable, the MPC is raised slightly. With the standard HI-TRAC design, the transfer lid door locking pins are removed and the doors are opened. With the HI-TRAC 100D and 125D, the pool lid is removed using the mating device. The MPC is lowered into HI-STORM. Following verification that the MPC is fully lowered, slings are disconnected and lowered onto the MPC lid. For the HI-STORM 100, the doors are closed and the HI-TRAC is prepared for removal from on top of HI-STORM (with HI-TRAC 100D and 125D, the transfer cask must first be disconnected from the mating device). For the HI-STORM 100S and HI-STORM 100S Version B, the standard design HI-TRAC may need to be lifted above the overpack to a height sufficient to allow closure of the transfer lid doors without interfering with the MPC lift cleats. The HI-TRAC is then removed and placed in its designated storage location. The MPC lift cleats and slings are removed from atop the MPC. The alignment device, vent duct shield inserts, and/or mating device is/are removed, as applicable. The pool lid is removed from the mating device and re-attached to the HI-TRAC 100D or 125D prior to its next use. The HI-STORM lid is installed, and the upper vent screens and gamma shield cross plates are installed. The HI-STORM lid studs are installed and torqued.

For MPC transfers outside of the fuel building, the empty HI-STORM overpack is inspected and staged with the lid removed, the alignment device positioned, and, for the HI-STORM 100, the vent duct shield inserts installed. For HI-TRAC 100D and 125D, the mating device is positioned (bolted if required by generic or site specific seismic evaluation) atop the overpack. The loaded HI-TRAC is transported to the cask transfer facility in the vertical or horizontal orientation. A number of methods may be utilized as long as the handling limitations prescribed in the technical specifications are not exceeded.

To place the loaded HI-TRAC in a horizontal orientation, a transport frame or "cradle" is utilized. If the cradle is equipped with rotation trunnions they are used to engage the HI-TRAC 100 or 125 pocket trunnions. While the loaded HI-TRAC is lifted by the lifting trunnions, the HI-TRAC is lowered onto the cradle rotation trunnions. Then, the crane lowers and the HI-TRAC pivots around the pocket trunnions and is placed in the horizontal position in the cradle.

The HI-TRAC 100D and 125D do not include pocket trunnions in their designs. Therefore, the user must downend the transfer cask onto the transport frame using appropriately designed rigging in accordance with the site's heavy load control program.

If the loaded HI-TRAC is transferred to the cask transfer facility in the horizontal orientation, the HI-TRAC transport frame and/or cradle are placed on a transport vehicle. The transport vehicle may be an air pad, railcar, heavy-haul trailer, dolly, etc. If the loaded HI-TRAC is transferred to the cask transfer facility in the vertical orientation, the HI-TRAC may be lifted by the lifting trunnions or seated on the transport vehicle. During the transport of the loaded HI-TRAC, standard plant heavy load handling practices shall be applied including administrative controls for the travel path and tie-down mechanisms.

For MPCs containing any HBF and a decay heat load that would yield a peak HBF cladding temperature above the long-term temperature limit, the Supplemental Cooling System (SCS) is required to be operational during the time the loaded and backfilled MPC is in HI-TRAC to ensure fuel cladding temperatures remain within limits. The SCS is discussed in detail in Section 4.5 and the design criteria for the system are provided in Appendix 2.C. The SCS is not required when the MPC is inside the HI-STORM overpack, regardless of decay heat load.

After the loaded HI-TRAC arrives at the cask transfer facility, the HI-TRAC is upended by a crane if the HI-TRAC is in a horizontal orientation. The loaded HI-TRAC is then placed, using the crane located in the transfer area, on top of HI-STORM, which has been inspected and staged with the lid removed, vent duct shield inserts installed, the alignment device positioned, and the mating device installed, as applicable.

After the HI-TRAC is positioned atop the HI-STORM or the mating device, the MPC is raised slightly. In the standard design, the transfer lid door locking pins are removed and the doors are opened. With the HI-TRAC 100D and 125D, the pool lid is removed using the mating device. The MPC is lowered into HI-STORM. Following verification that the MPC is fully lowered, slings are disconnected and lowered onto the MPC lid. For the HI-STORM 100, the doors are closed and HI-TRAC is removed from on top of HI-STORM or disconnected from the mating device, as applicable. For the HI-STORM 100S and the HI-STORM 100S Version B, the standard design HI-TRAC may need to be lifted above the overpack to a height sufficient to allow closure of the transfer lid doors without interfering with the MPC lift cleats. The HI-TRAC is then removed and placed in its designated storage location. The MPC lift cleats and slings are removed from atop the MPC. The alignment device, vent duct shield inserts, and mating device is/are removed, as applicable. The pool lid is removed from the mating device and re-attached to the HI-TRAC 100D or 125D prior to its next use. The HI-STORM lid is installed, and the upper vent screens and gamma shield cross plates are installed. The HI-STORM lid studs and nuts are installed.

After the HI-STORM has been loaded either within the fuel building or at a dedicated cask transfer facility, the HI-STORM is then moved to its designated position on the ISFSI pad. The HI-STORM overpack may be moved using a number of methods as long as the handling limitations listed in the technical specifications are not exceeded. The loaded HI-STORM must be handled in the vertical orientation, and may be lifted from the top by the anchor blocks or from the bottom by the inlet vents. After the loaded HI-STORM is lifted, it may be placed on a transport mechanism or continue to be lifted by the lid studs and transported to the storage location. The transport mechanism may be an air pad, crawler, railcar, heavy-haul trailer, dolly, etc. During the transport of the loaded HI-STORM, standard plant heavy load handling practices shall be applied including administrative controls for the travel path and tie-down mechanisms. Once in position at the storage pad, vent operability testing is performed to ensure that the system is functioning within its design parameters.

In the case of HI-STORM 100A, the anchor studs are installed and fastened into the anchor receptacles in the ISFSI pad in accordance with the design requirements.

Unloading Operations

The HI-STORM 100 System unloading procedures describe the general actions necessary to prepare the MPC for unloading, cool the stored fuel assemblies in the MPC, flood the MPC cavity, remove the lid welds, unload the spent fuel assemblies, and recover HI-TRAC and empty the MPC. Special precautions are outlined to ensure personnel safety during the unloading operations, and to prevent the risk of MPC overpressurization and thermal shock to the stored spent fuel assemblies.

The MPC is recovered from HI-STORM either at the cask transfer facility or the fuel building using any of the methodologies described in Section 8.1. The HI-STORM lid is removed, the alignment device positioned, and, for the HI-STORM 100, the vent duct shield inserts are installed, and the MPC lift cleats are attached to the MPC. For HI-TRAC 100D and 125D, the mating device is installed. Rigging is attached to the MPC lift cleats. For the HI-STORM 100S and HI-STORM 100S Version B with the standard HI-TRAC design, the transfer doors may need to be opened to avoid interfering with the MPC lift cleats. For the HI-TRAC 100D and 125D, the mating device (possibly containing the pool lid) is secured to the top of the overpack. HI-TRAC is raised and positioned on top of HI-STORM or bolted (if necessary) to the mating device, as applicable. For the HI-TRAC 100D and 125D, the pool lid is ensured to be out of the transfer path for the MPC. The MPC is raised into HI-TRAC. Once the MPC is raised into HI-TRAC, the standard design HI-TRAC transfer lid doors are closed and the locking pins are installed. For the HI-TRAC 100D and 125D, the pool lid is installed and the transfer cask is unsecured from the mating device. HI-TRAC is removed from on top of HI-STORM. As required based on the presence of high burnup fuel and the decay heat load, the Supplemental Cooling System is installed and placed into operation.

The HI-TRAC is brought into the fuel building and, for the standard design, manipulated for bottom lid replacement. The transfer lid is replaced with the pool lid. The MPC lift cleats and rigging support the MPC during lid transfer operations.

HI-TRAC and its enclosed MPC are returned to the designated preparation area and the rigging, MPC lift cleats, and HI-TRAC top lid are removed. The annulus is filled with plant demineralized water (borated, if necessary). The annulus and HI-TRAC top surfaces are protected from debris that will be produced when removing the MPC lid.

The MPC closure ring and vent and drain port cover plates are core drilled. Local ventilation is established around the MPC ports. The RVOAs are attached to the vent and drain port. The RVOAs allow access to the inner cavity of the MPC, while providing a hermetic seal. The MPC is flooded with borated or unborated water, as required. The MPC lid-to-MPC shell weld is removed. Then, all weld removal equipment is removed with the MPC lid left in place.

The MPC lid is rigged to the lift yoke and the lift yoke is engaged to HI-TRAC lifting trunnions. If weight limitations require, the neutron shield jacket is drained. HI-TRAC is placed in the spent fuel pool and the MPC lid is removed. All fuel assemblies are returned to the spent fuel storage racks and the MPC fuel cells are vacuumed to remove any assembly debris. HI-TRAC and MPC are returned to the designated preparation area where the MPC water is removed. The annulus water is drained and the MPC and HI-TRAC are decontaminated in preparation for re-utilization.

1.2.2.3 Identification of Subjects for Safety and Reliability Analysis

1.2.2.3.1 Criticality Prevention

Criticality is controlled by geometry and neutron absorbing materials in the fuel basket. The MPC-24/24E/24EF (all with lower enriched fuel) and the MPC-68/68F/68FF do not rely on soluble boron credit during loading or the assurance that water cannot enter the MPC during storage to meet the stipulated criticality limits.

Each MPC model is equipped with neutron absorber plates affixed to the fuel cell walls as shown on the drawings in Section 1.5. The minimum ^{10}B areal density specified for the neutron absorber in each MPC model is shown in Table 1.2.2. These values are chosen to be consistent with the assumptions made in the criticality analyses.

The MPC-24, MPC-24E and 24EF (all with higher enriched fuel) and the MPC-32 and MPC-32F take credit for soluble boron in the MPC water for criticality prevention during wet loading and unloading operations. Boron credit is only necessary for these PWR MPCs during loading and unloading operations that take place under water. During storage, with the MPC cavity dry and sealed from the environment, criticality control measures beyond the fixed neutron poisons affixed to the storage cell walls are not necessary because of the low reactivity of the fuel in the dry, helium filled canister and the design features that prevent water from intruding into the canister during storage.

1.2.2.3.2 Chemical Safety

There are no chemical safety hazards associated with operations of the HI-STORM 100 dry storage system. A detailed evaluation is provided in Section 3.4.

1.2.2.3.3 Operation Shutdown Modes

The HI-STORM 100 System is totally passive and consequently, operation shutdown modes are unnecessary. Guidance is provided in Chapter 8, which outlines the HI-STORM 100 unloading procedures, and Chapter 11, which outlines the corrective course of action in the wake of postulated accidents.

1.2.2.3.4 Instrumentation

As stated earlier, the HI-STORM 100 confinement boundary is the MPC, which is seal welded, non-destructively examined and pressure tested. The HI-STORM 100 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. At the option of the user, temperature elements may be utilized to monitor the air temperature of the HI-STORM overpack exit vents in lieu of routinely inspecting the ducts for blockage. See Subsection 2.3.3.2 for additional details.

1.2.2.3.5 Maintenance Technique

Because of their passive nature, the HI-STORM 100 System requires minimal maintenance over its lifetime. No special maintenance program is required. Chapter 9 describes the acceptance criteria and maintenance program set forth for the HI-STORM 100.

1.2.3 Cask Contents

The HI-STORM 100 System is designed to house different types of MPCs. The MPCs are designed to store both BWR and PWR spent nuclear fuel assemblies. Tables 1.2.1 and 1.2.2 provide 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 Table 1.0.1. A summary of the types of fuel authorized for storage in each MPC model is provided below. All fuel assemblies, non-fuel hardware, and neutron sources 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.

MPC-24

The MPC-24 is designed to accommodate up to twenty-four (24) PWR fuel assemblies classified as intact fuel assemblies, with or without non-fuel hardware.

MPC 24E and MPC-24EF

The MPC-24E and MPC-24EF are designed to accommodate up to twenty-four (24) PWR fuel assemblies, with or without non-fuel hardware. Up to four (4) fuel assemblies may be classified as damaged fuel assemblies or fuel debris, with the balance being classified as intact fuel assemblies. Damaged fuel assemblies and fuel debris must be stored in fuel storage locations 3, 6, 19, and/or 22 (see Figure 1.2.4).

MPC-32 and MPC-32F

The MPC-32 and MPC-32F are designed to store up to thirty two (32) PWR fuel assemblies with or without non-fuel hardware. Up to eight (8) of these assemblies may be classified as damaged fuel assemblies or fuel debris, with the balance being classified as intact fuel assemblies. Damaged fuel assemblies and fuel debris must be stored in fuel storage locations 1, 4, 5, 10, 23, 28, 29, and/or 32 (see Figure 1.2.3).

MPC-68F

The MPC-68F is designed to accommodate up to sixty-eight (68) Dresden Unit 1 or Humboldt Bay BWR fuel assemblies (with or without channels) made up of any combination of fuel assemblies classified as intact fuel assemblies, damaged fuel assemblies, and up to four (4) fuel assemblies classified as fuel debris.

MPC-68 and MPC-68FF

The MPC-68 and MPC-68FF are designed to accommodate up to sixty-eight (68) BWR fuel assemblies with or without channels. Any number of these fuel assemblies may be Dresden Unit 1 or Humboldt Bay BWR fuel assemblies classified as intact fuel or damaged fuel. Dresden Unit 1 and Humboldt Bay fuel debris is limited to eight (8) DFCs. DFCs containing Dresden Unit 1 or Humboldt Bay fuel debris may be stored in any fuel storage location. For BWR fuel assemblies from plants other than Dresden Unit 1 and Humboldt Bay, the total number of fuel assemblies classified as damaged fuel assemblies or fuel debris is limited to sixteen (16), with up to eight (8) of the 16 fuel assemblies classified as fuel debris. These fuel assemblies must be stored in fuel storage locations 1, 2, 3, 8, 9, 16, 25, 34, 35, 44, 53, 60, 61, 66, 67, and/or 68 (see Figure 1.2.2). The balance of the fuel storage locations may be filled with intact BWR fuel assemblies, up to a total of 68.

Table 1.2.1

KEY SYSTEM DATA FOR HI-STORM 100 SYSTEM

ITEM	QUANTITY	NOTES
Types of MPCs	8	5 for PWR 3 for BWR
MPC storage capacity†:	MPC-24 MPC-24E MPC-24EF	Up to 24 intact ZR or stainless steel clad PWR fuel assemblies with or without non-fuel hardware. Up to four damaged fuel assemblies and/or fuel assemblies classified as fuel debris may be stored in the MPC-24E or MPC-24EF OR
	MPC-32 MPC-32F	Up to 32 intact ZR or stainless steel clad PWR fuel assemblies with or without non-fuel hardware. Up to 8 damaged fuel assemblies and/or fuel assemblies classified as fuel debris may be stored in the MPC-32 or MPC-32F.

† See Section 2.1 for a complete description of authorized cask contents and fuel specifications.

Table 1.2.1 (continued)
KEY SYSTEM DATA FOR HI-STORM 100 SYSTEM

ITEM	QUANTITY	NOTES
MPC storage capacity:	MPC-68F	Up to 4 damaged fuel containers with ZR clad Dresden Unit 1 (D-1) or Humboldt Bay (HB) BWR fuel debris and the complement damaged ZR clad Dresden Unit 1 or Humboldt Bay BWR fuel assemblies in damaged fuel containers or intact Dresden Unit 1 or Humboldt Bay BWR intact fuel assemblies. OR
	MPC-68 MPC-68FF	Up to 68 Dresden Unit 1 or Humboldt Bay intact fuel or damaged fuel and up to 8 damaged fuel containers containing D-1 or HB fuel debris. For other BWR plants, up to 16 damaged fuel containers containing BWR damaged fuel and/or fuel debris with the complement intact fuel assemblies, up to a total of 68. The number of damaged fuel containers containing BWR fuel debris is limited to eight (8) for all BWR plants.

Table 1.2.2

KEY PARAMETERS FOR HI-STORM 100 MULTI-PURPOSE CANISTERS

	PWR	BWR
Pre-disposal service life (years)	40	40
Design temperature, max./min. (°F)	725°[†]/-40°[††]	725°[†]/-40°[††]
Design internal pressure (psig) Normal conditions Off-normal conditions Accident Conditions	 100 110 200	 100 110 200
Total heat load, max. (kW)	36.9	36.9
Maximum permissible peak fuel cladding temperature: Long Term Normal (°F) Short Term Operations (°F) Off-normal and Accident (°F)	 752 752 or 1058[†††] 1058	 752 752 or 1058[†††] 1058

† Maximum normal condition design temperatures for the MPC fuel basket. A complete listing of design temperatures for all components is provided in Table 2.2.3.

†† Temperature based on off-normal minimum environmental temperatures specified in Section 2.2.2.2 and no fuel decay heat load.

††† See Section 4.5 for discussion of the applicability of the 1058°F temperature limit during MPC drying.

Table 1.2.2 (cont'd)

KEY PARAMETERS FOR HI-STORM 100 MULTI-PURPOSE CANISTERS

	PWR	BWR
MPC internal environment Helium fill (99.995% fill helium purity) (See Note 2)	(all pressure ranges are at a reference temperature of 70°F)	(all pressure ranges are at a reference temperature of 70°F)
MPC-24 (heat load ≤ 27.77 kW)	≥ 29.3 psig and ≤ 48.5 psig OR 0.1212 +/-10% g-moles/liter	
(heat load > 27.77 kW)	≥ 45.5 psig and ≤ 48.5 psig	
MPC-24E/24EF (heat load ≤ 28.17 kW)	≥ 29.3 psig and ≤ 48.5 psig OR 0.1212 +/-10% g-moles/liter	
(heat load > 28.17 kW)	≥ 45.5 psig and ≤ 48.5 psig	
MPC-68/68F/68FF (heat load ≤ 28.19 kW)		≥ 29.3 psig and ≤ 48.5 psig OR 0.1218 +/-10% g-moles/liter
(heat load >28.19 kW)		≥ 45.5 psig and ≤ 48.5 psig
MPC-32/32F (heat load ≤ 28.74 kW)	≥ 29.3 psig and ≤ 48.5 psig	
(heat load >28.74 kW)	≥ 45.5 psig and ≤ 48.5 psig	
Maximum permissible multiplication factor (k_{eff}) including all uncertainties and biases	< 0.95	< 0.95
Fixed Neutron Absorber ^{10}B Areal Density (g/cm^2) Boral/Metamic	0.0267/0.0223 (MPC-24) 0.0372/0.0310 (MPC-24E, MPC-24EF MPC-32 & MPC-32F)	0.0372/0.0310 (MPC-68 & MPC-68FF) 0.01/NA (MPC-68F) (See Note 1)
End closure(s)	Welded	Welded
Fuel handling	Opening compatible with standard grapples	Opening compatible with standard grapples
Heat dissipation	Passive	Passive

NOTE:
1. All MPC-68F canisters are equipped with Boral neutron absorber.
2. Refer to Section 4.4.5.1 for detailed information on heat load values.

Table 1.2.3

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Table 1.2.4

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Table 1.2.5

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Table 1.2.6

HI-STORM 100 OPERATIONS SEQUENCE

Site-specific handling and operations procedures will be prepared, reviewed, and approved by each owner/user.	
1	HI-TRAC and MPC lowered into the fuel pool without lids
2	Fuel assemblies transferred into the MPC fuel basket
3	MPC lid lowered onto the MPC
4	HI-TRAC/MPC assembly moved to the decon pit and MPC lid welded in place, volumetrically or multi-layer PT examined, and pressure and leakage tested
5	MPC dewatered, moisture removed, backfilled with helium, and the closure ring welded
6	HI-TRAC annulus drained and external surfaces decontaminated
7	MPC lifting cleats installed and MPC weight supported by rigging
8	HI-TRAC pool lid removed and transfer lid attached (not applicable to HI-TRAC 100D or 125D)
9	MPC lowered and seated on HI-TRAC transfer lid (not applicable to HI-TRAC 100D or 125D)
9a	HI-STORM mating device secured to top of empty HI-STORM overpack (HI-TRAC 100D and 125D only)
10	HI-TRAC/MPC assembly transferred to atop the HI-STORM overpack or mating device, as applicable
11	MPC weight supported by rigging and transfer lid doors opened (standard design HI-TRAC) or pool lid removed (HI-TRAC 100D and 125D)
12	MPC lowered into HI-STORM overpack, and HI-TRAC removed from atop the HI-STORM overpack/mating device
12a	HI-STORM mating device removed (HI-TRAC 100D and 125D only)
13	HI-STORM overpack lid installed and bolted in place
14	HI-STORM overpack placed in storage at the ISFSI pad
15	For HI-STORM 100A (or 100SA) users, the overpack is anchored to the ISFSI pad by installation of nuts onto studs and torquing to the minimum required torque.

Table 1.2.7

REPRESENTATIVE ASME BOLTING AND THREADED ROD MATERIALS ACCEPTABLE
FOR THE HI-STORM 100A ANCHORAGE SYSTEM

ASME MATERIALS FOR BOLTING

Composition	I.D.	Type Grade or UNC No.	Ultimate Strength (ksi)	Yield Strength (ksi)	Code Permitted Size Range†
C	SA-354	BC K04100	125	109	t ≤ 2.5"
¾ Cr	SA-574	51B37M	170	135	t ≥ 5/8"
1 Cr – 1/5 Mo	SA-574	4142	170	135	t ≥ 5/8"
1 Cr-1/2 Mo-V	SA-540	B21 (K 14073)	165	150	t ≤ 4"
5 Cr – ½ Mo	SA-193	B7	125	105	t ≤ 2.5"
$2N_i$ – ¾ Cr – ¼ Mo	SA-540	B23 (H-43400)	135	120	
$2N_i$ – ¾ Cr – 1/3 Mo	SA-540	B-24 (K-24064)	135	120	
17Cr-4Ni-4Cu	SA-564	630 (H-1100)	140	115	
17Cr-4Ni-4Cu	SA-564	630 (H-1075)	145	125	
25Ni-15Cr-2Ti	SA-638	660	130	85	
22CR-13Ni-5Mn	SA-479	XM-19 (S20910)	135	105	

Note: The materials listed in this table are representative of acceptable materials and have been abstracted from the ASME Code, Section II, Part D, Table 3. Other materials listed in the Code are also acceptable as long as they meet the size requirements, the minimum requirements on yield and ultimate strength (see Table 2.0.4), and are suitable for the environment.

† Nominal diameter of the bolt (or rod) as listed in the Code tables. Two-inch diameter studs/rods are specified for the HI-STORM 100A.

Table 1.2.8

METAMIC® DATA FOR HOLTEC MPCs

MPC Type	Min. B-10 areal density required by criticality analysis (g/cm²)	Nominal Weight Percent of B_4C and Reference *METAMIC®* Panel Thickness			
		100% Credit	90% Credit	75% Credit	Ref. Thickness (inch) (see note)
MPC-24	0.020	27.6	31	37.2	0.075
MPC-68, -68FF, -32, -32F, -24E, and -24EF	0.0279	27.8	31	37.4	0.104

Note: The drawings in Section 1.5 show slightly larger thickness to ensure that the minimum B-10 areal density is conservative under all conditions.

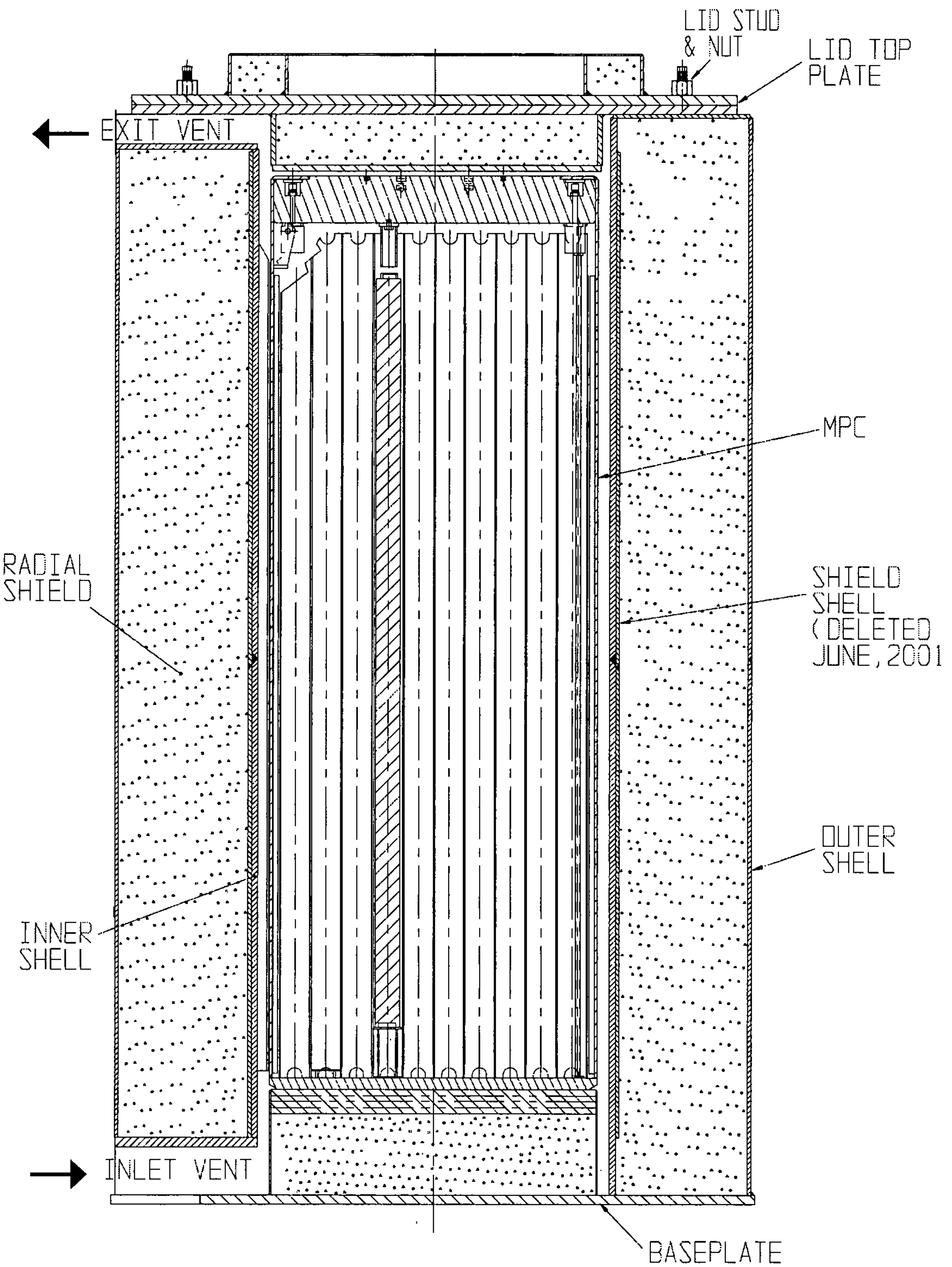

FIGURE 1.2.1; CROSS SECTION VIEW OF THE HI-STORM 100 SYSTEM

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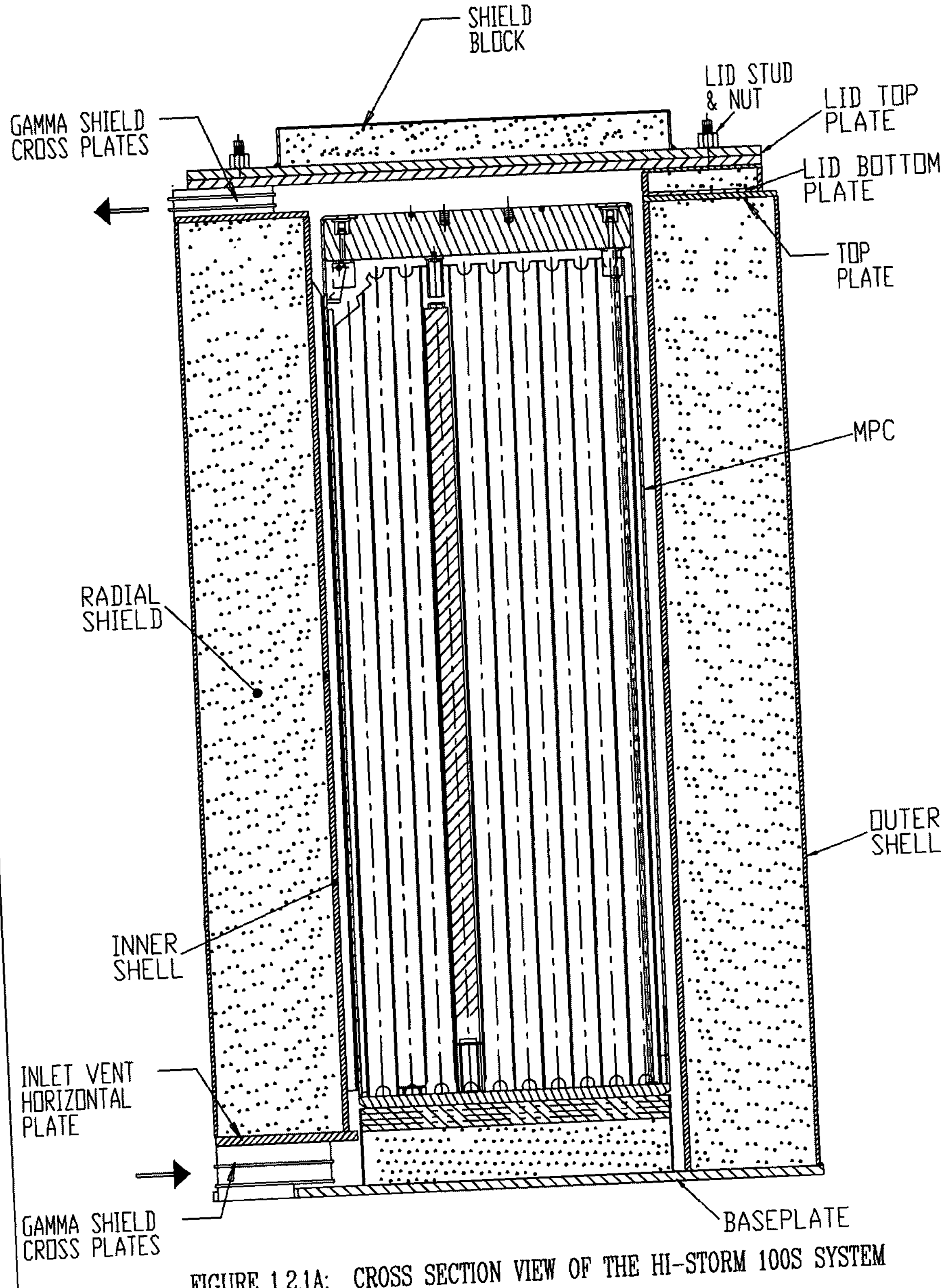

FIGURE 1.2.1A; CROSS SECTION VIEW OF THE HI-STORM 100S SYSTEM

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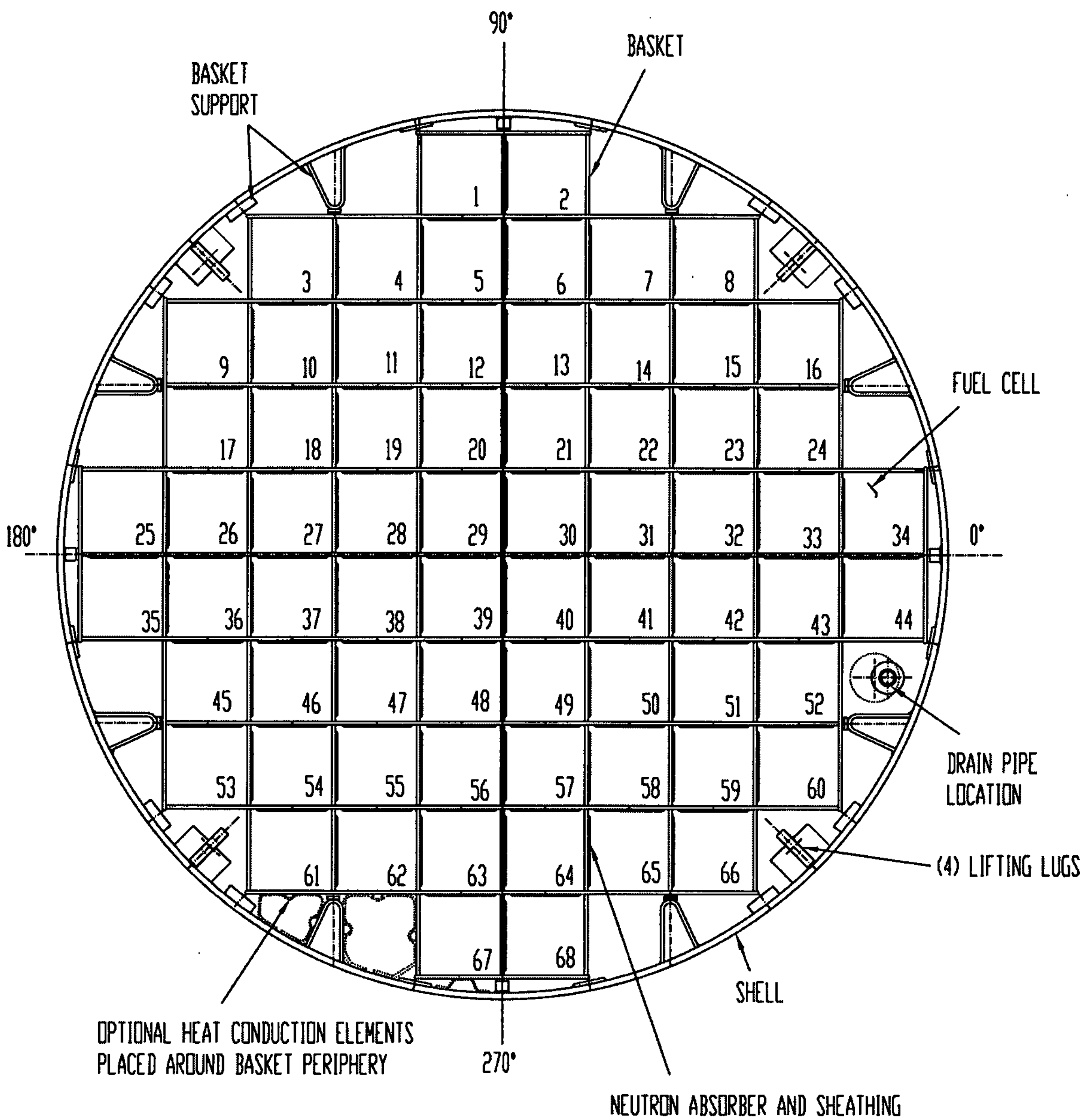

FIGURE 1.2.2; MPC-68/68F/68FF CROSS SECTION VIEW

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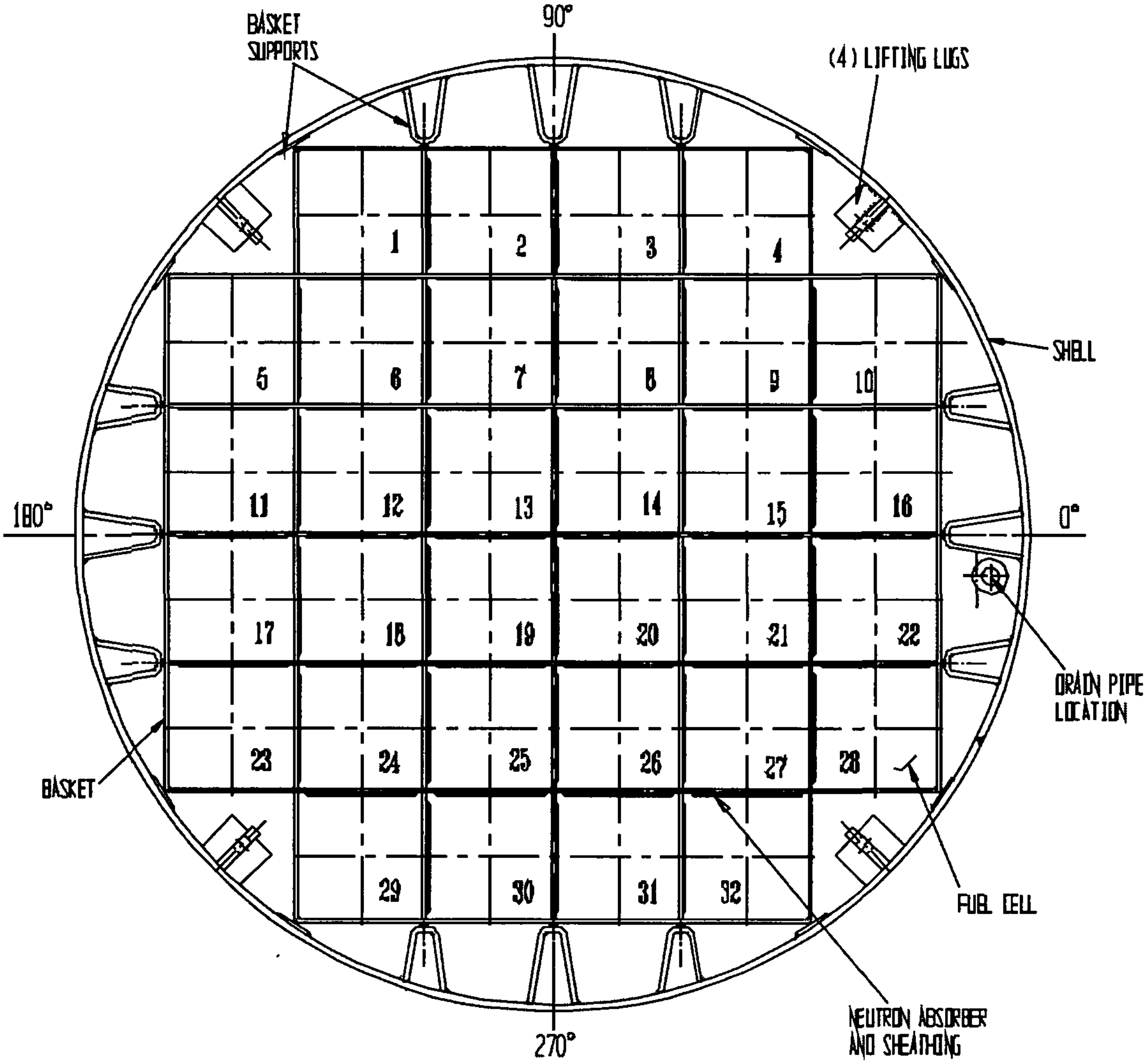

FIGURE 1.2.3; MPC-32/32F CROSS SECTION

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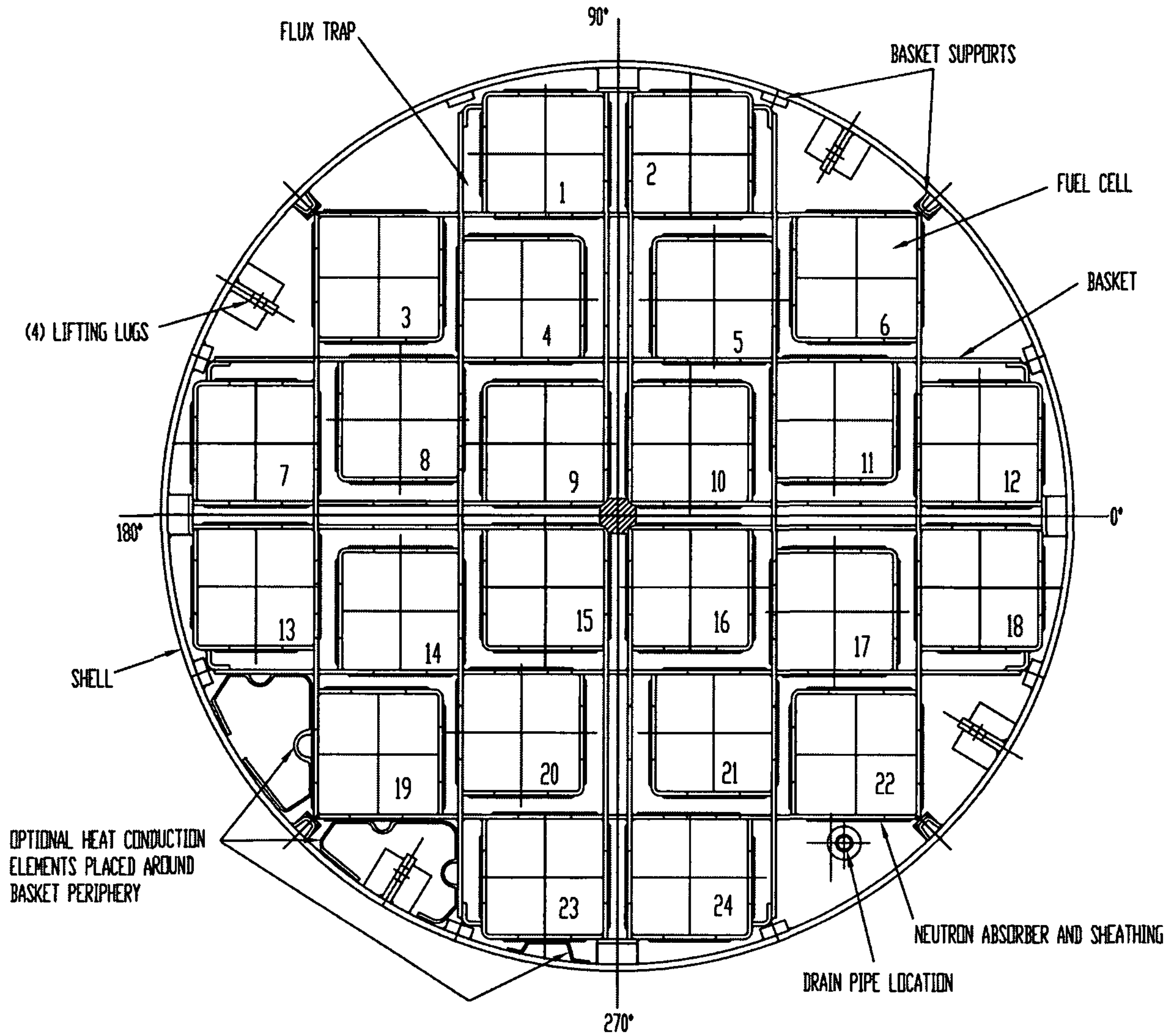

FIGURE 1.2.4; MPC-24/24E/24EF CROSS SECTION VIEW

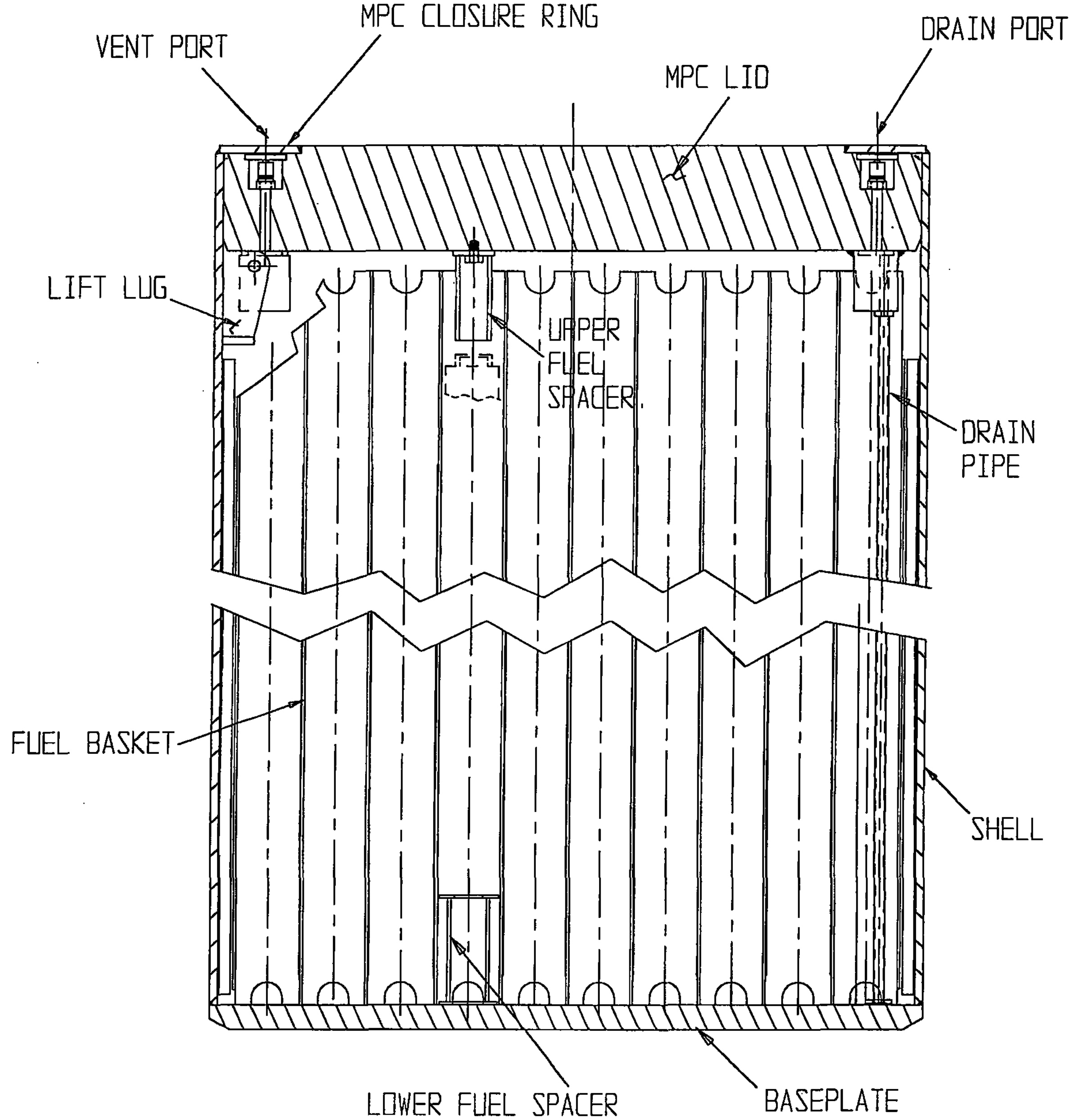

FIGURE 1.2.5; CROSS SECTION ELEVATION VIEW OF MPC

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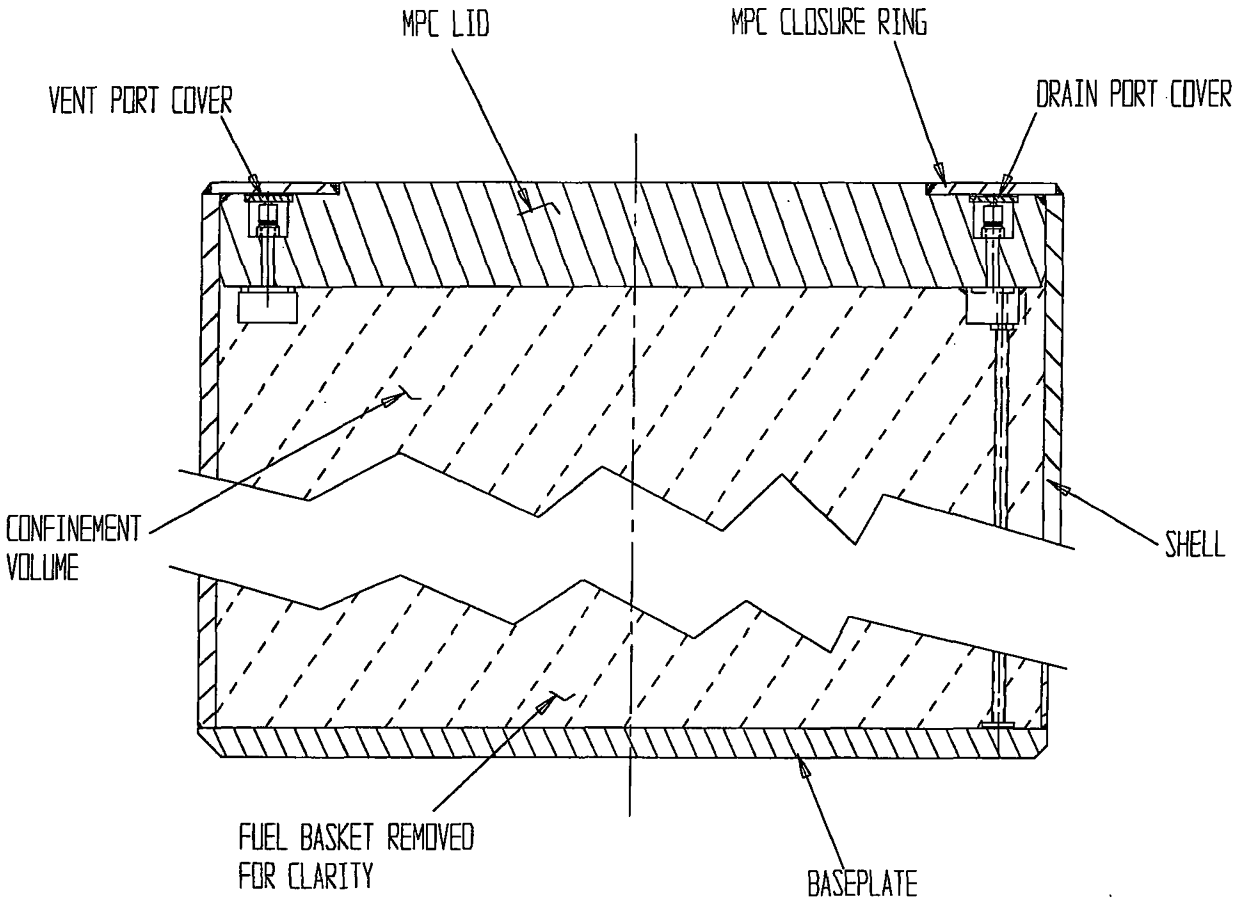

FIGURE 1.2.6; MPC CONFINEMENT BOUNDARY

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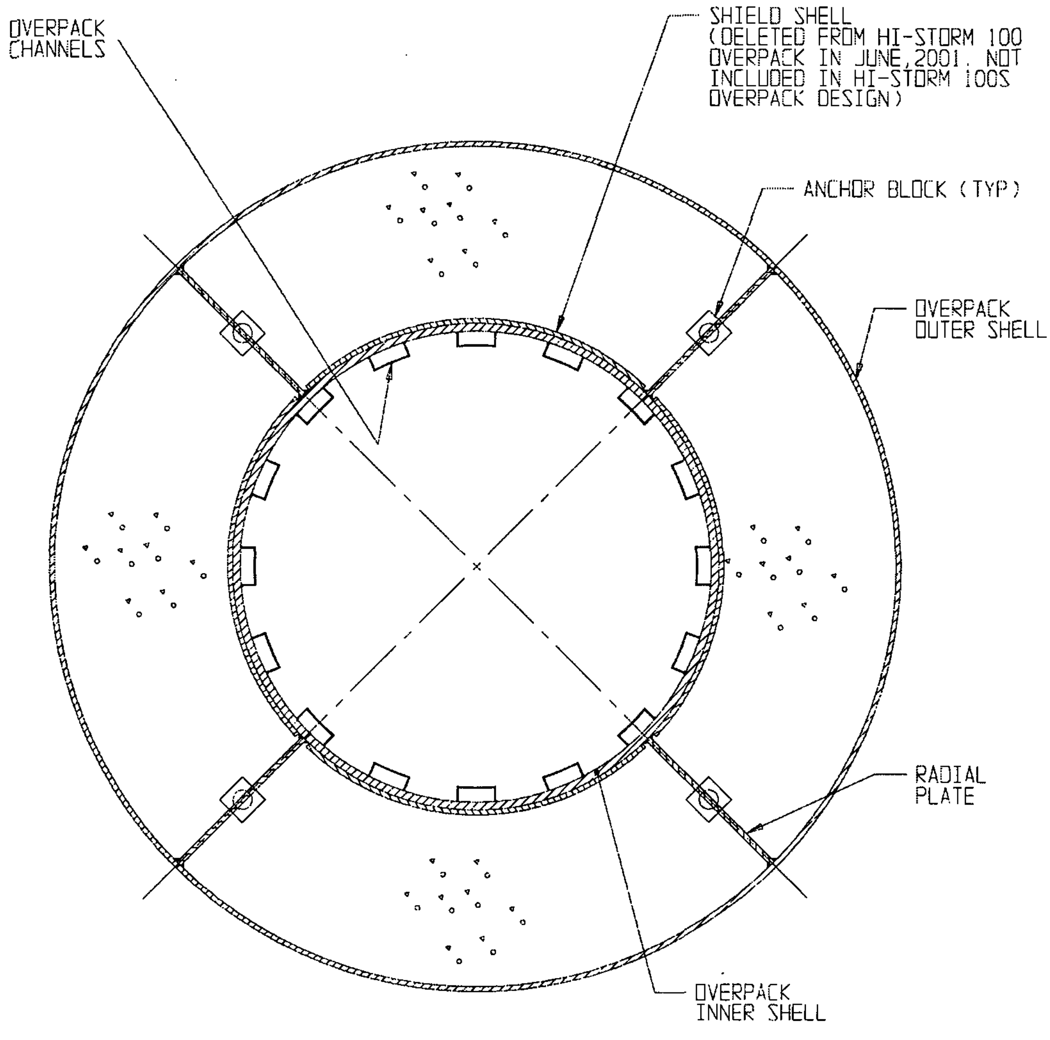

FIGURE 1.2.7; CROSS SECTION OF HI-STORM OVERPACK

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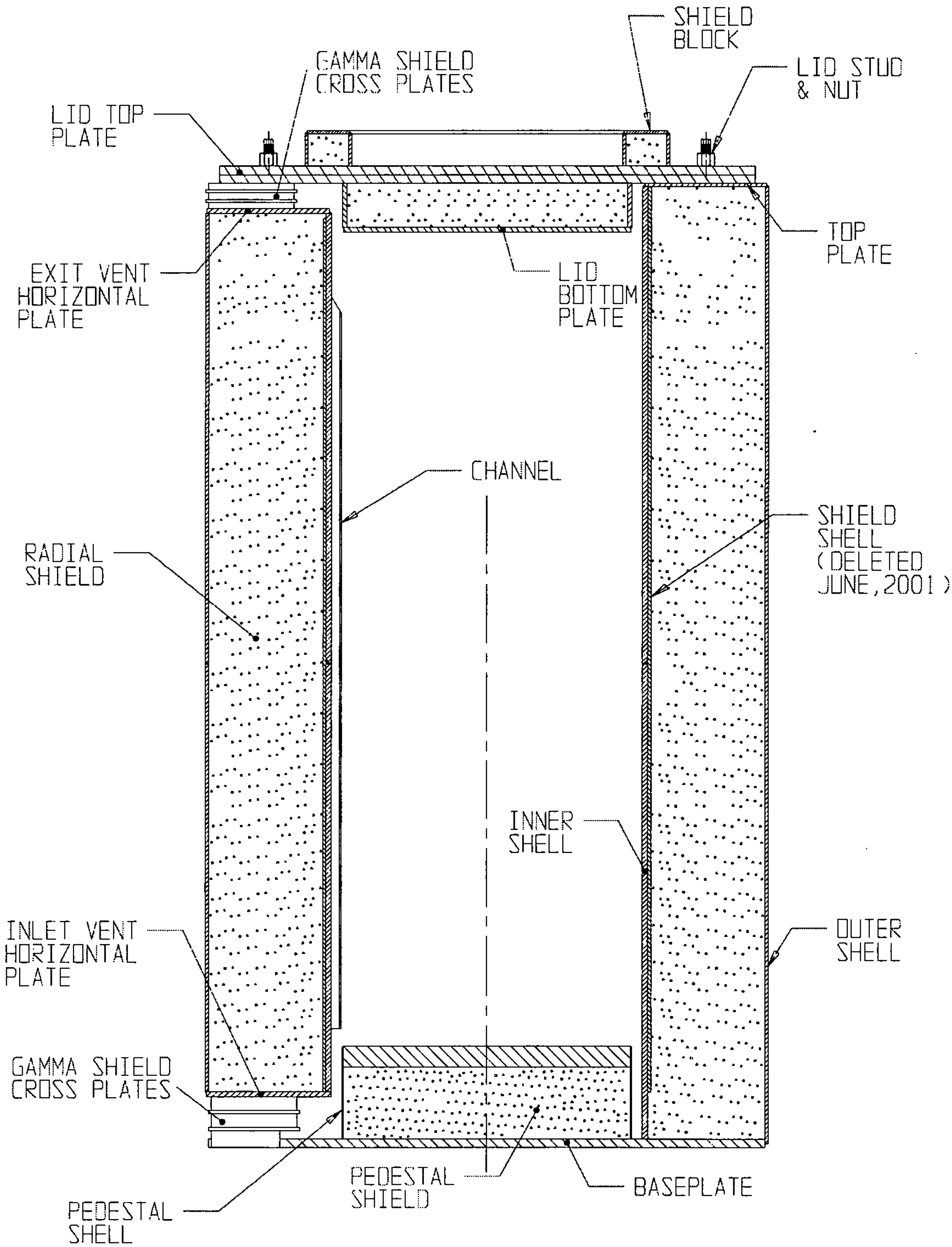

FIGURE 1.2.8; HI-STORM 100 OVERPACK CROSS SECTIONAL ELEVATION VIEW

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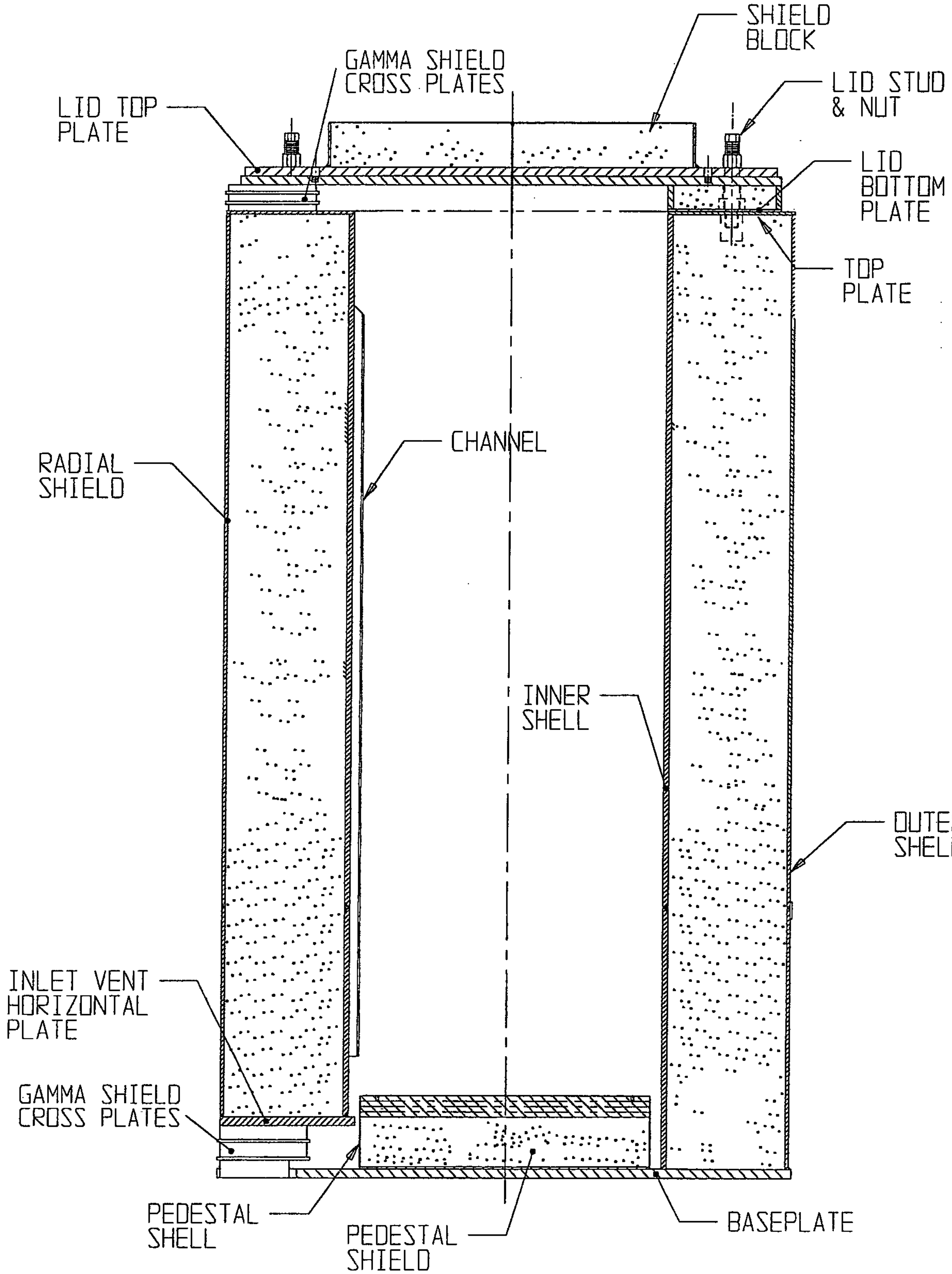

FIGURE 1.2.8A; HI-STORM 100S OVERPACK CROSS SECTIONAL ELEVATION VIEW

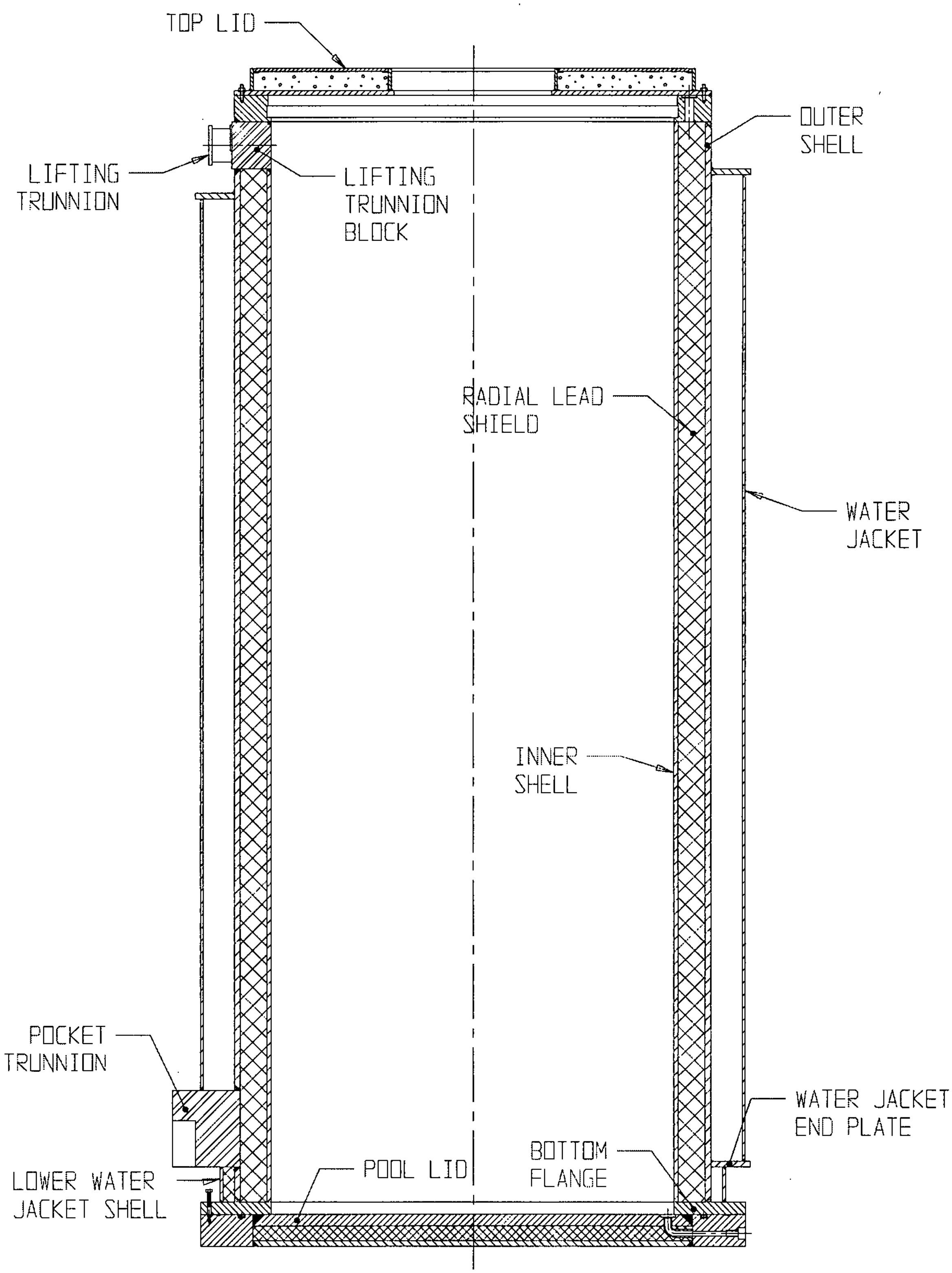

FIGURE 1.2.9; 125TON HI-TRAC TRANSFER CASK WITH POOL LID CROSS SECTIONAL ELEVATION VIEW

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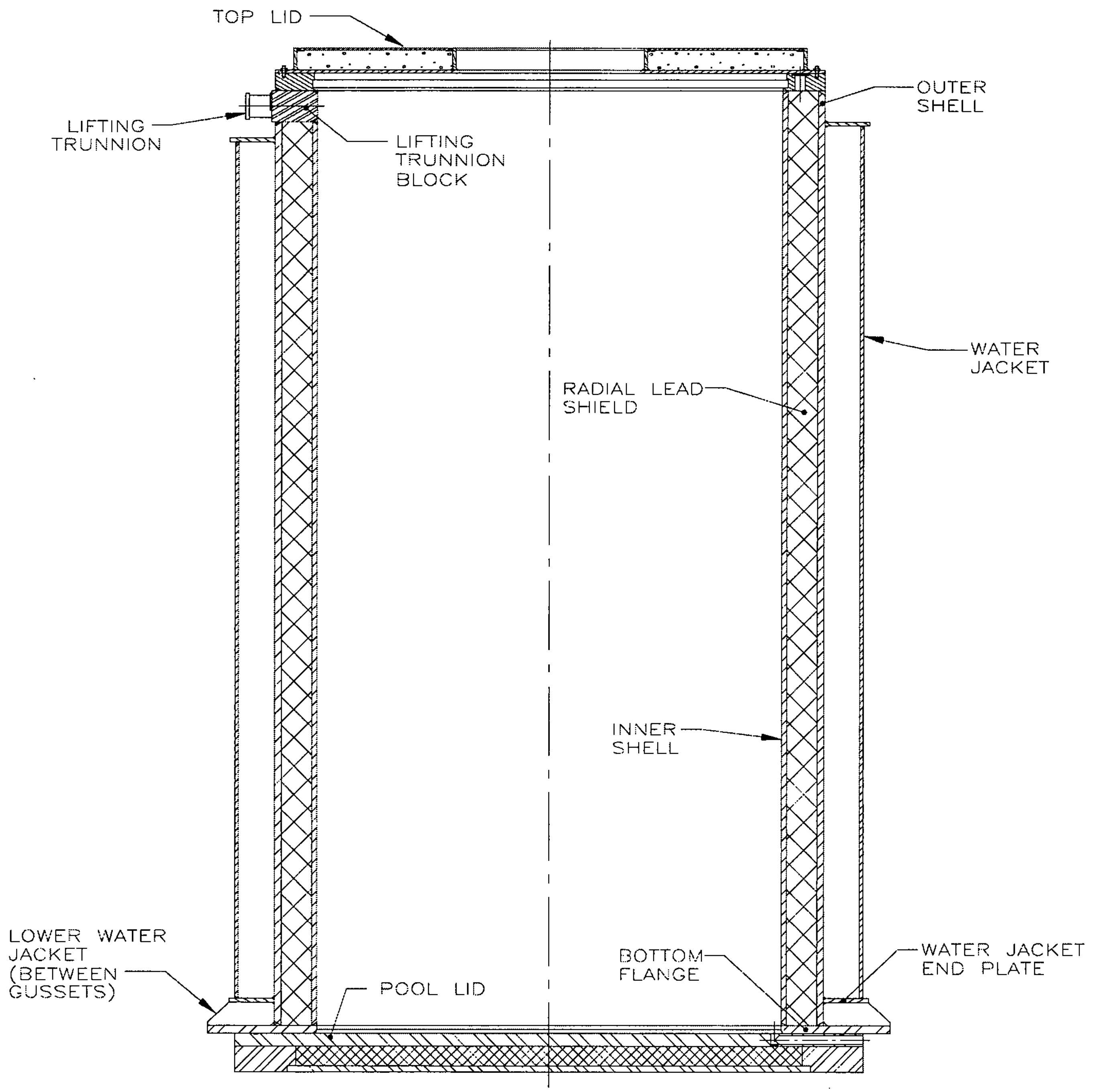

FIGURE 1.2.9A; HI-TRAC 125D TRANSFER CASK CROSS SECTIONAL ELEVATION VIEW

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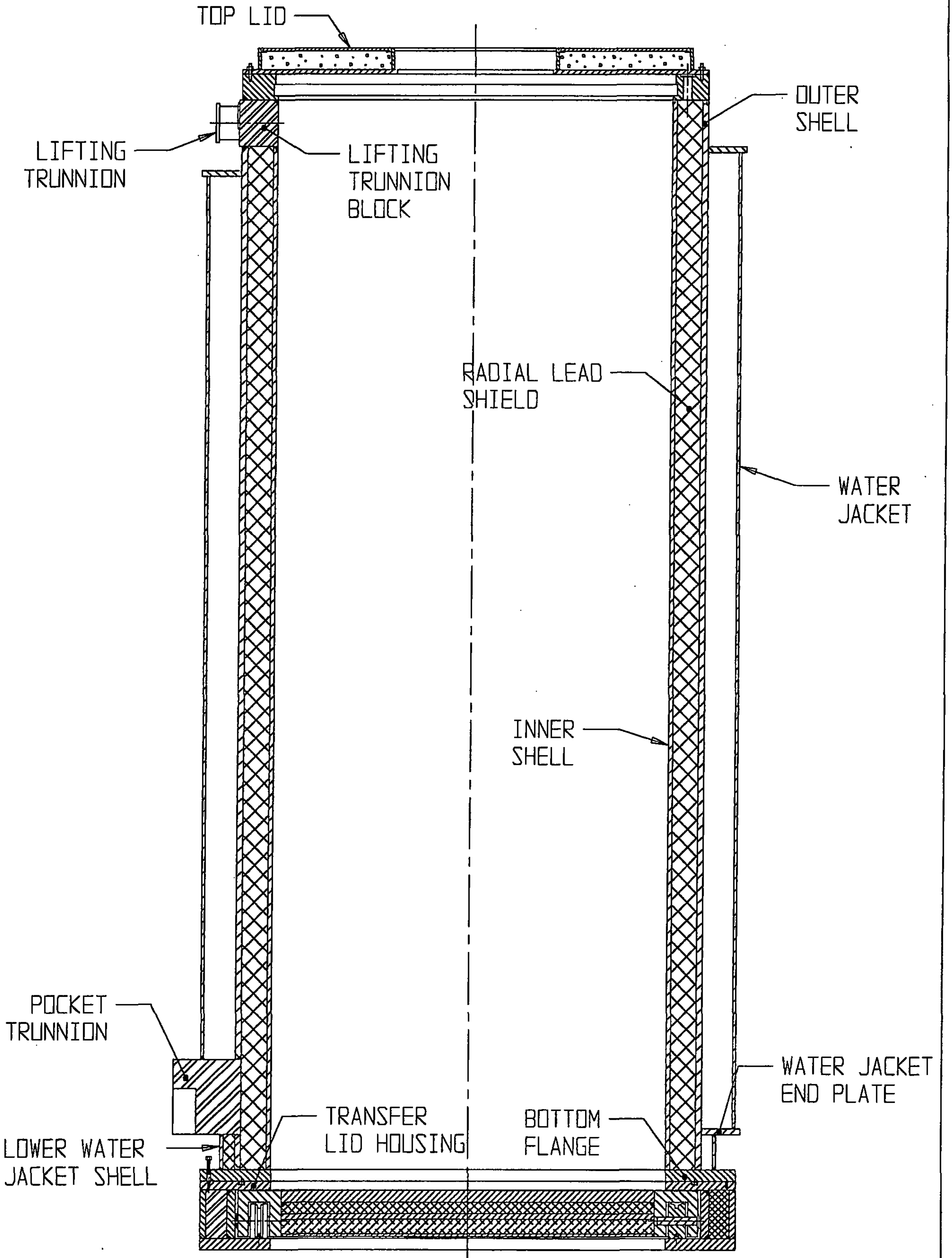

FIGURE 1.2.10; 125TON HI-TRAC TRANSFER CASK WITH TRANSFER LID CROSS SECTIONAL ELEVATION VIEW

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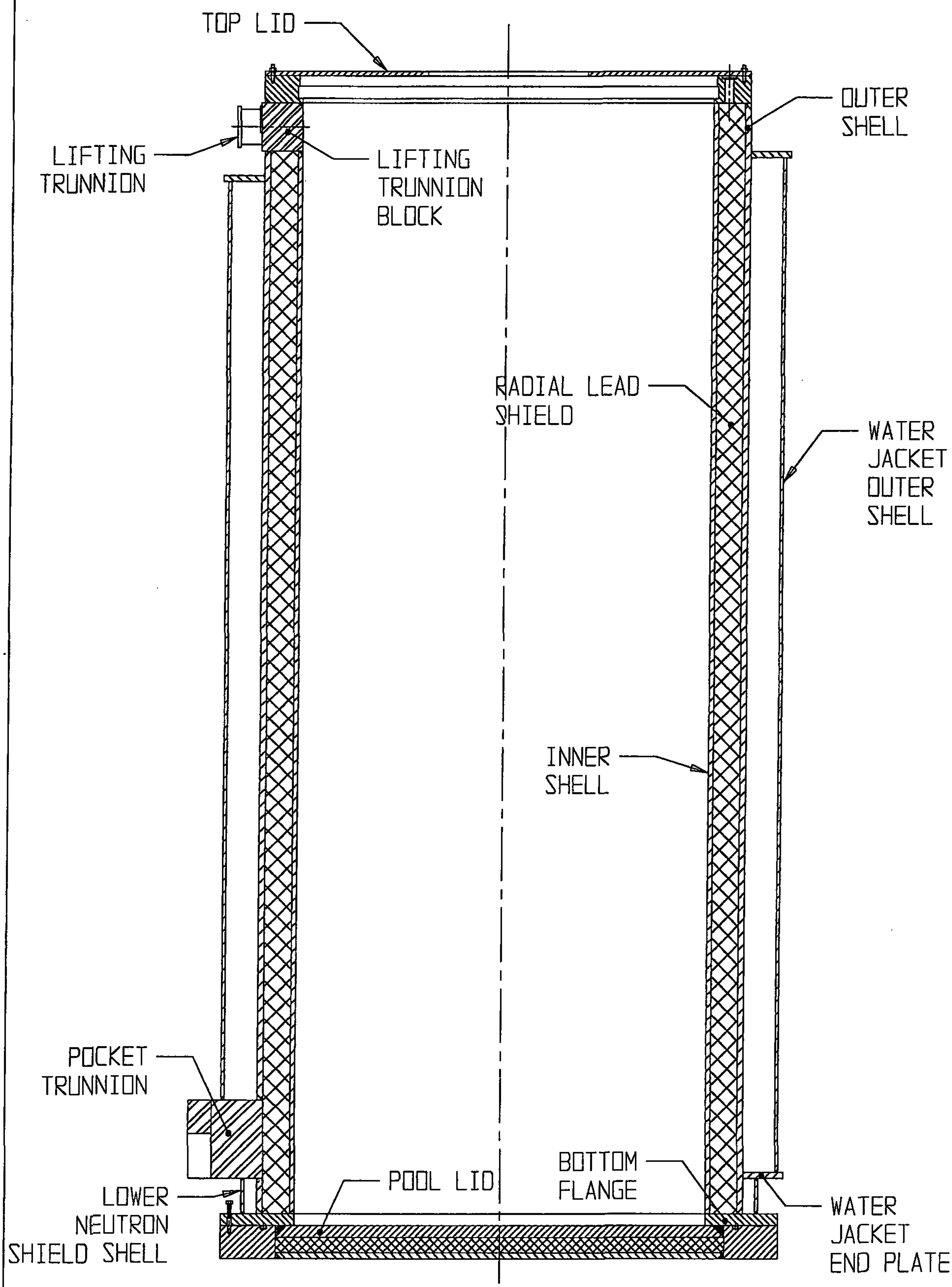

FIGURE 1.2.11; 100 HI-TRAC TRANSFER CASK WITH POOL LID CROSS SECTIONAL ELEVATION VIEW

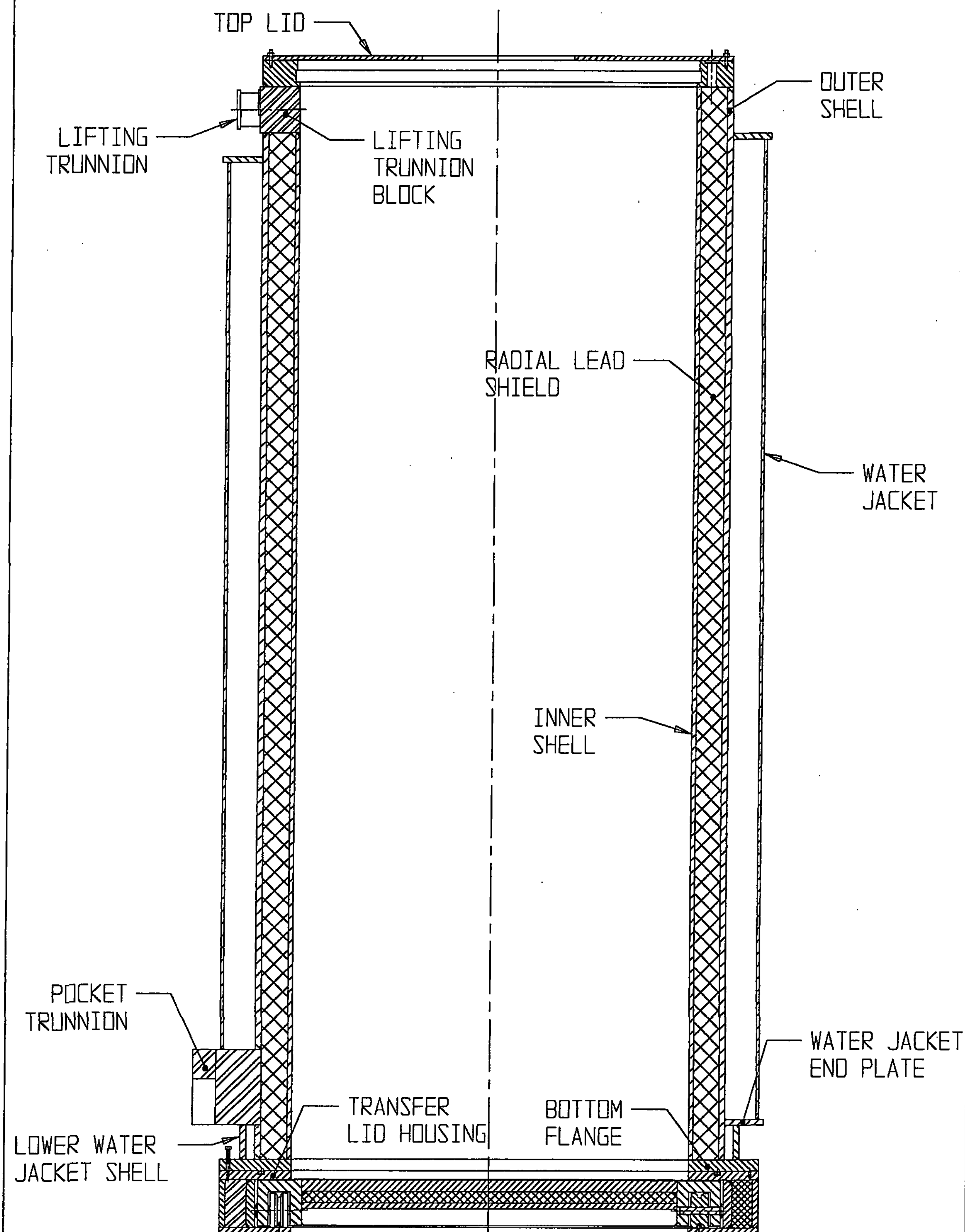

FIGURE 1.2.12; 100 TON HI-TRAC TRANSFER CASK WITH TRANSFER LID CROSS SECTIONAL ELEVATION VIEW

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FIGURE 1.2.13; DELETED

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FIGURE 1.2.14; DELETED

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FIGURE 1.2.15; DELETED

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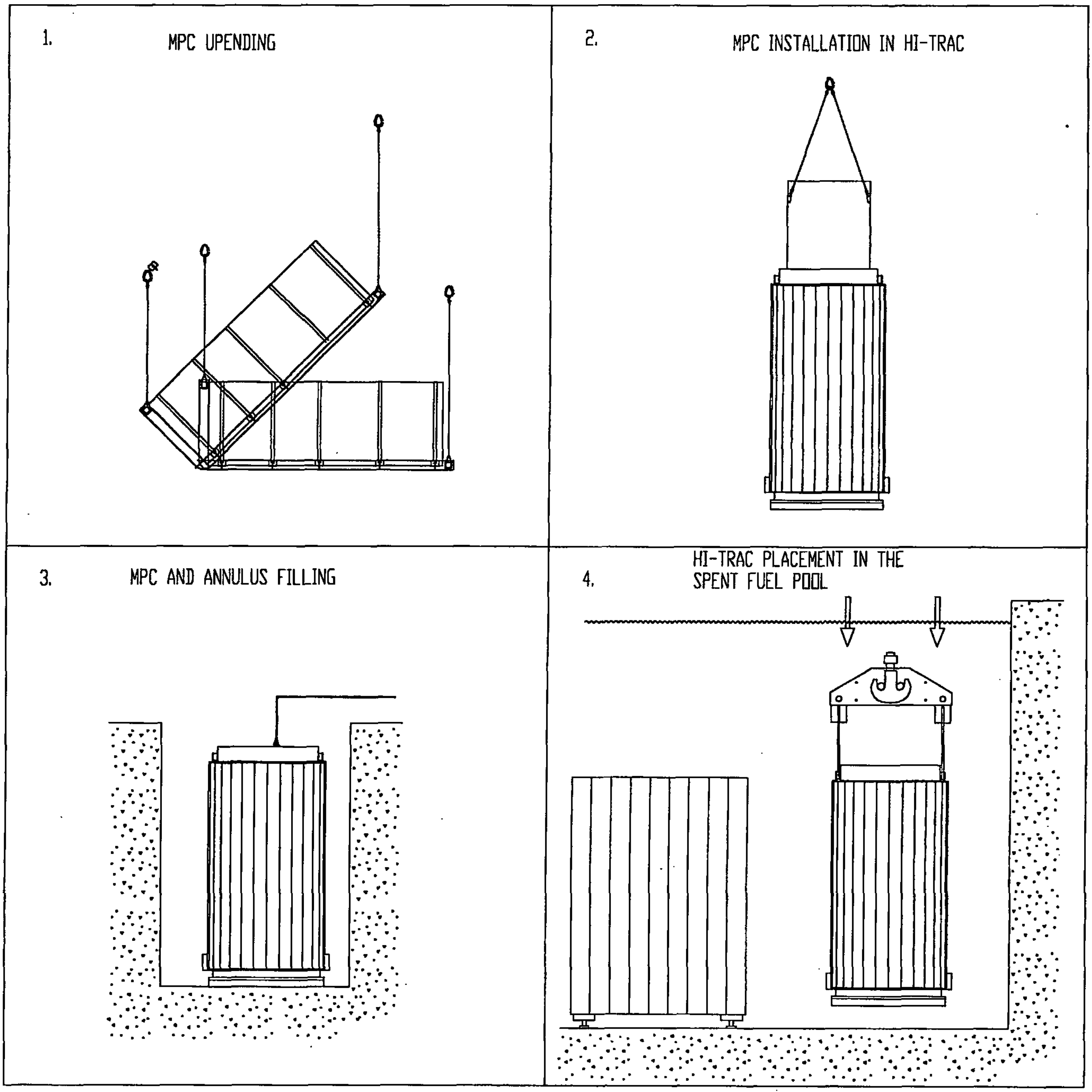

Figure 1.2.16a; Major HI-STORM 100 Loading Operations (Sheet 1 of 6)

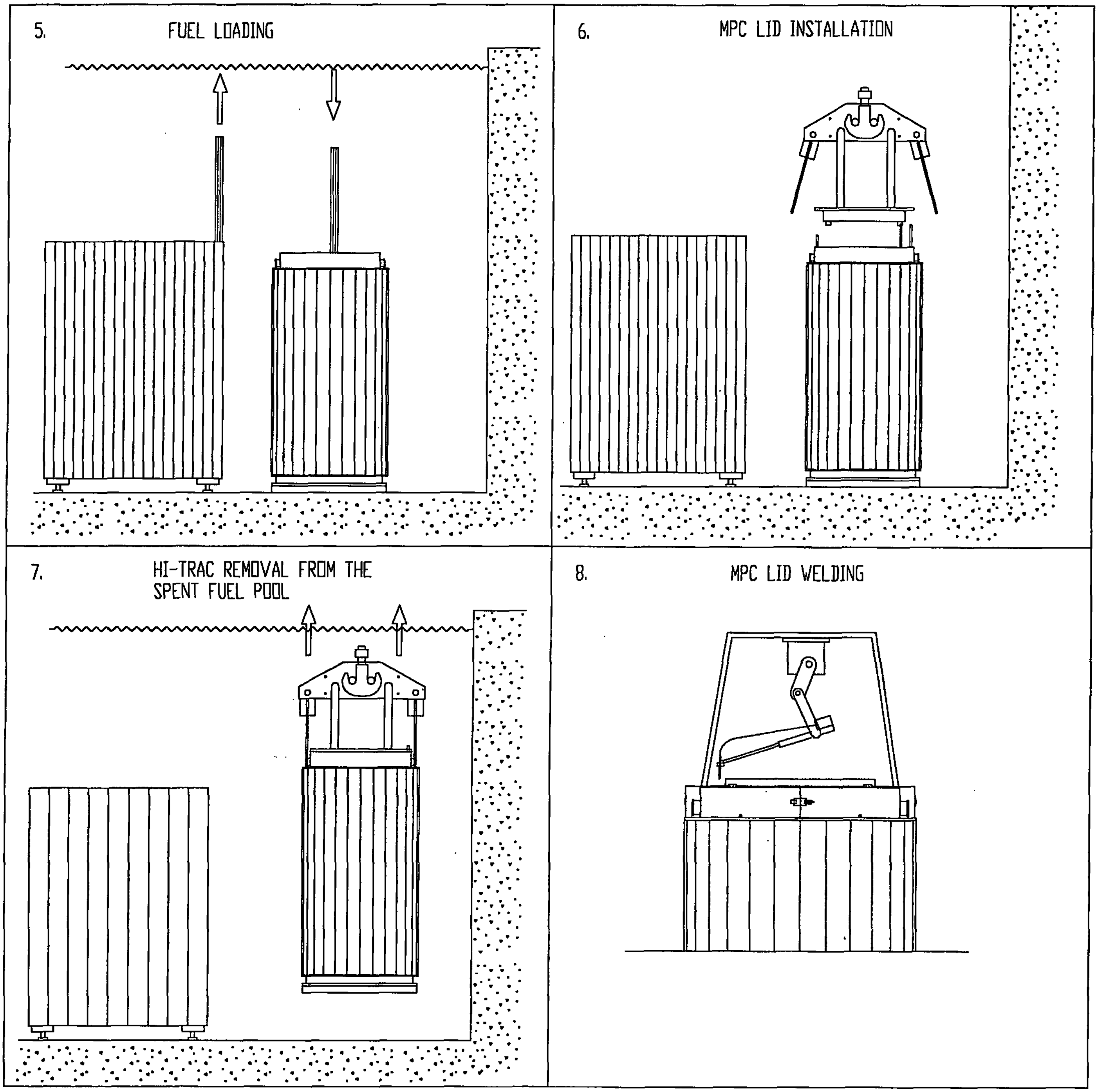

Figure 1.2.16b; Major HI-STORM 100 Loading Operations (Sheet 2 of 6)

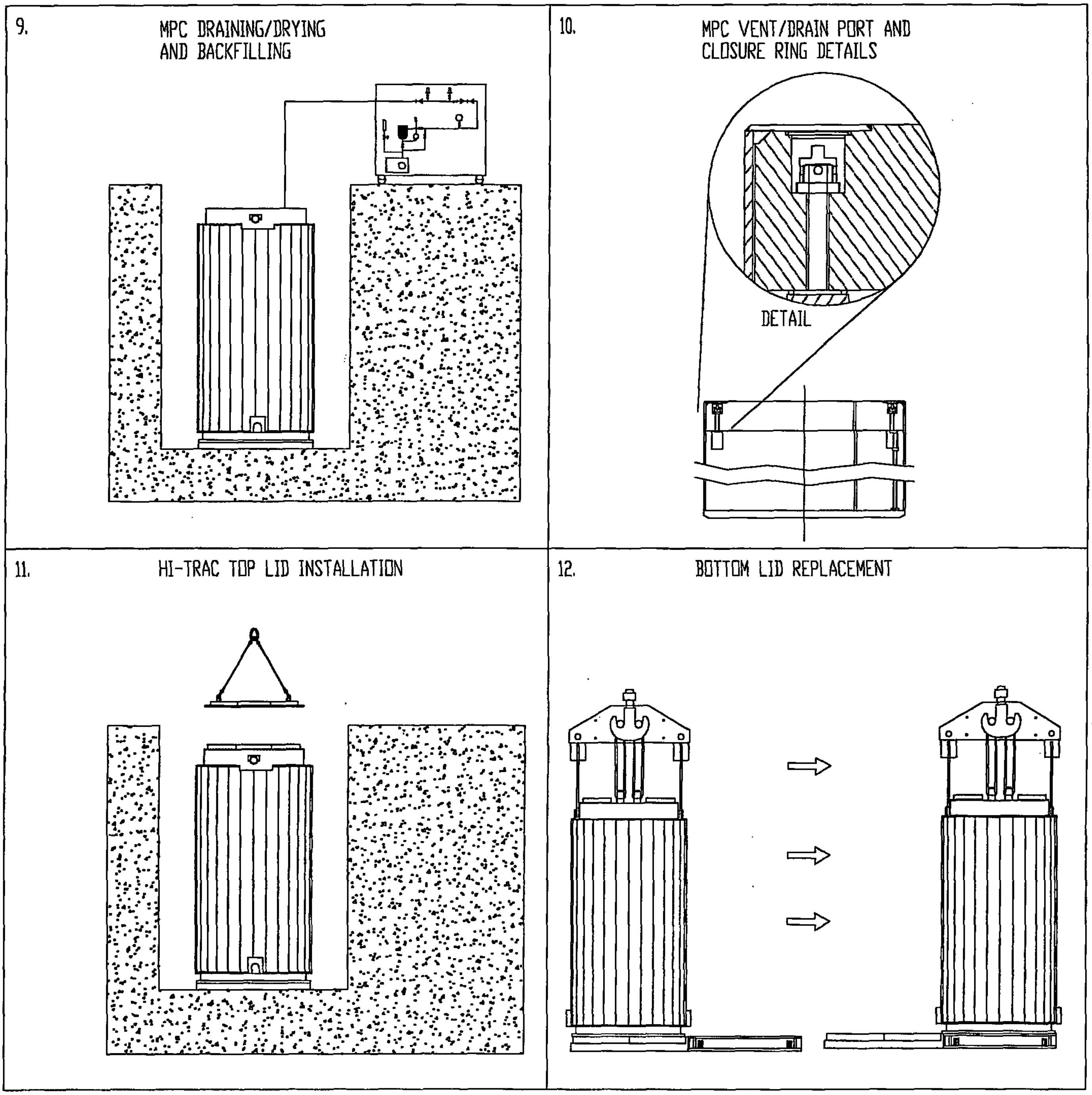

Figure 1.2.16c; Major HI-STORM 100 Loading Operations (Sheet 3 of 6)

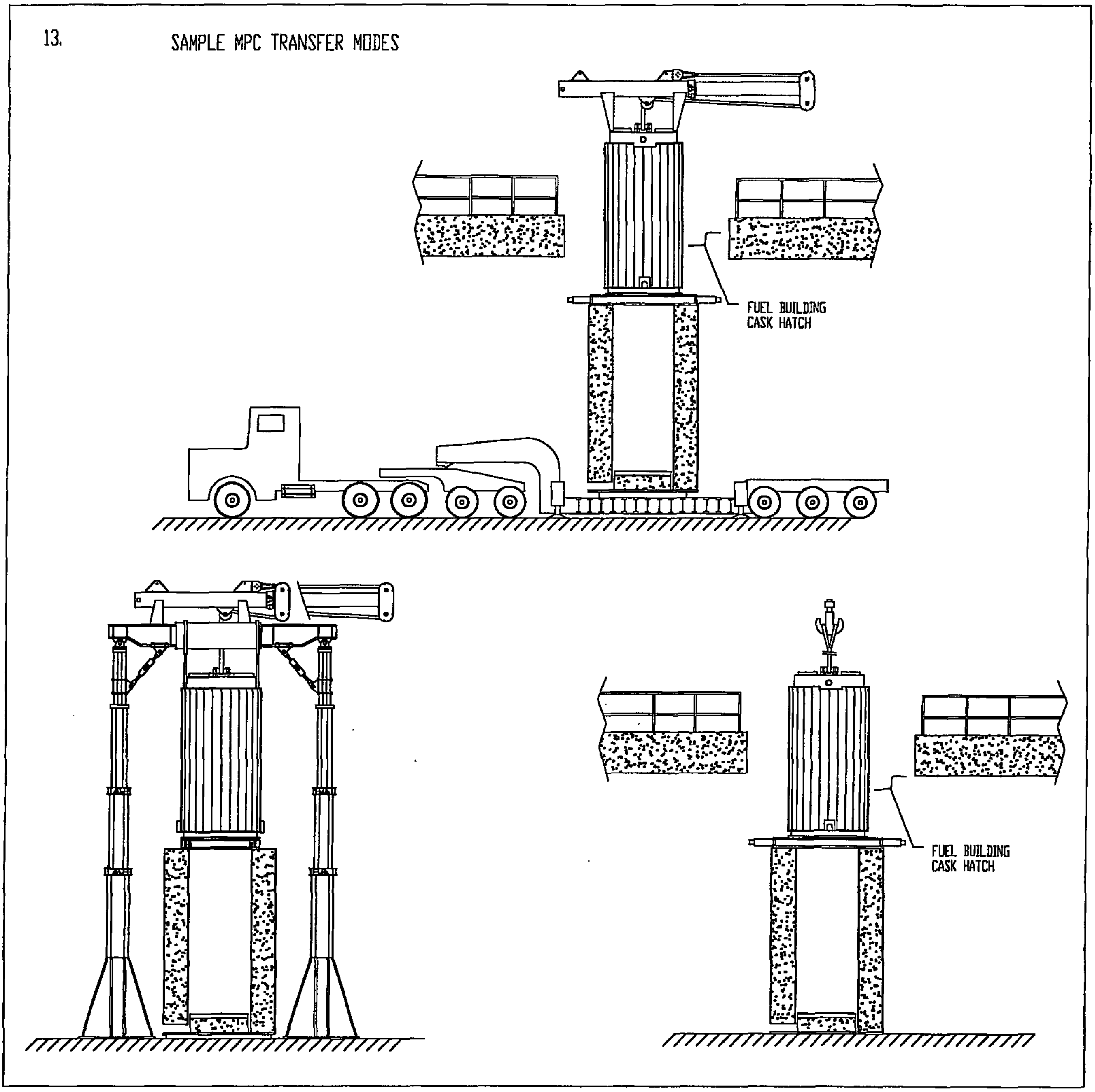

Figure 1.2.16d; Major HI-STORM 100 Loading Operations (Sheet 4 of 6)

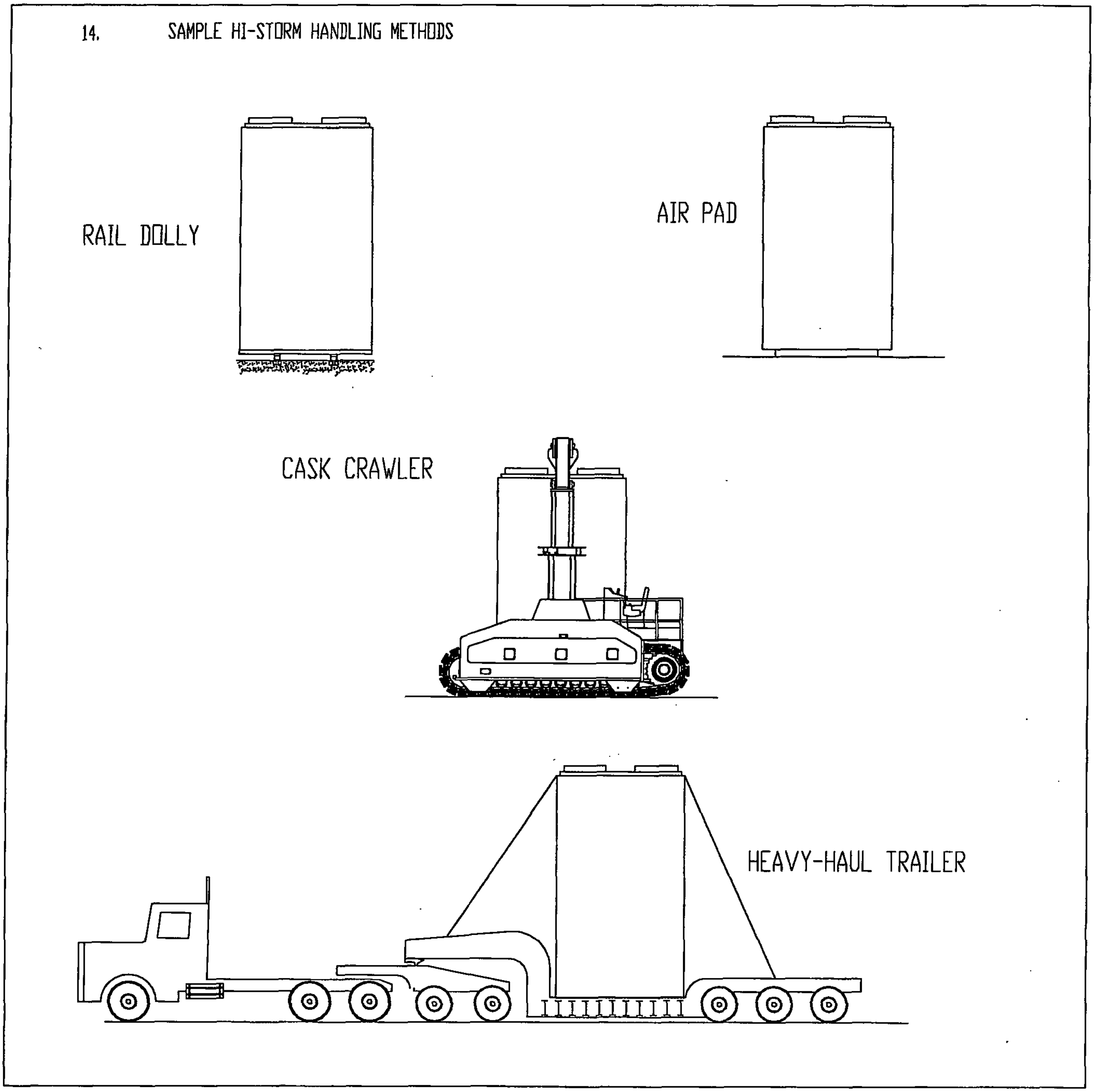

Figure 1.2.16e; Example of HI-STORM 100 Handling Options (Sheet 5 of 6)

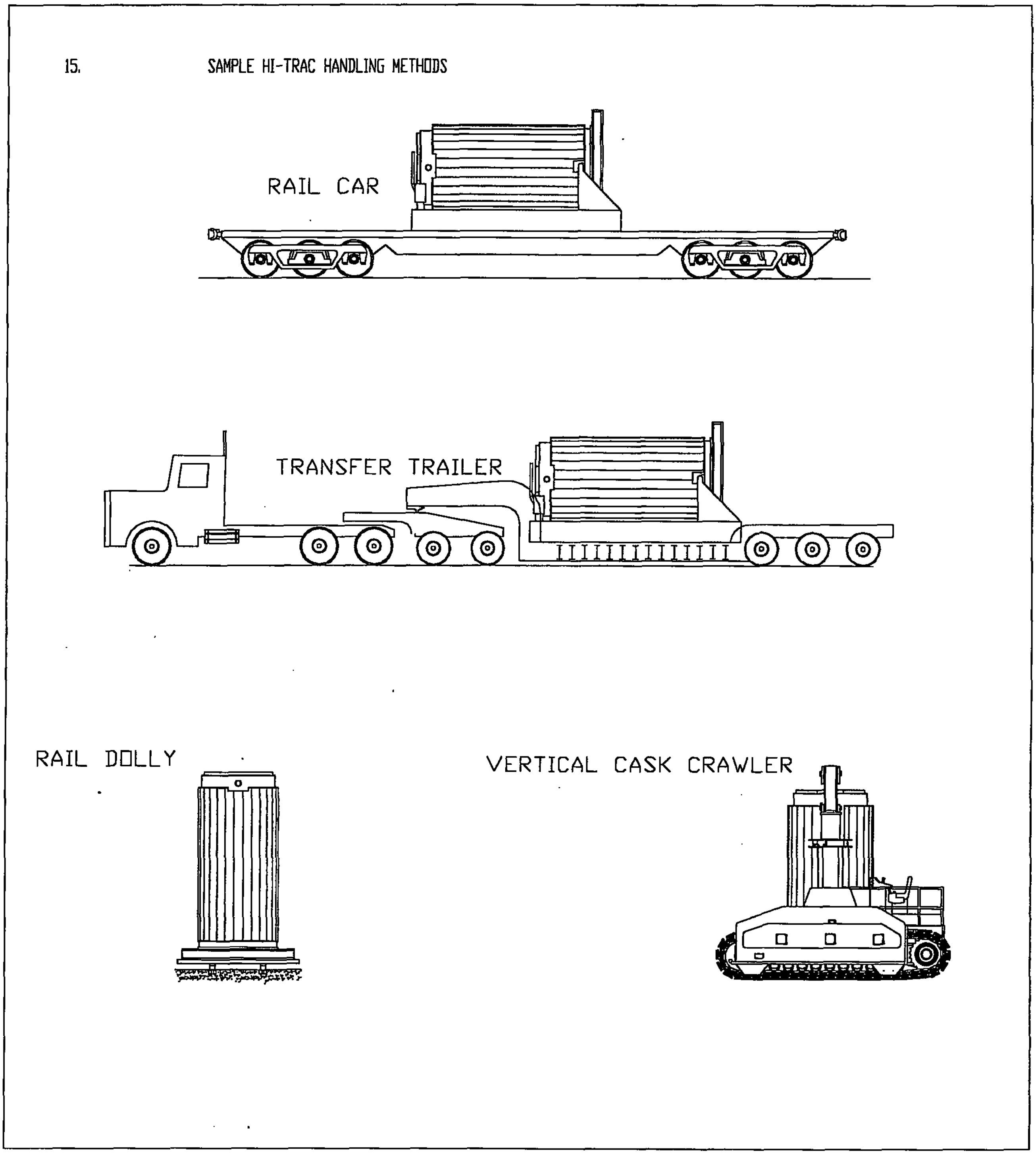

Figure 1.2.16f; Example of HI-TRAC Handling Options (Sheet 6 of 6)

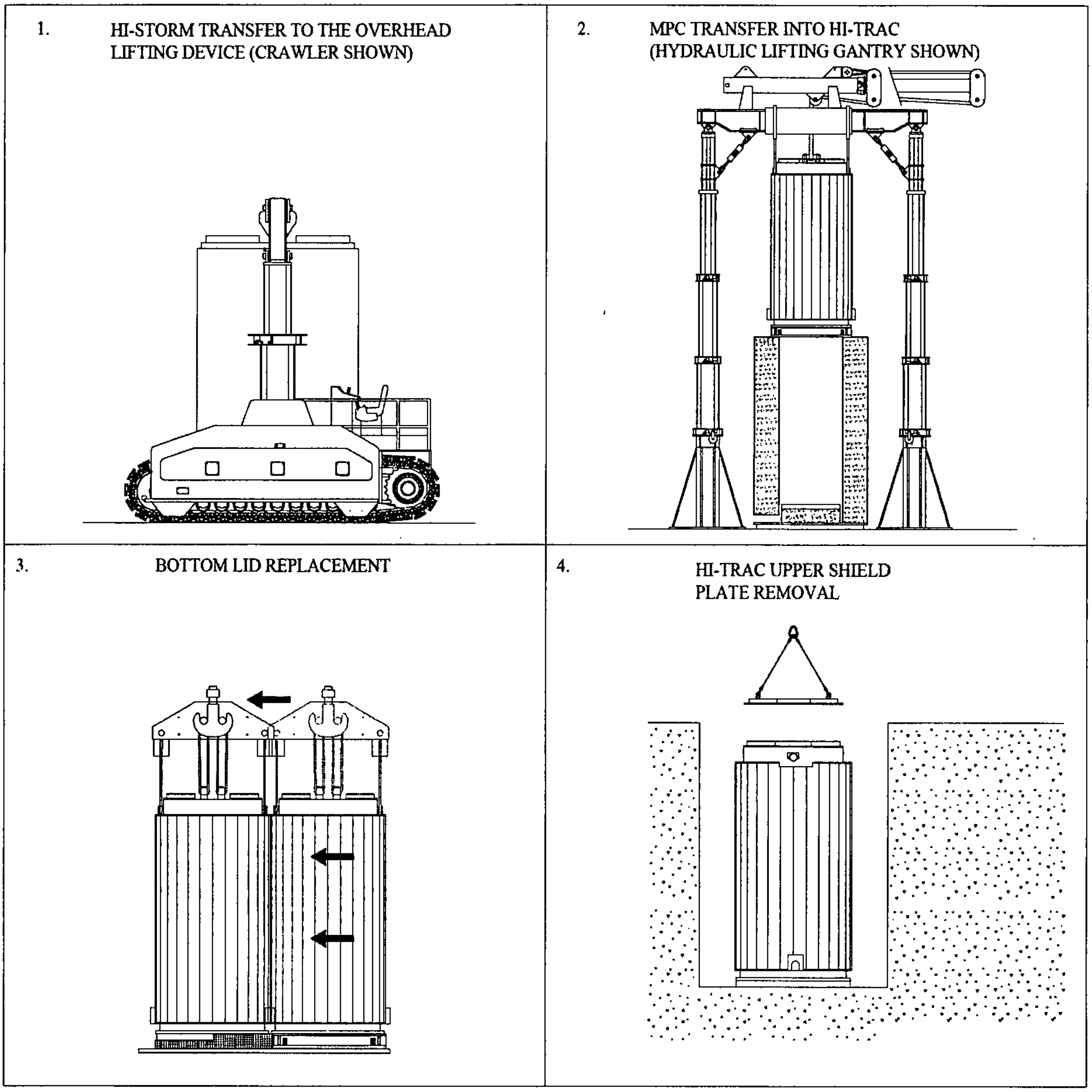

Figure 1.2.17a; Major HI-STORM 100 Unloading Operations (Sheet 1 of 4)

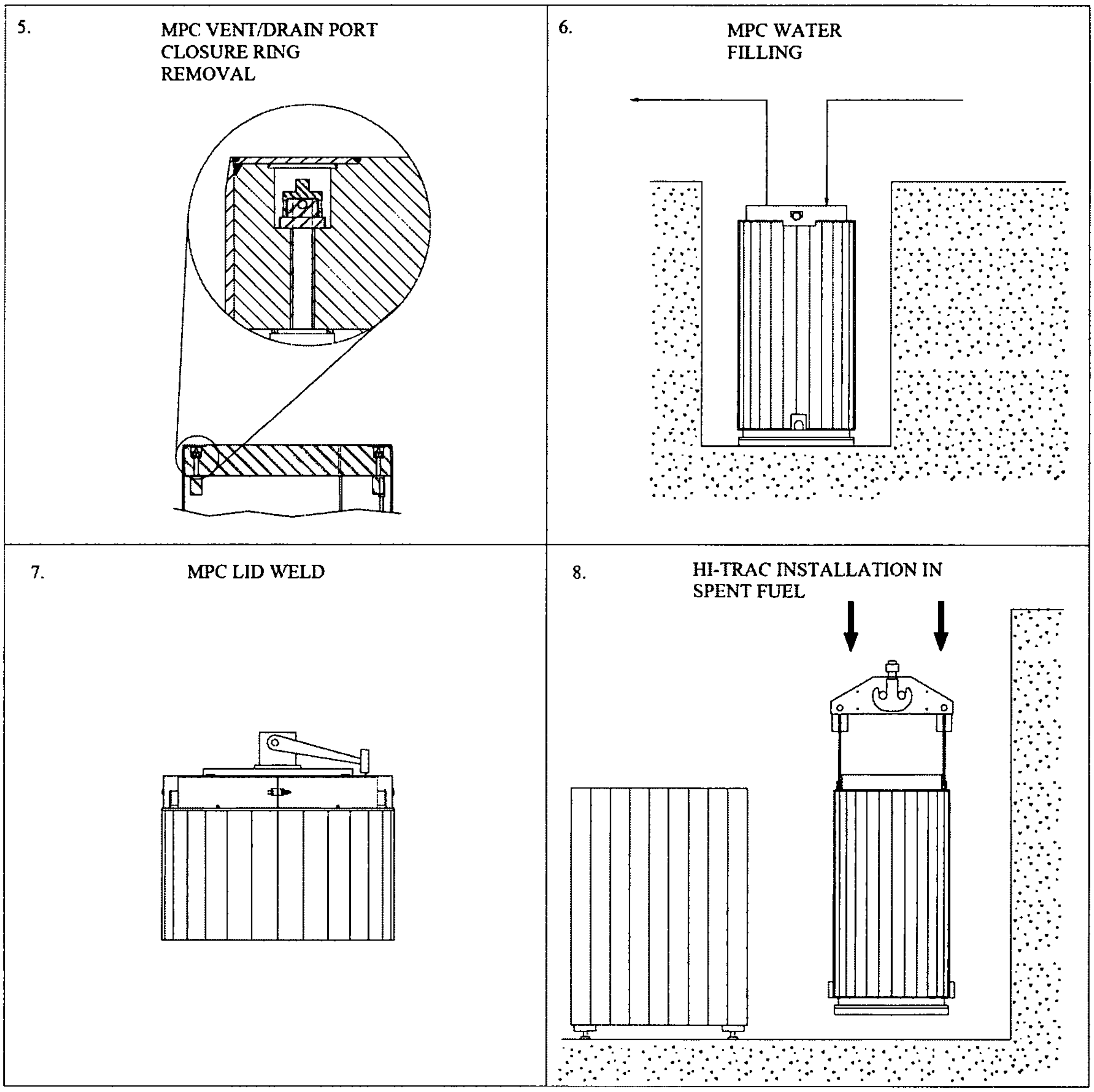

Figure 1.2.17b; Major HI-STORM 100 Unloading Operations (Sheet 2 of 4)

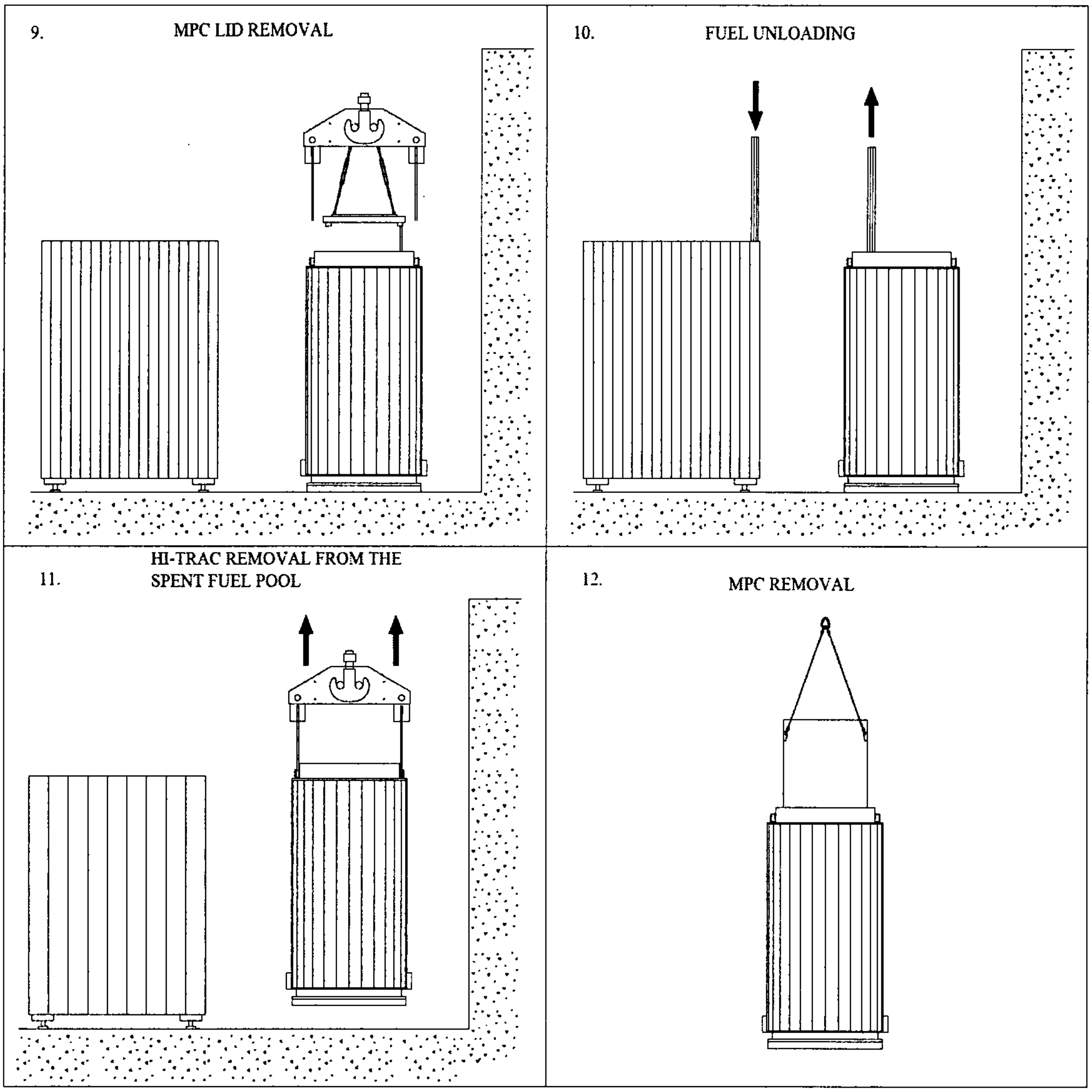

Figure 1.2.17c; Major HI-STORM 100 Unloading Operations (Sheet 3 of 4)

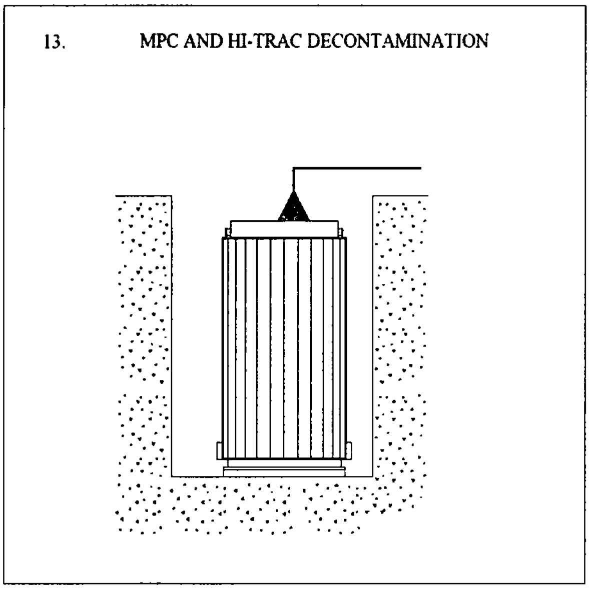

Figure 1.2.17d; Major HI-STORM 100 Unloading Operations (Sheet 4 of 4)

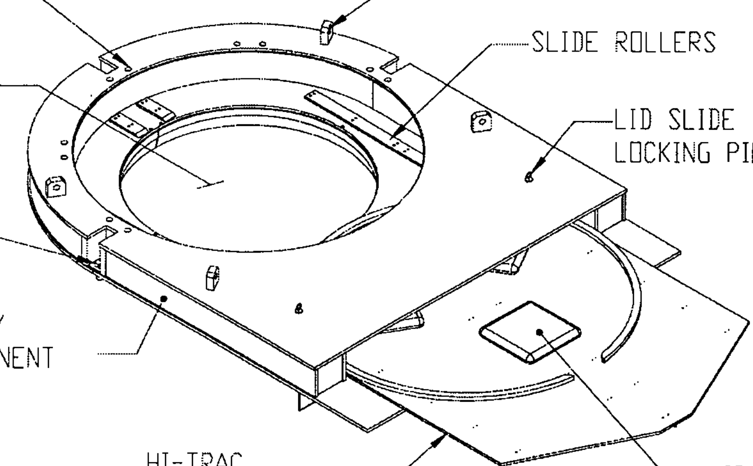

FIGURE 1.2.18; HI-STORM MATING DEVICE

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1.3 IDENTIFICATION OF AGENTS AND CONTRACTORS

Holtec International is a specialty engineering company with a principal focus on spent fuel storage technologies. Holtec 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 pool for increased storage capacity) in numerous plants around the world. Over 45 plants in the U.S., Britain, Brazil, Korea, and Taiwan have utilized Holtec's wet storage technology to extend their in-pool storage capacity.

Holtec's corporate engineering consists of experts with advanced degrees (Ph.D.'s) in every discipline germane to the fuel storage technologies, namely structural mechanics, heat transfer, computational fluid dynamics, and nuclear physics. All engineering analyses for Holtec's fuel storage projects (including HI-STORM 100) are carried out in-house.

Holtec International's quality assurance program was originally developed to meet NRC requirements delineated in 10CFR50, Appendix B, and was expanded to include provisions of 10CFR71, 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 as described in Chapter 13.

The HI-STORM 100 System is fabricated by Holtec Manufacturing Division (HMD) of Pittsburgh, Pennsylvania; formerly UST&D. HMD is an N-Stamp holder and a highly respected fabricator of nuclear components. HMD is on Holtec's Approved Vendors List (AVL) and has a quality assurance program meeting 10CFR50 Appendix B criteria. Extensive prototypical fabrication of the MPCs has been carried out at the HMD shop to resolve fixturing and tolerance issues. If another fabricator is to be used for the fabrication of any part of the HI-STORM 100 System, the proposed fabricator will be evaluated and audited in accordance with Holtec International's quality assurance program.

Construction, assembly, and operations on-site may be performed by Holtec or a licensee as the prime contractor. A licensee shall be suitably qualified and experienced to perform selected activities. Typical licensees are technically qualified and experienced in commercial nuclear power plant construction and operation activities under a quality assurance program meeting 10CFR50 Appendix B criteria.

1.4 GENERIC CASK ARRAYS

The HI-STORM 100 System is stored in a vertical configuration. The required center-to-center spacing between the modules (layout pitch) is guided by operational considerations. Tables 1.4.1 and 1.4.2 provide the nominal layout pitch information. Site-specific pitches are determined by practical operation with supporting heat transfer calculations in Chapter 4. The pitch values in Tables 1.4.1 and 1.4.2 are nominal and may be varied to suit the user's specific needs.

Table 1.4.1 provides recommended cask spacing data for array(s) of two by N casks. The pitch between adjacent rows of casks and between each adjacent column of casks are denoted by P_1 and P_2 In Table 1.4.1. There may be an unlimited number of rows. The distance between adjacent arrays of two by N casks (P3) shall be as specified in Table 1.4.1. See Figure 1.4.1 for further clarification. The pattern of required pitches and distances may be repeated for an unlimited number of columns.

For a square array of casks the pitch between adjacent casks may be in accordance with Table 1.4.2. See Figure 1.4.2 for further clarification. The data in Table 1.4.2 provide nominal values for large ISFSIs (i.e., those with hundreds of casks in a uniform layout), where access of feed air to the centrally located casks may become a matter of thermal consideration. From a thermal standpoint, regardless of the size of the ISFSI, the casks should be arrayed in such a manner that the tributary area for each cask (open ISFSI area attributable to a cask) is a minimum of 225 ft^2. Subsection 4.4.1.1.7 provides the detailed thermal evaluation of the required tributary area. For specific sites, a smaller tributary area can be utilized after appropriate thermal evaluations for the site-specific conditions are performed.

Table 1.4.1

CASK LAYOUT PITCH DATA FOR 2 BY N ARRAYS

Orientation	**Nominal Cask Pitch (ft.)**
Between adjacent rows, P1, and adjacent columns, P2	13.5
Between adjacent sets of two columns, P3	38

Table 1.4.2

CASK LAYOUT PITCH DATA FOR SQUARE ARRAYS

Orientation	**Nominal Cask Pitch (ft.)**
Between adjacent casks	18' - 8"

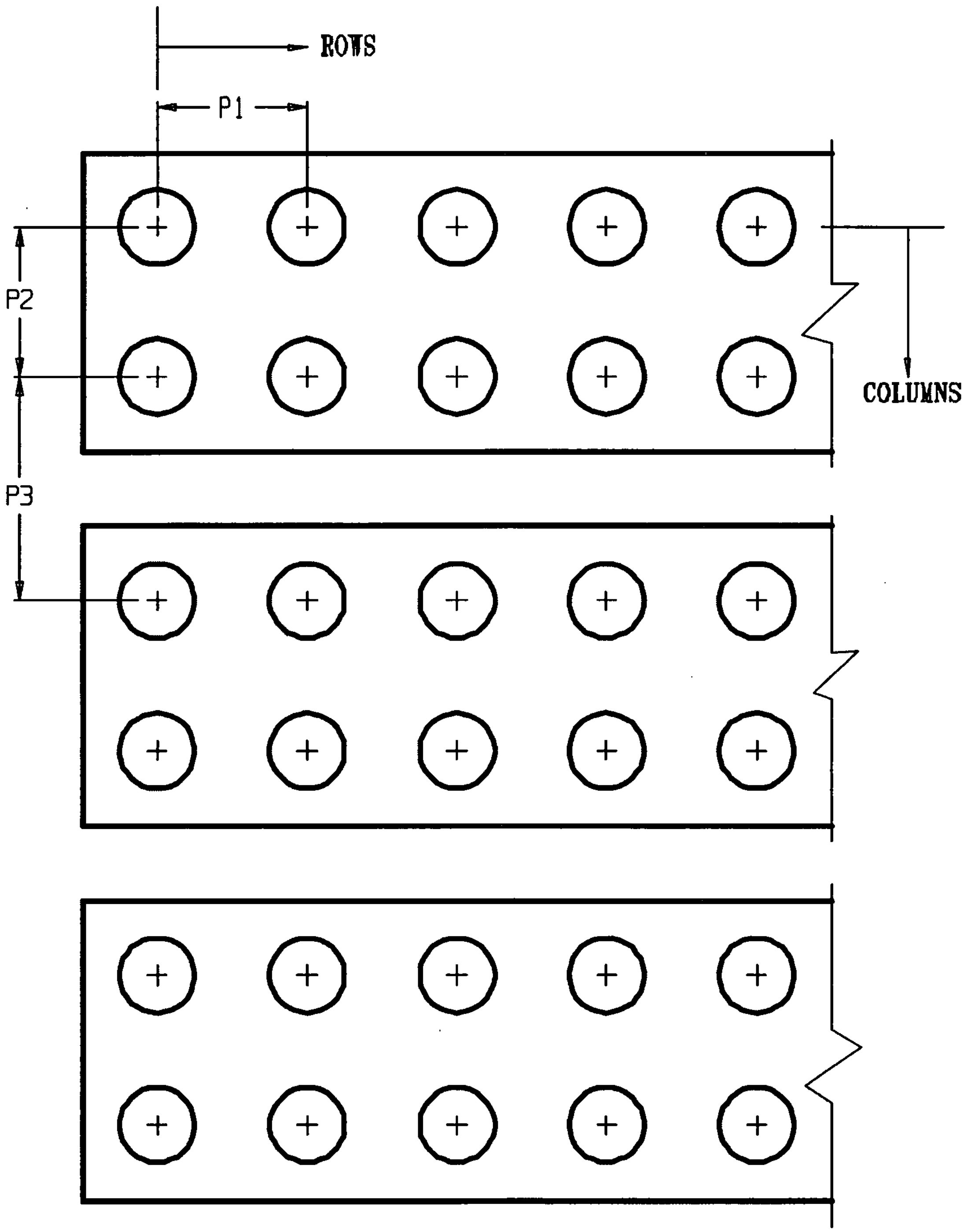

FIGURE 1.4.1; CASK LAYOUT PITCH REQUIREMENTS BASED ON 2 BY N ARRAY(S)

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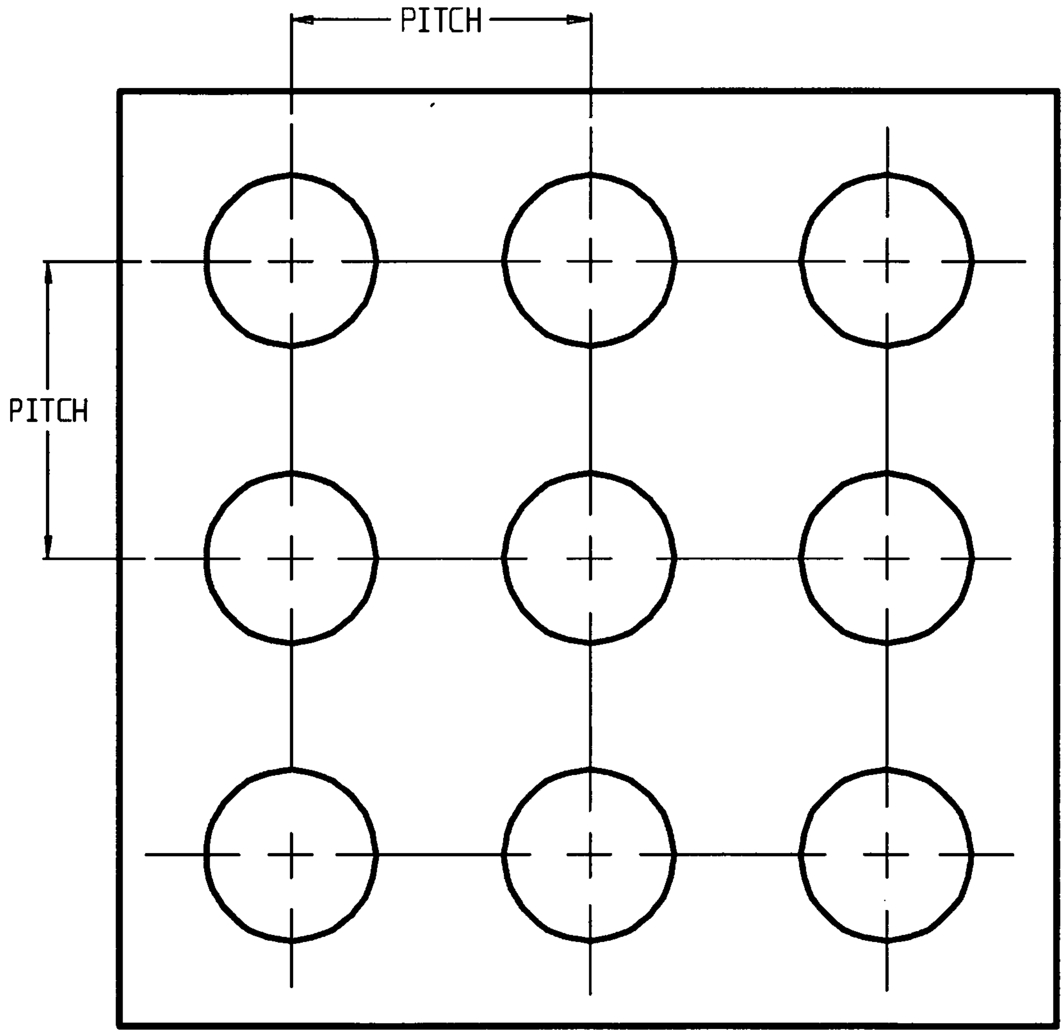

FIGURE 1.4.2; CASK LAYOUT PITCH REQUIREMENTS
BASED ON A SQUARE ARRAY

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1.5 DRAWINGS

The following HI-STORM 100 System drawings and bills of materials are provided on subsequent pages in this subsection:

Drawing Number/Sheet	Description	Rev.
3923	MPC Enclosure Vessel	30
3925	MPC-24E/EF Fuel Basket Assembly	9
3926	MPC-24 Fuel Basket Assembly	12
3927	MPC-32 Fuel Basket Assembly	16
3928	MPC-68/68F/68FF Basket Assembly	16
7195	MPC-68M Basket Assembly	4
1495 Sht 1/6	HI-STORM 100 Assembly	13
1495 Sht 2/6	Cross Section "Z" - "Z" View of HI-STORM	18
1495 Sht 3/6	Section "Y" - "Y" of HI-STORM	12
1495 Sht 4/6	Section "X" -"X" of HI-STORM	13
1495 Sht 5/6	Section "W" -"W" of HI-STORM	15
1561 Sht 1/6	View "A" -"A" of HI-STORM	11
1561 Sht 2/6	Detail "B" of HI-STORM	15
1561 Sht 3/6	Detail of Air Inlet of HI-STORM	11
1561 Sht 4/6	Detail of Air Outlet of HI-STORM	12
3669	HI-STORM 100S Assembly	19
1880 Sht 1/10	125 Ton HI-TRAC Outline with Pool Lid	9
1880 Sht 2/10	125 Ton HI-TRAC Body Sectioned Elevation	10
1880 Sht 3/10	125 Ton HI-TRAC Body Sectioned Elevation "B" - "B"	9
1880 Sht 4/10	125 Ton Transfer Cask Detail of Bottom Flange	10
1880 Sht 5/10	125 Ton Transfer Cask Detail of Pool Lid	10
1880 Sht 6/10	125 Ton Transfer Cask Detail of Top Flange	10
1880 Sht 7/10	125 Ton Transfer Cask Detail of Top Lid	9
1880 Sht 8/10	125 Ton Transfer Cask View "Y" - "Y"	9
1880 Sht 9/10	125 Ton Transfer Cask Lifting Trunnion and Locking Pad	7
1880 Sht 10/10	125 Ton Transfer Cask View "Z" - "Z"	9
1928 Sht 1/2	125 Ton HI-TRAC Transfer Lid Housing Detail	11
1928 Sht 2/2	125 Ton HI-TRAC Transfer Lid Door Detail	10
2145 Sht 1/10	100 Ton HI-TRAC Outline with Pool Lid	8
2145 Sht 2/10	100 Ton HI-TRAC Body Sectioned Elevation	8
2145 Sht 3/10	100 Ton HI-TRAC Body Sectioned Elevation 'B-B'	8
2145 Sht 4/10	100 Ton HI-TRAC Detail of Bottom Flange	7
2145 Sht 5/10	100 Ton HI-TRAC Detail of Pool Lid	6
2145 Sht 6/10	100 Ton HI-TRAC Detail of Top Flange	8
2145 Sht 7/10	100 Ton HI-TRAC Detail of Top Lid	8
2145 Sht 8/10	100 Ton HI-TRAC View Y-Y	8
2145 Sht 9/10	100 Ton HI-TRAC Lifting Trunnions and Locking Pad	5
2145 Sht 10/10	100 Ton HI-TRAC View Z-Z	7

Drawing Number/Sheet	Description	Rev.
2152 Sht 1/2	100 Ton HI-TRAC Transfer Lid Housing Detail	10
2152 Sht 2/2	100 Ton HI-TRAC Transfer Lid Door Detail	8
3187	Lug and Anchoring Detail for HI-STORM 100A	2
BM-1575, Sht 1/2	Bill-of-Materials HI-STORM 100 Storage Overpack	19
BM-1575, Sht 2/2	Bill-of-Materials HI-STORM 100 Storage Overpack	19
BM-1880, Sht 1/2	Bill-of-Material for 125 Ton HI-TRAC	9
BM-1880, Sht 2/2	Bill-of-Material for 125 Ton HI-TRAC	7
BM-1928, Sht 1/1	Bill-of-Material for 125 Ton HI-TRAC Transfer Lid	10
BM-2145 Sht 1/2	Bill-of-Material for 100 Ton HI-TRAC	6
BM-2145 Sht 2/2	Bill-of-Material for 100 Ton HI-TRAC	5
BM-2152 Sht 1/1	Bill-of-Material for 100 Ton HI-TRAC Transfer Lid	8
3768	125 Ton HI-TRAC 125D Assembly	12
4116	HI-STORM 100S Version B	24
4128	100 Ton HI-TRAC 100D Assembly	9

[DRAWING # 7195 Rev. 4 WITHHELD PER 10 CFR 2.390]

1.6 REFERENCES

[1.0.1] 10CFR Part 72, "Licensing Requirements for the Storage of Spent Fuel in an Independent Spent Fuel Storage Installation", Title 10 of the Code of Federal Regulations, 1998 Edition, Office of the Federal Register, Washington, D.C.

[1.0.2] Regulatory Guide 3.61 (Task CE306-4) "Standard Format for a Topical Safety Analysis Report for a Spent Fuel Storage Cask", USNRC, February 1989.

[1.0.3] NUREG-1536, "Standard Review Plan for Dry Cask Storage Systems", U.S. Nuclear Regulatory Commission, January 1997.

[1.0.4] American Concrete Institute, "Code Requirements for Nuclear Safety Related Concrete Structures", ACI 349-85, ACI, Detroit, Michigan.†

[1.0.5] American Concrete Institute, "Building Code Requirements for Structural Plain Concrete (ACI 318.1-89) (Revised 1992) and Commentary - ACI 318.1R-89 (Revised 1992)".

[1.0.6] "Spent Nuclear Fuel Effective Thermal Conductivity Report," U.S. Department of Energy Document Identifier BBA000000-01717-5705-00010, Rev. 00, Tables S-1 through S-4.

[1.1.1] ASME Boiler & Pressure Vessel Code, Section III, Subsection NB, American Society of Mechanical Engineers, 1995 with Addenda through 1997.

[1.1.2] USNRC Docket No. 72-1008, Final Safety Analysis Report for the (Holtec International Storage, Transport, and Repository) HI-STAR System, latest revision.

[1.1.3] USNRC Docket No. 71-9261, Safety Analysis Report for Packaging for the (Holtec International Storage, Transport, and Repository) HI-STAR System, latest revision.

[1.1.4] 10CFR Part 50, "Domestic Licensing of Production and Utilization Facilities", Title 10 of the Code of Federal Regulations, 1998 Edition, Office of the Federal Register, Washington, D.C.

[1.1.5] Deleted.

[1.2.1] U.S. NRC Information Notice 96-34, "Hydrogen Gas Ignition During Closure Welding of a VSC-24 Multi-Assembly Sealed Basket".

† The 1997 edition of ACI-349 is specified for embedment design for deployment of the anchored HI-STORM 100A and HI-STORM 100SA.

[1.2.2] Directory of Nuclear Reactors, Vol. II, Research, Test & Experimental Reactors, International Atomic Energy Agency, Vienna, 1959.

[1.2.3] V.L. McKinney and T. Rockwell III, "Boral: A New Thermal-Neutron Shield", USAEC Report AECD-3625, August 29, 1949.

[1.2.4] Reactor Shielding Design Manual, USAEC Report TID-7004, March 1956.

[1.2.5] "Safety Analysis Report for the NAC Storable Transport Cask", Revision 8, September 1994, Nuclear Assurance Corporation (USNRC Docket No. 71-9235).

[1.2.6] Deleted.

[1.2.7] Materials Handbook, 13th Edition, Brady, G.S. and H.R. Clauser, McGraw-Hill, 1991, Page 310.

[1.2.8] Deleted.

[1.2.9] 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," American National Standards Institute, June, 1993.

[1.2.10] Deleted.

[1.2.11] "Qualification of METAMIC® for Spent Fuel Storage Application," EPRI, 1003137, Final Report, October 2001.

[1.2.12] "Safety Evaluation by the Office of Nuclear Reactor Regulation Related to Holtec International Report HI-2022871 Regarding Use of Metamic in Fuel Pool Applications," Facility Operating License Nos. DPR-51 and NPF-6, Entergy Operations, Inc., Docket No. 50-313 and 50-368, USNRC, June 2003.

[1.2.13] "Metamic 6061+40% Boron Carbide Metal Matrix Composite Test", California Consolidated Tech. Inc. Report dated August 21, 2001 to NAC International.

[1.2.14] "Recommendations for Preparing the Criticality Safety Evaluation for Transportation Packages," NUREG/CR-5661, USNRC, Dyer and Parks, ORNL.

APPENDIX 1.A: ALLOY X DESCRIPTION

1.A ALLOY X DESCRIPTION

1.A.1 Alloy X Introduction

Alloy X is used within this licensing application to designate a group of stainless steel alloys. Alloy X can be any one of the following alloys:

- Type 316
- Type 316LN
- Type 304
- Type 304LN

Qualification of structures made of Alloy X is accomplished by using the least favorable mechanical and thermal properties of the entire group for all MPC mechanical, structural, neutronic, radiological, and thermal conditions. The Alloy X approach is conservative because no matter which material is ultimately utilized, the Alloy X approach guarantees that the performance of the MPC will meet or exceed the analytical predictions.

This appendix defines the least favorable material properties of Alloy X.

1.A.2 Alloy X Common Material Properties

Several material properties do not vary significantly from one Alloy X constituent to the next. These common material properties are as follows:

- density
- specific heat
- Young's Modulus (Modulus of Elasticity)
- Poisson's Ratio

The values utilized for this licensing application are provided in their appropriate chapters.

1.A.3 Alloy X Least Favorable Material Properties

The following material properties vary between the Alloy X constituents:

- Design Stress Intensity (S_m)
- Tensile (Ultimate) Strength (S_u)
- Yield Strength (S_y)
- Coefficient of Thermal Expansion (α)
- Coefficient of Thermal Conductivity (k)

Each of these material properties are provided in the ASME Code Section II [1.A.1]. Tables 1.A.1 through 1.A.5 provide the ASME Code values for each constituent of Alloy X along with the least favorable value utilized in this licensing application. The ASME Code only provides values to -20°F. The design temperature of the MPC is -40°F to 725°F as stated in Table 1.2.2. Most of the above-mentioned properties become increasingly favorable as the temperature drops. Conservatively, the values at the lowest design temperature for the HI-STORM 100 System have been assumed to be equal to the lowest value stated in the ASME Code. The lone exception is the thermal conductivity. The thermal conductivity decreases with the decreasing temperature. The thermal conductivity value for -40°F is linearly extrapolated from the 70°F value using the difference from 70°F to 100°F.

The Alloy X material properties are the minimum values of the group for the design stress intensity, tensile strength, yield strength, and coefficient of thermal conductivity. Using minimum values of design stress intensity is conservative because lower design stress intensities lead to lower allowables that are based on design stress intensity. Similarly, using minimum values of tensile strength and yield strength is conservative because lower values of tensile strength and yield strength lead to lower allowables that are based on tensile strength and yield strength. When compared to calculated values, these lower allowables result in factors of safety that are conservative for any of the constituent materials of Alloy X. Further discussion of the justification for using the minimum values of coefficient of thermal conductivity is given in Chapter 3. The maximum and minimum values are used for the coefficient of thermal expansion of Alloy X. The maximum and minimum coefficients of thermal expansion are used as appropriate in this submittal. Figures 1.A.1-1.A.5 provide a graphical representation of the varying material properties with temperature for the Alloy X materials.

1.A.4 References

[1.A.1] ASME Boiler & Pressure Vessel Code Section II, 1995 ed. with Addenda through 1997.

Table 1.A.1

ALLOY X AND CONSTITUENT DESIGN STRESS INTENSITY (S_m) vs. TEMPERATURE

Temp. (°F)	Type 304	Type 304LN	Type 316	Type 316LN	Alloy X (minimum of constituent values)
-40	20.0	20.0	20.0	20.0	20.0
100	20.0	20.0	20.0	20.0	20.0
200	20.0	20.0	20.0	20.0	20.0
300	20.0	20.0	20.0	20.0	20.0
400	18.7	18.7	19.3	18.9	18.7
500	17.5	17.5	18.0	17.5	17.5
600	16.4	16.4	17.0	16.5	16.4
650	16.2	16.2	16.7	16.0	16.0
700	16.0	16.0	16.3	15.6	15.6
750	15.6	15.6	16.1	15.2	15.2
800	15.2	15.2	15.9	14.9	14.9

Notes:

1. Source: Table 2A on pages 314, 318, 326, and 330 of [1.A.1].
2. Units of design stress intensity values are ksi.

Table 1.A.2

ALLOY X AND CONSTITUENT TENSILE STRENGTH (S_u) vs. TEMPERATURE

Temp. (°F)	Type 304	Type 304LN	Type 316	Type 316LN	Alloy X (minimum of constituent values)
-40	75.0 (70.0)	75.0 (70.0)	75.0 (70.0)	75.0 (70.0)	75.0 (70.0)
100	75.0 (70.0)	75.0 (70.0)	75.0 (70.0)	75.0 (70.0)	75.0 (70.0)
200	71.0 (66.2)	71.0 (66.2)	75.0 (70.0)	75.0 (70.0)	71.0 (66.2)
300	66.0 (61.5)	66.0 (61.5)	73.4 (68.5)	70.9 (66.0)	66.0 (61.5)
400	64.4 (60.0)	64.4 (60.0)	71.8 (67.0)	67.1 (62.6)	64.4 (60.0)
500	63.5 (59.3)	63.5 (59.3)	71.8 (67.0)	64.6 (60.3)	63.5 (59.3)
600	63.5 (59.3)	63.5 (59.3)	71.8 (67.0)	63.1 (58.9)	63.1 (58.9)
650	63.5 (59.3)	63.5 (59.3)	71.8 (67.0)	62.8 (58.6)	62.8 (58.6)
700	63.5 (59.3)	63.5 (59.3)	71.8 (67.0)	62.5 (58.4)	62.5 (58.4)
750	63.1 (58.9)	63.1 (58.9)	71.4 (66.5)	62.2 (58.1)	62.2 (58.1)
800	62.7 (58.5)	62.7 (58.5)	70.9 (66.2)	61.7 (57.6)	61.7 (57.6)

Notes:

1. Source: Table U on pages 437, 439, 441, and 443 of [1.A.1].
2. Units of tensile strength are ksi.
3. The ultimate stress of Alloy X is dependent on the product form of the material (i.e., forging vs. plate). Values in parentheses are based on SA-336 forged materials (type F304, F304LN, F316, and F316LN), which are used solely for the one-piece construction MPC lids. All other values correspond to SA-240 plate material.

Table 1.A.3

ALLOY X AND CONSTITUENT YIELD STRESSES (S_y) vs. TEMPERATURE

Temp. (°F)	Type 304	Type 304LN	Type 316	Type 316LN	Alloy X (minimum of constituent values)
-40	30.0	30.0	30.0	30.0	30.0
100	30.0	30.0	30.0	30.0	30.0
200	25.0	25.0	25.8	25.5	25.0
300	22.5	22.5	23.3	22.9	22.5
400	20.7	20.7	21.4	21.0	20.7
500	19.4	19.4	19.9	19.4	19.4
600	18.2	18.2	18.8	18.3	18.2
650	17.9	17.9	18.5	17.8	17.8
700	17.7	17.7	18.1	17.3	17.3
750	17.3	17.3	17.8	16.9	16.9
800	16.8	16.8	17.6	16.6	16.6

Notes:

1. Source: Table Y-1 on pages 518, 519, 522, 523, 530, 531, 534, and 535 of [1.A.1].

2. Units of yield stress are ksi.

Table 1.A.4

ALLOY X AND CONSTITUENT COEFFICIENT OF THERMAL EXPANSION vs. TEMPERATURE

Temp. (°F)	Type 304 and Type 304LN	Type 316 and Type 316LN	Alloy X Maximum	Alloy X Minimum
-40	8.55	8.54	8.55	8.54
100	8.55	8.54	8.55	8.54
150	8.67	8.64	8.67	8.64
200	8.79	8.76	8.79	8.76
250	8.90	8.88	8.90	8.88
300	9.00	8.97	9.00	8.97
350	9.10	9.11	9.11	9.10
400	9.19	9.21	9.21	9.19
450	9.28	9.32	9.32	9.28
500	9.37	9.42	9.42	9.37
550	9.45	9.50	9.50	9.45
600	9.53	9.60	9.60	9.53
650	9.61	9.69	9.69	9.61
700	9.69	9.76	9.76	9.69
750	9.76	9.81	9.81	9.76
800	9.82	9.90	9.90	9.82

Notes:

1. Source: Table TE-1 on pages 590 and 591 of [1.A.1].

2. Units of coefficient of thermal expansion are in./in.-°F x 10^{-6}.

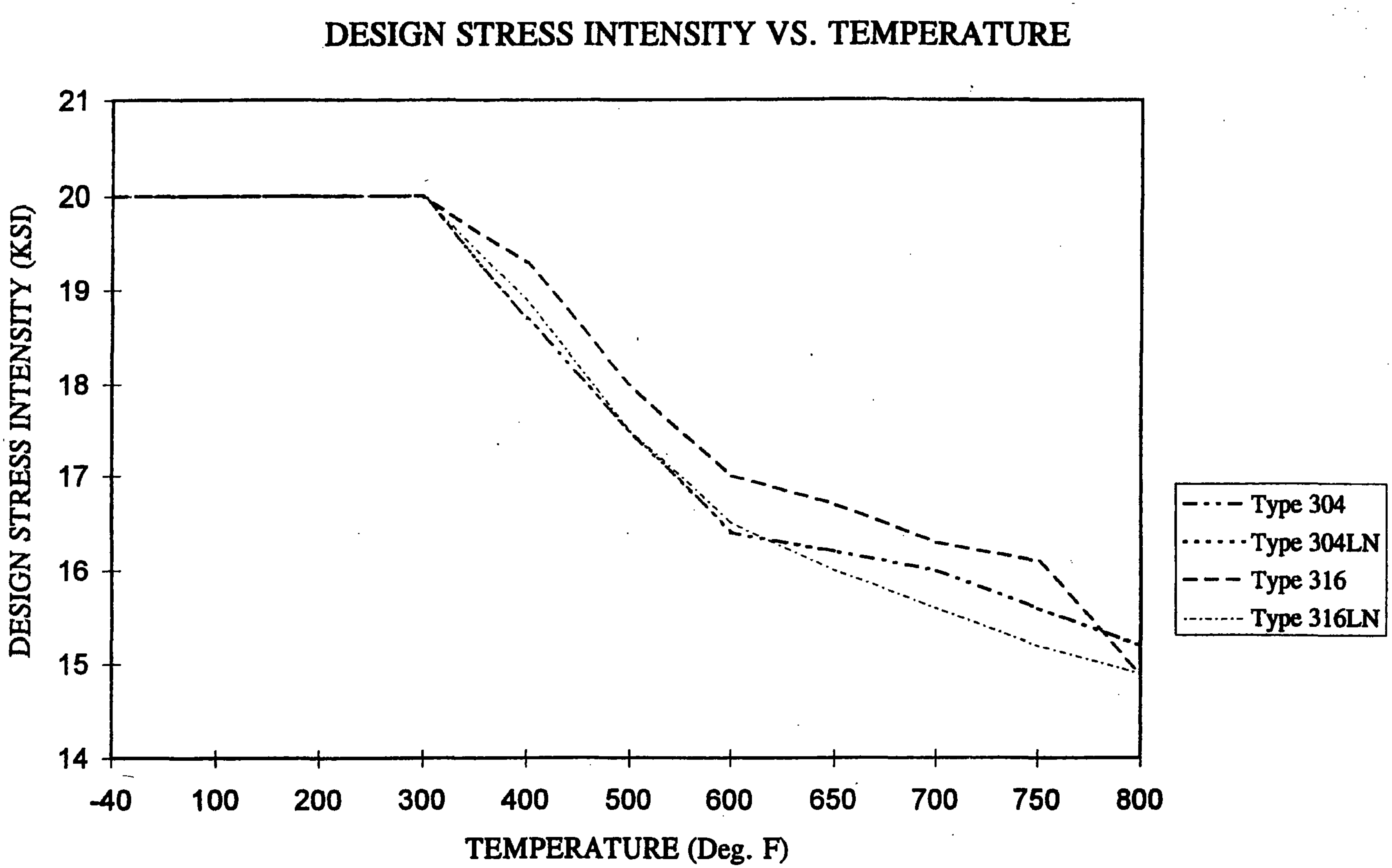
Table 1.A.5

ALLOY X AND CONSTITUENT THERMAL CONDUCTIVITY vs. TEMPERATURE

Temp. (°F)	Type 304 and Type 304LN	Type 316 and Type 316LN	Alloy X (minimum of constituent values)
-40	8.23	6.96	6.96
70	8.6	7.7	7.7
100	8.7	7.9	7.9
150	9.0	8.2	8.2
200	9.3	8.4	8.4
250	9.6	8.7	8.7
300	9.8	9.0	9.0
350	10.1	9.2	9.2
400	10.4	9.5	9.5
450	10.6	9.8	9.8
500	10.9	10.0	10.0
550	11.1	10.3	10.3
600	11.3	10.5	10.5
650	11.6	10.7	10.7
700	11.8	11.0	11.0
750	12.0	11.2	11.2
800	12.2	11.5	11.5

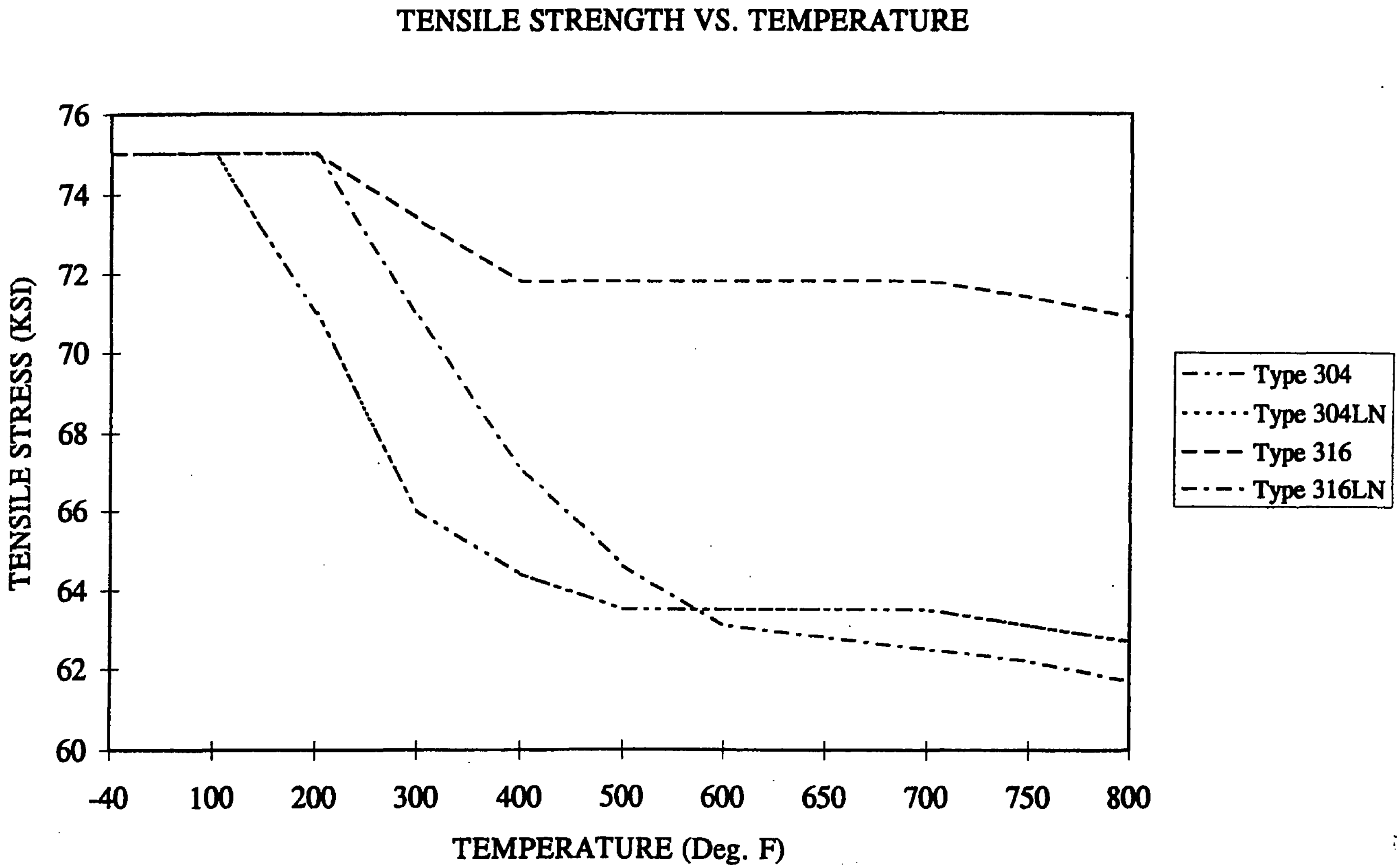
Notes:

1. Source: Table TCD on page 606 of [1.A.1].
2. Units of thermal conductivity are Btu/hr-ft-°F.



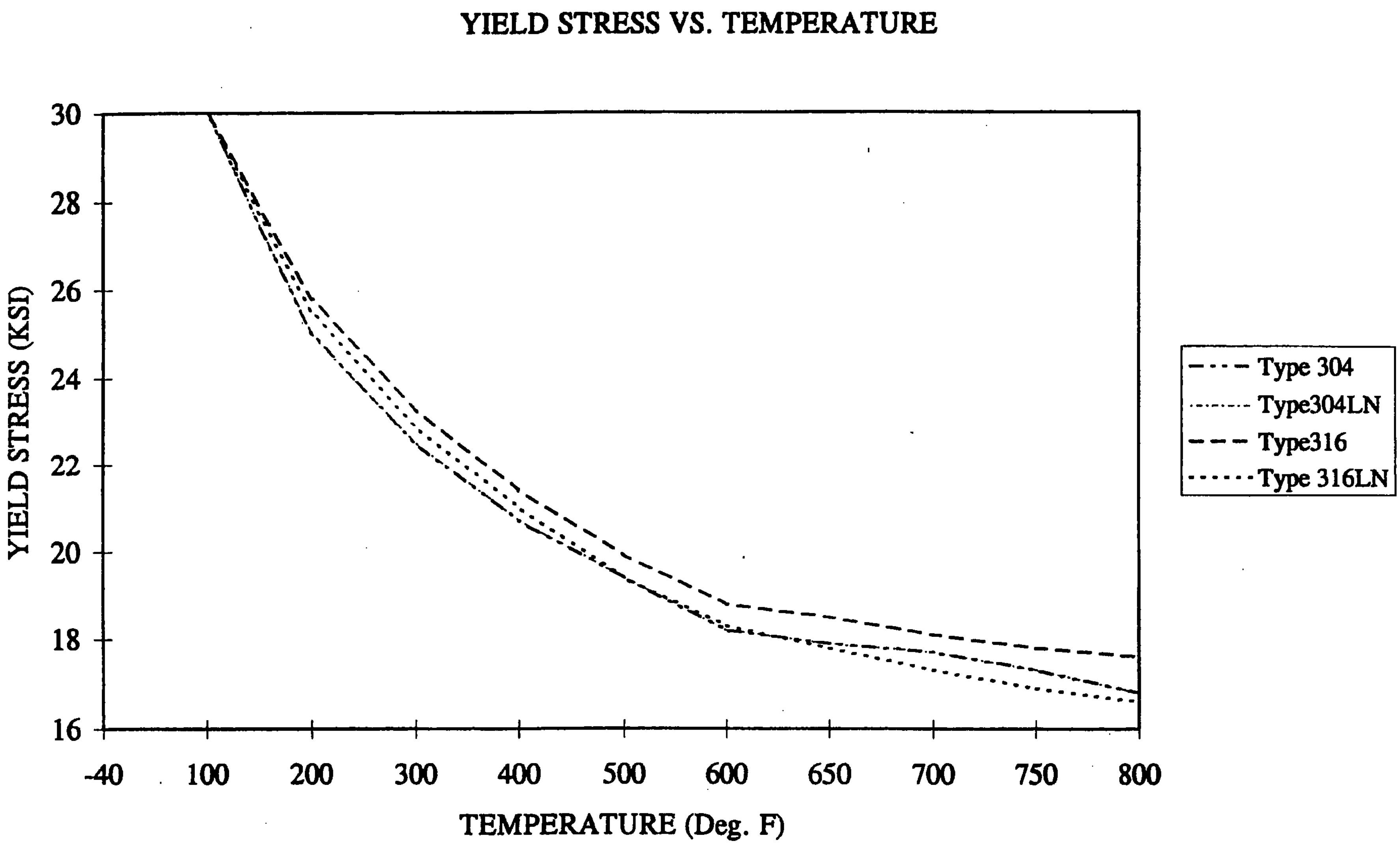
SOURCE: TABLE 1.A.1

FIGURE 1.A.1; DESIGN STRESS INTENSITY VS. TEMPERATURE



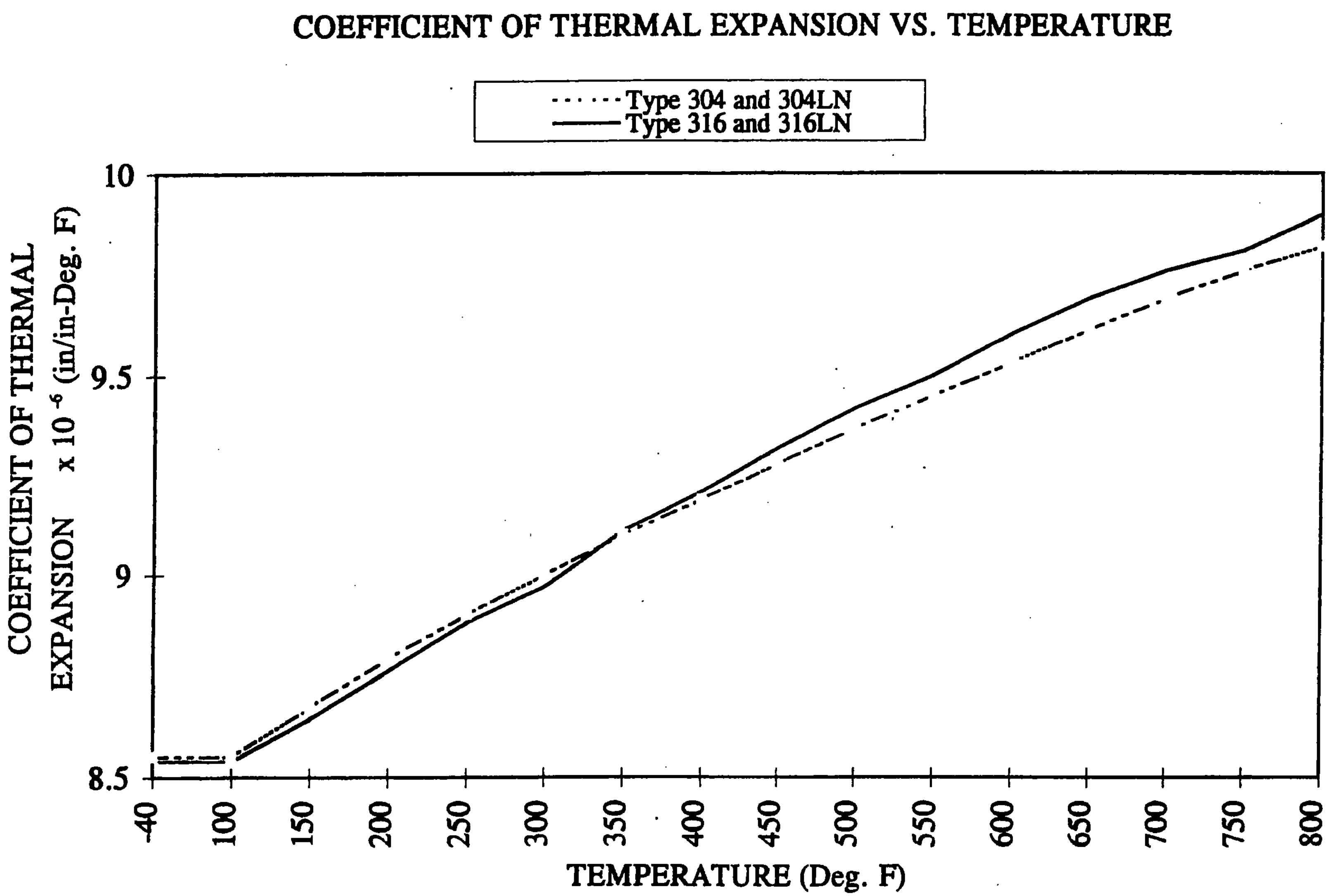
SOURCE: TABLE 1.A.2

FIGURE 1.A.2; TENSILE STRENGTH VS. TEMPERATURE



SOURCE: TABLE 1.A.3

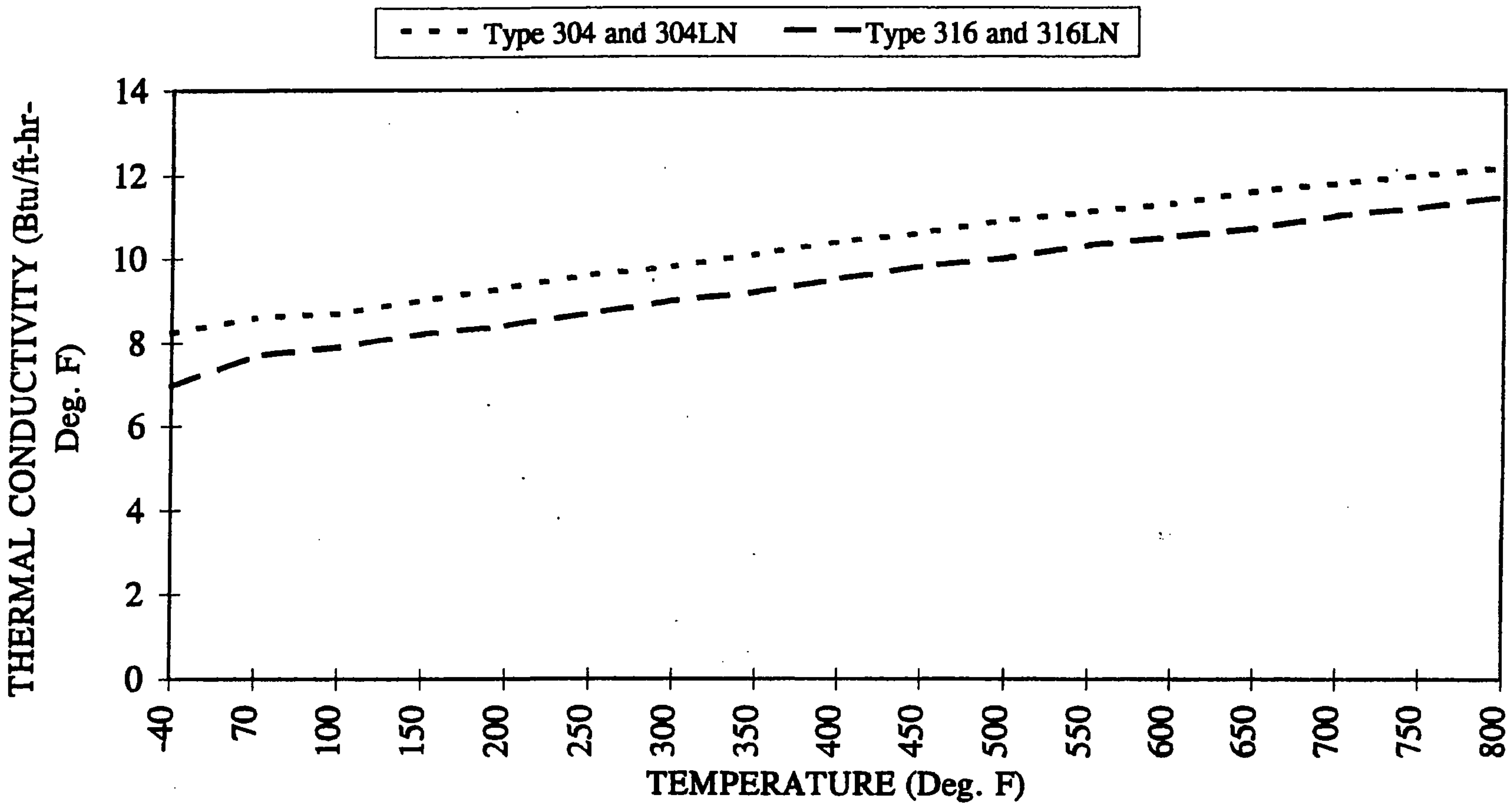
FIGURE 1.A.3; YIELD STRESS VS. TEMPERATURE



SOURCE: TABLE 1.A.4

FIGURE 1.A.4; COEFFICIENT OF THERMAL EXPANSION VS. TEMPERATURE

THERMAL CONDUCTIVITY VS. TEMPERATURE



SOURCE: TABLE 1.A.5

FIGURE 1.A.5; THERMAL CONDUCTIVITY VS. TEMPERATURE

APPENDIX 1.B: HOLTITE ™ MATERIAL DATA

The information provided in this appendix describes the neutron absorber material, Holtite-A for the purpose of confirming its suitability for use as a neutron shield material in spent fuel storage casks. Holtite-A is one of the family of Holtite neutron shield materials denoted by the generic name Holtite™. It is currently the only solid neutron shield material approved for installation in the HI-TRAC transfer cask. It is chemically identical to NS-4-FR which was originally developed by Bisco Inc. and used for many years as a shield material with B_4C or Pb added.

Holtite-A contains aluminum hydroxide ($Al(OH)_3$) in an epoxy resin binder. Aluminum hydroxide is also known by the industrial trade name of aluminum tri-hydrate or ATH. ATH is often used commercially as a fire-retardant. Holtite-A contains approximately 62% ATH supported in a typical 2-part epoxy resin as a binder. Holtite-A contains 1% (nominal) by weight B_4C, a chemically inert material added to enhance the neutron absorption property. Pertinent properties of Holtite-A are listed in Table 1.B.1.

The essential properties of Holtite-A are:

1. the hydrogen density (needed to thermalize neutrons),
2. thermal stability of the hydrogen density, and
3. the uniformity in distribution of B_4C needed to absorb the thermalized neutrons.

ATH and the resin binder contain nearly the same hydrogen density so that the hydrogen density of the mixture is not sensitive to the proportion of ATH and resin in the Holtite-A mixture. B_4C is added as a finely divided powder and does not settle out during the resin curing process. Once the resin is cured (polymerized), the ATH and B_4C are physically retained in the hardened resin. Qualification testing for B_4C throughout a column of Holtite-A has confirmed that the B_4C is uniformly distributed with no evidence of settling or non-uniformity. Furthermore, an excess of B_4C is specified in the Holtite-A mixing and pouring procedure as a precaution to assure that the B_4C concentration is always adequate throughout the mixture.

The specific gravity specified in Table 1.B.1 does not include an allowance for weight loss. The specific gravity assumed in the shielding analysis includes a 4% reduction to conservatively account for potential weight loss at the design temperatures listed in Table 1.B.1. or an inability to reach theoretical density. Tests on the stability of Holtite-A were performed by Holtec International. The results of the tests are summarized in Holtec Reports HI-2002396, "Holtite-A Development History and Thermal Performance Data" and HI-2002420, "Results of Pre- and Post-Irradiation Test Measurements." The information provided in these reports demonstrates that Holtite-A™ possesses the necessary thermal and radiation stability characteristics to function as a reliable shielding material in the HI-TRAC transfer cask.

The Holtite-A is encapsulated in the HI-TRAC transfer cask lid and, therefore, should experience a very small weight reduction during the design life of the cask. The data and test results confirm that Holtite-A remains stable under design thermal and radiation conditions, the material properties meet or exceed that assumed in the shielding analysis, and the B_4C remains uniformly distributed with no evidence of settling or non-uniformity.

Based on the information described above, Holtite-A meets all of the requirements for an acceptable neutron shield material.

Table 1.B.1

REFERENCE PROPERTIES OF HOLTITE-A NEUTRON SHIELD MATERIAL

PHYSICAL PROPERTIES	
% ATH	62 nominal
Specific Gravity	1.68 g/cc nominal
Max. Continuous Operating Temperature	300°F
Max. Short-Term Operating Temperature	350°F (Note 1)
Hydrogen Density	0.096 g/cc minimum
Radiation Resistance	Excellent
CHEMICAL PROPERTIES (Nominal)	
wt% Aluminum	21.5
wt% Hydrogen	6.0
wt% Carbon	27.7
wt% Oxygen	42.8
wt% Nitrogen	2.0
wt% B_4C	1.0

NOTES:

1. As defined in Section 2.2, all operations involving the HI-TRAC transfer cask are short-term operating conditions. The short-term operating temperature limit is, therefore, the appropriate maximum design temperature for the Holtite-A in the HI-TRAC transfer cask.

APPENDIX 1.C: MISCELLANEOUS MATERIAL DATA
(Total of 1 Page Including This Page)

The information provided in this appendix specifies the paint properties and demonstrates their suitability for use in spent nuclear fuel storage casks.

Thermaline 450 or functionally equivalent paint/coating is specified to coat the overpack to the maximum extent practical and the inner cavity of the HI-TRAC transfer cask. Carboline 890 or functionally equivalent paint/coating is specified to coat external surfaces of the HI-TRAC transfer cask. The paints are suitable for the design temperatures (see Table 2.2.3) and the environment.

APPENDIX 1.D: Requirements on HI-STORM 100 Shielding Concrete

1.D.1 Introduction

The HI-STORM 100 overpack utilizes plain concrete for neutron and gamma shielding. Plain concrete used in the HI-STORM overpack provides only a compressive strength structural function due to the fact that both the primary and secondary load bearing members of the overpack are made of carbon steel. While most of the shielding concrete used in the HI-STORM 100 overpack is installed in the annulus between the concentric structural shells, smaller quantities of concrete are also present in the pedestal shield and the overpack lid. Because plain concrete has little ability to withstand tensile stresses, but is competent in withstanding compressive and bearing loads, the design of the HI-STORM 100 overpack places no reliance on the tension-competence of the shielding concrete.

During normal operations of the HI-STORM, the stresses in the concrete continuum are negligible, arising solely from its self-weight. ACI 318.1-89(92) provides formulas for permissible compressive and bearing stresses in plain concrete, which incorporate a penalty over the corresponding permissible values in reinforced concrete. The formulas for permissible compressive and bearing stresses set forth in ACI 318.1-89(92)are used in calculations supporting this FSAR in load cases involving compression or bearing loads on the overpack concrete. However, since the overpack concrete is designated as an ITS Category B material, it is appropriate to ensure that all "*critical characteristics*" of the concrete, as defined herein, are fully satisfied. During normal storage operations, the overpack concrete is completely enclosed by the overpack steel structure, protecting it from the deleterious effects of direct exposure to the environment, typical of most concrete structures governed by the ACI codes.

The "*critical characteristics*" of the plain concrete in the HI-STORM overpack are: (i) its density and (ii) its compressive strength. This appendix provides the complete set of criteria applicable to the plain concrete in the HI-STORM 100 overpack.

1.D.2 Design Requirements

The primary function of the plain concrete is to provide neutron and gamma shielding. As plain concrete is a competent structural member in compression, the plain concrete's effect on the performance of the HI-STORM overpack under compression loadings is considered and modeled in the structural analyses, as necessary. The formulas for permissible compressive and bearing stresses set forth in ACI 318.1-89(92)are used. However, as plain concrete has very limited capabilities in tension, no tensile strength capability is allotted to the HI-STORM concrete.

The steel structure of the HI-STORM overpack provides the strength to meet all load combinations specified in Chapters 2 and 3, due to the fact that both the primary and secondary load bearing members (as defined in the ASME Code, Section III, Subsection NF-1215) of the HI-STORM overpack are made from carbon steel. Credit for the structural strength of the plain concrete is only taken to enhance the compressive load carrying capability of the concrete in calculations appropriate to handling and transfer operations, and to demonstrate that the HI-STORM 100 System continues to provide functional performance in a post-accident environment. Therefore, the load combinations provided in ACI 349 and NUREG-1536, Table 3-1 are not applicable to the plain concrete in the HI-STORM overpack.

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 demonstrate that the plain concrete does not exceed the allowable long term temperature limit provided in Table 1.D.1. Under accident conditions, the bulk of the plain concrete in the HI-STORM overpack does not exceed the allowable short term temperature limit provided in Table 1.D.1. Any portion of the plain concrete, which exceeds the short-term temperature limit under accident conditions, is neglected in the post-accident shielding analysis and in any post-accident structural analysis.

1.D.2.1 Test Results to Support Normal Condition Temperature Limit

Note 3 to Table 1.D.1 references Paragraph A.4.3 of ACI-349, which requires that normal condition temperatures in excess of 150°F bulk and 200°F local must be supported by test data to demonstrate that strength reductions are acceptable and that concrete deterioration does not occur. Such data are described and discussed in this subsection.

With respect to concrete compressive strength at bulk temperatures up to 300°F, test studies for elevated temperatures were performed by Carette and Malhorta [1.D.1] that examined conditions very similar to those of the HI-STORM concrete. Their tests were performed on 4" diameter by 8" long test cylinders. The test condition most closely matching the HI-STORM concrete was: 0.6 water-to-cement ratio, limestone aggregate and 300°F for four months. While the HI-STORM storage period is much greater than 4 months, the investigators state "any major strength loss is found to occur within the first month of exposure." The four-month compressive strength for these conditions was actually determined to be greater than the nominal concrete strengths despite the elevated temperatures. This is attributable to the increase in compressive strength that accompanies concrete aging, which more than offsets the temperature effects.

With respect to concrete shielding performance at local temperatures above 300°F, a report by Schneider and Horvath [1.D.2] examined weight loss of concrete at elevated temperatures. Tests were performed on 12mm diameter by 40 mm long test cylinders in an apparatus called a thermo-balance. A variety of aggregates (i.e., quartz, limestone and basalt) were tested. The test results indicate a worst-case weight loss of 0.666% from 300°F to 390°F for quartz aggregates. This maximum level of weight loss would reduce the concrete density from 2.24 gm/cc to 2.225 gm/cc. If the entire weight loss is attributed to water loss, the corresponding limiting reduction in hydrogen content is from 0.6% to 0.529%. As discussed in Section 5.3.2, such reductions are negligible with respect to shielding performance.

1.D.3 Material Requirements

Table 1.D.1 provides the material limitations and requirements applicable to the overpack plain concrete. These requirements, drawn from ACI 349-85 and supplemented by the provisions of NUREG 1536 (page 3-21), are intended to ensure that the "*critical characteristics*" of the concrete placed in the HI-STORM overpack comply with the requirements of this Appendix and standard good practice. Two different minimum concrete densities are specified for the overpack concrete, based on the presence or absence of the steel shield shell. The steel shield shell was deleted from the overpack design after the construction of overpack serial number 1024-7.

ACI 349 was developed to govern the design and construction of steel reinforced concrete structures for the entire array of nuclear power plant applications, except for concrete reactor vessels and containment structures. Therefore, ACI 349 contains many requirements not germane to the plain concrete installed in and completely enclosed by the steel HI-STORM overpack structure. For example, the overpack concrete is not exposed to the environment, so provisions in the standard for protecting concrete from the environment would not be applicable to the concrete contained in the overpack.

In accordance with the requirement in Section 3.3 of Appendix B of the HI-STORM 100 CoC, Section 1.D.4, Table 1.D.1 and Table 1.D.2 were developed using the guidance of ACI 349-85, to the extent it needs to be applied to the unique application of placing unreinforced concrete inside the steel enclosure of the HI-STORM overpack. Other concrete standards were used, as appropriate, to provide the controls necessary to assure that the *critical characteristics* of the overpack concrete will be achieved and that the concrete will perform its design function.

1.D.3.1 Essential Requirements for Concrete Supplier and Lab Testing Support

The material used in HI-STORM related concrete shall be procured from suppliers that have been qualified under Holtec QA program through appropriate validation and surveillance. The QA surveillance record on the concrete supplier must be current at the time of concrete placement. Among the many missions of the surveillance program are activities that are crucial to insure that all required *critical characteristics* shall be met such as, all scales used in the batching process are calibrated, delivery trucks are in good working condition, and all aggregate material stored at the facility is segregated. These parameters ensure that the batched concrete is in compliance with the Holtec concrete mix design.

With respect to the test lab services, surveillance of the lab ensures that all equipment used in testing of aggregates and concrete cylinder samples are calibrated. Additionally, inspections are completed on the concrete cylinder storage facilities as well as basic material controls. With these controls in place, the results of any aggregate testing or concrete cylinder testing can be confirmed to be accurate and reliable.

1.D.3.2 Concrete Mix Design and Material Requirements

A concrete mix design shall first be established to determine the necessary recipe to produce a HI-STORM concrete that meets the *critical characteristics* of the HI-STORM as specified in this section. Once the mix design is formulated, actual site testing shall be conducted to confirm the mix design. At the batch plant, the mix design will be used to make concrete for initial testing purposes. This initial batch shall be checked for slump and density. The mix design may be altered as necessary at this time until the desired results are achieved. Additionally, a total of ten cylinders from the final acceptable batch shall be taken for laboratory testing. These cylinders shall be used for compressive strength break test to determine the strength of the concrete mix.

With respect to individual aggregate testing, the provisions from ACI 349 those are germane to the plain concrete installed in and completely enclosed by the steel HI-STORM overpack structure are summarized herein. For example, the overpack concrete is not exposed to the environment, so provisions in the ACI standards for protecting concrete from the environment would not be applicable to the concrete contained in the overpack.

For the standard use local course and fine aggregates supplied by the local batch, a high level of confidence based on continued use in area concrete obviates the need for many of the aggregate testing recommended by ASTM C33. However, certain testing relevant to confirming the acceptability of the aggregate is required by this specification. For both the local fine and course aggregate, laboratory testing shall be carried out to confirm grading per ASTM C33 as well as the test per ASTM C117 to determine materials finer than 200 sieve. A laboratory technician shall also visually inspect the source pile to evaluate the aggregates for any deleterious substances or organic impurities. If this visual inspection reveals any evidence of deleterious substances or organic impurities, additional aggregate testing that addresses deleterious substances per ASTM C33 for both fine and course aggregates as well as organic impurities testing per ASTM C40 for the local fine aggregate shall be conducted.

For the specially supplied dense aggregate that is supplied from an outside source, applicable grading and 200 sieve testing shall be completed.

1.D.4 Construction Requirements

Method of placement of the concrete is important to achieving the desired properties in the concrete. It is imperative to achieve a concrete placement with no voids. In order to accomplish this, procedural steps shall be in place to control the placement technique with respect to lift height and vibratory agitation. The concrete shall be placed in the HI-STORM in two foot (approximate) lifts. Vibration of poured concrete shall be such that the vibrator is inserted and removed in a vertical movement with no dragging of the vibrator through the concrete. Vibrator placement shall be based on the size of the vibrator as detailed in ACI-309R.

The slump of the concrete shall be checked as necessary prior to placement to ensure that the concrete is suitable for pumping.

Appropriate measures shall be taken for hot and cold weather conditions as prescribed by ACI-305R and ACI-306R, respectively.

1.D.5 Testing Requirements

Concrete may be tested for temperature, slump, and density for each truck prior to placement in the HI-STORM for informational purposes. Official samples, as required by the applicable Holtec procedure, shall be taken from the approximate middle of the truck discharge and will become the sample of record for slump, temperature, and density. Additionally, compressive test cylinder samples shall be taken of a quantity to support required break tests as detailed in the governing Holtec procedure and will ensure a representative sample of the concrete is tested in accordance with ACI 349-85. At a minimum one set of samples must be taken for each HI-STORM. Samples taken in the field should be stored as best possible to protect the samples from extreme temperature conditions. Compressive break strengths of the official concrete cylinder samples taken shall be tested for the required minimum concrete strength. The compressive strength of concrete is observed to increase monotonically with the time of curing [1.D.3]. Therefore, break tests resulting in a compressive strength exceeding the minimum required compressive strength may be used as the official concrete break data in lieu of waiting for 28-day breaks.

1.D.6 References

[1.D.1] Carette and Malhorta, "Performance of Dolostone and Limestone Concretes at Sustained High Temperatures," Temperature Effects on Concrete, ASTM STP 858.

[1.D.2] Schneider and Horvath, "Behaviour of Ordinary Concrete at High Temperature," Vienna Technical University – Institute for Building Materials and Fire Protection, Research Report Volume 9.

[1.D.3] Concrete Manual, 8th Edition, US Bureau of Proclamation, Denver, Colorado, 1975.

Table 1.D.1
Requirements for Plain Concrete

ITEM	APPLICABLE LIMIT OR REFERENCE
Density in overpack body (Minimum) (see Table 3.2.1 for information on maximum concrete density)	140 lb/ft^3
Density in lid and pedestal (Minimum) (See Table 3.2.1 for information on maximum concrete density)	140 lb/ft^3 (HI-STORM 100S Version B does not have a concrete-filled pedestal)
Specified Compressive Strength	3,300 psi (min.)
Compressive and Bearing Stress Limit	Per ACI 318.1-89(92)
Cement Type and Mill Test Report	Type II; (ASTM C 150 or ASTM C595)
Aggregate Type	Fine and coarse aggregate as required (Note 2)
Nominal Maximum Aggregate Size	1-1/2 (inch)
Water Quality	Deleted
Material Testing	See Note 4.
Admixtures	Deleted
Maximum Water to Cement Ratio	0.5 (Table 4.5.2)
Maximum Water Soluble Chloride Ion Cl in Concrete	1.00 percent by weight of cement (Table 4.5.4) (See Table 1.D.2, Note 1)
Concrete Quality	Deleted
Mixing and Placing	See Note 6.
Consolidation	Deleted
Quality Assurance	Per Holtec Quality Assurance Manual, 10 CFR Part 72, Appendix G commitments
Through-Thickness Section Average† Temperature Limit Under Long Term Conditions	300°F (See Note 3)
Through-Thickness Section Average† Temperature Limit Under Short Term Conditions	350°F (Appendix A, Paragraph A.4.2)
Aggregate Maximum Value†† of Coefficient of Thermal Expansion (tangent in the range of 70°F to 100°F)	6E-06 inch/inch/°F (NUREG-1536, 3.V.2.b.i.(2)(c)2.b)

† The through-thickness section average is the same quantity as that defined in Paragraph A.4.3 of Appendix A to ACI 349 as the mean temperature distribution. A formula for determining this value, consistent with the inner and outer surface averaging used in this FSAR, is presented in Figure A-1 of the commentary on ACI 349. Use of this quantity as an acceptance criterion is, therefore, in accordance with the governing ACI code.

†† The following aggregate types are a priori acceptable: limestone, marble, basalt, granite, gabbros, or rhyolite. The thermal expansion coefficient limit does not apply when these aggregates are used. Careful consideration shall be given to the potential of long-term degradation of concrete due to chemical reactions between the aggregate and cement selected for HI-STORM overpack concrete.

Table 1.D.1 (continued)
Requirements for Plain Concrete

Notes:

1. Deleted

2. The coarse aggregate shall meet the requirements of ASTM C33 for class designation 1S from Table 3. However, if the requirements of ASTM C33 cannot be met, concrete aggregates that have been shown by special tests or actual service to produce concrete of adequate strength, unit weight, and durability meeting the requirements of Tables 1.D.1 and 1.D.2 are acceptable in accordance with ACI 349 Section 3.3.2. The high-density coarse aggregate percentage of Material Finer than No. 200 Sieve may be increased to 10 % if the material is essentially free of clay or shale.

3. The 300°F long term temperature limit is specified in accordance with Paragraph A.4.3 of Appendix A to ACI 349 for normal conditions considering the very low maximum stresses calculated and discussed in Section 3.4 of this FSAR for normal conditions. In accordance with this paragraph of the governing code, the specified concrete compressive strength is supported by test data and the concrete is shown not to deteriorate, as evidenced by a lack of reduction in concrete density or durability.

4. Tests of materials and concrete, as required, shall be made in accordance with standards of the American Society for Testing and Materials (ASTM) as specified here, to ensure that the *critical characteristics* for the HI-STORM concrete are achieved. ASTM Standards to be used include: C 31-96, C 33-82, C 39-96, C 88-76, C 131-81, C 138-92, C 143-98, C 150-97, C 172-90, C 192-95, C 494-92, C 637-73. More recent approved editions of the referenced standards may be used.

5. Deleted

6. Water and admixtures may be added at the job site to bring both the slump and wet unit weight of the concrete within the mix design limits. Water or admixtures shall not be added to the concrete after placement activities have started. The tolerance for individual and combined aggregate weights in the concrete batch may be outside of tolerances specified in ASTM C94, provided that the wet unit weight of the concrete is tested prior to placement and confirmed to be within the approved range.

Table 1.D.2: Testing Requirements for Plain Concrete

TEST	SPECIFICATION
Compression Test	ASTM C31, ASTM C39, ASTM C192
Unit Weight (Density)	ASTM C138
Maximum Water Soluble Chloride Ion Concentration	Federal Highway Administration Report FHWA-RD-77-85, "Sampling and Testing for Chloride Ion in Concrete" (Note 1)

Notes:

1. If the concrete or concrete aggregates are suspected of containing excessive amounts of chlorides, they will be tested to ensure that their contribution will not cause the water-soluble chloride concentration to exceed the required maximum. Factors to be considered will consist of the source of the aggregates (proximity to a salt water source, brackish area, etc.) and service history of the concrete made from aggregates originating from the same source. No specific tests are required unless the aggregates or water source are suspected of containing an excessive concentration of chloride ions.

SUPPLEMENT 1.I

GENERAL DESCRIPTION OF HI-STORM 100U SYSTEM

1.I.0 GENERAL INFORMATION

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

1.I.1 INTRODUCTION

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

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

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

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

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

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

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

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

- It provides an essentially impervious barrier of reinforced concrete against seepage of water from rain/snow into the subgrade.
- It provides the interface surface for the CEC flange.
- It helps maintain a clean, debris-free region around the VVMs.
- It provides the necessary riding surface for the cask transporter (see Figure 1.I.7).

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

1.I.3 IDENTIFICATION OF AGENTS AND CONTRACTORS

Same as in Section 1.3.

1.I.4 GENERIC CASK ARRAYS

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

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

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

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

1.I.5 FIGURES AND DRAWINGS

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

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

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

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

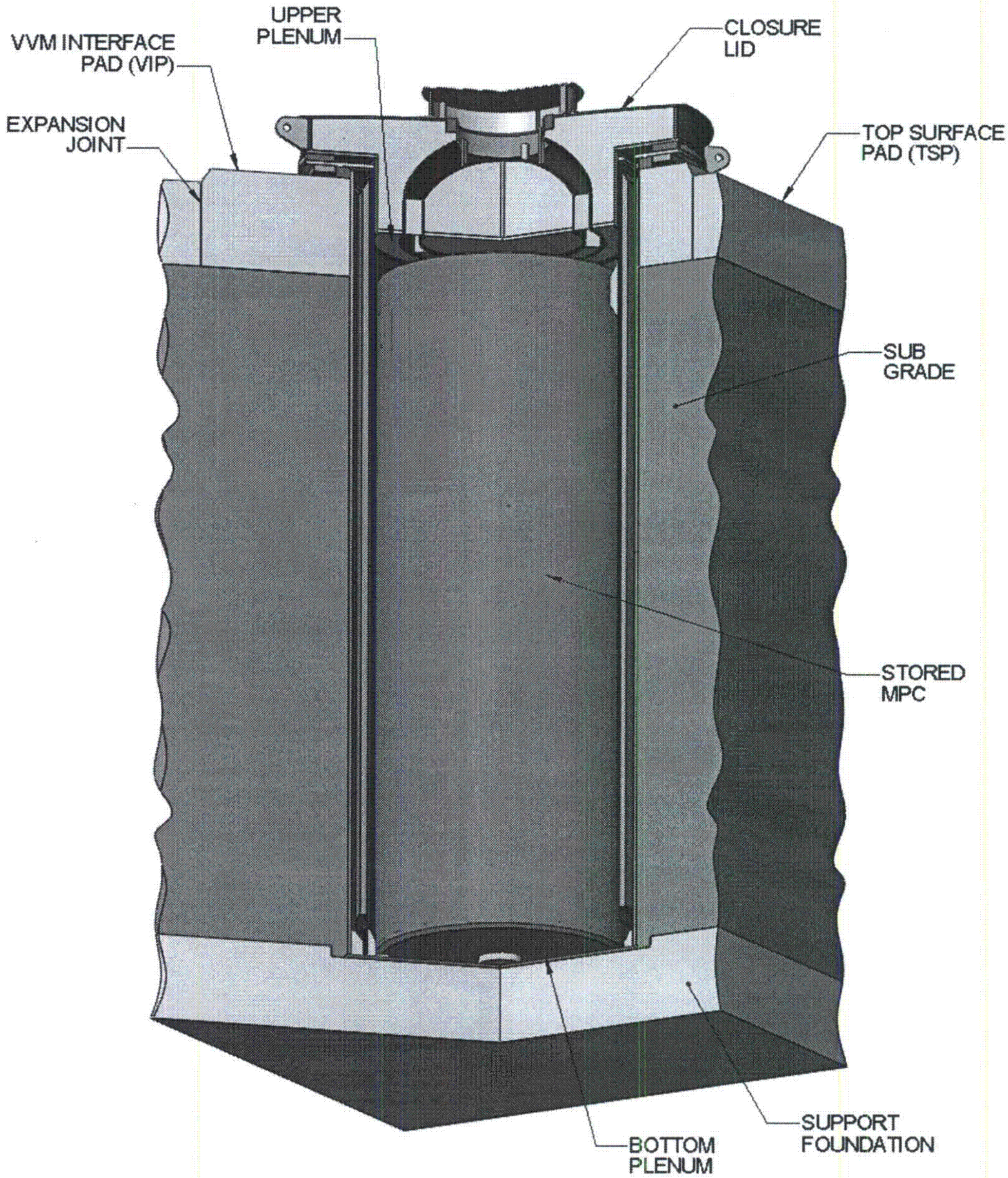


FIGURE 1.I.1: CUT-AWAY VIEW OF HI-STORM 100U SYSTEM)

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

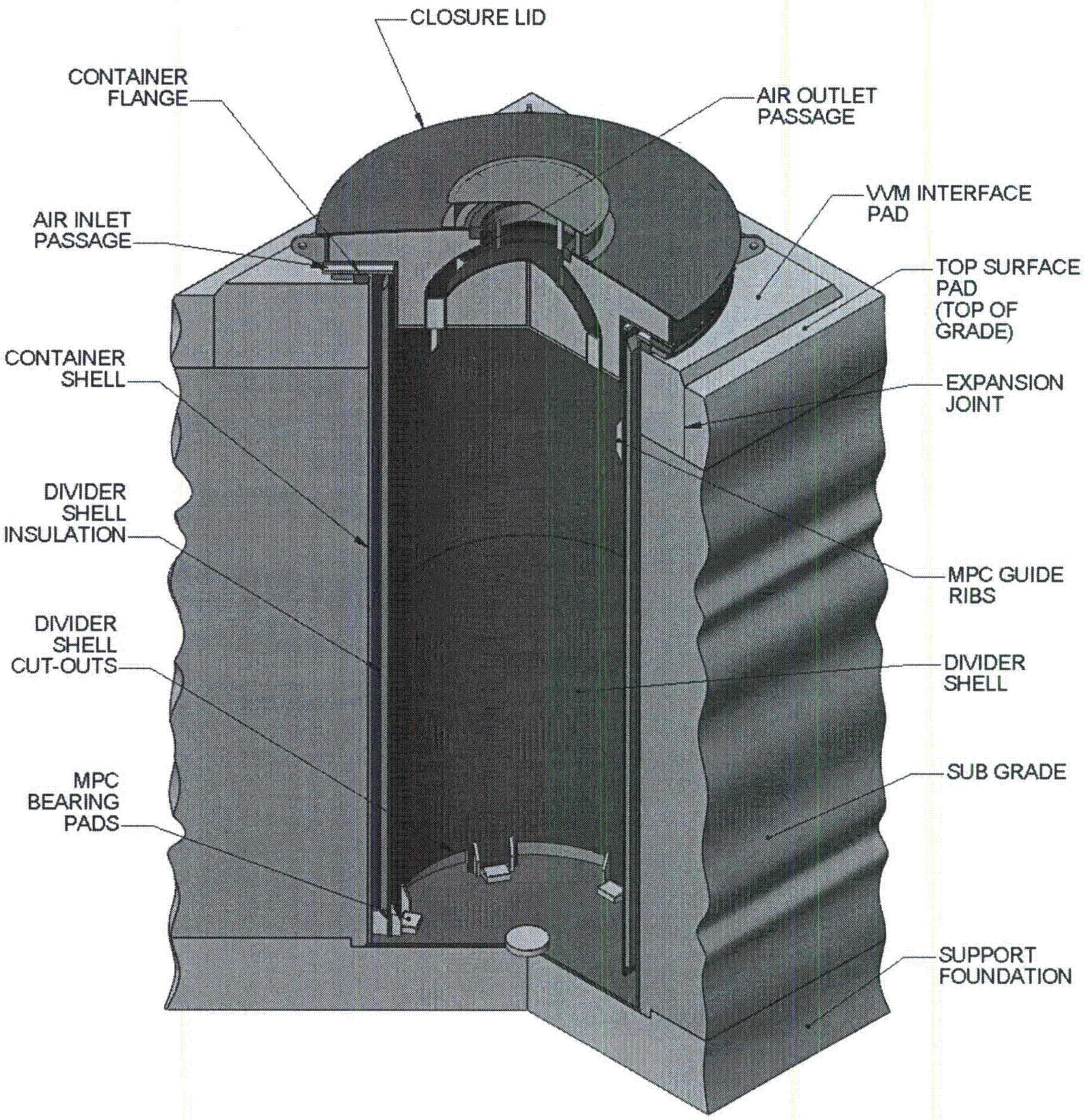


FIGURE 1.I.2: CUT-AWAY VIEW OF THE HI-STORM 100U VVM

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

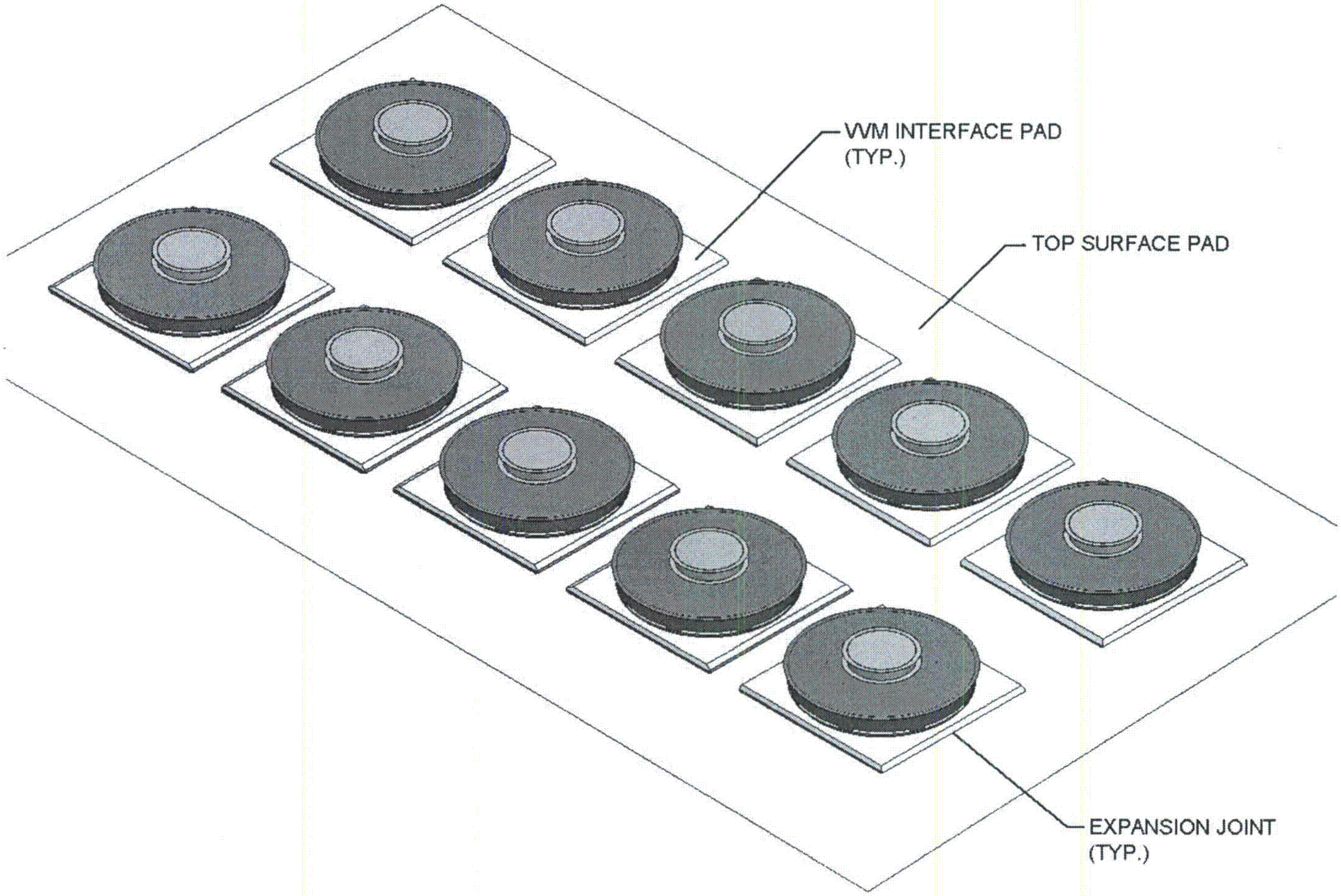


FIGURE 1.I.3: TYPICAL HI-STORM 100U SYSTEM ISFSI 2 x 5 ARRAY

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

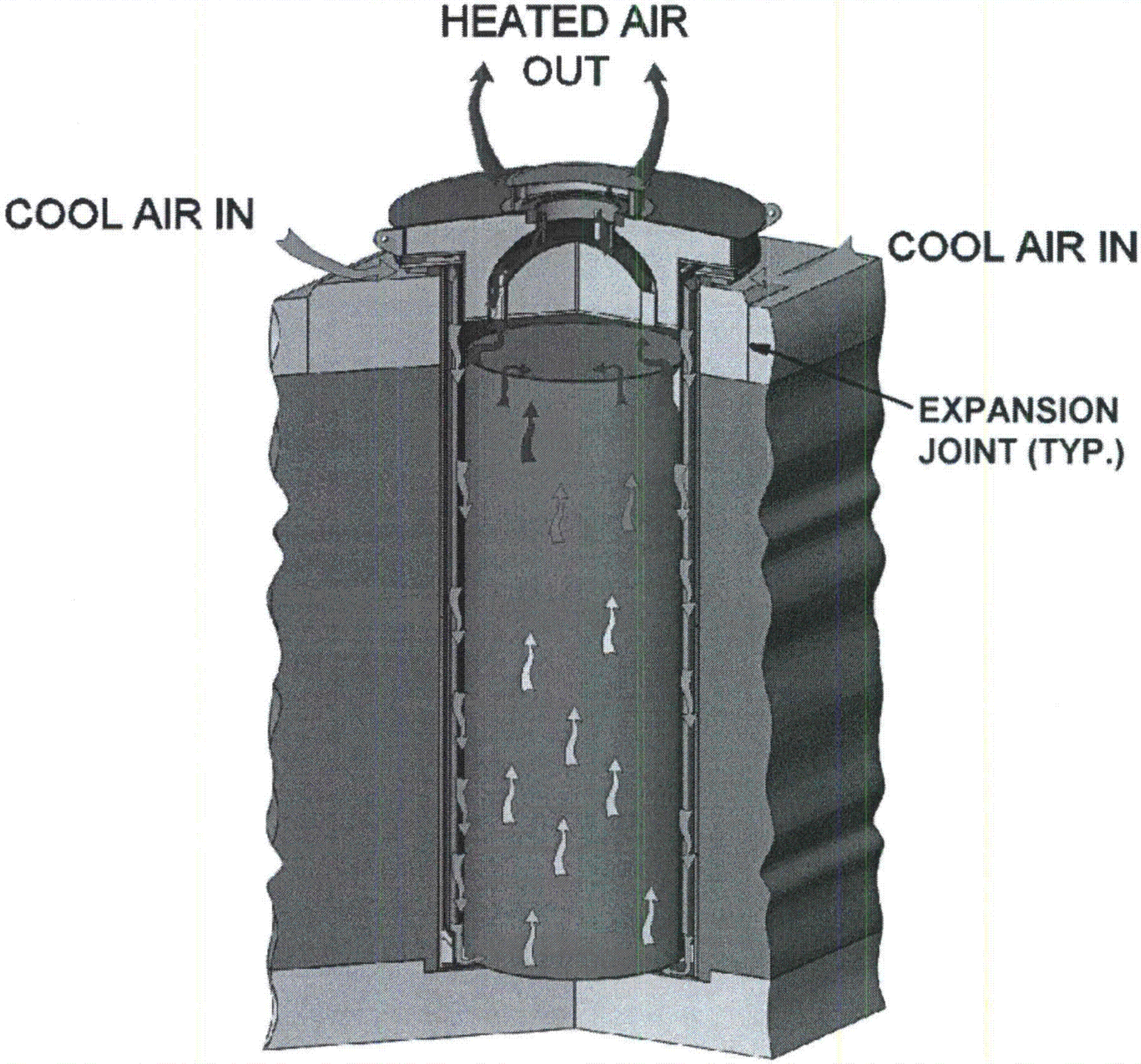


FIGURE 1.I.4: HI-STORM 100U SYSTEM AIR FLOW PATTERN

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

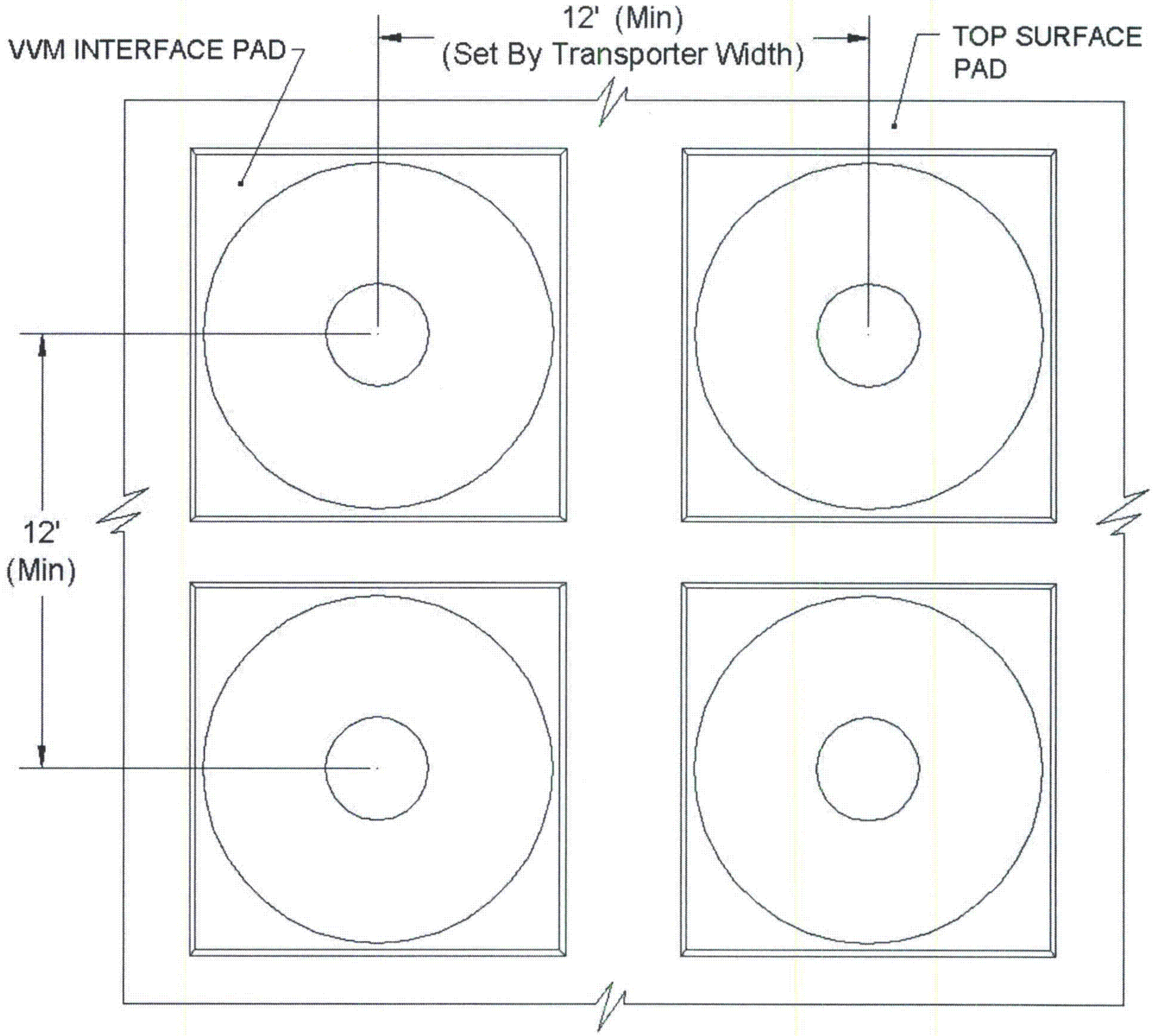


FIGURE 1.I.5: PLAN VIEW OF A 2X2 HI-STORM 100U SYSTEM STORAGE ARRAY

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

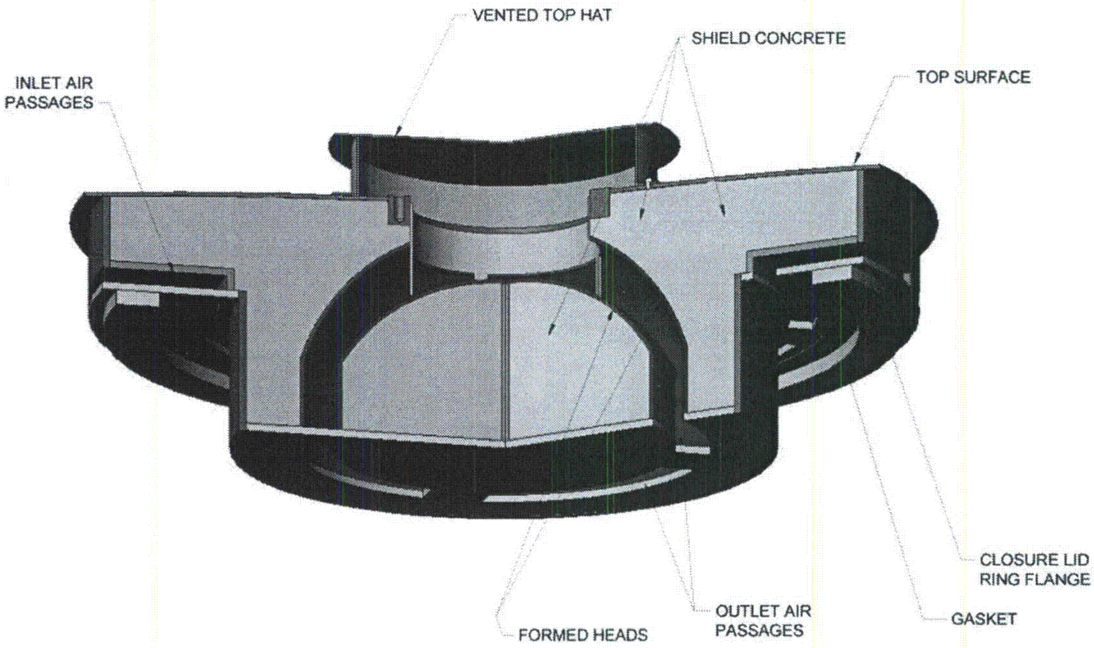


FIGURE 1.I.6; HI-STORM 100U VVM CLOSURE LID GENERAL ARRANGEMENT (SHOWN IN CUT-AWAY VIEW)

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

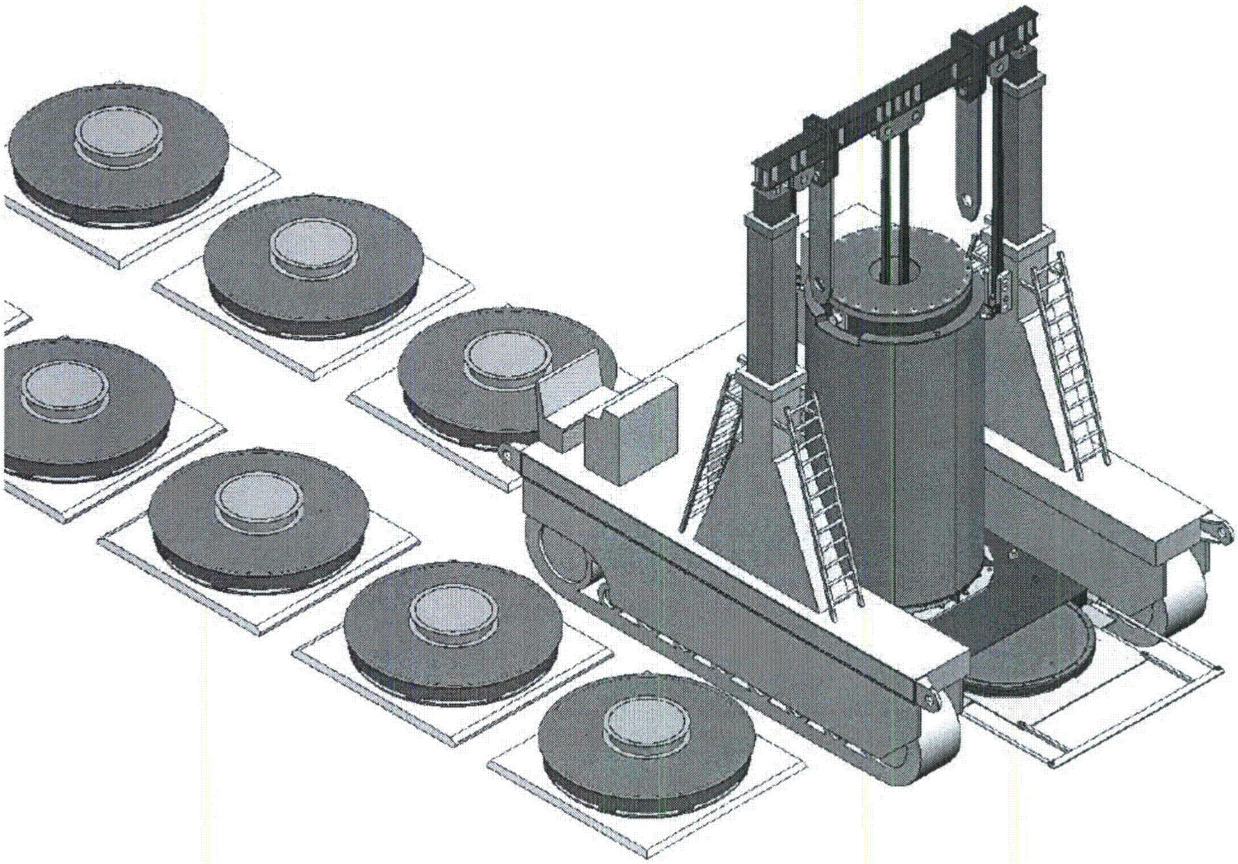


FIGURE 1.I.7; MPC TRANSFER IN A HI-STORM 100U VVM USING A VERTICAL CASK TRANSPORTER

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

SUPPLEMENT 1.III: GENERAL DESCRIPTION OF THE MPC-68M

1.III.0 GENERAL INFORMATION

The list of MPC models for use in the HI-STORM 100 System is expanded to include the MPC-68M model which consists of a Metamic-HT BWR fuel basket inside the existing MPC enclosure vessel. Information pertaining to the MPC-68M is contained in the "III" supplements to each chapter of this FSAR. Unless superseded or specifically modified by information in the "III" supplements, the information in the main FSAR is applicable to the HI-STORM 100 System with the MPC-68M.

Each chapter in the HI-STORM FSAR has been updated by the addition of a supplement labeled n.III (n = chapter number) that contains all necessary information in support of Licensing Amendment Request #1014-8 to the HI-STORM 100 CoC. This series of supplements is focused solely on incorporating one specific MPC model containing a new BWR fuel basket design into the HI-STORM 100 system.

1.III.1 INTRODUCTION

The safety evaluation in the "III" Supplements supports the use of an alternate fuel basket, made entirely of Metamic-HT, for use within the current MPC Enclosure Vessel. The canister is referred to as MPC-68M. The same design/service life applied to the current MPC models applies to the MPC-68M.

1.III.2 GENERAL DESCRIPTION OF THE MPC-68M

1.III.2.1 MPC-68M Characteristics

The MPC-68M contains a 68 storage cell BWR fuel basket made of co-planar slotted plates of Metamic-HT (See Figure 1.III.1). The MPC is identified by the maximum number of fuel assemblies it can contain in the fuel basket. The Metamic-HT in the MPC-68M serves as the structural material of the basket and provides the necessary neutron absorption for maintaining the fuel in a sub-critical condition. The following design characteristics of MPC-68M are important to its function:

i. The fuel basket is assembled from a rectilinear gridwork of plates so that there are no bends or radii at the cell corners. This structural feature eliminates the source of severe bending stresses in the basket structure by eliminating the offset between the cell walls that must transfer the inertia load of the stored SNF to the basket/MPC interface during the various postulated accident events (e.g., non-mechanistic tipover, uncontrolled lowering of a cask during on-site transfer, or off-site transport accident events, etc.).

ii. Precision extruded aluminum shims (the so-called "*Basket Shims*") are installed in the peripheral space between the fuel basket and the Enclosure Vessel to provide conformal contact surfaces between the Basket Shims and the fuel basket and between the Basket Shims and the Enclosure Vessel shell. The axial holes in the corner basket shims serve as the passageway for the downwards flow of the helium gas under the thermosiphon action, which is intrinsic to the thermal performance of all MPCs in the HI-STORM 100 system.

iii. To facilitate an effective convective circulation inside the Canister, the Enclosure Vessel is pressurized to the same pressure level specified for the MPC-68 model. See Table 1.III.1.

iv. The fuel basket consists of adjacent square openings (cells) separated by one wall of neutron absorber.

The mechanical and thermophysical properties of Metamic-HT presented in Appendix 1.III.A to this supplement are extracted from the Metamic-HT Sourcebook referenced therein. The basket shims are made from creep resistant aluminum alloy similar to those used in HI-STAR 180 (Docket No. 71-9325) [2.III.6.2]. All design aspects of the MPC enclosure vessel (confinement boundary), including the vent and drain port arrangements in the MPC lid, are unchanged. The MPC-68M may be loaded in all licensed aboveground HI-STORM 100 overpacks.

1.III.2.2 Operational Characteristics

The MPC-68M canister is loaded in exactly the same manner as all other MPCs certified in the HI-STORM 100 docket, and uses the same ancillary equipment, (viz., lift cleats, lift yokes, Lid Welding Machine, Weld Removal Machine, Cask Transporter, Mating Device, Low Profile transporter or Zero Profile Transporter, Canister Upender, Forced Helium Dehydrator, the Hydrostatic pressure test system and the like). The operational characteristics of the HI-STORM overpack are unaffected.

All short-term operations, including draining of the MPC, welding of the lid, drying and filling of the MPC cavity with inert gas, and handling of the MPC remain unchanged from the existing practice, except that the dried and helium filled MPC-68M may reside indefinitely in the HI-TRAC transfer cask without the aid of the supplemental cooling system. The increased thermal conductivity of the Metamic-HT basket maintains the steady state fuel cladding temperatures below the ISG-11, Revision 3 [2.0.8] limits; thus eliminating the need for the supplemental cooling system. All other loading and unloading procedures and operations described in Chapter 8 apply to MPC-68M with the clarifications and limitations presented in Supplement 8.III.

1.III.2.2.1 Criticality Prevention

Metamic-HT is the designated neutron absorber and structural material in the MPC-68M. 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.III.A.

The entire basket is made of Metamic-HT, incorporating in the fuel basket a much greater B-10 concentration than is available in the fuel baskets designs with "attached" neutron absorber. This accrues three major safety and reliability advantages:

(i) The BWR basket may store high enrichment fuel (i.e., fuel with up to 4.8 wt% U-235 initial planar enrichment) without reliance on gadolinium or burn-up credit.
(ii) The neutron absorber cannot detach from the basket or displace within it.
(iii) Axial movement of the fuel with respect to the basket due to internal clearances has no reactivity consequence because the entire length of the basket contains the same concentration of the B-10 isotope.

During storage, criticality control measures beyond the integral neutron poison in the storage cell walls are not necessary because of the low reactivity of the fuel in the dry helium-filled canister and the design features that prevent water from intruding into the canister fuel storage space.

1.III.2.2.2 Structural Considerations

Due to the low density of the Metamic-HT material and the optimized fuel basket design, the loaded weight of the MPC-68M (see Supplement 3.III) is less than the loaded weight of the MPC-68. Therefore, the lifting features on the MPC are unchanged and all of the lifting and handling equipment used to lift and handle the loaded MPC-68 may also be used to lift and handle the loaded MPC-68M.

1.III.2.2.3 Thermal Considerations

The MPC-68M, for an identical heat load, is intrinsically capable of more cooling effectiveness than the MPC-68, due to the higher thermal conductivity of Metamic-HT (approximately 1 order of magnitude greater than the thermal conductivity of Alloy X), the use of full length aluminum basket shims, and the hard-anodizing of the basket and basket shim materials to obtain high emissivities. Thus satisfaction of the ISG-11 temperature limits with acceptable margins is assured.

1.III.2.2.4 Shielding Considerations

The MPC68M basket consists of homogeneously dispersed boron carbide (10% minimum by weight). The B-10 areal density of the Metamic-HT panels which make up the basket is consistent with the areal density of the Metamic classic neutron poison panels in the MPC-68, therefore provides equivalent neutron shielding. From an overall shielding perspective the MPC-68M is expected to provide similar, if not better, shielding characteristics as the MPC-68. The MPC enclosure vessel, overpack, and transfer cask shielding properties are not modified.

1.III.2.3 Cask Contents

The MPC-68M is designed to accommodate up to sixty-eight intact BWR fuel assemblies. Up to sixteen damaged fuel containers (DFCs) containing BWR damaged fuel assemblies and/or up to eight DFCs containing fuel debris may be stored in the following fuel storage locations: 1, 2, 3, 8, 9, 16, 25, 34, 35, 44, 53, 60, 61, 66, 67, and/or 68 (Figure 1.III.2), with the remaining fuel storage locations filled with intact BWR fuel assemblies. Table 1.2.2 as supplemented by Table 1.III.1 provides the key system data and parameters for the MPC-68M.

1.III.3 IDENTIFICATION OF AGENTS AND CONTRACTORS

Same as in Section 1.3.

1.III.4 GENERIC CASK ARRAYS

Same as in Section 1.4.

1.III.5 DRAWINGS

[DRAWINGS WITHHELD PER 10 CFR 2.390]

Table 1.III.1
Key Parameters for MPC-68M

	BWR
MPC internal environment Helium fill (99.995% fill helium purity) (heat load ≤ 28.19 kW) (heat load >28.19 kW)	(all pressure ranges are at a reference temperature of 70°F) > 29.3 psig and < 48.5 psig OR 0.1218 +/-10% g-moles/liter > 45.5 psig and < 48.5 psig
B_4C content in Metamic-HT (wt. %)	As specified on drawing in Section 1.5

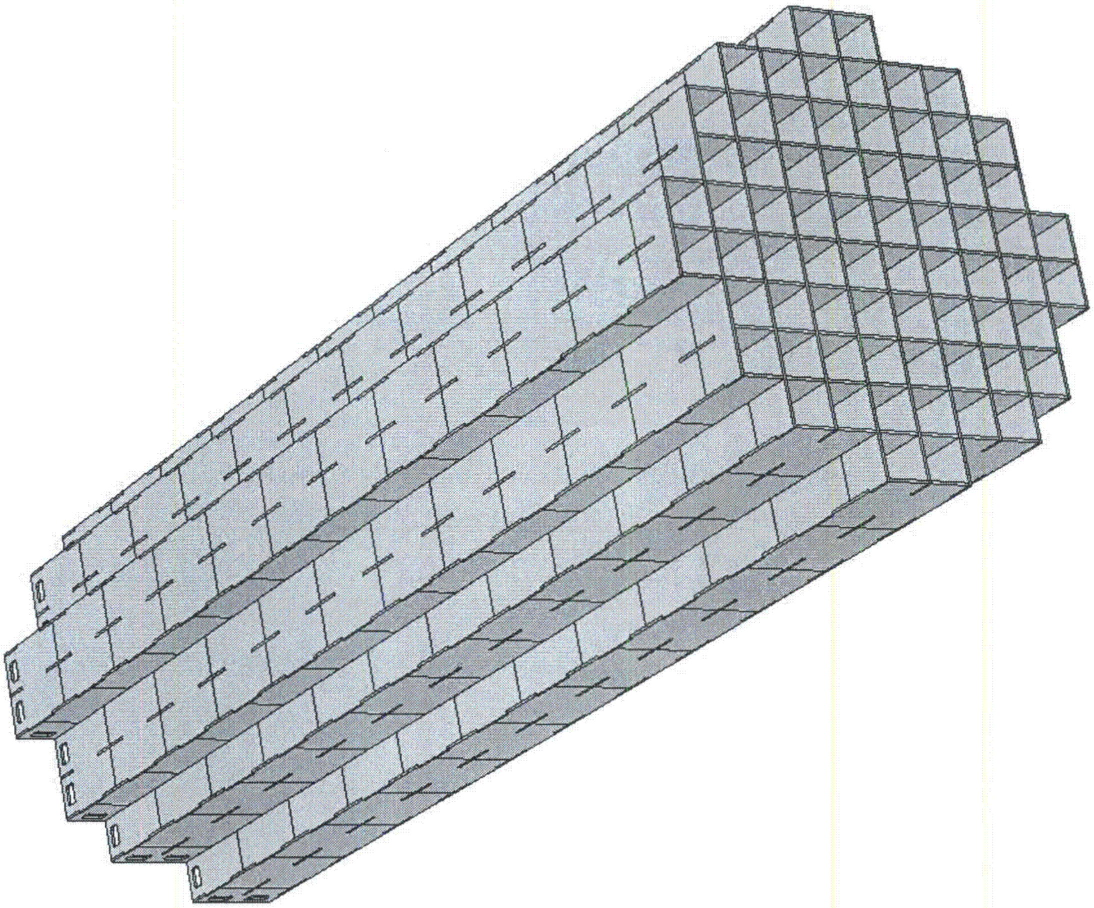


FIGURE 1.III.1: ISOMETRIC VIEW OF THE MPC-68M BASKET (BASKET SHIMS NOT SHOWN)

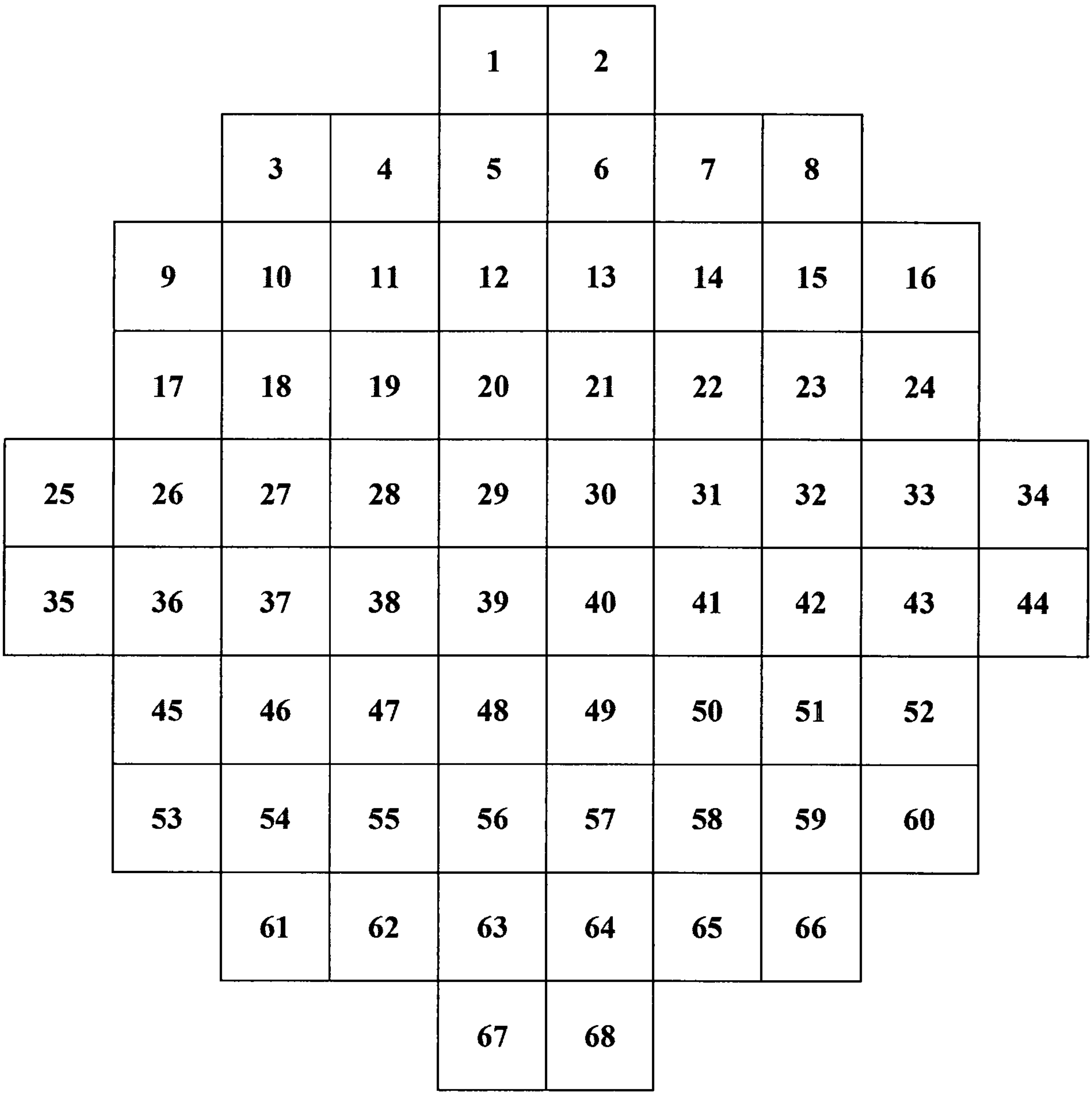


Figure 1.III.2 MPC-68M STORAGE LOCATIONS

APPENDIX 1.III.A: METAMIC-HT

[APPENDIX WITHHELD IN ITS ENTIRETY PER 10 CFR 2.390]

APPENDIX 1.III.B: METAMIC-HT[1] PROPERTIES SUPPORTING MPC-68M SHORT-TERM OPERATIONS AND ACCIDENT EVALUATIONS

The temperature range at which the mechanical and thermo physical properties of Metamic-HT have been provided in Appendix 1.III.A is exceeded under certain short-term operations and accident conditions. To facilitate the evaluation of Metamic-HT integrity, Minimum Guaranteed Values (MGV) of Metamic-HT properties are defined in the same manner as described in Appendix 1.III.A and adopted in this Appendix. Metamic-HT properties germane to structural and thermal evaluation are as follows:

- Ultimate Tensile Strength
- Yield Strength
- Area Reduction
- Young's Modulus
- Thermal Conductivity
- Emissivity
- Specific Heat

Reasonably bounding MGVs of above properties are defined in Table 1.III.B.1 up to 500°C, which comfortably bounds all temperatures.

1.III.B.1 High Temperature Tensile Testing

To characterize the mechanical properties of Metamic-HT for this higher temperature range the Ultimate, Yield, Area Reduction and Young's Modulus of Metamic-HT coupons were tested under bounding test temperatures. The testing was conducted at the Westmoreland testing lab in Youngstown, PA. The test specimens were prepared and tested in accordance with the ASTM standards adopted in the Metamic-HT sourcebook for qualification testing. A total of fifteen coupons were tested at 450°C and 500°C in the as-extruded condition and test results archived in the Metamic-HT Sourcebook [1.III.A.3]. Thermal aging and irradiation effects were not included in the testing as prior testing archived in the Metamic-HT sourcebook have discerned no significant difference due to these effects.

To characterize lower bound strength of Metamic-HT the Minimum Measured Values (MMV) of the above properties were obtained, archived in the Metamic-HT sourcebook and MGV compliance evaluated. In all cases the Metamic-HT properties meet or exceed Minimum Guaranteed Values prescribed in Table 1.III.B.1. The high temperature strength values of Metamic-HT support the following:

- Metamic-HT retains well over 50% of the operating temperature strength properties at a reasonably bounding 450°C accident temperature.

[1] This appendix is abstracted from the Metamic-HT Sourcebook [1.III.A.3].

- Under extremely high 500°C temperature reasonable values of strength properties are retained.
- The test data provides reasonable assurance of Metamic-HT integrity under thermally challenging events.

1.III.B.2 High Temperature Thermo-physical Properties

To characterize the thermal properties of Metamic-HT for this higher temperature range the conductivity, emissivity and heat capacity of Metamic-HT coupons were tested under bounding test temperatures. With the exception of emissivity property wherein prior testing adequately covered the high temperature range up to 500°C additional tests were conducted to measure the conductivity and specific heat properties. A total of two specimens were tested for each of the conductivity and specific heat properties in accordance with the ASTM standards adopted in the Metamic-HT Sourcebook [1.III.A.3]. As thermo-physical properties are principally a function of composition the properties were tested in the as-manufactured condition from the extrusion plant. The coupons were tested at 450°C and 500°C and test results archived in the Metamic-HT Sourcebook. The results are evaluated in the following.

Conductivity Measurements

To characterize the lower bound conductivity of Metamic-HT the Minimum Measured Value (MMV) were obtained and MGV compliance confirmed. To discern data trends the MMV conductivity values in the operating temperature range and high temperature range are tabulated below.

Temperature (°C)	205	370	450	500
Conductivity (W/m-°K)	188	187	193	193

The above data supports the observation that Metamic-HT thermal conductivity is essentially constant for the temperature range spanning all operating and accident temperatures. Therefore a single valued lower bound conductivity defined in the MGV tables provides a conservative characterization of Metamic-HT conductivity for evaluation under normal, off-normal and accident conditions.

Emissivity Measurements

Emissivity measurements in the high temperature range at an upper bound 500°C temperature are covered by prior testing reported in the Metamic-HT Sourcebook. The measured emissivity data supports the Table 1.III.B.1 MGV requirement that high temperature Metamic-HT emissivity meets or exceeds $\varepsilon = 0.8$.

Specific Heat Measurements

In accordance with definition of heat capacity as a reference property in Table 1.III.B.1 the mean value of the measurements were obtained and added to Metamic-HT Sourcebook. To discern data trends the mean heat capacity values in the operating temperature range and high temperature range are tabulated below.

Temperature (°C)	350	450	500
Heat Capacity (J/kg-°K)	1024.2	1129.2	1098.2

The above data supports the observation that the heat capacity of Metamic-HT is a weak function of temperature. To provide a reasonable characterization of heat capacity in the range of 350°C to 500°C a linear function fitting the end points of the range is obtained and added to Table 1.III.B.1.

Table 1.III.B.1:
Reference & Minimum Guaranteed Values (MGVs) of Metamic-HT Mechanical and Thermal Characteristics Supporting Accident Evaluations

	Property	Temperature, °C `	Design Value	Type
1.	Yield strength, σ_y (ksi)	450/500	8.5/6	MGV
2.	Tensile strength, σ_u (ksi)	450/500	9/6.5	MGV
3.	Young's Modulus, E (ksi)	450/500	4000/3500	MGV
4.	Area Reduction, A (%)	450/500	9.5/4	MGV
5.	Thermal conductivity, k (W/m°k)	450/500	180/180	MGV
6.	Emissivity (dimensionless), e	$350 \leq T \leq 500$	See Note 1	MGV
7.	Specific Heat, C_p (J/g-°C) (Note 2)	$350 \leq T \leq 500$	Note 3	Reference

Note 1: Emissivity Equation (Hard Anodized Metamic-HT)

$e = 0.2+0.6 \sin[\pi(T-100)/1304]$ $(100^{\circ}F \leq T \leq 752^{\circ}F)$

$e = 0.8$ $(T > 752^{\circ}F)$

Note 2: These properties are reference values (not MGVs). Property variations in the small do not have significant effect on the safety evaluations in which these properties are used. Reference properties are characterized by the mean of the measured data.

Note 3: Heat Capacity Function

$Cp = 1024.2 + 0.493(T-350)$

CHAPTER 2†: PRINCIPAL DESIGN CRITERIA

This chapter contains a compilation of design criteria applicable to the HI-STORM 100 System. The loadings and conditions prescribed herein for the MPC, particularly those pertaining to mechanical accidents, are far more severe in most cases than those required for 10CFR72 compliance. The MPC is designed to be in compliance with both 10CFR72 and 10CFR71 and therefore certain design criteria are overly conservative for storage. This chapter sets forth the loading conditions and relevant acceptance criteria; it does not provide results of any analyses. The analyses and results carried out to demonstrate compliance with the design criteria are presented in the subsequent chapters of this report.

This chapter is in full compliance with NUREG-1536, except for the exceptions and clarifications provided in Table 1.0.3. Table 1.0.3 provides the NUREG-1536 review guidance, the justification for the exception or clarification, and the Holtec approach to meet the intent of the NUREG-1536 guidance.

2.0 PRINCIPAL DESIGN CRITERIA

The design criteria for the MPC, HI-STORM overpack, and HI-TRAC transfer cask are summarized in Tables 2.0.1, 2.0.2, and 2.0.3, respectively, and described in the sections that follow.

2.0.1 MPC Design Criteria

General

The MPC is designed for 40 years of service, while satisfying the requirements of 10CFR72. The adequacy of the MPC design for the design life is discussed in Section 3.4.12.

Structural

The MPC is classified as important to safety. The MPC structural components include the internal fuel basket and the enclosure vessel. The fuel basket is designed and fabricated as a core support structure, in accordance with the applicable requirements of Section III, Subsection NG of the ASME Code, with certain NRC-approved alternatives, as discussed in Section 2.2.4. The enclosure vessel is designed and fabricated as a Class 1 component pressure vessel in accordance with Section III, Subsection NB of the ASME Code, with certain NRC-approved alternatives, as discussed in Section 2.2.4. The principal exception is the MPC lid, vent and drain port cover plates, and closure ring

† This chapter has been prepared in the format and section organization set forth in Regulatory Guide 3.61. However, the material content of this chapter also fulfills the requirements of NUREG-1536. Pagination and numbering of sections, figures, and tables are consistent with the convention set down in Chapter 1, Section 1.0, herein. Finally, all terms-of-art used in this chapter are consistent with the terminology of the glossary (Table 1.0.1) and component nomenclature of the Bill-of-Materials (Section 1.5).

welds to the MPC lid and shell, as discussed in Section 2.2.4. In addition, the threaded holes in the MPC lid are designed in accordance with the requirements of ANSI N14.6 for critical lifts to facilitate vertical MPC transfer.

Helium leakage testing of the MPC base metals (shell, baseplate, and MPC lid) and MPC shell to baseplate and shell to shell welds is performed on the unloaded MPC.

The MPC closure welds are partial penetration welds that are structurally qualified by analysis, as presented in Chapter 3. The MPC lid and closure ring welds are inspected by performing a liquid penetrant examination of the root pass and/or final weld surface (if more than one weld pass was required), in accordance with the drawings contained in Section 1.5. The integrity of the MPC lid weld is further verified by performing a volumetric (or multi-layer liquid penetrant) examination, 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, (performed on the vent and drain port cover plates), provides assurance of canister closure integrity in lieu of the specific weld joint requirements of Section III, Subsection NB.

Compliance with the ASME Code as it is applied to the design and fabrication of the MPC and the associated justification are discussed in Section 2.2.4. The MPC is designed for all design basis normal, off-normal, and postulated accident conditions, as defined in Section 2.2. These design loadings include postulated drop accidents while in the cavity of the HI-STORM overpack or the HI-TRAC transfer cask. The load combinations for which the MPC is designed are defined in Section 2.2.7. The maximum allowable weight and dimensions of a fuel assembly to be stored in the MPC are limited in accordance with Section 2.1.5.

Thermal

The design and operation of the HI-STORM 100 System meets the intent of the review guidance contained in ISG-11, Revision 3 [2.0.8]. 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 (including ZR and stainless steel fuel cladding materials) 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 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 High Burnup Fuel (HBF), operating restrictions are imposed to limit the maximum temperature excursion during short-term operations to 65°C (117°F).

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 <u>all</u> moderate burnup fuel, the fuel cladding temperature limit for short-term operations is set at 570°C (1058°F) because fuel cladding stress is shown to be less than approximately 90 MPa per Reference [2.0.9]. Appropriate analyses have been performed as discussed in Chapter 4 and operating restrictions added to ensure these limits are met (see Section 4.5).

ii. For MPCs containing at least one high burnup fuel (HBF) assembly or if the MPC heat load is greater than 28.74 kW (See Section 4.5.3.2), the forced helium dehydration (FHD) method of MPC cavity drying must be used to meet the normal operations PCT limit and satisfy the 65°C temperature excursion criterion for HBF.

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

iv. For MPCs loaded with one or more high burnup fuel assemblies or if the MPC heat load is greater than 28.74 kW(See Section 4.5.5.1), the Supplemental Cooling System (SCS) is required to ensure fuel cladding temperatures remain below the applicable temperature limit (see Section 4.5). The design criteria for the SCS are provided in Appendix 2.C.

The MPC cavity is dried using either a vacuum drying system, or a forced helium dehydration system (see Appendix 2.B). The MPC is backfilled with 99.995% pure helium in accordance with the limits in Table 1.2.2 during canister sealing operations to promote heat transfer and prevent cladding degradation.

The normal condition design temperatures for the structural steel components of the MPC are based on the temperature limits provided in ASME Section II, Part D, tables referenced in ASME Section III, Subsection NB and NG, for those load conditions under which material properties are relied on for a structural load combination. The specific design temperatures for the components of the MPC are provided in Table 2.2.3.

The MPCs are designed for a bounding thermal source term, as described in Section 2.1.6. The maximum allowable fuel assembly heat load for each MPC is limited as specified in Section 2.1.9.

Each MPC model, except MPC-68F, allows for two fuel loading strategies. The first is uniform fuel loading, wherein any authorized fuel assembly may be stored in any fuel storage location up to a maximum specific heat emission rate, subject to other restrictions, such as location requirements for damaged fuel containers (DFCs) and fuel with integral non-fuel hardware (e.g., APSR). The second is regionalized fuel loading, wherein the basket is segregated into two regions. Regionalized loading allows for storage of fuel assemblies with higher heat emission rates than would otherwise be authorized for uniform loading. Regionalized loading strategies must also comply with other requirements, such as those for DFCs and non-fuel hardware. Specific fuel assembly cooling time, burnup, and decay heat limits for regionalized loading are presented in Section 2.1.9. The two fuel loading regions are defined by fuel storage location number in Table 2.1.27 (refer to Figures 1.2.2 through 1.2.4). For MPC-68F, only uniform loading is permitted.

Shielding

The allowable doses for an ISFSI using the HI-STORM 100 System are delineated in 10CFR72.104 and 72.106. Compliance with these regulations for any particular array of casks at an ISFSI is necessarily site-specific and is to be demonstrated by the licensee, as discussed in Chapters 5 and 12. Compliance with these regulations for a single cask and several representative cask arrays is demonstrated in Chapters 5 and 10.

The MPC provides axial shielding at the top and bottom ends to maintain occupational exposures ALARA during canister closure and handling operations. The occupational doses are controlled in accordance with plant-specific procedures and ALARA requirements (discussed in Chapter 10).

The MPCs are designed for design basis fuel as described in Sections 2.1.7 and 5.2. The radiological source term for the MPCs is limited based on the burnup and cooling times specified in Section 2.1.9. Calculated dose rates for each MPC are provided in Section 5.1. These dose rates are used to perform an occupational exposure evaluation, as discussed in Chapter 10.

Criticality

The MPCs provide criticality control for all design basis normal, off-normal, and postulated accident conditions, as discussed in Section 6.1. The effective neutron multiplication factor is limited to $k_{eff} <$ 0.95 for fresh unirradiated fuel with optimum water moderation and close reflection, including all biases, uncertainties, and MPC manufacturing tolerances.

Criticality control is maintained by the geometric spacing of the fuel assemblies, fixed borated neutron absorbing materials incorporated into the fuel basket assembly, and, for certain MPC models, soluble boron in the MPC water. The minimum specified boron concentration verified during neutron absorber manufacture is further reduced by 25% for criticality analysis for Boral-equipped MPCs and by 10% for METAMIC®-equipped MPCs. No credit is taken for burnup. The maximum allowable initial enrichment for fuel assemblies to be stored in each MPC is limited. Enrichment limits and soluble boron concentration requirements are delineated in Section 2.1.9 consistent with the criticality analysis described in Chapter 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 Section 7.1, the Holtec MPC design meets the guidance in Interim Staff Guidance 18 to classify confinement boundary leakage as non-credible. Therefore, no confinement dose analysis is performed. The confinement function of the MPC is verified through pressure testing and helium leak testing on the vent and drain port cover plates, and weld examinations performed in accordance with the acceptance test program in Chapter 9.

Helium leakage testing of the MPC base metal (shell, baseplate and MPC Lid) and MPC shell to baseplate welds and shell to shell weld is performed on the unloaded MPC.

Operations

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

Generic operating procedures for the HI-STORM 100 System are provided in Chapter 8. Detailed operating procedures will be developed by the licensee based on Chapter 8, site-specific requirements that comply with the 10CFR50 Technical Specifications for the plant, and the HI-STORM 100 System CoC.

Acceptance Tests and Maintenance

The fabrication acceptance basis and maintenance program to be applied to the MPCs are described in Chapter 9. The operational controls and limits to be applied to the MPCs are discussed in Chapter 12. 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.

Decommissioning

The MPCs are designed to be transportable in the HI-STAR overpack and are not required to be unloaded prior to shipment off-site. Decommissioning of the HI-STORM 100 System is addressed in Section 2.4.

2.0.2 HI-STORM Overpack Design Criteria

General

The HI-STORM overpack is designed for 40 years of service, while satisfying the requirements of 10CFR72. The adequacy of the overpack design for the design life is discussed in Section 3.4.11.

Structural

The HI-STORM overpack includes both concrete and structural steel components that are classified as important to safety.

The concrete material is defined as important to safety because of its importance to the shielding analysis. The primary function of the HI-STORM overpack concrete is shielding of the gamma and neutron radiation emitted by the spent nuclear fuel.

Unlike other concrete storage casks, the HI-STORM overpack concrete is enclosed in steel inner and outer shells connected to each other by radial ribs, and top and bottom plates. Where typical concrete storage casks are reinforced by rebar, the HI-STORM overpack is supported by the inner and outer shells connected by radial ribs. As the HI-STORM overpack concrete is not reinforced, the structural analysis of the overpack only credits the compressive strength of the concrete. Providing further conservatism, the structural analyses for normal conditions demonstrate that the allowable stress limits of the structural steel are met even with no credit for the strength of the concrete. During accident conditions (e.g., tornado missile, tip-over, end drop, and earthquake), only the compressive strength of the concrete is accounted for in the analysis to provide an appropriate simulation of the accident condition. Where applicable, the compressive strength of the concrete is calculated in accordance with ACI-318.1-89 (92) [2.0.1].

In recognition of the conservative assessment of the HI-STORM overpack concrete strength and the primary function of the concrete being shielding, the applicable requirements of ACI-349 [2.0.2] are invoked in the design and construction of the HI-STORM overpack concrete as clarified in Appendix 1.D.

Steel components of the storage overpack are designed and fabricated in accordance with the requirements of ASME Code, Section III, Subsection NF for Class 3 plate and shell components with certain NRC-approved alternatives.

The overpack is designed for all normal, off-normal, and design basis accident condition loadings, as defined in Section 2.2. At a minimum, the overpack must protect the MPC from deformation, provide continued adequate performance, and allow the retrieval of the MPC under all conditions. These design loadings include a postulated drop accident from the maximum allowable handling height, consistent with the analysis described in Section 3.4.10. The load combinations for which the overpack is designed are defined in Section 2.2.7. The physical characteristics of the MPCs for which the overpack is designed are defined in Chapter 1.

Thermal

The allowable long-term through-thickness section average temperature limit for the overpack concrete is established in accordance with Paragraph A.4.3 of Appendix A to ACI 349, which allows the use of elevated temperature limits if test data supporting the compressive strength is available and an evaluation to show no concrete deterioration provided. Appendix 1.D specifies the cement and aggregate requirements to allow the utilization of the 300°F temperature limit. For short term conditions the through-thickness section average concrete temperature limit of 350°F is specified in accordance with Paragraph A.4.2 of Appendix A to ACI 349. The allowable temperatures for the structural steel components are based on the maximum temperature for which material properties and allowable stresses are provided in Section II of the ASME Code. The specific allowable temperatures for the structural steel components of the overpack are provided in Table 2.2.3.

The overpack is designed for extreme cold conditions, as discussed in Section 2.2.2.2. The structural steel materials used for the storage cask that are susceptible to brittle fracture are discussed in Section 3.1.2.3.

The overpack is designed for the maximum allowable heat load for steady-state normal conditions, in accordance with Section 2.1.6. The thermal characteristics of the MPCs for which the overpack is designed are defined in Chapter 4.

Shielding

The off-site dose for normal operating conditions to a 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 site-specific conditions (e.g., the ISFSI design and proximity to the controlled area boundary, and the number and arrangement of loaded storage casks on the ISFSI pad), the determination and comparison of ISFSI doses to this limit are necessarily site-specific. Dose rates for a single cask and a range of typical ISFSIs using the HI-STORM 100 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 in accordance with 10CFR72.212.

The overpack is designed to limit the calculated surface dose rates on the cask for all MPCs as defined in Section 2.3.5. The overpack is also designed to maintain occupational exposures ALARA during MPC transfer operations, in accordance with 10CFR20. The calculated overpack dose rates are determined in Section 5.1. These dose rates are used to perform a generic occupational exposure estimate for MPC transfer operations and a dose assessment for a typical ISFSI, as described in Chapter 10.

Confinement

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

Operations

There are no radioactive effluents that result from MPC transfer or storage operations using the overpack. Effluents generated during MPC loading and closure operations are handled by the plant's radwaste system and procedures under the licensee's 10CFR50 license.

Generic operating procedures for the HI-STORM 100 System are provided in Chapter 8. The licensee is required to develop detailed operating procedures based on Chapter 8, site-specific conditions and requirements that also comply with the applicable 10CFR50 technical specification requirements for the site, and the HI-STORM 100 System CoC.

Acceptance Tests and Maintenance

The fabrication acceptance basis and maintenance program to be applied to the overpack are described in Chapter 9. The operational controls and limits to be applied to the overpack are contained in Chapter 12. Application of these requirements will assure that the overpack is fabricated, operated, and maintained in a manner that satisfies the design criteria defined in this chapter.

Decommissioning

Decommissioning considerations for the HI-STORM 100 System, including the overpack, are addressed in Section 2.4.

2.0.3 HI-TRAC Transfer Cask Design Criteria

General

The HI-TRAC transfer cask is designed for 40 years of service, while satisfying the requirements of 10CFR72. The adequacy of the HI-TRAC design for the design life is discussed in Section 3.4.11.

Structural

The HI-TRAC transfer cask includes both structural and non-structural biological shielding components that are classified as important to safety. The structural steel components of the HI-TRAC, with the exception of the lifting trunnions, are designed and fabricated in accordance with the applicable requirements of Section III, Subsection NF, of the ASME Code with certain NRC-approved alternatives, as discussed in Section 2.2.4. The lifting trunnions and associated attachments are designed in accordance with the requirements of NUREG-0612 and ANSI N14.6 for non-redundant lifting devices.

The HI-TRAC transfer cask is designed for all normal, off-normal, and design basis accident condition loadings, as defined in Section 2.2. At a minimum, the HI-TRAC transfer cask must protect the MPC from deformation, provide continued adequate performance, and allow the retrieval of the MPC under all conditions. These design loadings include a side drop from the maximum allowable handling height, consistent with the technical specifications. The load combinations for which the HI-TRAC is designed are defined in Section 2.2.7. The physical characteristics of each

MPC for which the HI-TRAC is designed are defined in Chapter 1.

Thermal

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 top lids of the HI-TRAC 125 and HI-TRAC 125D incorporate Holtite-A shielding material. This material has a maximum allowable temperature in accordance with the manufacturer's test data. The specific allowable temperatures for the structural steel and shielding components of the HI-TRAC are provided in Table 2.2.3. The HI-TRAC is designed for off-normal environmental cold conditions, as discussed in Section 2.2.2.2. The structural steel materials susceptible to brittle fracture are discussed in Section 3.1.2.3.

The HI-TRAC is designed for the maximum heat load analyzed for storage operations. When the MPC contains any high burnup fuel assemblies or if the MPC decay heat is greater than 28.74 kW (See Section 4.5.5.1), the Supplemental Cooling System (SCS) will be required for certain time periods while the MPC is inside the HI-TRAC transfer cask (see Section 4.5). The design criteria for the SCS are provided in Appendix 2.C. The HI-TRAC water jacket maximum allowable temperature 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 limited to less than the saturation temperature at the shell design pressure. In addition, the water is precluded from freezing during off-normal cold conditions by limiting the minimum allowable temperature and adding ethylene glycol. The thermal characteristics of the fuel for each MPC for which the transfer cask is designed are defined in Section 2.1.6. The working area ambient temperature limit for loading operations is limited in accordance with the design criteria established for the transfer cask.

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 to below either 125 tons or 100 tons, or less, depending on whether the HI-TRAC 125 or HI-TRAC 100 transfer cask is utilized. The HI-TRAC calculated dose rates are reported in Section 5.1. These dose rates are used to perform a generic occupational exposure estimate for MPC loading, closure, and transfer operations, as described in Chapter 10. A postulated HI-TRAC accident condition, which includes the loss of the liquid neutron shield (water), is also evaluated in Section 5.1.2. In addition,

HI-TRAC dose rates are controlled in accordance with plant-specific procedures and ALARA requirements (discussed in Chapter 10).

The HI-TRAC 125 and 125D provide better shielding than the HI-TRAC 100 or 100D. Provided the licensee is capable of utilizing the 125-ton HI-TRAC, ALARA considerations would normally dictate that the 125-ton HI-TRAC should be used. However, sites may not be capable of utilizing the 125-ton HI-TRAC due to crane capacity limitations, floor loading limits, or other site-specific considerations. As with other dose reduction-based plant activities, individual users who cannot accommodate the 125-ton HI-TRAC should perform a cost-benefit analysis of the actions (e.g., modifications), which would be necessary to use the 125-ton HI-TRAC. The cost of the action(s) would be weighed against the value of the projected reduction in radiation exposure and a decision made based on each plant's particular ALARA implementation philosophy.

The HI-TRAC provides a means to isolate the annular area between the MPC outer surface and the HI-TRAC inner surface 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. The maximum permissible surface contamination for the HI-TRAC is in accordance with plant-specific procedures and ALARA requirements (discussed in Chapter 10).

Confinement

The HI-TRAC transfer cask does not perform any confinement function. Confinement during MPC transfer operations is provided by the MPC, and is addressed in Chapter 7. The HI-TRAC provides physical protection and biological shielding for the MPC confinement boundary during MPC closure and transfer operations.

Operations

There are no radioactive effluents that result from MPC transfer operations using HI-TRAC. Effluents generated during MPC loading and closure operations are handled by the plant's radwaste system and procedures.

Generic operating procedures for the HI-STORM 100 System are provided in Chapter 8. The licensee will develop detailed operating procedures based on Chapter 8, plant-specific requirements including the Part 50 Technical Specifications, and the HI-STORM 100 System CoC.

Acceptance Tests and Maintenance

The fabrication acceptance basis and maintenance program to be applied to the HI-TRAC Transfer Cask are described in Chapter 9. The operational controls and limits to be applied to the HI-TRAC are contained in Chapter 12. Application of these requirements will assure that the HI-TRAC is fabricated, operated, and maintained in a manner that satisfies the design criteria defined in this chapter.

Decommissioning

Decommissioning considerations for the HI-STORM 100 Systems, including the HI-TRAC Transfer Cask, are addressed in Section 2.4.

2.0.4 Principal Design Criteria for the ISFSI Pad

2.0.4.1 Design and Construction Criteria

In compliance with 10CFR72, Subpart F, "General Design Criteria", the HI-STORM 100 cask system is classified as "important-to-safety" (ITS). This final safety analysis report (FSAR) explicitly recognizes the HI-STORM 100 System as an assemblage of equipment containing numerous ITS components. The reinforced concrete pad, on which the cask is situated, however, is designated as a non-ITS structure. This is principally because, in most cases, cask systems for storing spent nuclear fuel on reinforced concrete pads are installed as free-standing structures. The lack of a physical connection between the cask and the pad permits the latter to be designated as not important-to-safety.

However, if the ZPAs at the surface of an ISFSI pad exceed the threshold limit for free-standing HI-STORM installation set forth in this FSAR, then the cask must be installed in an anchored configuration (HI-STORM 100A).

In contrast to an ISFSI containing free-standing casks, a constrained-cask installation relies on the structural capacity of the pad to ensure structural safety. The Part 72 regulations require consideration of natural phenomenon in the design. Since an ISFSI pad in an anchored cask installation participates in maintaining the stability of the cask during "natural phenomena" on the cask and pad, it is an ITS structure. The procedure suggested in Regulatory Guide 7.10 [2.0.4] and the associated NUREG [2.0.5] indicates that an ISFSI pad used to secure anchored casks should be classified as a Category C ITS structure.

Because tipover of a cask installed in an anchored configuration is not feasible, the pad does not need to be engineered to accommodate this non-mechanistic event. However, the permissible carry height for a loaded HI-STORM 100A overpack must be established for the specific ISFSI pad using the methodology described in this FSAR, if the load handling device is not designed in accordance with ANSI N 14.6 and does not have redundant drop protection design features. These requirements are specified in the CoC. However, to serve as an effective and reliable anchor, the pad must be made appropriately stiff and suitably secured to preclude pad uplift during a seismic event.

Because the geological conditions vary widely across the United States, it is not possible to, a'priori, define the detailed design of the pad. Accordingly, in this FSAR, the limiting requirements on the design and installation of the pad are provided. The user of the HI-STORM 100A System bears the responsibility to ensure that all requirements on the pad set forth in this FSAR are fulfilled by the pad design. Specifically, the ISFSI owner must ensure that:

- The pad design complies with the structural provisions of this report. In particular, the requirements of ACI-349-97 [2.0.2] with respect to embedments must be assured.

- The material of construction of the pad (viz., the additives used in the pad concrete), and the attachment system are compatible with the ambient environment at the ISFSI site.

- The pad is designed and constructed in accordance with a Part 72, Subpart G-compliant QA program.

- The design and manufacturing of the cask attachment system are consistent with the provisions of this report.
- Evaluations are performed (e.g., per 72.212) to demonstrate that the seismic and other inertial loadings at the site are enveloped by the respective bounding loadings defined in this report.

A complete listing of design and construction requirements for an ISFSI pad on which an anchored HI-STORM 100A will be deployed is provided in Appendix 2.A. A sample embedment design is depicted in Figure 2.A.1.

2.0.4.2 Applicable Codes

Factored load combinations for ISFSI pad design are provided in NUREG-1536 [2.1.5], which is consistent with ACI-349-85. The factored loads applicable to the pad design consist of dead weight of the cask, thermal gradient loads, impact loads arising from handling and accident events, external missiles, and bounding environmental phenomena (such as earthquakes, wind, tornado, and flood). 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" should be used in the design and construction of the concrete pad, as applicable. The embedment design for the HI-STORM 100A (and 100SA) are the responsibility of the ISFSI owner and shall comply with Appendix B to ACI-349-97 as described in Appendix 2.A. A later Code edition may be used provided a written reconciliation is performed.

The factored load combinations presented in Table 3-1 of NUREG 1536 are reduced in the following to a bounding set of load combinations that are applied to demonstrate adherence to its acceptance criteria.

a. Definitions

D = dead load including the loading due to pre-stress in the anchor studs
L = live load
W = wind load
W_t = tornado load
T = thermal load
F = hydrological load
E = DBE seismic load
A = accident load
H = lateral soil pressure
T_a = accident thermal load
U_c= reinforced concrete available strength

Note that in the context of a complete ISFSI design, the DBE seismic load includes both the inertia load on the pad due to its self mass plus the interface loads transmitted to the pad to resist the inertia loads on the cask due to the loaded cask self mass. It is only these interface loads that are provided herein for possible use in the ISFSI structural analyses. The inertia load associated with the seismic excitation of the self mass of the slab needs to be considered in the ISFSI owner's assessment of overall ISFSI system stability in the presence of large uplift, overturning, and sliding forces at the base of the ISFSI pad. Such considerations are site specific and thus beyond the purview of this document.

b. Load Combinations for the Concrete Pad

The notation and acceptance criteria of NUREG-1536 apply.

Normal Events

$U_c > 1.4D + 1.7L$

$U_c > 1.4D + 1.7 (L+H)$

Off-Normal Events

$U_c > 1.05D + 1.275 (L+H+T)$

$U_c > 1.05D + 1.275 (L+H+T+W)$

Accident-Level Events

$U_c > D+L+H+T+F$

$U_c > D+L+H+T_a$

$U_c > D+L+H+T+E$

$U_c > D+L+H+T+W_t$

$U_c > D+L+H+T+A$

In all of the above load combinations, the loaded cask weight is considered as a live load L on the pad. The structural analyses presented in Chapter 3 provide the interface loads contributing to "E", "F" and "W_t", which, for high-seismic sites, are the most significant loadings. The above set of load combinations can be reduced to a more limited set by recognizing that the thermal loads acting on the ISFSI slab are small because of the low decay heat loads from the cask. In addition, standard construction practices for slabs serve to ensure that extreme fluctuations in environmental temperatures are accommodated without extraordinary design measures. Therefore, all thermal loads are eliminated in the above combinations. Likewise, lateral soil pressure load "H" will also be bounded by "F" (hydrological) and "E" (earthquake) loads. Accident loads "A", resulting from a tipover, have no significance for an anchored cask. The following three load combinations are therefore deemed sufficient for structural qualification of the ISFSI slab supporting an anchored cask system.

Normal Events

$U_c > 1.4D + 1.7 (L)$

Off-Normal Events

$U_c > 1.05D + 1.275 (L+F)$

Accident-Level Events

$U_c > D+L+E$ (or W_t)

c. Load Combination for the Anchor Studs

The attachment bolts are considered to be governed by the ASME Code, Section III, Subsection NF and Appendix F [2.0.7]. Therefore, applicable load combinations and allowable stress limits for the attachment bolts are as follows:

Event Class and Load Combination	Governing ASME Code Section III Article for Stress Limits
Normal Events D	 NF-3322.1, 3324.6
Off-Normal Events D+F	 NF-3322.1, 3324.6 with all stress limits increased by 1.33
Accident-Level Events D+E and D+W_t	 Appendix F, Section F-1334, 1335

2.0.4.3 Limiting Design Parameters

Since the loaded HI-STORM overpack will be carried over the pad, the permissible lift height for the cask must be determined site-specifically to ensure the integrity of the storage system in the event of a handling accident (uncontrolled lowering of the load). To determine the acceptable lift height, it is necessary to set down the limiting ISFSI design parameters. The limiting design parameters for an anchored cask ISFSI pad and the anchor studs, as applicable, are tabulated in Table 2.0.4. The design of steel embedments in reinforced concrete structures is governed by Appendix B of ACI-349-97. Section B.5 in that appendix states that "anchorage design shall be controlled by the strength of embedment steel…". Therefore, limits on the strength of embedment steel and on the anchor studs must be set down not only for the purposes of quantifying structural margins for the design basis load combinations, but also for the use of the ISFSI pad designer to establish the appropriate embedment anchorage in the ISFSI pad. The anchored cask pad design parameters presented in Table 2.0.4 allow for a much stiffer pad than the pad for free-standing HI-STORMs (Table 2.2.9). This increased stiffness has the effect of reducing the allowable lift height. However, a lift height for a loaded HI-STORM 100 cask (free-standing or anchored) is not required to be established if the cask is being lifted with a lift device designed in accordance with ANSI N14.6 having redundant drop protection design features.

In summary, the requirements for the ISFSI pad for free-standing and anchored HI-STORM deployment are similar with a few differences. Table 2.0.5 summarizes their commonality and differences in a succinct manner with the basis for the difference fully explained.

2.0.4.4 Anchored Cask/ISFSI Interface

The contact surface between the baseplate of overpack and the top surface of the ISFSI pad defines the structural interface between the HI-STORM overpack and the ISFSI pad. When HI-STORM is deployed in an anchored configuration, the structural interface also includes the surface where the nuts on the anchor studs bear upon the sector lugs on the overpack baseplate. The anchor studs and their fastening arrangements into the ISFSI pad are outside of the structural boundary of the storage cask. While the details of the ISFSI pad design for the anchored configuration, like that for the free-standing geometry, must be custom engineered for each site, certain design and acceptance criteria are specified herein (Appendix 2.A) to ensure that the design and construction of the pad fully comports with the structural requirements of the HI-STORM System.

Table 2.0.1
MPC DESIGN CRITERIA SUMMARY

Type	Criteria	Basis	FSAR Reference
Design Life:			
Design	40 yrs.	-	Table 1.2.2
License	20 yrs.	10CFR72.42(a) and 10CFR72.236(g)	-
Structural:			
Design Codes:			
Enclosure Vessel	ASME Code, Section III, Subsection NB	10CFR72.24(c)(4)	Section 2.0.1
Fuel Basket	ASME Code, Section III, Subsection NG for core supports (NG-1121)	10CFR72.24(c)(4)	Section 2.0.1
MPC Fuel Basket Supports (Angled Plates)	ASME Code, Section III, Subsection NG for internal structures (NG-1122)	10CFR72.24(c)(4)	Section 2.0.1
MPC Lifting Points	ANSI N14.6/NUREG-0612	10CFR72.24(c)(4)	Section 1.2.1.4
Dead Weights†:			
Max. Loaded Canister (dry)	90,000 lb.	R.G. 3.61	Table 3.2.1
Empty Canister (dry)	42,000 lb. (MPC-24) 45,000 lb. (MPC-24E/EF) 39,000 lb. (MPC-68/68F/68FF) 36,000 lb. (MPC-32)	R.G. 3.61	Table 3.2.1
Design Cavity Pressures:			
Normal:	100 psig	ANSI/ANS 57.9	Section 2.2.1.3
Off-Normal:	110 psig	ANSI/ANS 57.9	Section 2.2.2.1
Accident (Internal)	200 psig	ANSI/ANS 57.9	Section 2.2.3.8
Accident (External)	60 psig	ANSI/ANS 57.9	Sections 2.2.3.6 and 2.2.3.10

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

Table 2.0.1 (continued)
MPC DESIGN CRITERIA SUMMARY

Type	Criteria	Basis	FSAR Reference
Response and Degradation Limits	SNF assemblies confined in dry, inert environment	10CFR72.122(h)(l)	Section 2.0.1
Thermal:			
Maximum Design Temperatures:			
Structural Materials:			
Stainless Steel (Normal)	725° F	ASME Code Section II, Part D	Table 2.2.3
Stainless Steel (Accident)	950° F	See Subsection 2.2.2.3	Table 2.2.3
Neutron Poison:			
Neutron Absorber (normal)	800° F	See Table 4.3.1 and Subsection 1.2.1.3.1	Table 2.2.3
Neutron Absorber (accident)	1000° F	See Table 4.3.1 and Subsection 1.2.1.3.1	Table 2.2.3
Canister Drying	≤ 3 torr for ≥ 30 minutes (VDS) ≤ 21°F exiting the demoisturizer for ≥ 30 minutes or a dew point of the MPC exit gas ≤ 22.9°F for ≥ 30 minutes(FHD)	NUREG-1536, ISG-11, Rev. 3	Section 4.5, Appendix 2.B
Canister Backfill Gas	Helium	-	Section 4.4
Canister Backfill	Varies (see Table 1.2.2)	Thermal Analysis	Section 4. 4
Fuel cladding temperature limit for long term storage conditions	752 °F (400 °C)	ISG-11, Rev. 3	Section 4.3
Fuel cladding temperature limit for normal short-term operating conditions (e.g., MPC drying and onsite transport)	752 °F (400 °C), except certain MPCs containing all moderate burnup fuel (MBF) may use 1058°F (570°C) for normal short-term operating conditions	ISG-11, Rev. 3	Sections 4.3 and 4.5
Fuel cladding temperature limit for	1058° F (570 °C)	ISG-11, Rev. 3	Sections 2.0.1 and 4.3

Table 2.0.1 (continued)
MPC DESIGN CRITERIA SUMMARY

Type	Criteria	Basis	FSAR Reference
Off-Normal and Accident Events			
Insolation	Protected by overpack or HI-TRAC	-	Section 4.3
Confinement:		10CFR72.128(a)(3) and 10CFR72.236(d) and (e)	
Closure Welds:			
Shell Seams and Shell-to-Baseplate	Full Penetration	-	Section 1.5 and Table 9.1.4
MPC Lid	Multi-pass Partial Penetration	10CFR72.236(e)	Section 1.5 and Table 9.1.4
MPC Closure Ring	Partial Penetration		
Port Covers	Partial Penetration		
NDE:			
Shell Seams and Shell-to-Baseplate	100% RT or UT	-	Table 9.1.4
MPC Lid	Root Pass and Final Surface 100% PT; Volumetric Inspection or 100% Surface PT each 3/8" of weld depth	-	Chapter 8 and Table 9.1.4
Closure Ring	Root Pass (if more than one pass is required) and Final Surface 100% PT	-	Chapter 8 and Table 9.1.4
Port Covers	Root Pass (if more than one pass is required) and Final Surface 100% PT	-	Chapter 8 and Table 9.1.4
Leak Testing:			
Welds Tested	MPC shell to shell and MPC shell to baseplate welds (Fabrication). Port covers-to-MPC lid (field)	ISG-25 ISG-18	Section 9.1
Base Metals Tested	MPC shell, MPC baseplate,	ISG-25	Section 9.1

Table 2.0.1 (continued)
MPC DESIGN CRITERIA SUMMARY

Type	Criteria	Basis	FSAR Reference
	MPC lid (Fabrication). MPC vent and drain port cover plates (Field).		
Medium	Helium	ANSI N14.5	Section 9.1
Max. Leak Rate	Leaktight	ANSI N14.5	Section 9.1
Monitoring System	None	10CFR72.128(a)(1)	Section 2.3.2.1
Pressure Testing:			
Minimum Test Pressure	125 psig (hydrostatic) 120 psig (pneumatic)	-	Sections 8.1 and 9.1
Welds Tested	MPC Lid-to-Shell, MPC Shell seams, MPC Shell-to-Baseplate	-	Sections 8.1 and 9.1
Medium	Water or helium	-	Section 8.1 and Chapter 9
Retrievability:			
Normal and Off-normal:	No Encroachment on Fuel Assemblies	10CFR72.122(f) & (l)	Sections 3.4 and 3.1.2
Post (design basis) Accident			
Criticality:		10CFR72.124 & 10CFR72.236(c)	
Method of Control	Fixed Borated Neutron Absorber, Geometry, and Soluble Boron	-	Section 2.3.4
Min. ^{10}B Loading (Boral/METAMIC®)	0.0267/0.0223 g/cm^2 (MPC-24) 0.0372/0.0310 g/cm^2 (MPC-68, MPC-68FF, MPC-24E,MPC-24EF, MPC-32 and MPC-32F) 0.01 g/cm^2 (MPC-68F)	-	Sections 2.1.8 and 6.1
Minimum Soluble Boron	Varies (see Tables 2.1.14 and 2.1.16)	Criticality Analysis	Sections 2.1.9 and 6.1
Max. k_{eff}	0.95	-	Sections 6.1 and 2.3.4
Min. Burnup	0.0 GWd/MTU (fresh fuel)	-	Section 6.1
Radiation Protection/Shielding:		10CFR72.126, & 10CFR72.128(a)(2)	

Table 2.0.1 (continued)
MPC DESIGN CRITERIA SUMMARY

Type	Criteria	Basis	FSAR Reference
MPC: (normal/off-normal/accident)			
MPC Closure	ALARA	10CFR20	Sections 10.1, 10.2, & 10.3
MPC Transfer	ALARA	10CFR20	Sections 10.1, 10.2, & 10.3
Exterior of Shielding: (normal/off-normal/accident)			
Transfer Mode Position	See Table 2.0.3	10CFR20	Section 5.1.1
ISFSI Controlled Area Boundary	See Table 2.0.2	10CFR72.104 & 10CFR72.106	Section 5.1.1 and Chapter 10
Design Bases:		10CFR72.236(a)	
Spent Fuel Specification:			
Assemblies/Canister	Up to 24 (MPC-24, MPC-24E & MPC-24EF) Up to 32 (MPC-32 and MPC-32F) Up to 68 (MPC-68, MPC-68F, & MPC-68FF)	-	Table 1.2.1 and Section 2.1.9
Type of Cladding	ZR and Stainless Steel	-	Section 2.1.9
Fuel Condition	Intact, Damaged, and Debris	-	Sections 2.1.2, 2.1.3, and 2.1.9
PWR Fuel Assemblies:			
Type/Configuration	Various	-	Section 2.1.9
Max. Burnup	68,200 MWD/MTU	-	Sections 2.1.9 and 6.2
Max. Enrichment	Varies by fuel design	-	Table 2.1.3 and Section 2.1.9
Max. Decay Heat/ MPC†:	36.9 kW	-	Section 4.4
Minimum Cooling Time:	3 years (Intact ZR Clad Fuel) 8 years (Intact SS Clad Fuel)	-	Section 2.19
Max. Fuel Assembly Weight:	1,720 lb. for fuel assemblies that	-	Section 2.1.9

† Section 2.1.9.1 describes the decay heat limits per assembly

Table 2.0.1 (continued)
MPC DESIGN CRITERIA SUMMARY

Type	Criteria	Basis	FSAR Reference
(including non-fuel hardware and DFC, as applicable)	do not require fuel spacers, otherwise 1,680 lb.		
Max. Fuel Assembly Length: (Unirradiated Nominal)	176.8 in.	-	Section 2.1.9
Max. Fuel Assembly Width (Unirradiated Nominal)	8.54 in.	-	Section 2.1.9
BWR Fuel Assemblies:			
Type	Various	-	Sections 2.1.9 and 6.2
Max. Burnup	65,000 MWD/MTU	-	Section 2.1.9
Max. Enrichment	Varies by fuel design	-	Section 2.1.9, Table 2.1.4
Max. Decay Heat/ MPC†.	36.9 kW	-	Section 4.4
Minimum Cooling Time:	3 years (Intact ZR Clad Fuel) 8 years (Intact SS Clad Fuel)		Section 2.1.9
Max. Fuel Assembly Weight:			
w/channels and DFC, as applicable	730 lb.	-	Section 2.1.9
Max. Fuel Assembly Length (Unirradiated Nominal)	176.5in.	-	Section 2.1.9
Max. Fuel Assembly Width (Unirradiated Nominal)	5.85 in.	-	Section 2.1.9
Normal Design Event Conditions:		10CFR72.122(b)(1)	
Ambient Temperatures	See Tables 2.0.2 and 2.0.3	ANSI/ANS 57.9	Section 2.2.1.4
Handling:			Section 2.2.1.2
Handling Loads	115% of Dead Weight	CMAA #70	Section 2.2.1.2
Lifting Attachment Acceptance Criteria	1/10 Ultimate 1/6 Yield	NUREG-0612 ANSI N14.6	Section 3.4.3
Attachment/Component Interface Acceptance Criteria	1/3 Yield	Regulatory Guide 3.61	Section 3.4.3

† Section 2.1.9.1 describes the decay heat limits per assembly.

Table 2.0.1 (continued)
MPC DESIGN CRITERIA SUMMARY

Type	Criteria	Basis	FSAR Reference
Away from Attachment Acceptance Criteria	ASME Code Level A	ASME Code	Section 3.4.3
Wet/Dry Loading	Wet or Dry	-	Section 1.2.2.2
Transfer Orientation	Vertical	-	Section 1.2.2.2
Storage Orientation	Vertical	-	Section 1.2.2.2
Fuel Rod Rupture Releases:			
Source Term Release Fraction	1%	NUREG-1536	Sections 2.2.1.3
Fill Gases	100%	NUREG-1536	Sections 2.2.1.3
Fission Gases	30%	NUREG-1536	Sections 2.2.1.3
Snow and Ice	Protected by Overpack	ASCE 7-88	Section 2.2.1.6
Off-Normal Design Event Conditions:		10CFR72.122(b)(1)	
Ambient Temperature	See Tables 2.0.2 and 2.0.3	ANSI/ANS 57.9	Section 2.2.2.2
Leakage of One Seal	N/A	ISG-18	Sections 2.2.2.4 and 7.1
Partial Blockage of Overpack Air Inlets	50% of Air Inlets Blocked	-	Section 2.2.2.5
Source Term Release Fraction:			
Fuel Rod Failures	10%	NUREG-1536	Sections 2.2.2.1
Fill Gases	100%	NUREG-1536	Sections 2.2.2.1
Fission Gases	30%	NUREG-1536	Sections 2.2.2.1
Design-Basis (Postulated) Accident Design Events and Conditions:		10CFR72.24(d)(2) & 10CFR72.94	
Tip Over	See Table 2.0.2	-	Section 2.2.3.2
End Drop	See Table 2.0.2	-	Section 2.2.3.1
Side Drop	See Table 2.0.3	-	Section 2.2.3.1
Fire	See Tables 2.0.2 and 2.0.3	10CFR72.122(c)	Section 2.2.3.3
Fuel Rod Rupture Releases:			
Fuel Rod Failures (including non-fuel hardware)	100%	NUREG-1536	Sections 2.2.3.8
Fill Gases	100%	NUREG-1536	Sections 2.2.3.8

Table 2.0.1 (continued)
MPC DESIGN CRITERIA SUMMARY

Type	Criteria	Basis	FSAR Reference
Fission Gases	30%	NUREG-1536	Sections 2.2.3.8
Particulates & Volatiles	See Table 7.3.1	-	Sections 2.2.3.9
Confinement Boundary Leakage	None	ISG-18 / ANSI N 14.5	Sections 2.2.3.9 and 7.1
Explosive Overpressure	60 psig (external)	10CFR72.122(c)	Section 2.2.3.10
Airflow Blockage:			
Vent Blockage	100% of Overpack Air Inlets Blocked	10CFR72.128(a)(4)	Section 2.2.3.13
Partial Blockage of MPC Basket Vent Holes	Crud Depth (Table 2.2.8)	ESEERCO Project EP91-29	Section 2.2.3.4
Design Basis Natural Phenomenon Design Events and Conditions:		10CFR72.92 & 10CFR72.122(b)(2)	
Flood Water Depth	125 ft.	ANSI/ANS 57.9	Section 2.2.3.6
Seismic	See Table 2.0.2	10CFR72.102(f)	Section 2.2.3.7
Wind	Protected by Overpack	ASCE-7-88	Section 2.2.3.5
Tornado & Missiles	Protected by Overpack	RG 1.76 & NUREG-0800	Section 2.2.3.5
Burial Under Debris	Maximum Decay Heat Load	-	Section 2.2.3.12
Lightning	See Table 2.0.2	NFPA 78	Section 2.2.3.11
Extreme Environmental Temperature	See Table 2.0.2	-	Section 2.2.3.14

Table 2.0.2
HI-STORM OVERPACK DESIGN CRITERIA SUMMARY

Type	Criteria	Basis	FSAR Reference
Design Life:			
Design	40 yrs.	-	Section 2.0.2
License	20 yrs.	10CFR72.42(a) & 10CFR72.236(g)	
Structural:			
Design & Fabrication Codes:			
Concrete			
Design	ACI 349 as clarified in Appendix 1.D	10CFR72.24(c)(4)	Section 2.0.2 and Appendix 1.D
Fabrication	ACI 349 as clarified in Appendix 1.D	10CFR72.24(c)(4)	Section 2.0.2 and Appendix 1.D
Compressive Strength	ACI 318.1-89 (92)as clarified in Appendix 1.D	10CFR72.24(c)(4)	Section 2.0.2 and Appendix 1.D
Structural Steel			
Design	ASME Code Section III, Subsection NF	10CFR72.24(c)(4)	Section 2.0.2
Fabrication	ASME Code Section III, Subsection NF	10CFR72.24(c)(4)	Section 2.0.2
Dead Weights†:			
Max. Loaded MPC (Dry)	90,000 lb. (MPC- 32)	R.G. 3.61	Table 3.2.1
Max. Empty Overpack Assembled with Top Lid (150 pcf concrete/200pcf concrete)	270,000/320,000 lb.	R.G. 3.61	Table 3.2.1
Max. MPC/Overpack (150 pcf concrete/200pcf concrete)	360,000/410,000 lb.	R.G. 3.61	Table 3.2.1
Design Cavity Pressures	N/A	-	Section 2.2.1.3

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

Table 2.0.2 (continued)
HI-STORM 100 OVERPACK DESIGN CRITERIA SUMMARY

Type	Criteria	Basis	FSAR Reference
Response and Degradation Limits	Protect MPC from deformation	10CFR72.122(b) 10CFR72.122(c)	Sections 2.0.2 and 3.1
	Continued adequate performance of overpack	10CFR72.122(b) 10CFR72.122(c)	
	Retrieval of MPC	10CFR72.122(l)	
Thermal:			
Maximum Design Temperatures:			
Concrete			
Through-Thickness Section Average (Normal)	300° F	ACI 349, Appendix A (Paragraph A.4.3)	Section 2.0.2, and Tables 1.D.1 and 2.2.3
Through-Thickness Section Average (Off-Normal and Accident)	350° F	ACI 349 Appendix A (Paragraph A.4.2)	Section 2.0.2, and Tables 1.D.1 and 2.2.3
Steel Structure (other than lid bottom and top plates) Lid Bottom and Top Plates	350° F 450°F	ASME Code Section II, Part D	Table 2.2.3
Insolation:	Averaged Over 24 Hours	10CFR71.71	Section 4.4.1.1.8
Confinement:	None	10CFR72.128(a)(3) & 10CFR72.236(d) & (e)	N/A
Retrievability:			
Normal and Off-Normal	No damage that precludes Retrieval of MPC	10CFR72.122(f) & (l)	Section 3.4
Accident			Section 3.4
Criticality:	Protection of MPC and Fuel Assemblies	10CFR72.124 & 10CFR72.236(c)	Section 6.1
Radiation Protection/Shielding:		10CFR72.126 & 10CFR72.128(a)(2)	
Overpack (Normal/Off-Normal/Accident)			
Surface	ALARA	10CFR20	Chapters 5 and 10
Position	ALARA	10CFR20	Chapters 5 and 10

Table 2.0.2 (continued)
HI-STORM 100 OVERPACK DESIGN CRITERIA SUMMARY

Type	Criteria	Basis	FSAR Reference
Beyond Controlled Area During Normal Operation and Anticipated Occurrences	25 mrem/yr. to whole body 75 mrem/yr. to thyroid 25 mrem/yr. to any critical organ	10CFR72.104	Sections 5.1.1, 7.2, and 10.1
At Controlled Area Boundary from Design Basis Accident	5 rem TEDE or sum of DDE and CDE to any individual organ or tissue (other than lens of eye) ≤ 50 rem. 15 rem lens dose. 50 rem shallow dose to skin or extremity.	10CFR72.106	Sections 5.1.2, 7.3, and 10.1
Design Bases:			
Spent Fuel Specification	See Table 2.0.1	10CFR72.236(a)	Section 2.1.9
Normal Design Event Conditions:		10CFR72.122(b)(1)	
Ambient Outside Temperatures:			
Max. Yearly Average	80° F	ANSI/ANS 57.9	Section 2.2.1.4
Live Load†:		ANSI/ANS 57.9	-
Loaded Transfer Cask (max.)	250,000 lb. (HI-TRAC 125 w/transfer lid)	R.G. 3.61	Table 3.2.4 Section 2.2.1.2
Dry Loaded MPC (max.)	90,000 lb.	R.G. 3.61	Table 3.2.1 and Section 2.2.1.2
Handling:			Section 2.2.1.2
Handling Loads	115% of Dead Weight	CMAA #70	Section 2.2.1.2
Lifting Attachment Acceptance Criteria	1/10 Ultimate 1/6 Yield	NUREG-0612 ANSI N14.6	Section 3.4.3
Attachment/Component Interface Acceptance Criteria	1/3 Yield	Regulatory Guide 3.61	Section 3.4.3
Away from Attachment	ASME Code	ASME Code	Section 3.4.3

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

Table 2.0.2 (continued)
HI-STORM 100 OVERPACK DESIGN CRITERIA SUMMARY

Type	Criteria	Basis	FSAR Reference
Acceptance Criteria	Level A		
Minimum Temperature During Handling Operations	0° F	ANSI/ANS 57.9	Section 2.2.1.2
Snow and Ice Load	100 lb./ft^2	ASCE 7-88	Section 2.2.1.6
Wet/Dry Loading	Dry	-	Section 1.2.2.2
Storage Orientation	Vertical	-	Section 1.2.2.2
Off-Normal Design Event Conditions:		10CFR72.122(b)(1)	
Ambient Temperature			
Minimum	-40° F	ANSI/ANS 57.9	Section 2.2.2.2
Maximum	100° F	ANSI/ANS 57.9	Section 2.2.2.2
Partial Blockage of Air Inlets	50% of Air Inlets Blocked	-	Section 2.2.2.5
Design-Basis (Postulated) Accident Design Events and Conditions:		10CFR72.94	
Drop Cases:			
End	11 in.	-	Section 2.2.3.1
Tip-Over (Not applicable for HI-STORM 100A)	Assumed (Non-mechanistic)	-	Section 2.2.3.2
Fire:			
Duration	217 seconds	10CFR72.122(c)	Section 2.2.3.3
Temperature	1,475° F	10CFR72.122(c)	Section 2.2.3.3
Fuel Rod Rupture	See Table 2.0.1	-	Section 2.2.3.8
Air Flow Blockage:			
Vent Blockage	100% of Air Inlets Blocked	10CFR72.128(a)(4)	Section 2.2.3.13
Ambient Temperature	80° F	10CFR72.128(a)(4)	Section 2.2.3.13
Explosive Overpressure External Differential Pressure	10 psid instantaneous, 5 psid steady state	10 CFR 72.128(a)(4)	Table 2.2.1

Table 2.0.2 (continued)
HI-STORM 100 OVERPACK DESIGN CRITERIA SUMMARY

Type	Criteria	Basis	FSAR Reference
Design-Basis Natural Phenomenon Design Events and Conditions:		10CFR72.92 & 10CFR72.122(b)(2)	
Flood			
Height	125 ft.	RG 1.59	Section 2.2.3.6
Velocity	15 ft/sec.	RG 1.59	Section 2.2.3.6
Seismic			
Max. acceleration at top of ISFSI pad	Free Standing: $G_H + 0.53G_V \leq 0.53$ Anchored: $G_H \leq 2.12$, $G_V \leq 1.5$	10CFR72.102(f)	Section 3.4.7.1 Section 3.4.7.3
Tornado			
Wind			
Max. Wind Speed	360 mph	RG 1.76	Section 2.2.3.5
Pressure Drop	3.0 psi	RG 1.76	Section 2.2.3.5
Missiles			Section 2.2.3.5
Automobile			
Weight	1,800 kg	NUREG-0800	Table 2.2.5
Velocity	126 mph	NUREG-0800	Table 2.2.5
Rigid Solid Steel Cylinder			
Weight	125 kg	NUREG-0800	Table 2.2.5
Velocity	126 mph	NUREG-0800	Table 2.2.5
Diameter	8 in.	NUREG-0800	Table 2.2.5
Steel Sphere			
Weight	0.22 kg	NUREG-0800	Table 2.2.5
Velocity	126 mph	NUREG-0800	Table 2.2.5
Diameter	1 in.	NUREG-0800	Table 2.2.5
Burial Under Debris	Maximum Decay Heat Load	-	Section 2.2.3.12
Lightning	Resistance Heat-Up	NFPA 70 & 78	Section 2.2.3.11
Extreme Environmental Temperature	125° F	-	Section 2.2.3.14
Load Combinations:	See Table 2.2.14 and Table 3.1.5	ANSI/ANS 57.9 and NUREG-1536	Section 2.2.7

TABLE 2.0.3
HI-TRAC TRANSFER CASK DESIGN CRITERIA SUMMARY

Type	Criteria	Basis	FSAR Reference
Design Life:			
Design	40 yrs.	-	Section 2.0.3
License	20 yrs.	10CFR72.42(a) & 10CFR72.236(g)	
Structural:			
Design Codes:			
Structural Steel	ASME Code, Section III, Subsection NF	10CFR72.24(c)(4)	Section 2.0.3
Lifting Trunnions	NUREG-0612 & ANSI N14.6	10CFR72.24(c)(4)	Section 1.2.1.4
Dead Weights†:			
Max. Empty Cask:			
w/top lid and pool lid installed and water jacket filled	143,500 lb. (HI-TRAC 125) 102,000 lb. (HI-TRAC 100) 102,000 lb. (HI-TRAC 100D) 146,000 lb. (HI-TRAC 125D)	R.G. 3.61	Table 3.2.2
w/top lid and transfer lid installed and water jacket filled (N/A for HI-TRAC 100D and 125D)	155,000 lb. (HI-TRAC 125) 111,000 lb. (HI-TRAC 100)	R.G. 3.61	Table 3.2.2
Max. MPC/HI-TRAC with Yoke (in-pool lift):	250,000 lb. (HI-TRAC 125 and 125D) 200,000 lb. (HI-TRAC 100 and 100D)	R.G. 3.61	Table 3.2.4
Design Cavity Pressures:			
HI-TRAC Cavity	Hydrostatic	ANSI/ANS 57.9	Section 2.2.1.3
Water Jacket Cavity	60 psig (internal)	ANSI/ANS 57.9	Section 2.2.1.3

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

TABLE 2.0.3 (continued)
HI-TRAC TRANSFER CASK DESIGN CRITERIA SUMMARY

Type	Criteria	Basis	FSAR Reference
Response and Degradation Limits	Protect MPC from deformation	10CFR72.122(b) 10CFR72.122(c)	Section 2.0.3
	Continued adequate performance of HI-TRAC transfer cask	10CFR72.122(b) 10CFR72.122(c)	
	Retrieval of MPC	10CFR72.122(l)	
Thermal:			
Maximum Design Temperature			
Structural Materials	400° F	ASME Code Section II, Part D	Table 2.2.3
Shielding Materials			
Lead	350° F (max.)		Table 2.2.3
Liquid Neutron Shield	307° F (max.)	-	Table 2.2.3
Solid Neutron Shield	300° F (max.) (long term) 350°F (max.) (short term)	Test Data	Appendix 1.B and Table 2.2.3
Insolation:	Averaged Over 24 Hours	10CFR71.71	Section 4.5.1.1.3
Confinement:	None	10CFR72.128(a)(3) & 10CFR72.236(d) & (e)	N/A
Retrievability:			
Normal and Off-Normal	No encroachment on MPC	10CFR72.122(f) & (l)	Section 3.4
After Design-basis (Postulated) Accident			Section 3.4
Criticality:	Protection of MPC and Fuel Assemblies	10CFR72.124 & 10CFR72.236(c)	Section 6.1
Radiation Protection/Shielding:		10CFR72.126 & 10CFR72.128(a)(2)	
Transfer Cask (Normal/Off-Normal/Accident)			
Surface	ALARA	10CFR20	Chapters 5 and 10
Position	ALARA	10CFR20	Chapters 5 and 10

TABLE 2.0.3 (continued)
HI-TRAC TRANSFER CASK DESIGN CRITERIA SUMMARY

Type	Criteria	Basis	FSAR Reference
Design Bases:			
Spent Fuel Specification	See Table 2.0.1	10CFR72.236(a)	Section 2.1
Normal Design Event Conditions:		10CFR72.122(b)(1)	
Ambient Temperature:	80° F	ANSI/ANS 57.9	Section 2.2.1.4
Live Load†			
Max. Loaded Canister			
Dry	90,000 lb.	R.G. 3.61	Table 3.2.1
Wet (including water in HI-TRAC annulus)	106,570 lb.	R.G. 3.61	Table 3.2.4
Handling:			Section 2.2.1.2
Handling Loads	115% of Dead Weight	CMAA #70	Section 2.2.1.2
Lifting Attachment Acceptance Criteria	1/10 Ultimate 1/6 Yield	NUREG-0612 ANSI N14.6	Section 3.4.3
Attachment/Component Interface Acceptance Criteria	1/3 Yield	Regulatory Guide 3.61	Section 3.4.3
Away from Attachment Acceptance Criteria	ASME Code Level A	ASME Code	Section 3.4.3
Minimum Temperature for Handling Operations	0° F	ANSI/ANS 57.9	Section 2.2.1.2
Wet/Dry Loading	Wet or Dry	-	Section 1.2.2.2
Transfer Orientation	Vertical	-	Section 1.2.2.2
Test Loads:			
Trunnions	300% of vertical design load	NUREG-0612 & ANSI N14.6	Section 9.1.2.1
Design-Basis (Postulated) Accident Design Events and Conditions:		10CFR72.24(d)(2) & 10CFR72.94	
Side Drop	42 in.	-	Section 2.2.3.1
Fire			
Duration	4.8 minutes	10CFR72.122(c)	Section 2.2.3.3

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

TABLE 2.0.3 (continued)
HI-TRAC TRANSFER CASK DESIGN CRITERIA SUMMARY

Type	Criteria	Basis	FSAR Reference
Temperature	1,475° F	10CFR72.122(c)	Section 2.2.3.3
Fuel Rod Rupture	See Table 2.0.1		Section 2.2.3.8
Design-Basis Natural Phenomenon Design Events and Conditions:		10CFR72.92 & 10CFR72.122(b)(2)	
Missiles			Section 2.2.3.5
Automobile			
Weight	1800 kg	NUREG-0800	Table 2.2.5
Velocity	126 mph	NUREG-0800	Table 2.2.5
Rigid Solid Steel Cylinder			
Weight	125 kg	NUREG-0800	Table 2.2.5
Velocity	126 mph	NUREG-0800	Table 2.2.5
Diameter	8 in.	NUREG-0800	Table 2.2.5
Steel Sphere			
Weight	0.22 kg	NUREG-0800	Table 2.2.5
Velocity	126 mph	NUREG-0800	Table 2.2.5
Diameter	1 in.	NUREG-0800	Table 2.2.5
Load Combinations:	See Table 2.2.14 and Table 3.1.5	ANSI/ANS-57.9 & NUREG-1536	Section 2.2.7

TABLE 2.0.4
LIMITING DESIGN PARAMETERS FOR ISFSI PADS AND ANCHOR STUDS FOR HI-STORM 100A

Item	**Maximum Permitted Value†**	**Minimum Permitted Value**
ISFSI PAD		
Pad Thickness	---	48 inches
Subgrade Young's Modulus from Static Tests (needed if pad is not founded on rock)	---	10,000 psi
Concrete compressive strength at 28 days	---	4,000 psi
ANCHOR STUDS		
Yield Strength at Ambient Temperature	None	80,000 psi
Ultimate Strength at Ambient Temperature	None	125,000 psi
Initial Stud Tension	65 ksi	55 ksi

† Pad and anchor stud parameters to be determined site-specifically, except where noted.

TABLE 2.0.5
ISFSI PAD REQUIREMENTS FOR FREE-STANDING AND ANCHORED HI-STORM INSTALLATION

Item	Free-Standing	Anchored	Comments
1. Interface between cask and ISFSI	Contact surface between cask and top surface of ISFSI pad	Same as free-standing with the addition of the bearing surface between the anchor stud nut and the overpack baseplate. (The interface between the anchor stud and the anchor receptacle is at the applicable threaded or bearing surface).	All components below the top surface of the ISFSI pad and in contact with the pad concrete are part of the pad design. A non-integral component such as the anchor stud is not part of the embedment even though it may be put in place when the ISFSI pad is formed. The embedment for the load transfer from the anchor studs to the concrete ISFSI pad shall be exclusively cast-in-place.
2. Applicable ACI Code	At the discretion of the ISFSI owner. ACI-318 and ACI-349 are available candidate codes.	ACI-349-97. A later edition of this Code may be used if a written reconciliation is performed.	ACI-349-97 recognizes increased structural role of the ISFSI pad in an anchored cask storage configuration and imposes requirements on embedment design.
3. Limitations on the pad design parameters	Per Table 2.2.9	Per Table 2.0.4	In free-standing cask storage, the non-mechanistic tipover requirement limits the stiffness of the pad. In the anchored storage configuration, increased pad stiffness is permitted; however, the permissible HI-STORM carry height is reduced.
4. HI-STORM Carry Height	11 inches (for ISFSI pad parameter Set A or Set B) or, otherwise, site-specific. Not applicable if the cask is lifted with a device designed in accordance with ANSI N14.6 and having redundant drop protection features.	Determined site-specifically. Not applicable if the cask is lifted with a device designed in accordance with ANSI N14.6 and having redundant drop protection features.	Appendix 3.A provides the technical basis for free-standing installation. Depending on the final ISFSI pad configuration (thickness, concrete strength, subgrade,etc.), and the method of transport, an allowable carry height may need to be established.

TABLE 2.0.5 (continued)
ISFSI PAD REQUIREMENTS FOR FREE-STANDING AND ANCHORED HI-STORM INSTALLATION

Item		Free-Standing	Anchored	Comments
5.	Maximum seismic input on the pad/cask contact surface. G_H is the vectorial sum of the two horizontal ZPAs and G_V is the vertical ZPA	$G_H + \mu G_V \leq \mu$ (see note 1 below)	$G_H \leq 2.12$ AND $G_V \leq 1.5$	
6.	Required minimum value of cask to pad static coefficient of friction (μ, must be confirmed by testing if a value greater than 0.53 is used).	Greater than or equal to 0.53 (per Table 2.2.9).	Not applicable	
7.	Applicable Wind and Large Missile Loads	Per Table 2.2.4, missile and wind loading different from the tabulated values, require 10CFR 72.48 evaluation	The maximum overturning moment at the base of the cask due to lateral missile and/or wind action must be less than 1 x 10^7 ft-lb.	The bases are provided in Section 3.4.8 for free-standing casks; the limit for anchored casks ensures that the anchorage system will have the same structural margins established for seismic loading.
8.	Small and medium missiles (penetrant missile)	Per Table 2.2.5, missiles and wind loading different from the tabulated value, require 10CFR 72.48 evaluation.	Same as for free-standing cask construction.	
9.	Design Loadings for the ISFSI Pad	Per load combinations in Section 2.0.4 using site-specific load.	Same as for free-standing cask.	

Note 1 – GH and GV may be the coincident values of the instantaneous horizontal and vertical accelerations, and the inequality shall be evaluated at each time step.

2.1 SPENT FUEL TO BE STORED

2.1.1 Determination of The Design Basis Fuel

The HI-STORM 100 System is designed to store most types of fuel assemblies generated in the commercial U.S. nuclear industry. Boiling-water reactor (BWR) fuel assemblies have been supplied by The General Electric Company (GE), Siemens, Exxon Nuclear, ANF, UNC, ABB Combustion Engineering, and Gulf Atomic. Pressurized-water reactor (PWR) fuel assemblies are generally supplied by Westinghouse, Babcock & Wilcox, ANF, and ABB Combustion Engineering. ANF, Exxon, and Siemens are historically the same manufacturing company under different ownership. Within this report, SPC is used to designate fuel manufactured by ANF, Exxon, or Siemens. Publications such as Refs. [2.1.1] and [2.1.2] provide a comprehensive description of fuel discharged from U.S. reactors. A central object in the design of the HI-STORM 100 System is to ensure that a majority of SNF discharged from the U.S. reactors can be stored in one of the MPCs.

The cell openings and lengths in the fuel basket have been sized to accommodate the BWR and PWR assemblies listed in Refs. [2.1.1] and [2.1.2] except as noted below. Similarly, the cavity lengths of the multi-purpose canisters have been set at dimensions which permit storing most types of PWR fuel assemblies and BWR fuel assemblies with or without fuel channels. The one exception is as follows:

i. The South Texas Units 1 & 2 SNF, and CE 16x16 System 80 SNF are too long to be accommodated in the available MPC cavity lengths.

In addition to satisfying the cross sectional and length compatibility, the active fuel region of the SNF must be enveloped in the axial direction by the neutron absorber located in the MPC fuel basket. Alignment of the neutron absorber with the active fuel region is ensured by the use of upper and lower fuel spacers suitably designed to support the bottom and restrain the top of the fuel assembly. The spacers axially position the SNF assembly such that its active fuel region is properly aligned with the neutron absorber in the fuel basket. Figure 2.1.5 provides a pictorial representation of the fuel spacers positioning the fuel assembly active fuel region. Both the upper and lower fuel spacers are designed to perform their function under normal, off-normal, and accident conditions of storage.

In summary, the geometric compatibility of the SNF with the MPC designs does not require the definition of a design basis fuel assembly. This, however, is not the case for structural, confinement, shielding, thermal-hydraulic, and criticality criteria. In fact, a particular fuel type in a category (PWR or BWR) may not control the cask design in all of the above-mentioned criteria. To ensure that no SNF listed in Refs. [2.1.1] and [2.1.2] which is geometrically admissible in the MPC is precluded, it is necessary to determine the governing fuel specification for each analysis criterion. To make the necessary determinations, potential candidate fuel assemblies for each qualification criterion were considered. Table 2.1.1 lists the PWR fuel assemblies that were evaluated. These fuel assemblies were evaluated to define the governing design criteria for PWR fuel. The BWR fuel assembly designs evaluated are listed in Table 2.1.2.

Tables 2.1.3 and 2.1.4 provide the fuel characteristics determined to be acceptable for storage in the HI-STORM 100 System. Section 2.1.9 summarizes the authorized contents for the HI-STORM 100 System. Any fuel assembly that has fuel characteristics within the range of Tables 2.1.3 and 2.1.4 and meets the other limits specified in Section 2.1.9 is acceptable for storage in the HI-STORM 100 System. Tables 2.1.3 and 2.1.4 present the groups of fuel assembly types defined as "array/classes" as described in further detail in Chapter 6. Table 2.1.5 lists the BWR and PWR fuel assembly designs which are found to govern for three qualification criteria, namely reactivity, shielding, and thermal. Additional information on the design basis fuel definition is presented in the following subsections.

2.1.2 Intact SNF Specifications

Intact fuel assemblies are defined as fuel assemblies without known or suspected cladding defects greater than pinhole leaks and hairline cracks, and which can be handled by normal means. The design payload for the HI-STORM 100 System is intact ZR or stainless steel (SS) clad fuel assemblies with the characteristics listed in Tables 2.1.17 through 2.1.24.

Intact fuel assemblies without fuel rods in fuel rod locations cannot be loaded into the HI-STORM 100 unless dummy fuel rods, which occupy a volume greater than or equal to the original fuel rods, replace the missing rods prior to loading. Any intact fuel assembly that falls within the geometric, thermal, and nuclear limits established for the design basis intact fuel assembly, as defined in Section 2.1.9 can be safely stored in the HI-STORM 100 System.

The range of fuel characteristics specified in Tables 2.1.3 and 2.1.4 have been evaluated in this FSAR and are acceptable for storage in the HI-STORM 100 System within the decay heat, burnup, and cooling time limits specified in Section 2.1.9 for intact fuel assemblies.

2.1.3 Damaged SNF and Fuel Debris Specifications

Damaged fuel and fuel debris are defined in Table 1.0.1.

Damaged fuel assemblies and fuel debris will be loaded into stainless steel damaged fuel containers (DFCs) provided with mesh screens having between 40x40 and 250x250 openings per inch, for storage in the HI-STORM 100 System (see Figures 2.1.1 and 2.1.2B, C, and D). The MPC-24, MPC-24EF, MPC-32 and MPC-32F are designed to accommodate PWR damaged fuel and fuel debris. The MPC-68, MPC-68F and MPC-68FF are designed to accommodate BWR damaged fuel and fuel debris. The appropriate structural, thermal, shielding, criticality, and confinement analyses 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 Section 2.1.9. Dresden Unit 1 fuel assemblies contained in Transnuclear-designed damaged fuel canisters and one Dresden Unit 1 thoria rod canister have been approved for storage directly in the HI-STORM 100 System without re-packaging (see Figures 2.1.2 and 2.1.2A).

MPC contents classified as fuel debris are required to be stored in DFCs. The basket designs for the standard and "F" model MPCs are identical. The lid and shell designs of the "F" models are unique in that the upper shell portion of the canister is thickened for additional strength needed to qualify as a secondary containment, which used to be required under hypothetical accident conditions of transportation under 10 CFR 71. Figure 2.1.9 shows the details of the differences between the standard and "F" model MPC shells. These details are common for both the PWR and BWR series MPC models.

2.1.4 Deleted

2.1.5 Structural Parameters for Design Basis SNF

The main physical parameters of an SNF assembly applicable to the structural evaluation are the fuel assembly length, envelope (cross sectional dimensions), and weight. These parameters, which define the mechanical and structural design, are specified in Section 2.1.9. The centers of gravity reported in Section 3.2 are based on the maximum fuel assembly weight. Upper and lower fuel spacers (as appropriate) maintain the axial position of the fuel assembly within the MPC basket and, therefore, the location of the center of gravity. The upper and lower fuel spacers are designed to withstand normal, off-normal, and accident conditions of storage. An axial clearance of approximately 2 to 2-1/2 inches is provided to account for the irradiation and thermal growth of the fuel assemblies. The suggested upper and lower fuel spacer lengths are listed in Tables 2.1.9 and 2.1.10. In order to qualify for storage in the MPC, the SNF must satisfy the physical parameters listed in Section 2.1.9.

2.1.6 Thermal Parameters for Design Basis SNF

The principal thermal design parameter for the stored fuel is the peak fuel cladding temperature, which is a function of the maximum heat generation rate per assembly and the decay heat removal capabilities of the HI-STORM 100 System. No attempt is made to link the maximum allowable decay heat per fuel assembly with burnup, enrichment, or cooling time. Rather, the decay heat per fuel assembly is adjusted to yield peak fuel cladding temperatures with an allowance for margin to the temperature limit.

To ensure the permissible fuel cladding temperature limits are not exceeded, Section 2.1.9 specifies the allowable decay heat per assembly for each MPC model. For both uniform and regionalized loading of moderate and high burnup fuel assemblies, the allowable decay heat per assembly is presented in Section 2.1.9.

Section 2.1.9 also includes separate cooling time, burnup, and decay heat limits for uniform fuel loading and regionalized fuel loading. Regionalized loading allows higher heat emitting fuel assemblies to be stored in the center fuel storage locations than would otherwise be authorized for storage under uniform loading conditions.

The fuel cladding temperature is also affected by the heat transfer characteristics of the fuel assemblies. The bounding fuel assembly design for thermal calculations for each fuel type is provided in Table 2.1.5.

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 Refs. [2.1.7] and [2.1.8] are utilized and summarized in Table 2.1.11 and Figures 2.1.3 and 2.1.4 for reference. 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 100 System.

Except for MPC-68F, fuel may be stored in the MPC using one of two storage strategies, namely, uniform loading and regionalized loading. Uniform loading allows storage of any fuel assembly in any fuel storage location, subject to additional restrictions, such as those for loading of fuel assemblies containing non-fuel hardware as defined in Table 1.0.1. Regionalized fuel loading allows for higher heat emitting fuel assemblies to be stored in some storage locations with lower heat emitting fuel assemblies in the remaining fuel storage locations. Regionalized loading allows storage of higher heat emitting fuel assemblies than would otherwise be permitted using the uniform loading strategy. The definition of the regions for each MPC model is provided in Table 2.1.27. Regionalized fuel loading is not permitted in MPC-68F.

2.1.7 Radiological Parameters for Design Basis SNF

The principal radiological design criteria for the HI-STORM 100 System are the 10CFR72.104 site boundary dose rate limits and maintaining operational dose rates as low as reasonably achievable (ALARA). The radiation dose is directly affected by the gamma and neutron source terms of the SNF assembly.

The gamma and neutron sources are separate and are affected differently by enrichment, burnup, and cooling time. It is recognized that, at a given burnup, the radiological source terms increase monotonically as the initial enrichment is reduced. The shielding design basis fuel assembly, therefore, is evaluated at conservatively high burnups, low cooling times, and low enrichments, as discussed in Chapter 5. The shielding design basis fuel assembly thus bounds all other fuel assemblies.

The design basis dose rates can be met by a variety of burnup levels and cooling times. Section 2.1.9 provides the procedure for determining burnup and cooling time limits for all of the authorized fuel assembly array/classes for both uniform fuel loading and regionalized loading. Table 2.1.11 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 100 System.

Thoria rods placed in Dresden Unit 1 Thoria Rod Canisters meeting the requirements of Table 2.1.12 and Dresden Unit 1 fuel assemblies with one Antimony-Beryllium neutron source have been qualified for storage. Up to one Thoria Rod Canister is authorized for storage in combination with other intact and damaged fuel, and fuel debris as specified in Section 2.1.9.

Non-fuel hardware, as defined in Table 1.0.1, has been evaluated and is authorized for storage in the PWR MPCs as specified in Section 2.1.9.

2.1.8 Criticality Parameters for Design Basis SNF

As discussed earlier, the MPC-68, MPC-68F, MPC-68FF, MPC-32 and MPC-32F feature a basket without flux traps. In the aforementioned baskets, there is one panel of neutron absorber between two adjacent fuel assemblies. The MPC-24, MPC-24E, and MPC-24EF employ a construction wherein two neighboring fuel assemblies are separated by two panels of neutron absorber with a water gap between them (flux trap construction).

The minimum ^{10}B areal density in the neutron absorber panels for each MPC model is shown in Table 2.1.15.

For all MPCs, the ^{10}B areal density used for the criticality analysis is conservatively established below the minimum values shown in Table 2.1.15. For Boral, the value used in the analysis is 75% of the minimum value, while for METAMIC, it is 90% of the minimum value. This is consistent with NUREG-1536 [2.1.5] which suggests a 25% reduction in ^{10}B areal density credit when subject to standard acceptance tests, and which allows a smaller reduction when more comprehensive tests of the areal density are performed.

The criticality analyses for the MPC-24, MPC-24E and MPC-24EF (all with higher enriched fuel) and for the MPC-32 and MPC-32F were performed with credit taken for soluble boron in the MPC water during wet loading and unloading operations. Table 2.1.14 and 2.1.16 provide the required soluble boron concentrations for these MPCs.

2.1.9 Summary of Authorized Contents

Tables 2.1.3, 2.1.4, 2.1.12, and 2.1.17 through 2.1.29 together specify the limits for spent fuel and non-fuel hardware authorized for storage in the HI-STORM 100 System. The limits in these tables are derived from the safety analyses described in the following chapters of this FSAR. Fuel classified as damaged fuel assemblies or fuel debris must be stored in damaged fuel containers for storage in the HI-STORM 100 System.

Tables 2.1.17 through 2.1.24 are the baseline tables that specify the fuel assembly limits for each of the MPC models, with appropriate references to the other tables in this section for certain other limits. Tables 2.1.17 through 2.1.24 refer to Section 2.1.9.1 for ZR-clad fuel limits on minimum cooling time, maximum decay heat, and maximum burnup for uniform and regionalized fuel loading.

2.1.9.1 Decay Heat, Burnup, and Cooling Time Limits for ZR-Clad Fuel

Each ZR-clad fuel assembly and any PWR integral non-fuel hardware (NFH) to be stored in the

HI-STORM 100 System must meet the following limits, in addition to meeting the physical limits specified elsewhere in this section, to be authorized for storage in the HI-STORM 100 System. The contents of each fuel storage location (fuel assembly and NFH) to be stored must be verified to have, as applicable:

- A decay heat less than or equal to the maximum allowable value.
- An assembly average enrichment greater than or equal to the minimum value used in determining the maximum allowable burnup.
- A burnup less than or equal to the maximum allowable value.
- A cooling time greater than or equal to the minimum allowable value.

The maximum allowable ZR-clad fuel storage location decay heat values are determined using the methodology described in Section 2.1.9.1.1 or 2.1.9.1.2 depending on whether uniform fuel loading or regionalized fuel loading is being implemented†. The total permissible MPC heat load, for both uniform and regionalized loading, is determined in the following two subsections 2.1.9.1.1 and 2.1.9.1.2. The decay heat limits are independent of burnup, cooling time, or enrichment and are based strictly on the thermal analysis described in Chapter 4. Decay heat limits must be met for all contents in a fuel storage location (i.e., fuel and PWR non-fuel hardware, as applicable).

The maximum allowable average burnup per fuel storage location is determined by calculation as a function of minimum enrichment, maximum allowable decay heat, and minimum cooling time from 3 to 20 years, as described in Section 2.1.9.1.3.

Section 12.2 describes how compliance with these limits may be verified, including practical examples.

2.1.9.1.1 Uniform Fuel Loading Decay Heat Limits for ZR-Clad Fuel

Table 2.1.26 provides the maximum allowable decay heat per fuel storage location for ZR-clad fuel in uniform fuel loading for each MPC model in aboveground storage*. Even if the limits in Table 2.1.26 are met, the user must follow the instructions in the next section to calculate Q_{CoC} to determine if certain operational steps are required per the CoC. If the user needs to load fuel assemblies with a decay heat higher than the limits in Table 2.1.26, a regionalized loading pattern discussed in the next section may be considered.

† Note that the stainless steel-clad fuel decay heat limits apply to all fuel in the MPC, if a mixture of stainless steel and ZR-clad fuel is stored in the same MPC. The stainless steel-clad fuel assembly decay heat limits may be found in Table 2.1.17 through 2.1.24

* Maximum allowable heat loads in 100U underground storage are defined in Supplement 2.I; however the discussion in Section 2.1.9.1 also applies to the 100U.

2.1.9.1.2 Design Heat Load for ZR-Clad Fuel

The discussion in this section provides the approach to determine the maximum permitted per cell heat load for long term-storage in a regionalized pattern. In addition, this section also provides the approach to determine the allowed per cell heat load for those operations that are dependent on the total MPC heat load. These include helium backfill pressure, supplemental cooling, drying method, and time requirements for clearing blockage on HI-STORM inlet vents.

The Design Basis heat load for the aboveground HI-STORM System, Q_d, is 34 kW. Q_d is based on the assumption that every storage cell in the MPC is generating an equal amount of heat. In other words, the specific heat generation rate, q, of each storage location is considered equal. Thus, in an MPC with n storage locations,

$$Q_d = n\,q \qquad \text{Equation a}$$

In reality, however, the population of SNF and associated NFH loaded in the MPC invariably has unequal decay heat. If we consider the loaded decay heat in a cell as r, and r_i denotes the loaded decay heat in location i, then the aggregate MPC heat load, Q_t, is given by a simple summation, i.e.,

$$Q_t = \sum_i^n r_i \qquad \text{Equation b}$$

For purposes of the CoC compliance for operations where the total MPC heat load needs to be calculated, the total MPC heat load is,

$$Q_{CoC} = r_{max}\, n \qquad \text{Equation c}$$

where r_{max} is the largest value of r_i in the population of SNF loaded in the MPC, i.e.,

$$r_{max} = \max \text{ of } [r_i,\ i = 1,2\ldots n] \qquad \text{Equation d}$$

In all cases, the aggregate MPC heat load, Q_t, is less than or equal to Q_{CoC} or Q_d. In some cases this difference can be quite large. This scenario can be illustrated by considering the example of a MPC-32 that has 31 cells containing 0.5kW and one cell containing 1 kW. The aggregate MPC heat load is (31)(0.5) + 1 = 16.5kW. However, because r_{max} = 1 kW, Q_{CoC} = (32)(1) = 32kW. Thus, $Q_{CoC} >> Q_t$. This condition prevails in all loaded MPCs to a varying degree.

Even though Q_t may be significantly less than Q_{CoC}, Q_{CoC} must be used to establish certain operational procedures and the pre-analyzed conditions. The aggregate total heat load Q_t may be used for time to boil calculations, when determining if the air mass flow rate test on a loaded system, per Condition 9 of the CoC, needs to be performed and when considering if time limits need to be applied to vacuum drying. It should be noted that equation c is used to determine Q_{CoC} when following the heat load limits for uniform loading (Table 2.1.26).

To utilize more of the design basis heat load and allow for more loading flexibility, the MPC is divided into two regions. This is referred to as "regionalized loading". The inner region (Region 1) and the outer region (Region 2) have maximum permitted heat load of 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 ratio X is NOT the ratio of the maximum values of the as-loaded storage locations in Region 1 and Region 2.The case where q_1 and q_2 are equal (X= 1) is referred to as "uniform storage". Q_{CoC} for regionalized loading is computed by:

$$Q_{CoC} = n_1 q_1 + n_2 q_2$$ Equation e

where n_1 and n_2 are the number of cells in Regions 1 and 2, respectively.

A functional relationship between Q and X was determined by performing an iterative thermal analysis. This led to the functional relationship Q(X):

$$Q(X) = \frac{2Q_d}{1+X^y}$$ Equation f

where X is a value greater than or equal to 0.5 and less than or equal to 3 and where y is also a function of X as defined below:

$$y(X) = \frac{0.23}{X^{0.1}}$$ Equation g

Table 2.1.30 is provided to give a list of permissible q_1 and q_2 for discrete values of X for all MPC types. The table was determined using the following approach:

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

(ii) Calculate q_2 using the following equation:

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

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 2.1.27
n_2 = Number of fuel storage locations in Region 2 from Table 2.1.27

(iii) Calculate q_1 using the following equation:

$$q_1 = X \times q_2$$ Equation i

Using the steps provided above we find for X=2 that q_1 = 1.43 kW and q_2 = 0.715 kW for MPC-32. The user can follow Table 2.1.30 for discrete values of X to determine q_1 and q_2 or calculate q_1 and q_2 for a specific value of X using the steps above. It should be noted that equation e is used to determine Q_{CoC} when following the heat load limits for regionalized loading.

It should be emphasized that the variable two-region scheme of storage does not introduce any new complication in the dry storage implementation. As compared to uniform loading in MPC-32, where q = 1.0625 kW for all cells, the regionalized loading gives the user the flexibility to load the MPC with more varying heat loads. It is noted that for $X < 1$ Q_{CoC} is greater than Q_d, for $X = 1$ Q_{CoC} equals Q_d, and for $X > 1$ Q_{CoC} is less than Q_d. For ALARA and regardless of which loading pattern is used, a plant should always seek to preferentially locate the fuel with the higher heat loads toward the center of the MPC. If the need arises to place younger fuel into dry storage a regionalized pattern with $X < 1$ may be more appropriate.

2.1.9.1.3 Burnup Limits as a Function of Cooling Time for ZR-Clad Fuel

The maximum allowable ZR-clad fuel assembly average burnup varies with the following parameters, based on the shielding analysis in Chapter 5:

- Minimum required fuel assembly cooling time
- Maximum allowable fuel assembly decay heat
- Minimum fuel assembly average enrichment

The calculation described in this section is used to determine the maximum allowable fuel assembly burnup for minimum cooling times between 3 and 20 years, using maximum decay heat and minimum enrichment as input values. This calculation may be used to create multiple burnup versus cooling time tables for a particular fuel assembly array/class and different minimum enrichments. The allowable maximum burnup for a specific fuel assembly may be calculated based on the assembly's particular enrichment and cooling time.

(i) Choose a fuel assembly minimum enrichment, E_{235}.

(ii) Calculate the maximum allowable fuel assembly average burnup for a minimum cooling time between 3 and 20 years using the equation below:

$$Bu = (A \times q) + (B \times q^2) + (C \times q^3) + [D \times (E_{235})^2] + (E \times q \times E_{235}) + (F \times q^2 \times E_{235}) + G$$

Equation j

Where:

Bu = Maximum allowable assembly average burnup (MWD/MTU)

q = Maximum allowable decay heat per fuel storage location determined in Section

2.1.9.1.1 or 2.1.9.1.2 (kW)

E_{235} = Minimum fuel assembly average enrichment (wt. % ^{235}U)
(e.g., for 4.05 wt. %, use 4.05)

A through G = Coefficients from Tables 2.1.28 or 2.1.29 for the applicable fuel assembly array/class and minimum cooling time.

2.1.9.1.4 Other Considerations

In computing the allowable maximum fuel storage location decay heats and fuel assembly average burnups, the following requirements apply:

- Calculated burnup limits shall be rounded down to the nearest integer
- Calculated burnup limits greater than 68,200 MWD/MTU for PWR fuel and 65,000 MWD/MTU for BWR fuel must be reduced to be equal to these values.
- Linear interpolation of calculated burnups between cooling times for a given fuel assembly maximum decay heat and minimum enrichment is permitted. For example, the allowable burnup for a minimum cooling time of 4.5 years may be interpolated between those burnups calculated for 4 and 5 years.
- ZR-clad fuel assemblies must have a minimum enrichment, as defined in Table 1.0.1, greater than or equal to the value used in determining the maximum allowable burnup per Section 2.1.9.1.3 to be authorized for storage in the MPC.
- When complying with the maximum fuel storage location decay heat limits, users must account for the decay heat from both the fuel assembly and any PWR non-fuel hardware, as applicable for the particular fuel storage location, to ensure the decay heat emitted by all contents in a storage location does not exceed the limit.

Section 12.2.10 provides a practical example of determining fuel storage location decay heat, burnup, and cooling time limits and verifying compliance for a set of example fuel assemblies.

Table 2.1.1

PWR FUEL ASSEMBLIES EVALUATED TO DETERMINE DESIGN BASIS SNF

Assembly Class	Array Type
B&W 15x15	All
B&W 17x17	All
CE 14x14	All
CE 16x16	All except System 80™
WE 14x14	All
WE 15x15	All
WE 17x17	All
St. Lucie	All
Ft. Calhoun	All
Haddam Neck (Stainless Steel Clad)	All
San Onofre 1 (Stainless Steel Clad)	All
Indian Point 1	All

Table 2.1.2

BWR FUEL ASSEMBLIES EVALUATED TO DETERMINE DESIGN BASIS SNF

Assembly Class	**Array Type**			
GE BWR/2-3	All 7x7	All 8x8	All 9x9	All 10x10
GE BWR/4-6	All 7x7	All 8x8	All 9x9	All 10x10
Humboldt Bay	All 6x6	All 7x7 (ZR Clad)		
Dresden-1	All 6x6	All 8x8		
LaCrosse (Stainless Steel Clad)	All			

Table 2.1.3
PWR FUEL ASSEMBLY CHARACTERISTICS (Note 1)

Fuel Assembly Array/ Class	**14x14 A**	**14x14 B**	**14x14 C**	**14x14 D**	**14x14E**
Clad Material (Note 2)	ZR	ZR	ZR	SS	SS
Design Initial U (kg/assy.) (Note 3)	$\leq$ 365	$\leq$ 412	$\leq$ 438	$\leq$ 400	$\leq$ 206
Initial Enrichment (MPC-24, 24E, and 24EF without soluble boron credit) (wt % ^{235}U) (Note 7)	$\leq$ 4.6 (24) $\leq$ 5.0 (24E/24EF)	$\leq$ 4.6 (24) $\leq$ 5.0 (24E/24EF)	$\leq$ 4.6 (24) $\leq$ 5.0 (24E/24EF)	$\leq$ 4.0 (24) $\leq$ 5.0 (24E/24EF)	$\leq$ 5.0 (24) $\leq$ 5.0 (24E/24EF)
Initial Enrichment (MPC-24, 24E, 24EF, 32 or 32F with soluble boron credit - see Note 5) (wt % ^{235}U)	$\leq$ 5.0	$\leq$ 5.0	$\leq$ 5.0	$\leq$ 5.0	$\leq$ 5.0
No. of Fuel Rod Locations	179	179	176	180	173
Fuel Clad O.D. (in.)	$\geq$ 0.400	$\geq$ 0.417	$\geq$ 0.440	$\geq$ 0.422	$\geq$ 0.3415
Fuel Clad I.D. (in.)	$\leq$ 0.3514	$\leq$ 0.3734	$\leq$ 0.3880	$\leq$ 0.3890	$\leq$ 0.3175
Fuel Pellet Dia. (in.) (Note 8)	$\leq$ 0.3444	$\leq$ 0.3659	$\leq$ 0.3805	$\leq$ 0.3835	$\leq$ 0.3130
Fuel Rod Pitch (in.)	$\leq$ 0.556	$\leq$ 0.556	$\leq$ 0.580	$\leq$ 0.556	Note 6
Active Fuel Length (in.)	$\leq$ 150	$\leq$ 150	$\leq$ 150	$\leq$ 144	$\leq$ 102
No. of Guide and/or Instrument Tubes	17	17	5 (Note 4)	16	0
Guide/Instrument Tube Thickness (in.)	$\geq$ 0.017	$\geq$ 0.017	$\geq$ 0.038	$\geq$ 0.0145	N/A

Table 2.1.3 (continued)
PWR FUEL ASSEMBLY CHARACTERISTICS (Note 1)

Fuel Assembly Array/Class	**15x15 A**	**15x15 B**	**15x15 C**	**15x15 D**	**15x15 E**	**15x15 F**
Clad Material (Note 2)	ZR	ZR	ZR	ZR	ZR	ZR
Design Initial U (kg/assy.) (Note 3)	≤ 473	≤ 473	≤ 473	≤ 495	≤ 495	≤ 495
Initial Enrichment (MPC-24, 24E, and 24EF without soluble boron credit) (wt % ^{235}U) (Note 7)	≤ 4.1 (24) ≤ 4.5 (24E/24EF)	≤ 4.1 (24) ≤ 4.5 (24E/24EF)	≤ 4.1 (24) ≤ 4.5 (24E/24EF)	≤ 4.1 (24) ≤ 4.5 (24E/24EF)	≤ 4.1 (24) ≤ 4.5 (24E/24EF)	≤ 4.1 (24) ≤ 4.5 (24E/24EF)
Initial Enrichment (MPC-24, 24E, 24EF, 32 or 32F with soluble boron credit – see Note 5) (wt % ^{235}U)	≤ 5.0	≤ 5.0	≤ 5.0	≤ 5.0	≤ 5.0	≤ 5.0
No. of Fuel Rod Locations	204	204	204	208	208	208
Fuel Clad O.D. (in.)	≥ 0.418	≥ 0.420	≥ 0.417	≥ 0.430	≥ 0.428	≥ 0.428
Fuel Clad I.D. (in.)	≤ 0.3660	≤ 0.3736	≤ 0.3640	≤ 0.3800	≤ 0.3790	≤ 0.3820
Fuel Pellet Dia. (in.) (Note 8)	≤ 0.3580	≤ 0.3671	≤ 0.3570	≤ 0.3735	≤ 0.3707	≤ 0.3742
Fuel Rod Pitch (in.)	≤ 0.550	≤ 0.563	≤ 0.563	≤ 0.568	≤ 0.568	≤ 0.568
Active Fuel Length (in.)	≤ 150	≤ 150	≤ 150	≤ 150	≤ 150	≤ 150
No. of Guide and/or Instrument Tubes	21	21	21	17	17	17
Guide/Instrument Tube Thickness (in.)	≥ 0.0165	≥ 0.015	≥ 0.0165	≥ 0.0150	≥ 0.0140	≥ 0.0140

Table 2.1.3 (continued)
PWR FUEL ASSEMBLY CHARACTERISTICS (Note 1)

Fuel Assembly Array and Class	**15x15 G**	**15x15H**	**15x15I**	**16x16 A**
Clad Material (Note 2)	SS	ZR	ZR	ZR
Design Initial U (kg/assy.) (Note 3)	≤ 420	≤ 495	≤ 495	≤ 448
Initial Enrichment (MPC-24, 24E, and 24EF without soluble boron credit) (wt % ^{235}U) (Note 7)	≤ 4.0 (24) ≤ 4.5 (24E/24EF)	≤ 3.8 (24) ≤ 4.2 (24E/24EF)	N/A (Note 9)	≤ 4.6 (24) ≤ 5.0 (24E/24EF)
Initial Enrichment (MPC-24, 24E, 24EF, 32 or 32F with soluble boron credit – see Note 5) (wt % ^{235}U)	≤ 5.0	≤ 5.0	≤ 5.0 (Note 9)	≤ 5.0
No. of Fuel Rod Locations	204	208	216	236
Fuel Clad O.D. (in.)	≥ 0.422	≥ 0.414	≥ 0.413	≥ 0.382
Fuel Clad I.D. (in.)	≤ 0.3890	≤ 0.3700	≤ 0.367	≤ 0.3350
Fuel Pellet Dia. (in.) (Note 8)	≤ 0.3825	≤ 0.3622	≤ 0.360	≤ 0.3255
Fuel Rod Pitch (in.)	≤ 0.563	≤ 0.568	≤ 0.550	≤ 0.506
Active Fuel length (in.)	≤ 144	≤ 150	≤ 150	≤ 150
No. of Guide and/or Instrument Tubes	21	17	9 (Note 10)	5 (Note 4)
Guide/Instrument Tube Thickness (in.)	≥ 0.0145	≥ 0.0140	≥ 0.0140	≥ 0.0350

Table 2.1.3 (continued)
PWR FUEL ASSEMBLY CHARACTERISTICS (Note 1)

Fuel Assembly Array and Class	**17x17A**	**17x17 B**	**17x17 C**
Clad Material (Note 2)	ZR	ZR	ZR
Design Initial U (kg/assy.) (Note 3)	≤ 433	≤ 474	≤ 480
Initial Enrichment (MPC-24, 24E, and 24EF without soluble boron credit) (wt % ^{235}U) (Note 7)	≤ 4.0 (24) ≤ 4.4 (24E/24EF)	≤ 4.0 (24) ≤ 4.4 (24E/24EF)	≤ 4.0 (24) ≤ 4.4 (24E/24EF)
Initial Enrichment (MPC-24, 24E, 24EF, 32 or 32F with soluble boron credit – see Note 5) (wt % ^{235}U)	≤ 5.0	≤ 5.0	≤ 5.0
No. of Fuel Rod Locations	264	264	264
Fuel Clad O.D. (in.)	≥ 0.360	≥ 0.372	≥ 0.377
Fuel Clad I.D. (in.)	≤ 0.3150	≤ 0.3310	≤ 0.3330
Fuel Pellet Dia. (in.) (Note 8)	≤ 0.3088	≤ 0.3232	≤ 0.3252
Fuel Rod Pitch (in.)	≤ 0.496	≤ 0.496	≤ 0.502
Active Fuel length (in.)	≤ 150	≤ 150	≤ 150
No. of Guide and/or Instrument Tubes	25	25	25
Guide/Instrument Tube Thickness (in.)	≥ 0.016	≥ 0.014	≥ 0.020

Table 2.1.3 (continued)
PWR 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. See Table 1.0.1 for the definition of "ZR."

3. Design initial uranium weight is the nominal uranium weight specified for each assembly by the fuel manufacturer or reactor user. For each PWR fuel assembly, the total uranium weight limit specified in this table may be increased up to 2.0 percent for comparison with users' fuel records to account for manufacturer's tolerances.

4. Each guide tube replaces four fuel rods.

5. Soluble boron concentration per Tables 2.1.14 and 2.1.16, as applicable.

6. This fuel assembly array/class includes only the Indian Point Unit 1 fuel assembly. This fuel assembly has two pitches in different sectors of the assembly. These pitches are 0.441 inches and 0.453 inches.

7. For those MPCs loaded with both intact fuel assemblies and damaged fuel assemblies or fuel debris, the maximum initial enrichment of the intact fuel assemblies, damaged fuel assemblies and fuel debris is 4.0 wt.% ^{235}U.

8. Annular fuel pellets are allowed in the top and bottom 12" of the active fuel length.

9. This fuel assembly array/class can only be loaded in MPC-32.

10. One Instrument Tube and eight Guide Bars (Solid Zr).

Table 2.1.4
BWR FUEL ASSEMBLY CHARACTERISTICS (Note 1)

Fuel Assembly Array and Class	**6x6 A**	**6x6 B**	**6x6 C**	**7x7 A**	**7x7 B**	**8x8 A**
Clad Material (Note 2)	ZR	ZR	ZR	ZR	ZR	ZR
Design Initial U (kg/assy.) (Note 3)	≤ 110	≤ 110	≤ 110	≤ 100	≤ 198	≤ 120
Maximum PLANAR-AVERAGE INITIAL ENRICHMENT (wt.% ^{235}U) (Note 14)	≤ 2.7	≤ 2.7 for UO_2 rods. See Note 4 for MOX rods	≤ 2.7	≤ 2.7	≤ 4.2	≤ 2.7
Initial Maximum Rod Enrichment (wt.% ^{235}U)	≤ 4.0	≤ 4.0	≤ 4.0	≤ 5.5	≤ 5.0	≤ 4.0
No. of Fuel Rod Locations	35 or 36	35 or 36 (up to 9 MOX rods)	36	49	49	63 or 64
Fuel Clad O.D. (in.)	≥ 0.5550	≥ 0.5625	≥ 0.5630	≥ 0.4860	≥ 0.5630	≥ 0.4120
Fuel Clad I.D. (in.)	≤ 0.5105	≤ 0.4945	≤ 0.4990	≤ 0.4204	≤ 0.4990	≤ 0.3620
Fuel Pellet Dia. (in.)	≤ 0.4980	≤ 0.4820	≤ 0.4880	≤ 0.4110	≤ 0.4910	≤ 0.3580
Fuel Rod Pitch (in.)	≤ 0.710	≤ 0.710	≤ 0.740	≤ 0.631	≤ 0.738	≤ 0.523
Active Fuel Length (in.)	≤ 120	≤ 120	≤ 77.5	≤ 80	≤ 150	≤ 120
No. of Water Rods (Note 11)	1 or 0	1 or 0	0	0	0	1 or 0
Water Rod Thickness (in.)	> 0	> 0	N/A	N/A	N/A	≥ 0
Channel Thickness (in.)	≤ 0.060	≤ 0.060	≤ 0.060	≤ 0.060	≤ 0.120	≤ 0.100

Table 2.1.4 (continued)
BWR FUEL ASSEMBLY CHARACTERISTICS (Note 1)

Fuel Assembly Array and Class	**8x8 B**	**8x8 C**	**8x8 D**	**8x8 E**	**8x8F**	**9x9 A**
Clad Material (Note 2)	ZR	ZR	ZR	ZR	ZR	ZR
Design Initial U (kg/assy.) (Note 3)	≤ 192	≤ 190	≤ 190	≤ 190	≤ 191	≤ 180
Maximum PLANAR-AVERAGE INITIAL ENRICHMENT (wt.% ^{235}U) (Note 14)	≤ 4.2	≤ 4.2	≤ 4.2	≤ 4.2	≤ 4.0	≤ 4.2
Initial Maximum Rod Enrichment (wt.% ^{235}U)	≤ 5.0	≤ 5.0	≤ 5.0	≤ 5.0	≤ 5.0	≤ 5.0
No. of Fuel Rod Locations	63 or 64	62	60 or 61	59	64	74/66 (Note 5)
Fuel Clad O.D. (in.)	≥ 0.4840	≥ 0.4830	≥ 0.4830	≥ 0.4930	≥ 0.4576	≥ 0.4400
Fuel Clad I.D. (in.)	≤ 0.4295	≤ 0.4250	≤ 0.4230	≤ 0.4250	≤ 0.3996	≤ 0.3840
Fuel Pellet Dia. (in.)	≤ 0.4195	≤ 0.4160	≤ 0.4140	≤ 0.4160	≤ 0.3913	≤ 0.3760
Fuel Rod Pitch (in.)	≤ 0.642	≤ 0.641	≤ 0.640	≤ 0.640	≤ 0.609	≤ 0.566
Design Active Fuel Length (in.)	≤ 150	≤ 150	≤ 150	≤ 150	≤ 150	≤ 150
No. of Water Rods (Note 11)	1 or 0	2	1 - 4 (Note 7)	5	N/A (Note 12)	2
Water Rod Thickness (in.)	≥ 0.034	> 0.00	> 0.00	≥ 0.034	≥ 0.0315	> 0.00
Channel Thickness (in.)	≤ 0.120	≤ 0.120	≤ 0.120	≤ 0.100	≤ 0.055	≤ 0.120

Table 2.1.4 (continued)
BWR FUEL ASSEMBLY CHARACTERISTICS (Note 1)

Fuel Assembly Array and Class	9x9 B	9x9 C	9x9 D	9x9 E (Note 13)	9x9 F (Note 13)	9x9 G
Clad Material (Note 2)	ZR	ZR	ZR	ZR	ZR	ZR
Design Initial U (kg/assy.) (Note 3)	≤ 180	≤ 182	≤ 182	≤ 183	≤ 183	≤ 164
Maximum PLANAR-AVERAGE INITIAL ENRICHMENT (wt.% ^{235}U) (Note 14)	≤ 4.2	≤ 4.2	≤ 4.2	≤ 4.0	≤ 4.0	≤ 4.2
Initial Maximum Rod Enrichment (wt.% ^{235}U)	≤ 5.0	≤ 5.0	≤ 5.0	≤ 5.0	≤ 5.0	≤ 5.0
No. of Fuel Rod Locations	72	80	79	76	76	72
Fuel Clad O.D. (in.)	≥ 0.4330	≥ 0.4230	≥ 0.4240	≥ 0.4170	≥ 0.4430	≥ 0.4240
Fuel Clad I.D. (in.)	≤ 0.3810	≤ 0.3640	≤ 0.3640	≤ 0.3640	≤ 0.3860	≤ 0.3640
Fuel Pellet Dia. (in.)	≤ 0.3740	≤ 0.3565	≤ 0.3565	≤ 0.3530	≤ 0.3745	≤ 0.3565
Fuel Rod Pitch (in.)	≤ 0.572	≤ 0.572	≤ 0.572	≤ 0.572	≤ 0.572	≤ 0.572
Design Active Fuel Length (in.)	≤ 150	≤ 150	≤ 150	≤ 150	≤ 150	≤ 150
No. of Water Rods (Note 11)	1 (Note 6)	1	2	5	5	1 (Note 6)
Water Rod Thickness (in.)	> 0.00	≥ 0.020	≥ 0.0300	≥ 0.0120	≥ 0.0120	≥ 0.0320
Channel Thickness (in.)	≤ 0.120	≤ 0.100	≤ 0.100	≤ 0.120	≤ 0.120	≤ 0.120

Table 2.1.4 (continued)
BWR FUEL ASSEMBLY CHARACTERISTICS (Note 1)

Fuel Assembly Array and Class	**10x10 A**	**10x10 B**	**10x10 C**	**10x10 D**	**10x10 E**
Clad Material (Note 2)	ZR	ZR	ZR	SS	SS
Design Initial U (kg/assy.) (Note 3)	≤ 188	≤ 188	≤ 179	≤ 125	≤ 125
Maximum Planar-Average Initial Enrichment (wt.% ^{235}U)(Note 14)	≤ 4.2	≤ 4.2	≤ 4.2	≤ 4.0	≤ 4.0
Initial Maximum Rod Enrichment (wt.% ^{235}U)	≤ 5.0	≤ 5.0	≤ 5.0	≤ 5.0	≤ 5.0
No. of Fuel Rod Locations	92/78 (Note 8)	91/83 (Note 9)	96	100	96
Fuel Clad O.D. (in.)	≥ 0.4040	≥ 0.3957	≥ 0.3780	≥ 0.3960	≥ 0.3940
Fuel Clad I.D. (in.)	≤ 0.3520	≤ 0.3480	≤ 0.3294	≤ 0.3560	≤ 0.3500
Fuel Pellet Dia. (in.)	≤ 0.3455	≤ 0.3420	≤ 0.3224	≤ 0.3500	≤ 0.3430
Fuel Rod Pitch (in.)	≤ 0.510	≤ 0.510	≤ 0.488	≤ 0.565	≤ 0.557
Design Active Fuel Length (in.)	≤ 150	≤ 150	≤ 150	≤ 83	≤ 83
No. of Water Rods (Note 11)	2	1 (Note 6)	5 (Note 10)	0	4
Water Rod Thickness (in.)	≥ 0.030	> 0.00	≥ 0.031	N/A	≥ 0.022
Channel Thickness (in.)	≤ 0.120	≤ 0.120	≤ 0.055	≤ 0.080	≤ 0.080

Table 2.1.4 (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. See Table 1.0.1 for the definition of "ZR."

3. Design initial uranium weight is the nominal uranium weight specified for each assembly by the fuel manufacturer or reactor user. For each BWR fuel assembly, the total uranium weight limit specified in this table may be increased up to 1.5 percent for comparison with users' fuel records to account for manufacturer tolerances.

4. $\leq$ 0.635 wt. % ^{235}U and $\leq$ 1.578 wt. % total fissile plutonium (^{239}Pu and ^{241}Pu), (wt. % of total fuel weight, i.e., UO_2 plus PuO_2)

5. This assembly class contains 74 total rods; 66 full length rods and 8 partial length rods.

6. Square, replacing nine fuel rods.

7. Variable.

8. This assembly contains 92 total fuel rods; 78 full length rods and 14 partial length rods.

9. This assembly class contains 91 total fuel rods; 83 full length rods and 8 partial length rods.

10. One diamond-shaped water rod replacing the four center fuel rods and four rectangular water rods dividing the assembly into four quadrants.

11. These rods may also be sealed at both ends and contain Zr material in lieu of water.

12. This assembly is known as "QUAD+." It has four rectangular water cross segments dividing the assembly into four quadrants.

13. 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.

14. For those MPCs loaded with both intact fuel assemblies and damaged fuel assemblies or fuel debris, the maximum planar average initial enrichment for the intact fuel assemblies is limited to 3.7 wt.% ^{235}U, as applicable.

Table 2.1.5

DESIGN BASIS FUEL ASSEMBLY FOR EACH DESIGN CRITERION

Criterion	BWR	PWR
Reactivity (Criticality)	GE12/14 10x10 with Partial Length Rods (Array/Class 10x10A)	B&W 15x15 (Array/Class 15x15F)
Shielding	GE 7x7	B&W 15x15
Thermal-Hydraulic	GE-12/14 10x10	W 17x17 OFA

Tables 2.1.6 through 2.1.8

INTENTIONALLY DELETED

Table 2.1.9

SUGGESTED PWR UPPER AND LOWER FUEL SPACER LENGTHS

Fuel Assembly Type	Assembly Length w/o NFH[1] (in.)	Location of Active Fuel from Bottom (in.)	Max. Active Fuel Length (in.)	Upper Fuel Spacer Length (in.)	Lower Fuel Spacer Length (in.)
CE 14x14	157	4.1	137	9.5	10.0
CE 16x16	176.8	4.7	150	0	0
BW 15x15	165.7	8.4	141.8	6.7	4.1
W 17x17 OFA	159.8	3.7	144	8.2	8.5
W 17x17 Std	159.8	3.7	144	8.2	8.5
W 17x17 V5H	160.1	3.7	144	7.9	8.5
W 15x15	159.8	3.7	144	8.2	8.5
W 14x14 Std	159.8	3.7	145.2	9.2	7.5
W 14x14 OFA	159.8	3.7	144	8.2	8.5
Ft. Calhoun	146	6.6	128	10.25	20.25
St. Lucie 2	158.2	5.2	136.7	10.25	8.05
B&W 15x15 SS	137.1	3.873	120.5	19.25	19.25
W 15x15 SS	137.1	3.7	122	19.25	19.25
W 14x14 SS	137.1	3.7	120	19.25	19.25
Indian Point 1	137.2	17.705	101.5	18.75	20.0

Note: Each user shall specify the fuel spacer length based on their fuel assembly length, presence of a DFC, and allowing an approximate two to 2-1/2 inch gap under the MPC lid. Fuel spacers shall be sized to ensure that the active fuel region of intact fuel assemblies remains within the neutron poison region of the MPC basket with water in the MPC.

[1] NFH is an abbreviation for non-fuel hardware, including control components. Fuel assemblies with control components may require shorter fuel spacers.

Table 2.1.10

SUGGESTED BWR UPPER AND LOWER FUEL SPACER LENGTHS

Fuel Assembly Type	Assembly Length (in.)	Location of Active Fuel from Bottom (in.)	Max. Active Fuel Length (in.)	Upper Fuel Spacer Length (in.)	Lower Fuel Spacer Length (in.)
GE/2-3	171.2	7.3	150	4.8	0
GE/4-6	176.2	7.3	150	0	0
Dresden 1	134.4	11.2	110	18.0	28.0
Humboldt Bay	95.0	8.0	79	40.5	40.5
Dresden 1 Damaged Fuel or Fuel Debris	142.1†	11.2	110	17.0	16.9
Humboldt Bay Damaged Fuel or Fuel Debris	105.5†	8.0	79	35.25	35.25
LaCrosse	102.5	10.5	83	37.0	37.5

Note: Each user shall specify the fuel spacer length based on their fuel assembly length, presence of a DFC, and allowing an approximate two to 2-1/2 inch gap under the MPC lid. Fuel spacers shall be sized to ensure that the active fuel region of intact fuel assemblies remains within the neutron poison region of the MPC basket with water in the MPC.

† Fuel assembly length includes the damaged fuel container.

Table 2.1.11
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
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

1 Reference 2.1.7
2 Reference 2.1.8

Table 2.1.12

DESIGN CHARACTERISTICS FOR THORIA RODS IN D-1 THORIA ROD CANISTERS

PARAMETER	**MPC-68 or MPC-68F**
Cladding Type	Zircaloy
Composition	98.2 wt.% ThO_2, 1.8 wt.% UO_2 with an enrichment of 93.5 wt. % ^{235}U
Number of Rods Per Thoria Canister	$\leq$ 18
Decay Heat Per Thoria Canister	$\leq$ 115 watts
Post-Irradiation Fuel Cooling Time and Average Burnup Per Thoria Canister	Cooling time $\geq$ 18 years and average burnup $\leq$ 16,000 MWD/MTIHM
Initial Heavy Metal Weight	$\leq$ 27 kg/canister
Fuel Cladding O.D.	$\geq$ 0.412 inches
Fuel Cladding I.D.	$\leq$ 0.362 inches
Fuel Pellet O.D.	$\leq$ 0.358 inches
Active Fuel Length	$\leq$ 111 inches
Canister Weight	$\leq$ 550 lbs., including Thoria Rods
Canister Material	Type 304 SS

Table 2.1.13

[INTENTIONALLY DELETED]

Table 2.1.14

Soluble Boron Requirements for MPC-24/24E/24EF Fuel Wet Loading and Unloading Operations

MPC MODEL	FUEL ASSEMBLY MAXIMUM AVERAGE ENRICHMENT (wt % ^{235}U)	MINIMUM SOLUBLE BORON CONCENTRATION (ppmb)
MPC-24	All fuel assemblies with initial enrichment[1] less than the prescribed value for soluble boron credit	0
MPC-24	One or more fuel assemblies with an initial enrichment[1] greater than or equal to the prescribed value for no soluble boron credit and ≤ 5.0 wt. %	≥ 400
MPC-24E/24EF	All fuel assemblies with initial enrichment[1] less than the prescribed value for soluble boron credit	0
MPC-24E/24EF	All fuel assemblies classified as intact fuel assemblies and one or more fuel assemblies with an initial enrichment[1] greater than or equal to the prescribed value for no soluble boron credit and ≤ 5.0 wt. %	≥ 300
MPC-24E/24EF	One or more fuel assemblies classified as damaged fuel or fuel debris and one or more fuel assemblies with initial enrichment > 4.0 wt.% and ≤ 5.0 wt.%	≥ 600

[1] Refer to Table 2.1.3 for these enrichments.

Table 2.1.15

MINIMUM BORAL ^{10}B LOADING IN NEUTRON ABSORBER PANELS

MPC MODEL	MINIMUM ^{10}B LOADING (g/cm^2)	
	Boral Neutron Absorber Panels	**METAMIC Neutron Absorber Panels**
MPC-24	0.0267	0.0223
MPC-24E and MPC-24EF	0.0372	0.0310
MPC-32/32F	0.0372	0.0310
MPC-68 and MPC-68FF	0.0372	0.0310
MPC-68F	0.01	N/A (Note 1)

Notes:

1. All MPC-68F canisters are equipped with Boral neutron absorber panels.

Table 2.1.16

Soluble Boron Requirements for MPC-32 and MPC-32F Wet Loading and Unloading Operations

Fuel Assembly Array/Class	All Intact Fuel Assemblies		One or More Damaged Fuel Assemblies or Fuel Debris	
	Max. Initial Enrichment ≤ 4.1 wt.% ^{235}U (ppmb)	**Max. Initial Enrichment 5.0 wt.% ^{235}U (ppmb)**	**Max. Initial Enrichment ≤ 4.1 wt.% ^{235}U (ppmb)**	**Max. Initial Enrichment 5.0 wt.% ^{235}U (ppmb)**
14x14A/B/C/D/E	1,300	1,900	1,500	2,300
15x15A/B/C/G/I	1,800	2,500	1,900	2,700
15x15D/E/F/H	1,900	2,600	2,100	2,900
16x16A	1,400	2,000	1,500	2,300
17x17A/B/C	1,900	2,600	2,100	2,900

Note:

1. For maximum initial enrichments between 4.1 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 4.1 wt% and 5.1 wt% ^{235}U.

Table 2.1.17

LIMITS FOR MATERIAL TO BE STORED IN MPC-24

PARAMETER	VALUE
Fuel Type	Uranium oxide, PWR intact fuel assemblies meeting the limits in Table 2.1.3 for the applicable array/class
Cladding Type	ZR or Stainless Steel (SS) as specified in Table 2.1.3 for the applicable array/class
Maximum Initial Enrichment per Assembly	As specified in Table 2.1.3 for the applicable array/class
Post-irradiation Cooling Time and Average Burnup per Assembly	ZR clad: As specified in Section 2.1.9.1 SS clad: $\geq$ 8 years and $\leq$ 40,000 MWD/MTU
Decay Heat Per Fuel Storage Location	ZR clad: As specified in Section 2.1.9.1 SS clad: $\leq$ 710 Watts
Non-Fuel Hardware Burnup and Cooling Time	As specified in Table 2.1.25
Fuel Assembly Length	$\leq$ 176.8 in. (nominal design)
Fuel Assembly Width	$\leq$ 8.54 in. (nominal design)
Fuel Assembly Weight	$\leq$ 1,720 lbs (including non-fuel hardware) for array/classes that do not require fuel spacers, otherwise $\leq$ 1,680 lbs (including non-fuel hardware)
Other Limitations	▪ Quantity is limited to up to 24 PWR intact fuel assemblies. ▪ Damaged fuel assemblies and fuel debris are not permitted for loading in MPC-24. ▪ One NSA is authorized to be loaded with a fuel assembly in fuel storage location 9, 10, 15, or 16. ▪ BPRAs, TPDs, WABAs, water displacement guide tube plugs, orifice rod assemblies, and/or vibration suppressor inserts, with or without ITTRs, may be stored with fuel assemblies in any fuel cell location. ▪ APSRs may be loaded with fuel assemblies in fuel cell locations 9, 10, 15, and/or 16 ▪ CRAs, RCCAs and/or CEAs may be stored with fuel assemblies in fuel cell locations 4, 5, 8 through 11, 14 through 17, 20, and/or 21. ▪ Soluble boron requirements during wet loading and unloading are specified in Table 2.1.14.

Table 2.1.18

[INTENTIONALLY DELETED]

Table 2.1.19

LIMITS FOR MATERIAL TO BE STORED IN MPC-68F

PARAMETER	VALUE (Notes 1 and 2)			
Fuel Type(s)	Uranium oxide, BWR intact fuel assemblies meeting the limits in Table 2.1.4 for array/class 6x6A, 6x6C, 7x7A, or 8x8A, with or without Zircaloy channels	Uranium oxide, BWR damaged fuel assemblies or fuel debris meeting the limits in Table 2.1.4 for array/class 6x6A, 6x6C, 7x7A, or 8x8A, with or without Zircaloy channels, placed in Damaged Fuel Containers (DFCs)	Mixed Oxide (MOX) BWR intact fuel assemblies meeting the limits in Table 2.1.4 for array/class 6x6B, with or without Zircaloy channels	Mixed Oxide (MOX) BWR damaged fuel assemblies or fuel debris meeting the limits in Table 2.1.4 for array/class 6x6B, with or without Zircaloy channels, placed in Damaged Fuel Containers (DFCs)
Cladding Type	ZR	ZR	ZR	ZR
Maximum Initial Planar-Average Enrichment per Assembly and Rod Enrichment	As specified in Table 2.1.4 for the applicable array/class	As specified in Table 2.1.4 for the applicable array/class	As specified in Table 2.1.4 for array/class 6x6B	As specified in Table 2.1.4 for array/class 6x6B
Post-irradiation Cooling Time, Average Burnup, and Minimum Initial Enrichment per Assembly	Cooling time ≥ 18 years and average burnup ≤ 30,000 MWD/MTU.	Cooling time ≥ 18 years and average burnup ≤ 30,000 MWD/MTU.	Cooling time ≥ 18 years and average burnup ≤ 30,000 MWD/MTIHM.	Cooling time ≥ 18 years and average burnup ≤ 30,000 MWD/MTIHM.
Decay Heat Per Fuel Storage Location	≤ 115 Watts	≤ 115 Watts	≤ 115 Watts	≤ 115 Watts
Fuel Assembly Length	≤ 135.0 in. (nominal design)	≤ 135.0 in. (nominal design)	≤ 135.0 in. (nominal design)	≤ 135.0 in. (nominal design)
Fuel Assembly Width	≤ 4.70 in. (nominal design)	≤ 4.70 in. (nominal design)	≤ 4.70 in. (nominal design)	≤ 4.70 in. (nominal design)
Fuel Assembly Weight	≤ 400 lbs, (including channels)	≤ 550 lbs, (including channels and DFC)	≤ 400 lbs, (including channels)	≤ 550 lbs, (including channels and DFC)

Table 2.1.19 (cont'd)

LIMITS FOR MATERIAL TO BE STORED IN MPC-68F

PARAMETER	VALUE
Other Limitations	▪ Quantity is limited to up to four (4) DFCs containing Dresden Unit 1 or Humboldt Bay uranium oxide or MOX fuel debris. The remaining fuel storage locations may be filled with array/class 6x6A, 6x6B, 6x6C, 7x7A, and 8x8A fuel assemblies of the following type, as applicable: - uranium oxide BWR intact fuel assemblies - MOX BWR intact fuel assemblies - uranium oxide BWR damaged fuel assemblies in DFCs - MOX BWR damaged fuel assemblies in DFCs - up to one (1) Dresden Unit 1 thoria rod canister meeting the specifications listed in Table 2.1.12. ▪ Stainless steel channels are not permitted. ▪ Dresden Unit 1 fuel assemblies with one antimony-beryllium neutron source are permitted. The antimony-beryllium neutron source material shall be in a water rod location.

Notes:

1. A fuel assembly must meet the requirements of any one column and the other limitations to be authorized for storage.

2. Only fuel from the Dresden Unit 1 and Humboldt Bay plants are permitted for storage in the MPC-68F.

Table 2.1.20

LIMITS FOR MATERIAL TO BE STORED IN MPC-24E AND MPC-24EF

PARAMETER	VALUE (Note 1)	
Fuel Type	Uranium oxide PWR intact fuel assemblies meeting the limits in Table 2.1.3 for the applicable array/class	Uranium oxide PWR damaged fuel assemblies and/or fuel debris meeting the limits in Table 2.1.3 for the applicable array/class, placed in a Damaged Fuel Container (DFC)
Cladding Type	ZR or Stainless Steel (SS) assemblies as specified in Table 2.1.3 for the applicable array/class	ZR or Stainless Steel (SS) assemblies as specified in Table 2.1.3 for the applicable array/class
Maximum Initial Enrichment per Assembly	As specified in Table 2.1.3 for the applicable array/class	As specified in Table 2.1.3 for the applicable array/class
Post-irradiation Cooling Time, and Average Burnup per Assembly	ZR clad: As specified in Section 2.1.9.1 SS clad: ≥ 8 yrs and ≤ 40,000 MWD/MTU	ZR clad: As specified in Section 2.1.9.1 SS clad: ≥ 8 yrs and ≤ 40,000 MWD/MTU
Decay Heat Per Fuel Storage Location	ZR clad: As specified in Section 2.1.9.1 SS clad: ≤ 710 Watts	ZR clad: As specified in Section 2.1.9.1 SS clad: ≤ 710 Watts
Non-fuel hardware post-irradiation Cooling Time and Burnup	As specified in Table 2.1.25	As specified in Table 2.1.25
Fuel Assembly Length	≤ 176.8 in. (nominal design)	≤ 176.8 in. (nominal design)
Fuel Assembly Width	≤ 8.54 in. (nominal design)	≤ 8.54 in. (nominal design)
Fuel Assembly Weight	≤ 1,720 lbs (including non-fuel hardware) for array/classes that do not require fuel spacers, otherwise ≤ 1680 lbs (including non-fuel hardware)	≤ 1,720 lbs (including DFC and non-fuel hardware) for array/classes that do not require fuel spacers, otherwise ≤ 1680 lbs (including DFC and non-fuel hardware)

Table 2.1.20 (cont'd)

LIMITS FOR MATERIAL TO BE STORED IN MPC-24E AND MPC-24EF

PARAMETER	VALUE
Other Limitations	▪ Quantity is limited to up to 24 PWR intact fuel assemblies or up to four (4) damaged fuel assemblies and/or fuel classified as fuel debris in DFCs may be stored in fuel storage locations 3, 6, 19, and/or 22. The remaining fuel storage locations may be filled with intact fuel assemblies. ▪ One NSA is permitted for loading with a fuel assembly in fuel storage location 9, 10, 15, or 16. ▪ BPRAs, TPDs, WABAs, water displacement guide tube plugs, orifice rod assemblies, and/or vibration suppressor inserts, with or without ITTRs, may be stored with fuel assemblies in any fuel cell location. ▪ APSRs may be loaded with fuel assemblies in fuel cell locations 9, 10, 15, and/or 16. ▪ CRAs, RCCAs and/or CEAs may be stored with fuel assemblies in fuel cell locations 4, 5, 8 through 11, 14 through 17, 20, and/or 21. ▪ Soluble boron requirements during wet loading and unloading are specified in Table 2.1.14.

Notes:

1. A fuel assembly must meet the requirements of any one column and the other limitations to be authorized for storage.

Table 2.1.21

[INTENTIONALLY DELETED]

Table 2.1.22

LIMITS FOR MATERIAL TO BE STORED IN MPC-68 AND MPC-68FF

PARAMETER	VALUE (Note 1)	
Fuel Type	Uranium oxide or MOX BWR intact fuel assemblies meeting the limits in Table 2.1.4 for the applicable array/class, with or without channels.	Uranium oxide or MOX BWR damaged fuel assemblies or fuel debris meeting the limits in Table 2.1.4 for the applicable array/class, with or without channels, in DFCs.
Cladding Type	ZR or Stainless Steel (SS) assemblies as specified in Table 2.1.4 for the applicable array/class	ZR or Stainless Steel (SS) assemblies as specified in Table 2.1.4 for the applicable array/class
Maximum Initial Planar Average Enrichment per Assembly and Rod Enrichment	As specified in Table 2.1.4 for the applicable fuel assembly array/class	Planar Average: ≤ 2.7 wt% ^{235}U for array/classes 6x6A, 6x6B, 6x6C, 7x7A, and 8x8A; ≤ 4.0 wt% ^{235}U for all other array/classes Rod: As specified in Table 2.1.4
Post-irradiation cooling time and average burnup per Assembly	ZR clad: As specified in Section 2.1.9.1; except as provided in Notes 2 and 3. SS clad: Note 4	ZR clad: As specified in Section 2.1.9.1; except as provided in Notes 2 and 3. SS clad: Note 4.
Decay Heat Per Fuel Storage Location	ZR clad: As specified in Section 2.1.9.1; except as provided in Notes 2 and 3. SS clad: ≤ 95 Watts	ZR clad: As specified in Section 2.1.9.1; except as provided in Notes 2 and 3. SS clad: ≤ 95 Watts
Fuel Assembly Length	Array/classes 6x6A, 6x6B, 6x6C, 7x7A, and 8x8A: ≤ 135.0 in. (nominal design) All Other array/classes: ≤ 176.5 in. (nominal design)	Array/classes 6x6A, 6x6B, 6x6C, 7x7A, and 8x8A: ≤ 135.0 in. (nominal design) All Other array/classes: ≤ 176.5 in. (nominal design)

Table 2.1.22 (cont'd)

LIMITS FOR MATERIAL TO BE STORED IN MPC-68 AND MPC-68FF

<table>
<tr><th>PARAMETER</th><th colspan="2">VALUE (Note 1)</th></tr>
<tr><td>Fuel Assembly Width</td><td>Array/classes 6x6A, 6x6B, 6x6C, 7x7A, and 8x8A: ≤ 4.7 in. (nominal design)

All Other array/classes:

≤ 5.85 in. (nominal design)</td><td>Array/classes 6x6A, 6x6B, 6x6C, 7x7A, and 8x8A: ≤ 4.7 in. (nominal design)

All Other array/classes:

≤ 5.85 in. (nominal design)</td></tr>
<tr><td>Fuel Assembly Weight</td><td>Array/classes 6x6A, 6x6B, 6x6C, 7x7A, and 8x8A: ≤ 400 lbs. (including channels)

All Other array/classes:

≤ 730 lbs. (including channels)</td><td>Array/classes 6x6A, 6x6B, 6x6C, 7x7A, and 8x8A: ≤ 550 lbs. (including channels and DFC)

All Other array/classes:

≤ 730 lbs. (including channels and DFC)</td></tr>
<tr><td>Other Limitations</td><td colspan="2">▪ For assembly/class 6x6A, 6x6B, 6x6C, 7x7A, or 8x8A, up to 68 intact fuel assemblies or damaged fuel assemblies in DFCs may be stored. Fuel debris in DFCs may be stored in up to 8 locations. A Dresden Unit 1 Thoria Rod Container may be stored in one location.

▪ For all other array/classes, up to 16 DFCs containing damaged fuel assemblies and/or up to eight (8) DFCs containing fuel assemblies classified as fuel debris may be stored. DFCs shall be located only in fuel cell locations 1, 2, 3, 8, 9, 16, 25, 34, 35, 44, 53, 60, 61, 66, 67, and/or 68, with the balance comprised of intact fuel assemblies meeting the above specifications, up to a total of 68.

▪ SS-clad fuel assemblies with stainless steel channels must be stored in fuel cell locations 19 through 22, 28 through 31, 38 through 41, and/or 47 through 50.

▪ Dresden Unit 1 fuel assemblies with one antimony-beryllium neutron source are permitted. The antimony-beryllium neutron source material shall be in a water rod location.</td></tr>
</table>

NOTES:

1. A fuel assembly must meet the requirements of any one column and the other limitations to be authorized for storage.
2. Array/class 6x6A, 6x6B, 6x6C, 7x7A, and 8x8A fuel assemblies shall have a cooling time ≥ 18 years, an average burnup ≤ 30,000 MWD/MTU or MWD/MTIHM, and a decay heat ≤ 115 Watts.
3. Array/class 8x8F fuel assemblies shall have a cooling time ≥ 10 years, an average burnup ≤ 27,500 MWD/MTU, and a decay heat ≤ 183.5 Watts.
4. SS-clad fuel assemblies shall have a cooling time ≥ 10 years, and an average burnup ≤ 22,500 MWD/MTU.

Table 2.1.23

[INTENTIONALLY DELETED]

Table 2.1.24

LIMITS FOR MATERIAL TO BE STORED IN MPC-32 AND MPC-32F

PARAMETER	VALUE (Note 1)	
Fuel Type	Uranium oxide, PWR intact fuel assemblies meeting the limits in Table 2.1.3 for the applicable fuel assembly array/class	Uranium oxide, PWR damaged fuel assemblies and fuel debris in DFCs meeting the limits in Table 2.1.3 for the applicable fuel assembly array/class
Cladding Type	ZR or Stainless Steel (SS) as specified in Table 2.1.3 for the applicable fuel assembly array/class	ZR or Stainless Steel (SS) as specified in Table 2.1.3 for the applicable fuel assembly array/class
Maximum Initial Enrichment per Assembly	As specified in Table 2.1.3	As specified in Table 2.1.3
Post-irradiation Cooling Time, Average Burnup, and Minimum Initial Enrichment per Assembly	ZR clad: As specified in Section 2.1.9.1 SS clad: ≥ 9 years and ≤ 30,000 MWD/MTU or ≥ 20 years and ≤ 40,000MWD/MTU	ZR clad: As specified in Section 2.1.9.1 SS clad: ≥ 9 years and ≤ 30,000 MWD/MTU or ≥ 20 years and ≤ 40,000MWD/MTU
Decay Heat Per Fuel Storage Location	ZR clad: As specified in Section 2.1.9.1 SS clad: ≤ 500 Watts	ZR clad: As specified in Section 2.1.9.1 SS clad: ≤ 500 Watts
Non-fuel hardware post-irradiation Cooling Time and Burnup	As specified in Table 2.1.25	As specified in Table 2.1.25
Fuel Assembly Length	≤ 176.8 in. (nominal design)	≤ 176.8 in. (nominal design)
Fuel Assembly Width	≤ 8.54 in. (nominal design)	≤ 8.54 in. (nominal design)
Fuel Assembly Weight	≤ 1,720 lbs (including non-fuel hardware) for array/classes that do not require fuel spacers, otherwise ≤ 1,680 lbs (including non-fuel hardware)	≤ 1,720 lbs (including DFC and non-fuel hardware) for array/classes that do not require fuel spacers, otherwise ≤ 1,680 lbs (including DFC and non-fuel hardware)

Table 2.1.24 (cont'd)

LIMITS FOR MATERIAL TO BE STORED IN MPC-32 AND MPC-32F

PARAMETER	VALUE
Other Limitations	▪ Quantity is limited to up to 32 PWR intact fuel assemblies and/or up to eight (8) damaged fuel assemblies and/or fuel classified as fuel debris in DFCs in fuel cell locations 1, 4, 5, 10, 23, 28, 29, and/or 32, with the balance intact fuel assemblies up to a total of 32. ▪ One NSA is permitted for loading with a fuel assembly in fuel storage location 13, 14, 19, or 20. ▪ BPRAs, TPDs, WABAs, water displacement guide tube plugs, orifice rod assemblies, and/or vibration suppressor inserts, with or without ITTRs, may be stored with fuel assemblies in any fuel cell location. ▪ CRAs, RCCAs, CEAs, or APSRs may only be loaded with fuel assemblies in fuel cell locations 7, 8, 12-15, 18-21, 25 and/or 26. ▪ Soluble boron requirements during wet loading and unloading are specified in Table 2.1.16.

NOTES:

1. A fuel assembly must meet the requirements of any one column and the other limitations to be authorized for storage.

Table 2.1.25

NON-FUEL HARDWARE BURNUP AND COOLING TIME LIMITS (Notes 1, 2, 3, and 8)

Post-irradiation Cooling Time (yrs)	**Inserts (Note 4) Maximum Burnup (MWD/MTU)**	**NSA or Guide Tube Hardware (Note 5) Maximum Burnup (MWD/MTU)**	**Control Component (Note 6) Maximum Burnup (MWD/MTU)**	**APSR Maximum Burnup (MWD/MTU)**
≥ 3	≤ 24,635	N/A (Note 7)	N/A	N/A
≥ 4	≤ 30,000	≤ 20,000	N/A	N/A
≥ 5	≤ 36,748	≤ 25,000	≤ 630,000	≤ 45,000
≥ 6	≤ 44,102	≤ 30,000	-	≤ 54,500
≥ 7	≤ 52,900	≤ 40,000	-	≤ 68,000
≥ 8	≤ 60,000	≤ 45,000	-	≤ 83,000
≥ 9	-	≤ 50,000	-	≤ 111,000
≥ 10	-	≤ 60,000	-	≤ 180,000
≥ 11	-	≤ 75,000	-	≤ 630,000
≥ 12	-	≤ 90,000	-	-
≥ 13	-	≤ 180,000	-	-
≥ 14	-	≤ 630,000	-	-

NOTES:

1. 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.
2. Linear interpolation between points is permitted, except that NSA or Guide Tube Hardware and APSR burnups > 180,000 MWD/MTU and ≤ 630,000 MWD/MTU must be cooled ≥ 14 years and ≥ 11 years, respectively.
3. Applicable to uniform loading and regionalized loading.
4. Includes Burnable Poison Rod Assemblies (BPRAs), Wet Annular Burnable Absorbers (WABAs), and vibration suppressor inserts.
5. Includes Thimble Plug Devices (TPDs), water displacement guide tube plugs, and orifice rod assemblies.
6. Includes Control Rod Assemblies (CRAs), Control Element Assemblies (CEAs), and Rod Cluster Control Assemblies (RCCAs).
7. N/A means not authorized for loading at this cooling time.
8. Non-fuel hardware burnup and cooling time limits are not applicable to Instrument Tube Tie Rods (ITTRs), since they are installed post-irradiation.

Table 2.1.26
DESIGN HEAT EMISSION RATES
(UNIFORM LOADING, ZR-CLAD, ABOVEGROUND STORAGE[1])

MPC	Decay Heat (kW)	
	Per Intact Fuel Assembly[2]	Per MPC
MPC-24/24E/24EF	1.416	34
MPC-32/32F	1.062	34
MPC-68/68FF	0.5	34
	Per Damaged Fuel Assembly or Fuel Debris	Per MPC with Damaged Fuel Assembly or Fuel Debris
MPC-24E/24EF	$\leq$ 1.114	$\leq$ 26.7
MPC-32/32F	$\leq$ 0.718	$\leq$ 23
MPC-68/68FF	$\leq$ 0.393	$\leq$ 26.7

[1] Maximum allowable heat loads in 100U underground storage are defined in Supplement 2.I
[2] This limit applies to each storage cell and should include decay heat from any NFH

Table 2.1.27

MPC FUEL STORAGE REGIONS

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	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 1.2.2 through 1.2.4 for storage cell numbering				

Table 2.1.28

PWR FUEL ASSEMBLY COOLING TIME-DEPENDENT COEFFICIENTS
(ZR-CLAD FUEL)

Cooling Time (years)	Array/Class 14x14A						
	A	**B**	**C**	**D**	**E**	**F**	**G**
≥ 3	19311.5	275.367	-59.0252	-139.41	2851.12	-451.845	-615.413
≥ 4	33865.9	-5473.03	851.121	-132.739	3408.58	-656.479	-609.523
≥ 5	46686.2	-13226.9	2588.39	-150.149	3871.87	-806.533	-90.2065
≥ 6	56328.9	-20443.2	4547.38	-176.815	4299.19	-927.358	603.192
≥ 7	64136	-27137.5	6628.18	-200.933	4669.22	-1018.94	797.162
≥ 8	71744.1	-34290.3	9036.9	-214.249	4886.95	-1037.59	508.703
≥ 9	77262	-39724.2	11061	-228.2	5141.35	-1102.05	338.294
≥ 10	82939.8	-45575.6	13320.2	-233.691	5266.25	-1095.94	-73.3159
≥ 11	86541	-49289.6	14921.7	-242.092	5444.54	-1141.6	-83.0603
≥ 12	91383	-54456.7	17107	-242.881	5528.7	-1149.2	-547.579
≥ 13	95877.6	-59404.7	19268	-240.36	5524.35	-1094.72	-933.64
≥ 14	97648.3	-61091.6	20261.7	-244.234	5654.56	-1151.47	-749.836
≥ 15	102533	-66651.5	22799.7	-240.858	5647.05	-1120.32	-1293.34
≥ 16	106216	-70753.8	24830.1	-237.04	5647.63	-1099.12	-1583.89
≥ 17	109863	-75005	27038	-234.299	5652.45	-1080.98	-1862.07
≥ 18	111460	-76482.3	28076.5	-234.426	5703.52	-1104.39	-1695.77
≥ 19	114916	-80339.6	30126.5	-229.73	5663.21	-1065.48	-1941.83
≥ 20	119592	-86161.5	33258.2	-227.256	5700.49	-1100.21	-2474.01

Table 2.1.28 (cont'd)

PWR FUEL ASSEMBLY COOLING TIME-DEPENDENT COEFFICIENTS
(ZR-CLAD FUEL)

Cooling Time (years)	Array/Class 14x14B						
	A	B	C	D	E	F	G
≥ 3	18036.1	63.7639	-24.7251	-130.732	2449.87	-347.748	-858.192
≥ 4	30303.4	-4304.2	598.79	-118.757	2853.18	-486.453	-459.902
≥ 5	40779.6	-9922.93	1722.83	-138.174	3255.69	-608.267	245.251
≥ 6	48806.7	-15248.9	3021.47	-158.69	3570.24	-689.876	833.917
≥ 7	55070.5	-19934.6	4325.62	-179.964	3870.33	-765.849	1203.89
≥ 8	60619.6	-24346	5649.29	-189.701	4042.23	-795.324	1158.12
≥ 9	64605.7	-27677.1	6778.12	-205.459	4292.35	-877.966	1169.88
≥ 10	69083.8	-31509.4	8072.42	-206.157	4358.01	-875.041	856.449
≥ 11	72663.2	-34663.9	9228.96	-209.199	4442.68	-889.512	671.567
≥ 12	74808.9	-36367	9948.88	-214.344	4571.29	-942.418	765.261
≥ 13	78340.3	-39541.1	11173.8	-212.8	4615.06	-957.833	410.807
≥ 14	81274.8	-42172.3	12259.9	-209.758	4626.13	-958.016	190.59
≥ 15	83961.4	-44624.5	13329.1	-207.697	4632.16	-952.876	20.8575
≥ 16	84968.5	-44982.1	13615.8	-207.171	4683.41	-992.162	247.54
≥ 17	87721.6	-47543.1	14781.4	-203.373	4674.3	-988.577	37.9689
≥ 18	90562.9	-50100.4	15940.4	-198.649	4651.64	-982.459	-247.421
≥ 19	93011.6	-52316.6	17049.9	-194.964	4644.76	-994.63	-413.021
≥ 20	95567.8	-54566.6	18124	-190.22	4593.92	-963.412	-551.983

Table 2.1.28 (cont'd)

PWR FUEL ASSEMBLY COOLING TIME-DEPENDENT COEFFICIENTS
(ZR-CLAD FUEL)

Cooling Time (years)	Array/Class 14x14C						
	A	B	C	D	E	F	G
≥ 3	18263.7	174.161	-57.6694	-138.112	2539.74	-369.764	-1372.33
≥ 4	30514.5	-4291.52	562.37	-124.944	2869.17	-481.139	-889.883
≥ 5	41338	-10325.7	1752.96	-141.247	3146.48	-535.709	-248.078
≥ 6	48969.7	-15421.3	2966.33	-163.574	3429.74	-587.225	429.331
≥ 7	55384.6	-20228.9	4261.47	-180.846	3654.55	-617.255	599.251
≥ 8	60240.2	-24093.2	5418.86	-199.974	3893.72	-663.995	693.934
≥ 9	64729	-27745.7	6545.45	-205.385	3986.06	-650.124	512.528
≥ 10	68413.7	-30942.2	7651.29	-216.408	4174.71	-702.931	380.431
≥ 11	71870.6	-33906.7	8692.81	-218.813	4248.28	-704.458	160.645
≥ 12	74918.4	-36522	9660.01	-218.248	4283.68	-696.498	-29.0682
≥ 13	77348.3	-38613.7	10501.8	-220.644	4348.23	-702.266	-118.646
≥ 14	79817.1	-40661.8	11331.2	-218.711	4382.32	-710.578	-236.123
≥ 15	82354.2	-42858.3	12257.3	-215.835	4405.89	-718.805	-431.051
≥ 16	84787.2	-44994.5	13185.9	-213.386	4410.99	-711.437	-572.104
≥ 17	87084.6	-46866.1	14004.8	-206.788	4360.3	-679.542	-724.721
≥ 18	88083.1	-47387.1	14393.4	-208.681	4420.85	-709.311	-534.454
≥ 19	90783.6	-49760.6	15462.7	-203.649	4403.3	-705.741	-773.066
≥ 20	93212	-51753.3	16401.5	-197.232	4361.65	-692.925	-964.628

Table 2.1.28 (cont'd)

PWR FUEL ASSEMBLY COOLING TIME-DEPENDENT COEFFICIENTS
(ZR-CLAD FUEL)

Cooling Time (years)	Array/Class 15x15A/B/C						
	A	**B**	**C**	**D**	**E**	**F**	**G**
≥ 3	15037.3	108.689	-18.8378	-127.422	2050.02	-242.828	-580.66
≥ 4	25506.6	-2994.03	356.834	-116.45	2430.25	-350.901	-356.378
≥ 5	34788.8	-7173.07	1065.9	-124.785	2712.23	-424.681	267.705
≥ 6	41948.6	-11225.3	1912.12	-145.727	3003.29	-489.538	852.112
≥ 7	47524.9	-14770.9	2755.16	-165.889	3253.9	-542.7	1146.96
≥ 8	52596.9	-18348.8	3699.72	-177.17	3415.69	-567.012	1021.41
≥ 9	56055.4	-20837.1	4430.93	-192.168	3625.93	-623.325	1058.61
≥ 10	59611.3	-23402.1	5179.52	-195.105	3699.18	-626.448	868.517
≥ 11	62765.3	-25766.5	5924.71	-195.57	3749.91	-627.139	667.124
≥ 12	65664.4	-28004.8	6670.75	-195.08	3788.33	-628.904	410.783
≥ 13	67281.7	-29116.7	7120.59	-202.817	3929.38	-688.738	492.309
≥ 14	69961.4	-31158.6	7834.02	-197.988	3917.29	-677.565	266.561
≥ 15	72146	-32795.7	8453.67	-195.083	3931.47	-681.037	99.0606
≥ 16	74142.6	-34244.8	9023.57	-190.645	3905.54	-663.682	10.8885
≥ 17	76411.4	-36026.3	9729.98	-188.874	3911.21	-663.449	-151.805
≥ 18	77091	-36088	9884.09	-188.554	3965.08	-708.55	59.3839
≥ 19	79194.5	-37566.4	10477.5	-181.656	3906.93	-682.4	-117.952
≥ 20	81600.4	-39464.5	11281.9	-175.182	3869.49	-677.179	-367.705

Table 2.1.28 (cont'd)

PWR FUEL ASSEMBLY COOLING TIME-DEPENDENT COEFFICIENTS
(ZR-CLAD FUEL)

Cooling Time (years)	Array/Class 15x15D/E/F/H/I						
	A	**B**	**C**	**D**	**E**	**F**	**G**
≥ 3	14376.7	102.205	-20.6279	-126.017	1903.36	-210.883	-493.065
≥ 4	24351.4	-2686.57	297.975	-110.819	2233.78	-301.615	-152.713
≥ 5	33518.4	-6711.35	958.544	-122.85	2522.7	-371.286	392.608
≥ 6	40377	-10472.4	1718.53	-144.535	2793.29	-426.436	951.528
≥ 7	46105.8	-13996.2	2515.32	-157.827	2962.46	-445.314	1100.56
≥ 8	50219.7	-16677.7	3198.3	-175.057	3176.74	-492.727	1223.62
≥ 9	54281.2	-19555.6	3983.47	-181.703	3279.03	-499.997	1034.55
≥ 10	56761.6	-21287.3	4525.98	-195.045	3470.41	-559.074	1103.3
≥ 11	59820	-23445.2	5165.43	-194.997	3518.23	-561.422	862.68
≥ 12	62287.2	-25164.6	5709.9	-194.771	3552.69	-561.466	680.488
≥ 13	64799	-27023.7	6335.16	-192.121	3570.41	-561.326	469.583
≥ 14	66938.7	-28593.1	6892.63	-194.226	3632.92	-583.997	319.867
≥ 15	68116.5	-29148.6	7140.09	-192.545	3670.39	-607.278	395.344
≥ 16	70154.9	-30570.1	7662.91	-187.366	3649.14	-597.205	232.318
≥ 17	72042.5	-31867.6	8169.01	-183.453	3646.92	-603.907	96.0388
≥ 18	73719.8	-32926.1	8596.12	-177.896	3614.57	-592.868	46.6774
≥ 19	75183.1	-33727.4	8949.64	-172.386	3581.13	-586.347	3.57256
≥ 20	77306.1	-35449	9690.02	-173.784	3636.87	-626.321	-205.513

Table 2.1.28 (cont'd)

PWR FUEL ASSEMBLY COOLING TIME-DEPENDENT COEFFICIENTS
(ZR-CLAD FUEL)

Cooling Time (years)	Array/Class 16x16A						
	A	**B**	**C**	**D**	**E**	**F**	**G**
≥ 3	16226.8	143.714	-32.4809	-136.707	2255.33	-291.683	-699.947
≥ 4	27844.2	-3590.69	444.838	-124.301	2644.09	-411.598	-381.106
≥ 5	38191.5	-8678.48	1361.58	-132.855	2910.45	-473.183	224.473
≥ 6	46382.2	-13819.6	2511.32	-158.262	3216.92	-532.337	706.656
≥ 7	52692.3	-18289	3657.18	-179.765	3488.3	-583.133	908.839
≥ 8	57758.7	-22133.7	4736.88	-199.014	3717.42	-618.83	944.903
≥ 9	62363.3	-25798.7	5841.18	-207.025	3844.38	-625.741	734.928
≥ 10	66659.1	-29416.3	6993.31	-216.458	3981.97	-642.641	389.366
≥ 11	69262.7	-31452.7	7724.66	-220.836	4107.55	-681.043	407.121
≥ 12	72631.5	-34291.9	8704.8	-219.929	4131.5	-662.513	100.093
≥ 13	75375.3	-36589.3	9555.88	-217.994	4143.15	-644.014	-62.3294
≥ 14	78178.7	-39097.1	10532	-221.923	4226.28	-667.012	-317.743
≥ 15	79706.3	-40104	10993.3	-218.751	4242.12	-670.665	-205.579
≥ 16	82392.6	-42418.9	11940.7	-216.278	4274.09	-689.236	-479.752
≥ 17	84521.8	-44150.5	12683.3	-212.056	4245.99	-665.418	-558.901
≥ 18	86777.1	-45984.8	13479	-204.867	4180.8	-621.805	-716.366
≥ 19	89179.7	-48109.8	14434.5	-206.484	4230.03	-648.557	-902.1
≥ 20	90141.7	-48401.4	14702.6	-203.284	4245.54	-670.655	-734.604

Table 2.1.28 (cont'd)

PWR FUEL ASSEMBLY COOLING TIME-DEPENDENT COEFFICIENTS
(ZR-CLAD FUEL)

Cooling Time (years)	Array/Class 17x17A						
	A	**B**	**C**	**D**	**E**	**F**	**G**
≥ 3	15985.1	3.53963	-9.04955	-128.835	2149.5	-260.415	-262.997
≥ 4	27532.9	-3494.41	428.199	-119.504	2603.01	-390.91	-140.319
≥ 5	38481.2	-8870.98	1411.03	-139.279	3008.46	-492.881	388.377
≥ 6	47410.9	-14479.6	2679.08	-162.13	3335.48	-557.777	702.164
≥ 7	54596.8	-19703.2	4043.46	-181.339	3586.06	-587.634	804.05
≥ 8	60146.1	-24003.4	5271.54	-201.262	3830.32	-621.706	848.454
≥ 9	65006.3	-27951	6479.04	-210.753	3977.69	-627.805	615.84
≥ 10	69216	-31614.7	7712.58	-222.423	4173.4	-672.33	387.879
≥ 11	73001.3	-34871.1	8824.44	-225.128	4238.28	-657.259	101.654
≥ 12	76326.1	-37795.9	9887.35	-226.731	4298.11	-647.55	-122.236
≥ 13	78859.9	-40058.9	10797.1	-231.798	4402.14	-669.982	-203.383
≥ 14	82201.3	-43032.5	11934.1	-228.162	4417.99	-661.61	-561.969
≥ 15	84950	-45544.6	12972.4	-225.369	4417.84	-637.422	-771.254
≥ 16	87511.8	-47720	13857.7	-219.255	4365.24	-585.655	-907.775
≥ 17	90496.4	-50728.9	15186	-223.019	4446.51	-613.378	-1200.94
≥ 18	91392.5	-51002.4	15461.4	-220.272	4475.28	-636.398	-1003.81
≥ 19	94343.9	-53670.8	16631.6	-214.045	4441.31	-616.201	-1310.01
≥ 20	96562.9	-55591.2	17553.4	-209.917	4397.67	-573.199	-1380.64

Table 2.1.28 (cont'd)

PWR FUEL ASSEMBLY COOLING TIME-DEPENDENT COEFFICIENTS
(ZR-CLAD FUEL)

Cooling Time (years)	Array/Class 17x17B/C						
	A	**B**	**C**	**D**	**E**	**F**	**G**
≥ 3	14738	47.5402	-13.8187	-127.895	1946.58	-219.289	-389.029
≥ 4	25285.2	-3011.92	350.116	-115.75	2316.89	-319.23	-220.413
≥ 5	34589.6	-7130.34	1037.26	-128.673	2627.27	-394.58	459.642
≥ 6	42056.2	-11353.7	1908.68	-150.234	2897.38	-444.316	923.971
≥ 7	47977.6	-15204.8	2827.4	-173.349	3178.25	-504.16	1138.82
≥ 8	52924	-18547.6	3671.08	-183.025	3298.64	-501.278	1064.68
≥ 9	56465.5	-21139.4	4435.67	-200.386	3538	-569.712	1078.78
≥ 10	60190.9	-23872.7	5224.31	-203.233	3602.88	-562.312	805.336
≥ 11	63482.1	-26431.1	6035.79	-205.096	3668.84	-566.889	536.011
≥ 12	66095	-28311.8	6637.72	-204.367	3692.68	-555.305	372.223
≥ 13	67757.4	-29474.4	7094.08	-211.649	3826.42	-606.886	437.412
≥ 14	70403.7	-31517.4	7807.15	-207.668	3828.69	-601.081	183.09
≥ 15	72506.5	-33036.1	8372.59	-203.428	3823.38	-594.995	47.5175
≥ 16	74625.2	-34620.5	8974.32	-199.003	3798.57	-573.098	-95.0221
≥ 17	76549	-35952.6	9498.14	-193.459	3766.52	-556.928	-190.662
≥ 18	77871.9	-36785.5	9916.91	-195.592	3837.65	-599.45	-152.261
≥ 19	79834.8	-38191.6	10501.9	-190.83	3812.46	-589.635	-286.847
≥ 20	81975.5	-39777.2	11174.5	-185.767	3795.78	-595.664	-475.978

Table 2.1.29

BWR FUEL ASSEMBLY COOLING TIME-DEPENDENT COEFFICIENTS
(ZR-CLAD FUEL)

Cooling Time (years)	Array/Class 7x7B & 10x10F†						
	A	**B**	**C**	**D**	**E**	**F**	**G**
≥ 3	26409.1	28347.5	-16858	-147.076	5636.32	-1606.75	1177.88
≥ 4	61967.8	-6618.31	-4131.96	-113.949	6122.77	-2042.85	-96.7439
≥ 5	91601.1	-49298.3	17826.5	-132.045	6823.14	-2418.49	-185.189
≥ 6	111369	-80890.1	35713.8	-150.262	7288.51	-2471.1	86.6363
≥ 7	126904	-108669	53338.1	-167.764	7650.57	-2340.78	150.403
≥ 8	139181	-132294	69852.5	-187.317	8098.66	-2336.13	97.5285
≥ 9	150334	-154490	86148.1	-193.899	8232.84	-2040.37	-123.029
≥ 10	159897	-173614	100819	-194.156	8254.99	-1708.32	-373.605
≥ 11	166931	-186860	111502	-193.776	8251.55	-1393.91	-543.677
≥ 12	173691	-201687	125166	-202.578	8626.84	-1642.3	-650.814
≥ 13	180312	-215406	137518	-201.041	8642.19	-1469.45	-810.024
≥ 14	185927	-227005	148721	-197.938	8607.6	-1225.95	-892.876
≥ 15	191151	-236120	156781	-191.625	8451.86	-846.27	-1019.4
≥ 16	195761	-244598	165372	-187.043	8359.19	-572.561	-1068.19
≥ 17	200791	-256573	179816	-197.26	8914.28	-1393.37	-1218.63
≥ 18	206068	-266136	188841	-187.191	8569.56	-730.898	-1363.79
≥ 19	210187	-273609	197794	-182.151	8488.23	-584.727	-1335.59
≥ 20	213731	-278120	203074	-175.864	8395.63	-457.304	-1364.38

†Array/Class 10x10F for MPC-68M only.

Table 2.1.29 (cont'd)

BWR FUEL ASSEMBLY COOLING TIME-DEPENDENT COEFFICIENTS
(ZR-CLAD FUEL)

Cooling Time (years)	Array/Class 8x8B						
	A	**B**	**C**	**D**	**E**	**F**	**G**
≥ 3	28219.6	28963.7	-17616.2	-147.68	5887.41	-1730.96	1048.21
≥ 4	66061.8	-10742.4	-1961.82	-123.066	6565.54	-2356.05	-298.005
≥ 5	95790.7	-53401.7	19836.7	-134.584	7145.41	-2637.09	-298.858
≥ 6	117477	-90055.9	41383.9	-154.758	7613.43	-2612.69	-64.9921
≥ 7	134090	-120643	60983	-168.675	7809	-2183.3	-40.8885
≥ 8	148186	-149181	81418.7	-185.726	8190.07	-2040.31	-260.773
≥ 9	159082	-172081	99175.2	-197.185	8450.86	-1792.04	-381.705
≥ 10	168816	-191389	113810	-195.613	8359.87	-1244.22	-613.594
≥ 11	177221	-210599	131099	-208.3	8810	-1466.49	-819.773
≥ 12	183929	-224384	143405	-207.497	8841.33	-1227.71	-929.708
≥ 13	191093	-240384	158327	-204.95	8760.17	-811.708	-1154.76
≥ 14	196787	-252211	169664	-204.574	8810.95	-610.928	-1208.97
≥ 15	203345	-267656	186057	-208.962	9078.41	-828.954	-1383.76
≥ 16	207973	-276838	196071	-204.592	9024.17	-640.808	-1436.43
≥ 17	213891	-290411	211145	-202.169	9024.19	-482.1	-1595.28
≥ 18	217483	-294066	214600	-194.243	8859.35	-244.684	-1529.61
≥ 19	220504	-297897	219704	-190.161	8794.97	-10.9863	-1433.86
≥ 20	227821	-318395	245322	-194.682	9060.96	-350.308	-1741.16

Table 2.1.29 (cont'd)

BWR FUEL ASSEMBLY COOLING TIME-DEPENDENT COEFFICIENTS
(ZR-CLAD FUEL)

Cooling Time (years)	Array/Class 8x8C/D/E						
	A	**B**	**C**	**D**	**E**	**F**	**G**
≥ 3	28592.7	28691.5	-17773.6	-149.418	5969.45	-1746.07	1063.62
≥ 4	66720.8	-12115.7	-1154	-128.444	6787.16	-2529.99	-302.155
≥ 5	96929.1	-55827.5	21140.3	-136.228	7259.19	-2685.06	-334.328
≥ 6	118190	-92000.2	42602.5	-162.204	7907.46	-2853.42	-47.5465
≥ 7	135120	-123437	62827.1	-172.397	8059.72	-2385.81	-75.0053
≥ 8	149162	-152986	84543.1	-195.458	8559.11	-2306.54	-183.595
≥ 9	161041	-177511	103020	-200.087	8632.84	-1864.4	-433.081
≥ 10	171754	-201468	122929	-209.799	8952.06	-1802.86	-755.742
≥ 11	179364	-217723	137000	-215.803	9142.37	-1664.82	-847.268
≥ 12	186090	-232150	150255	-216.033	9218.36	-1441.92	-975.817
≥ 13	193571	-249160	165997	-213.204	9146.99	-1011.13	-1119.47
≥ 14	200034	-263671	180359	-210.559	9107.54	-694.626	-1312.55
≥ 15	205581	-275904	193585	-216.242	9446.57	-1040.65	-1428.13
≥ 16	212015	-290101	207594	-210.036	9212.93	-428.321	-1590.7
≥ 17	216775	-299399	218278	-204.611	9187.86	-398.353	-1657.6
≥ 18	220653	-306719	227133	-202.498	9186.34	-181.672	-1611.86
≥ 19	224859	-314004	235956	-193.902	8990.14	145.151	-1604.71
≥ 20	228541	-320787	245449	-200.727	9310.87	-230.252	-1570.18

Table 2.1.29 (cont'd)

BWR FUEL ASSEMBLY COOLING TIME-DEPENDENT COEFFICIENTS
(ZR-CLAD FUEL)

Cooling Time (years)	Array/Class 9x9A						
	A	B	C	D	E	F	G
≥ 3	30538.7	28463.2	-18105.5	-150.039	6226.92	-1876.69	1034.06
≥ 4	71040.1	-16692.2	1164.15	-128.241	7105.27	-2728.58	-414.09
≥ 5	100888	-60277.7	24150.1	-142.541	7896.11	-3272.86	-232.197
≥ 6	124846	-102954	50350.8	-161.849	8350.16	-3163.44	-91.1396
≥ 7	143516	-140615	76456.5	-185.538	8833.04	-2949.38	-104.802
≥ 8	158218	-171718	99788.2	-196.315	9048.88	-2529.26	-259.929
≥ 9	172226	-204312	126620	-214.214	9511.56	-2459.19	-624.954
≥ 10	182700	-227938	146736	-215.793	9555.41	-1959.92	-830.943
≥ 11	190734	-246174	163557	-218.071	9649.43	-1647.5	-935.021
≥ 12	199997	-269577	186406	-223.975	9884.92	-1534.34	-1235.27
≥ 13	207414	-287446	204723	-228.808	10131.7	-1614.49	-1358.61
≥ 14	215263	-306131	223440	-220.919	9928.27	-988.276	-1638.05
≥ 15	221920	-321612	239503	-217.949	9839.02	-554.709	-1784.04
≥ 16	226532	-331778	252234	-216.189	9893.43	-442.149	-1754.72
≥ 17	232959	-348593	272609	-219.907	10126.3	-663.84	-1915.3
≥ 18	240810	-369085	296809	-219.729	10294.6	-859.302	-2218.87
≥ 19	244637	-375057	304456	-210.997	10077.8	-425.446	-2127.83
≥ 20	248112	-379262	309391	-204.191	9863.67	100.27	-2059.39

Table 2.1.29 (cont'd)

BWR FUEL ASSEMBLY COOLING TIME-DEPENDENT COEFFICIENTS
(ZR-CLAD FUEL)

Cooling Time (years)	Array/Class 9x9B						
	A	B	C	D	E	F	G
≥ 3	30613.2	28985.3	-18371	-151.117	6321.55	-1881.28	988.92
≥ 4	71346.6	-15922.9	631.132	-128.876	7232.47	-2810.64	-471.737
≥ 5	102131	-60654.1	23762.7	-140.748	7881.6	-3156.38	-417.979
≥ 6	127187	-105842	51525.2	-162.228	8307.4	-2913.08	-342.13
≥ 7	146853	-145834	79146.5	-185.192	8718.74	-2529.57	-484.885
≥ 8	162013	-178244	103205	-197.825	8896.39	-1921.58	-584.013
≥ 9	176764	-212856	131577	-215.41	9328.18	-1737.12	-1041.11
≥ 10	186900	-235819	151238	-218.98	9388.08	-1179.87	-1202.83
≥ 11	196178	-257688	171031	-220.323	9408.47	-638.53	-1385.16
≥ 12	205366	-280266	192775	-223.715	9592.12	-472.261	-1661.6
≥ 13	215012	-306103	218866	-231.821	9853.37	-361.449	-1985.56
≥ 14	222368	-324558	238655	-228.062	9834.57	3.47358	-2178.84
≥ 15	226705	-332738	247316	-224.659	9696.59	632.172	-2090.75
≥ 16	233846	-349835	265676	-221.533	9649.93	913.747	-2243.34
≥ 17	243979	-379622	300077	-222.351	9792.17	1011.04	-2753.36
≥ 18	247774	-386203	308873	-220.306	9791.37	1164.58	-2612.25
≥ 19	254041	-401906	327901	-213.96	9645.47	1664.94	-2786.2
≥ 20	256003	-402034	330566	-215.242	9850.42	1359.46	-2550.06

Table 2.1.29 (cont'd)

BWR FUEL ASSEMBLY COOLING TIME-DEPENDENT COEFFICIENTS
(ZR-CLAD FUEL)

Cooling Time (years)	Array/Class 9x9C/D						
	A	B	C	D	E	F	G
≥ 3	30051.6	29548.7	-18614.2	-148.276	6148.44	-1810.34	1006
≥ 4	70472.7	-14696.6	-233.567	-127.728	7008.69	-2634.22	-444.373
≥ 5	101298	-59638.9	23065.2	-138.523	7627.57	-2958.03	-377.965
≥ 6	125546	-102740	49217.4	-160.811	8096.34	-2798.88	-259.767
≥ 7	143887	-139261	74100.4	-184.302	8550.86	-2517.19	-275.151
≥ 8	159633	-172741	98641.4	-194.351	8636.89	-1838.81	-486.731
≥ 9	173517	-204709	124803	-212.604	9151.98	-1853.27	-887.137
≥ 10	182895	-225481	142362	-218.251	9262.59	-1408.25	-978.356
≥ 11	192530	-247839	162173	-217.381	9213.58	-818.676	-1222.12
≥ 12	201127	-268201	181030	-215.552	9147.44	-232.221	-1481.55
≥ 13	209538	-289761	203291	-225.092	9588.12	-574.227	-1749.35
≥ 14	216798	-306958	220468	-222.578	9518.22	-69.9307	-1919.71
≥ 15	223515	-323254	237933	-217.398	9366.52	475.506	-2012.93
≥ 16	228796	-334529	250541	-215.004	9369.33	662.325	-2122.75
≥ 17	237256	-356311	273419	-206.483	9029.55	1551.3	-2367.96
≥ 18	242778	-369493	290354	-215.557	9600.71	659.297	-2589.32
≥ 19	246704	-377971	302630	-210.768	9509.41	1025.34	-2476.06
≥ 20	249944	-382059	308281	-205.495	9362.63	1389.71	-2350.49

Table 2.1.29 (cont'd)

BWR FUEL ASSEMBLY COOLING TIME-DEPENDENT COEFFICIENTS
(ZR-CLAD FUEL)

Cooling Time (years)	Array/Class 9x9E/F						
	A	**B**	**C**	**D**	**E**	**F**	**G**
≥ 3	30284.3	26949.5	-16926.4	-147.914	6017.02	-1854.81	1026.15
≥ 4	69727.4	-17117.2	1982.33	-127.983	6874.68	-2673.01	-359.962
≥ 5	98438.9	-58492	23382.2	-138.712	7513.55	-3038.23	-112.641
≥ 6	119765	-95024.1	45261	-159.669	8074.25	-3129.49	221.182
≥ 7	136740	-128219	67940.1	-182.439	8595.68	-3098.17	315.544
≥ 8	150745	-156607	88691.5	-193.941	8908.73	-2947.64	142.072
≥ 9	162915	-182667	109134	-198.37	8999.11	-2531	-93.4908
≥ 10	174000	-208668	131543	-210.777	9365.52	-2511.74	-445.876
≥ 11	181524	-224252	145280	-212.407	9489.67	-2387.49	-544.123
≥ 12	188946	-240952	160787	-210.65	9478.1	-2029.94	-652.339
≥ 13	193762	-250900	171363	-215.798	9742.31	-2179.24	-608.636
≥ 14	203288	-275191	196115	-218.113	9992.5	-2437.71	-1065.92
≥ 15	208108	-284395	205221	-213.956	9857.25	-1970.65	-1082.94
≥ 16	215093	-301828	224757	-209.736	9789.58	-1718.37	-1303.35
≥ 17	220056	-310906	234180	-201.494	9541.73	-1230.42	-1284.15
≥ 18	224545	-320969	247724	-206.807	9892.97	-1790.61	-1381.9
≥ 19	226901	-322168	250395	-204.073	9902.14	-1748.78	-1253.22
≥ 20	235561	-345414	276856	-198.306	9720.78	-1284.14	-1569.18

Table 2.1.29 (cont'd)

BWR FUEL ASSEMBLY COOLING TIME-DEPENDENT COEFFICIENTS
(ZR-CLAD FUEL)

Cooling Time (years)	Array/Class 9x9G						
	A	**B**	**C**	**D**	**E**	**F**	**G**
≥ 3	35158.5	26918.5	-17976.7	-149.915	6787.19	-2154.29	836.894
≥ 4	77137.2	-19760.1	2371.28	-130.934	8015.43	-3512.38	-455.424
≥ 5	113405	-77931.2	35511.2	-150.637	8932.55	-4099.48	-629.806
≥ 6	139938	-128700	68698.3	-173.799	9451.22	-3847.83	-455.905
≥ 7	164267	-183309	109526	-193.952	9737.91	-3046.84	-737.992
≥ 8	182646	-227630	146275	-210.936	10092.3	-2489.3	-1066.96
≥ 9	199309	-270496	184230	-218.617	10124.3	-1453.81	-1381.41
≥ 10	213186	-308612	221699	-235.828	10703.2	-1483.31	-1821.73
≥ 11	225587	-342892	256242	-236.112	10658.5	-612.076	-2134.65
≥ 12	235725	-370471	285195	-234.378	10604.9	118.591	-2417.89
≥ 13	247043	-404028	323049	-245.79	11158.2	-281.813	-2869.82
≥ 14	253649	-421134	342682	-243.142	11082.3	400.019	-2903.88
≥ 15	262750	-448593	376340	-245.435	11241.2	581.355	-3125.07
≥ 16	270816	-470846	402249	-236.294	10845.4	1791.46	-3293.07
≥ 17	279840	-500272	441964	-241.324	11222.6	1455.84	-3528.25
≥ 18	284533	-511287	458538	-240.905	11367.2	1459.68	-3520.94
≥ 19	295787	-545885	501824	-235.685	11188.2	2082.21	-3954.2
≥ 20	300209	-556936	519174	-229.539	10956	2942.09	-3872.87

Table 2.1.29 (cont'd)

BWR FUEL ASSEMBLY COOLING TIME-DEPENDENT COEFFICIENTS
(ZR-CLAD FUEL)

Cooling Time (years)	Array/Class 10x10A/B/G†						
	A	**B**	**C**	**D**	**E**	**F**	**G**
≥ 3	29285.4	27562.2	-16985	-148.415	5960.56	-1810.79	1001.45
≥ 4	67844.9	-14383	395.619	-127.723	6754.56	-2547.96	-369.267
≥ 5	96660.5	-55383.8	21180.4	-137.17	7296.6	-2793.58	-192.85
≥ 6	118098	-91995	42958	-162.985	7931.44	-2940.84	60.9197
≥ 7	135115	-123721	63588.9	-171.747	8060.23	-2485.59	73.6219
≥ 8	148721	-151690	84143.9	-190.26	8515.81	-2444.25	-63.4649
≥ 9	160770	-177397	104069	-197.534	8673.6	-2101.25	-331.046
≥ 10	170331	-198419	121817	-213.692	9178.33	-2351.54	-472.844
≥ 11	179130	-217799	138652	-209.75	9095.43	-1842.88	-705.254
≥ 12	186070	-232389	151792	-208.946	9104.52	-1565.11	-822.73
≥ 13	192407	-246005	164928	-209.696	9234.7	-1541.54	-979.245
≥ 14	200493	-265596	183851	-207.639	9159.83	-1095.72	-1240.61
≥ 15	205594	-276161	195760	-213.491	9564.23	-1672.22	-1333.64
≥ 16	209386	-282942	204110	-209.322	9515.83	-1506.86	-1286.82
≥ 17	214972	-295149	217095	-202.445	9292.34	-893.6	-1364.97
≥ 18	219312	-302748	225826	-198.667	9272.27	-878.536	-1379.58
≥ 19	223481	-310663	235908	-194.825	9252.9	-785.066	-1379.62
≥ 20	227628	-319115	247597	-199.194	9509.02	-1135.23	-1386.19

†Array/Class 10x10G for MPC-68M only.

Table 2.1.29 (cont'd)

BWR FUEL ASSEMBLY COOLING TIME-DEPENDENT COEFFICIENTS
(ZR-CLAD FUEL)

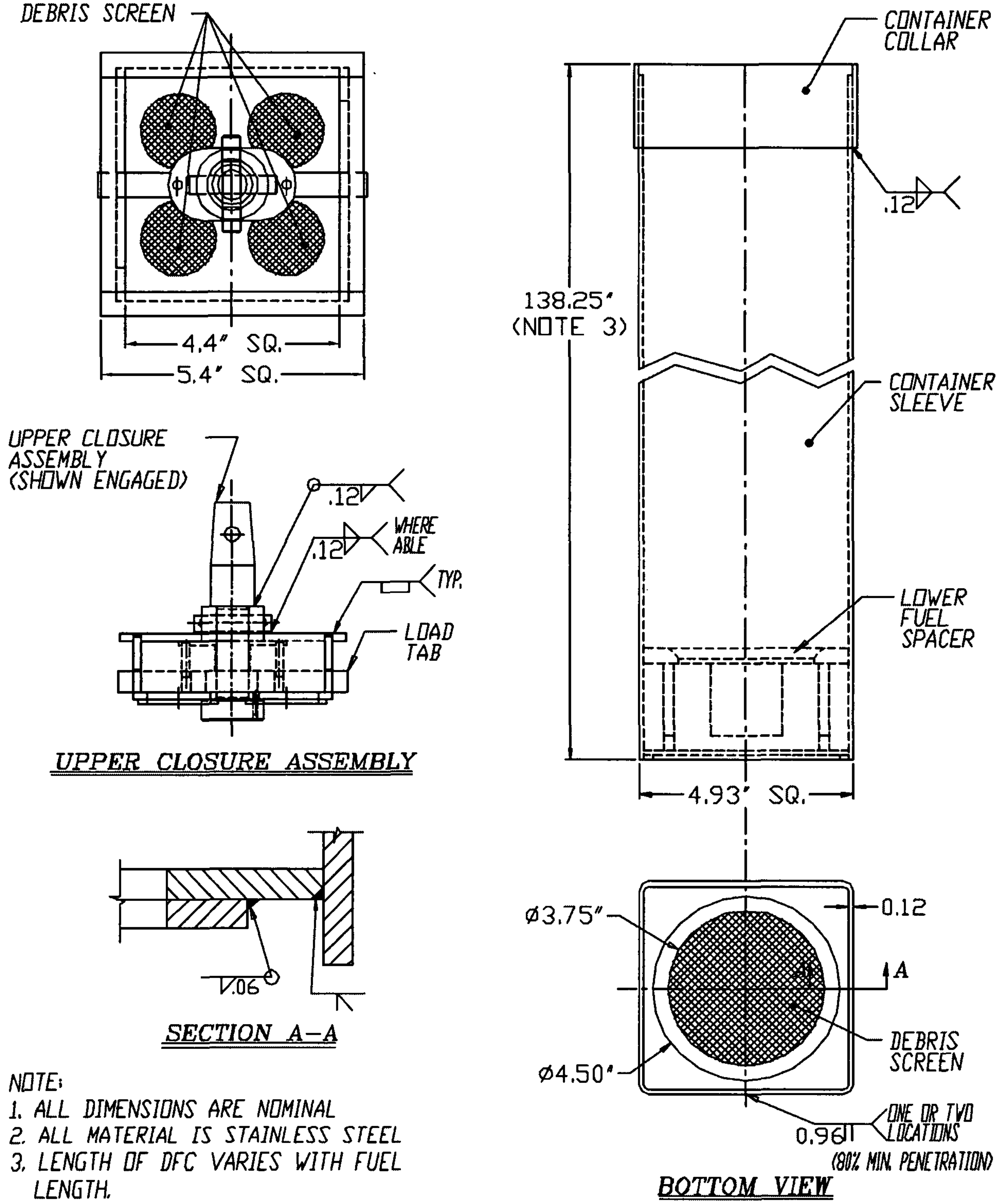
Cooling Time (years)	Array/Class 10x10C						
	A	B	C	D	E	F	G
≥ 3	31425.3	27358.9	-17413.3	-152.096	6367.53	-1967.91	925.763
≥ 4	71804	-16964.1	1000.4	-129.299	7227.18	-2806.44	-416.92
≥ 5	102685	-62383.3	24971.2	-142.316	7961	-3290.98	-354.784
≥ 6	126962	-105802	51444.6	-164.283	8421.44	-3104.21	-186.615
≥ 7	146284	-145608	79275.5	-188.967	8927.23	-2859.08	-251.163
≥ 8	162748	-181259	105859	-199.122	9052.91	-2206.31	-554.124
≥ 9	176612	-214183	133261	-217.56	9492.17	-1999.28	-860.669
≥ 10	187756	-239944	155315	-219.56	9532.45	-1470.9	-1113.42
≥ 11	196580	-260941	174536	-222.457	9591.64	-944.473	-1225.79
≥ 12	208017	-291492	204805	-233.488	10058.3	-1217.01	-1749.84
≥ 13	214920	-307772	221158	-234.747	10137.1	-897.23	-1868.04
≥ 14	222562	-326471	240234	-228.569	9929.34	-183.47	-2016.12
≥ 15	228844	-342382	258347	-226.944	9936.76	117.061	-2106.05
≥ 16	233907	-353008	270390	-223.179	9910.72	360.39	-2105.23
≥ 17	244153	-383017	304819	-227.266	10103.2	380.393	-2633.23
≥ 18	249240	-395456	321452	-226.989	10284.1	169.947	-2623.67
≥ 19	254343	-406555	335240	-220.569	10070.5	764.689	-2640.2
≥ 20	260202	-421069	354249	-216.255	10069.9	854.497	-2732.77

Table 2.1.30

MPC Regionalized Loading Heat Load Limits (q_1 and q_2) for Discrete Values of X

X	MPC-24		MPC-32		MPC-68	
	q_1 (kW)	q_2 (kW)	q_1 (kW)	q_2 (kW)	q_1 (kW)	q_2 (kW)
0.5	1.025	2.050	0.710	1.419	0.354	0.710
0.6	1.128	1.880	0.796	1.327	0.392	0.653
0.7	1.216	1.737	0.873	1.248	0.424	0.606
0.8	1.292	1.615	0.943	1.178	0.453	0.566
0.9	1.358	1.509	1.005	1.117	0.478	0.531
1	1.416	1.416	1.062	1.062	0.500	0.500
1.1	1.468	1.334	1.114	1.012	0.519	0.472
1.2	1.513	1.261	1.161	0.968	0.537	0.447
1.3	1.554	1.195	1.205	0.926	0.552	0.425
1.4	1.590	1.136	1.245	0.889	0.567	0.405
1.5	1.623	1.082	1.282	0.854	0.579	0.386
1.6	1.653	1.033	1.316	0.822	0.591	0.369
1.7	1.680	0.988	1.347	0.792	0.602	0.354
1.8	1.705	0.947	1.377	0.765	0.612	0.340
1.9	1.728	0.909	1.405	0.739	0.621	0.326
2	1.748	0.874	1.430	0.715	0.629	0.314
2.1	1.767	0.841	1.454	0.692	0.637	0.303
2.2	1.785	0.811	1.477	0.671	0.644	0.292
2.3	1.801	0.783	1.498	0.651	0.650	0.282
2.4	1.816	0.756	1.518	0.632	0.656	0.273
2.5	1.829	0.731	1.537	0.614	0.662	0.265
2.6	1.842	0.708	1.554	0.597	0.667	0.256
2.7	1.854	0.686	1.571	0.581	0.672	0.249
2.8	1.865	0.666	1.587	0.566	0.677	0.241
2.9	1.875	0.646	1.602	0.552	0.681	0.235
3	1.885	0.628	1.616	0.538	0.685	0.228

*See Table 2.1.27 for the number of storage cells (n) in each region for the specific MPC type listed.



NOTE:
1. ALL DIMENSIONS ARE NOMINAL
2. ALL MATERIAL IS STAINLESS STEEL
3. LENGTH OF DFC VARIES WITH FUEL LENGTH.

FIGURE 2.1.1; DAMAGED FUEL CONTAINER FOR DRESDEN UNIT-1/ HUMBOLDT BAY SNF

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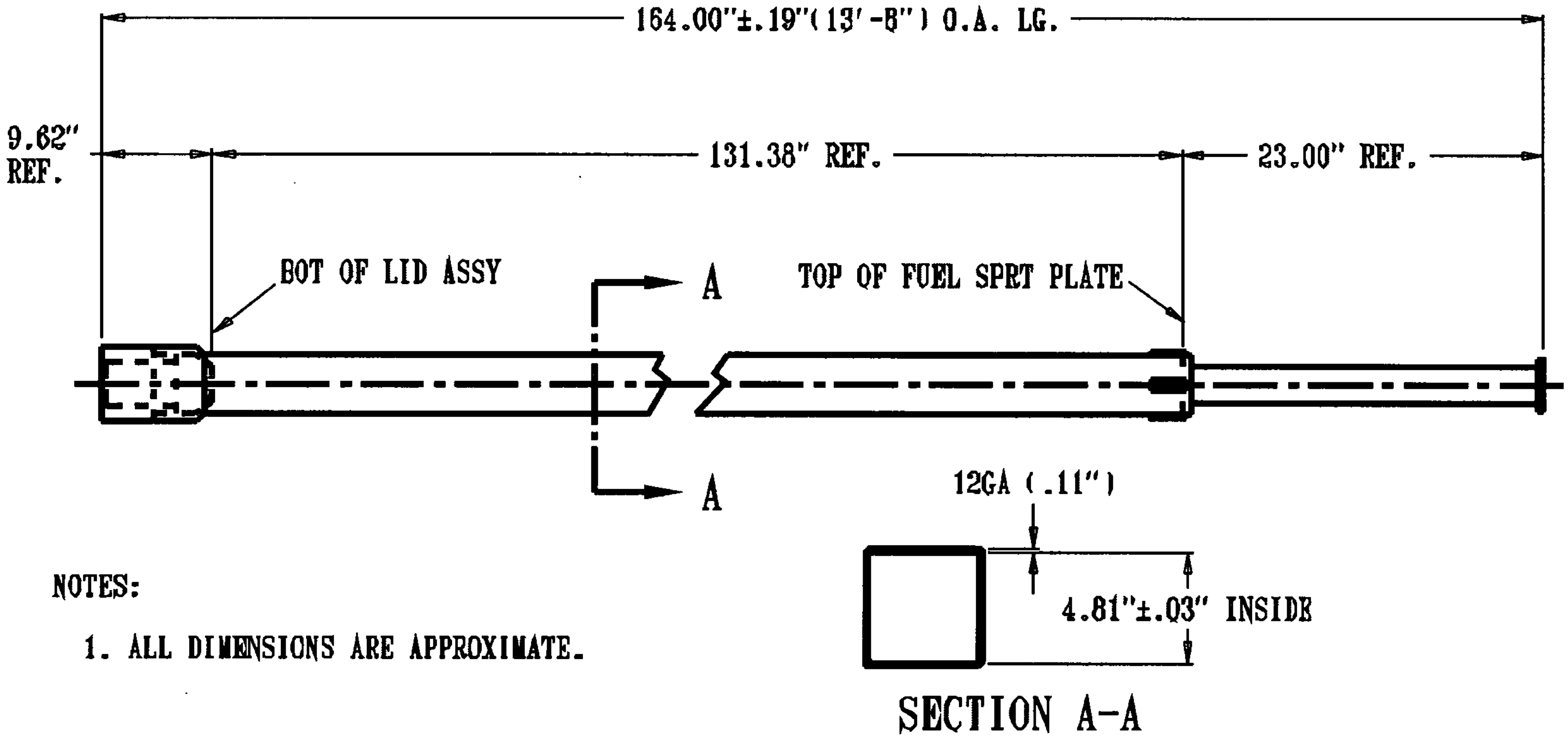

NOTES:

1. ALL DIMENSIONS ARE APPROXIMATE.

FIGURE 2.1.2; TN DAMAGED FUEL CANISTER FOR DRESDEN UNIT-1

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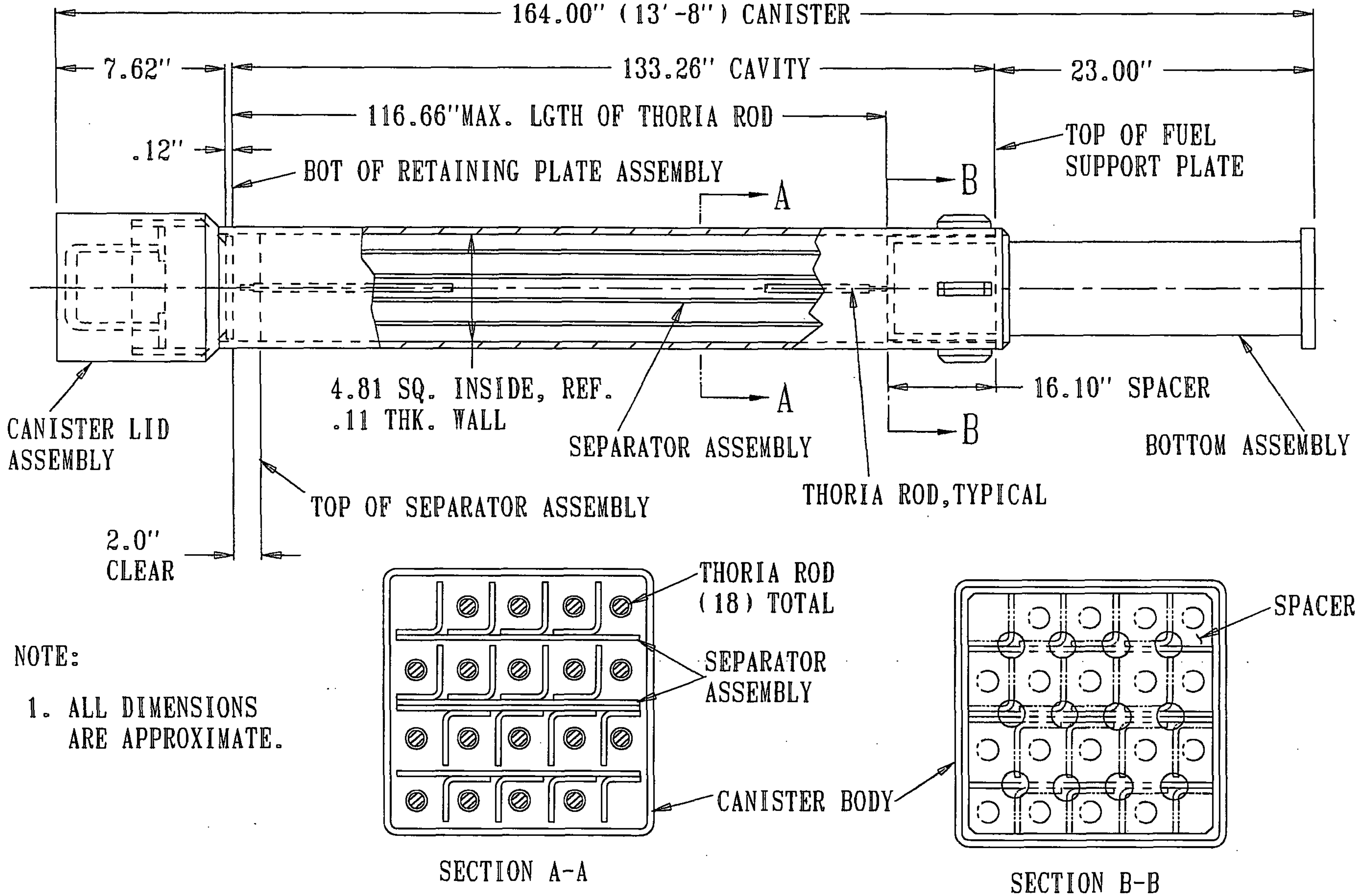

NOTE:

1. ALL DIMENSIONS ARE APPROXIMATE.

FIGURE 2.1.2A; TN THORIA ROD CANISTER FOR DRESDEN UNIT-1

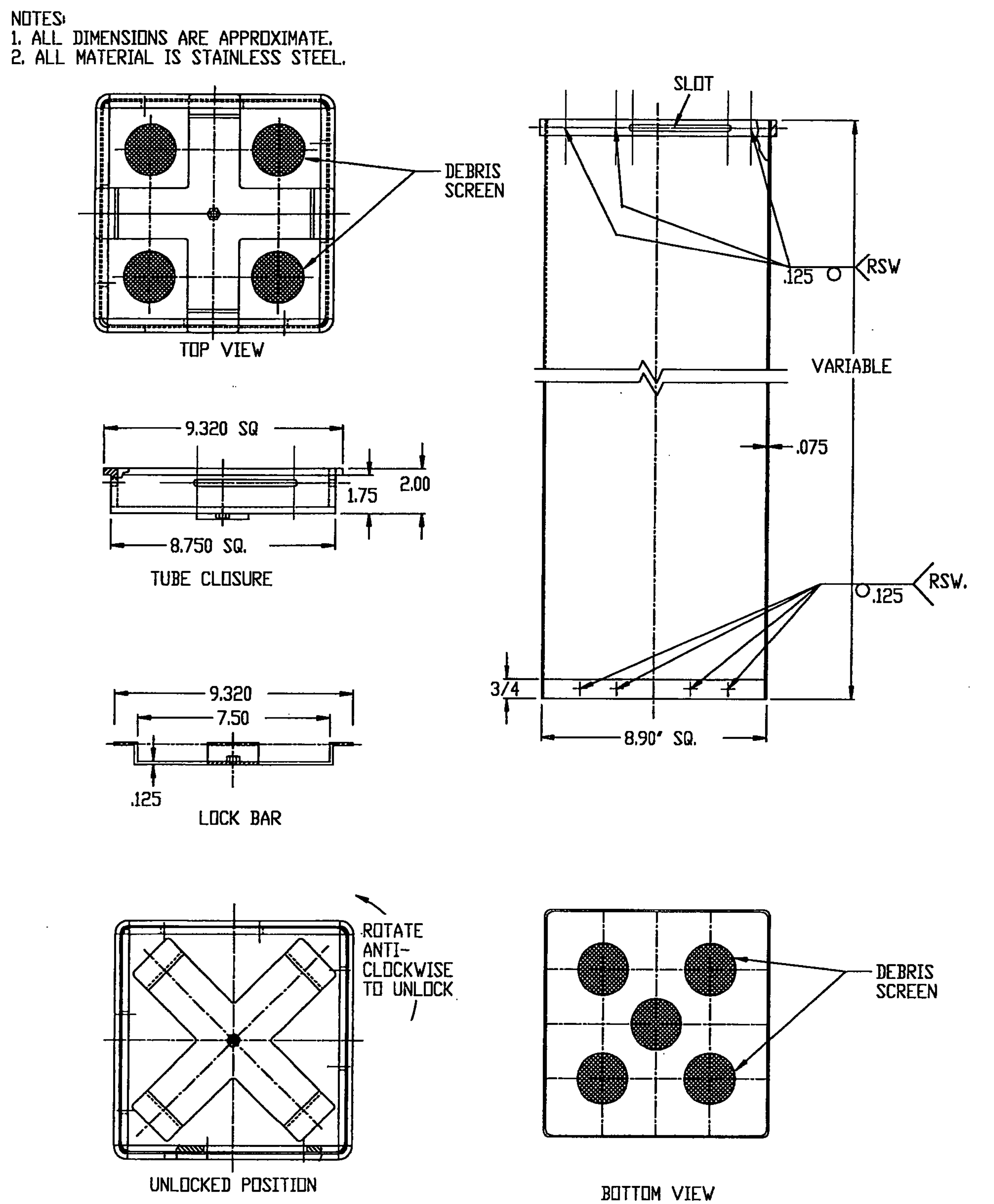

FIGURE 2.1.2B; HOLTEC DAMAGED FUEL CONTAINER FOR PWR SNF IN MPC-24E/24EF

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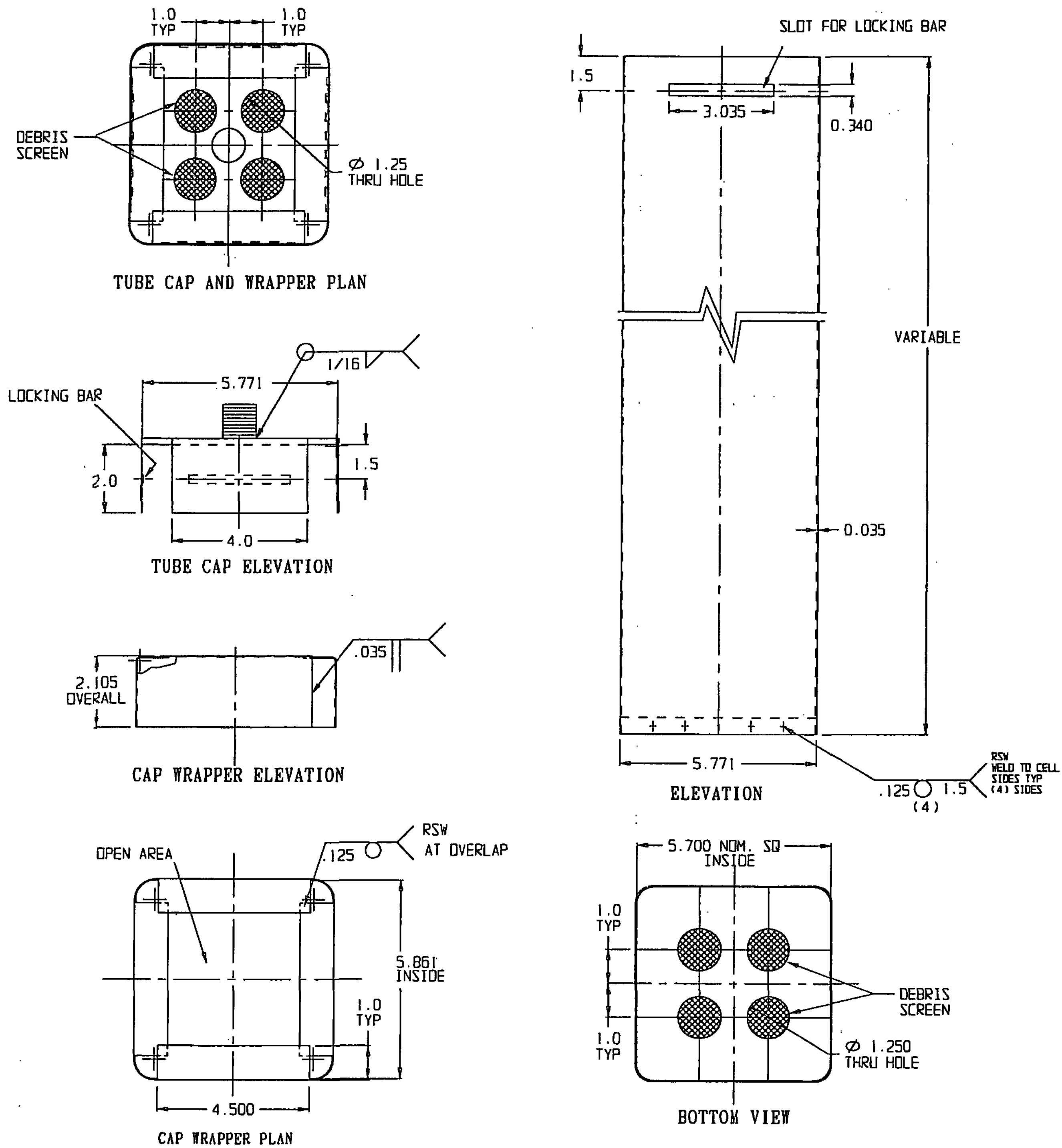

FIGURE 2.1.2C; HOLTEC DAMAGED FUEL CONTAINER FOR BWR SNF IN MPC-68/68FF

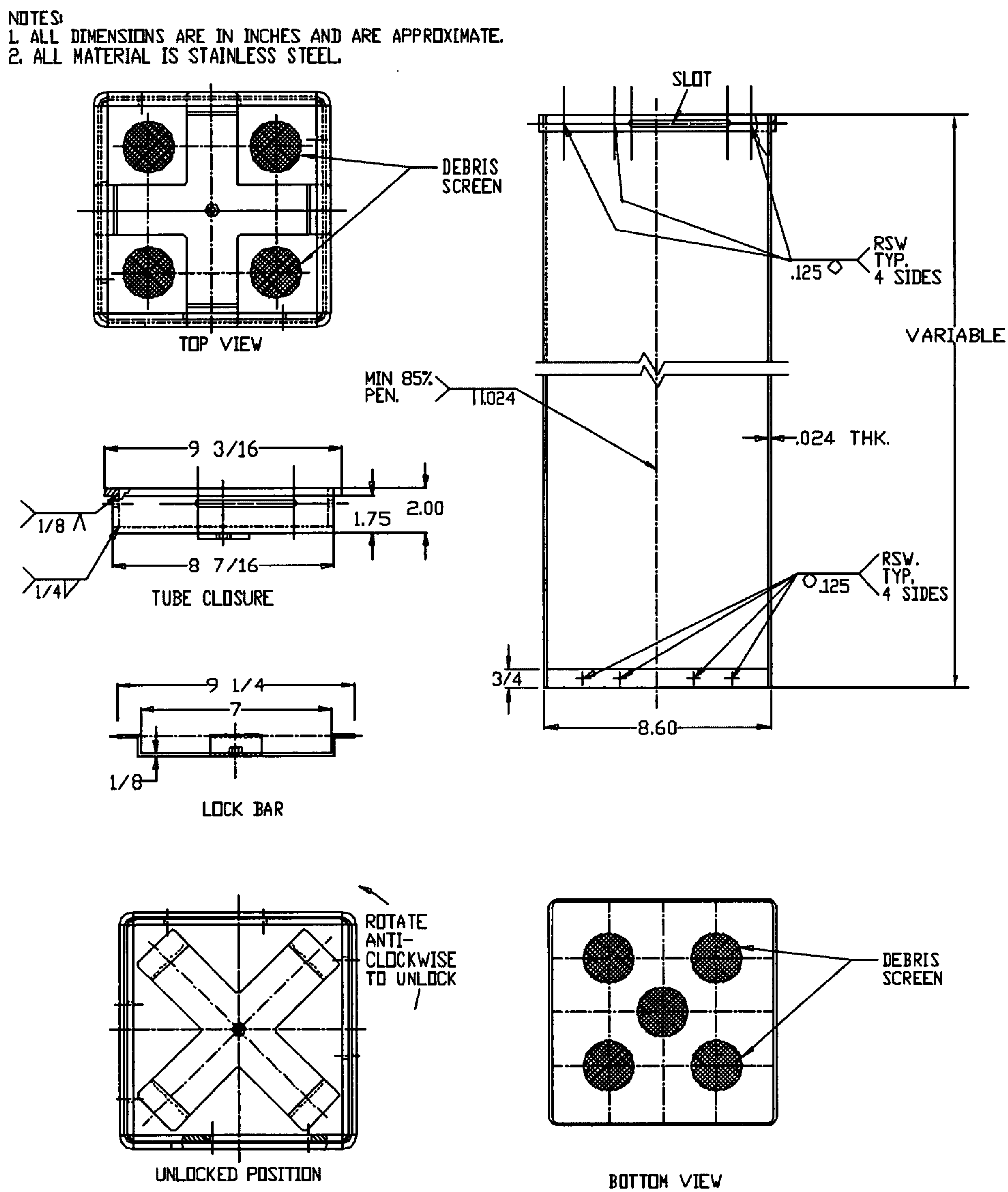

FIGURE 2.1.2D; HOLTEC DAMAGED FUEL CONTAINER FOR PWR SNF IN MPC-32/32F

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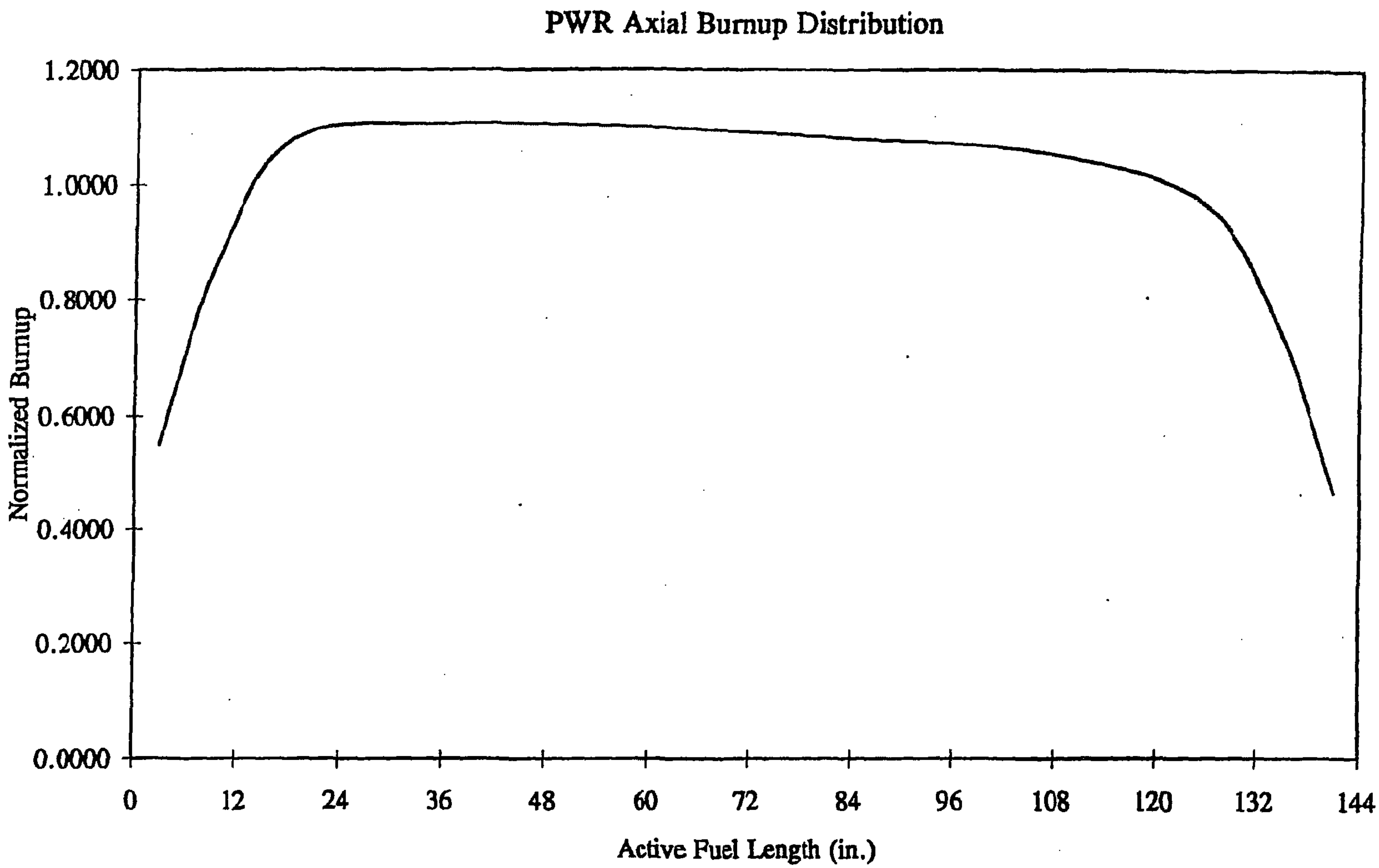

Figure 2.1.3; PWR Axial Burnup Profile with Normalized Distribution

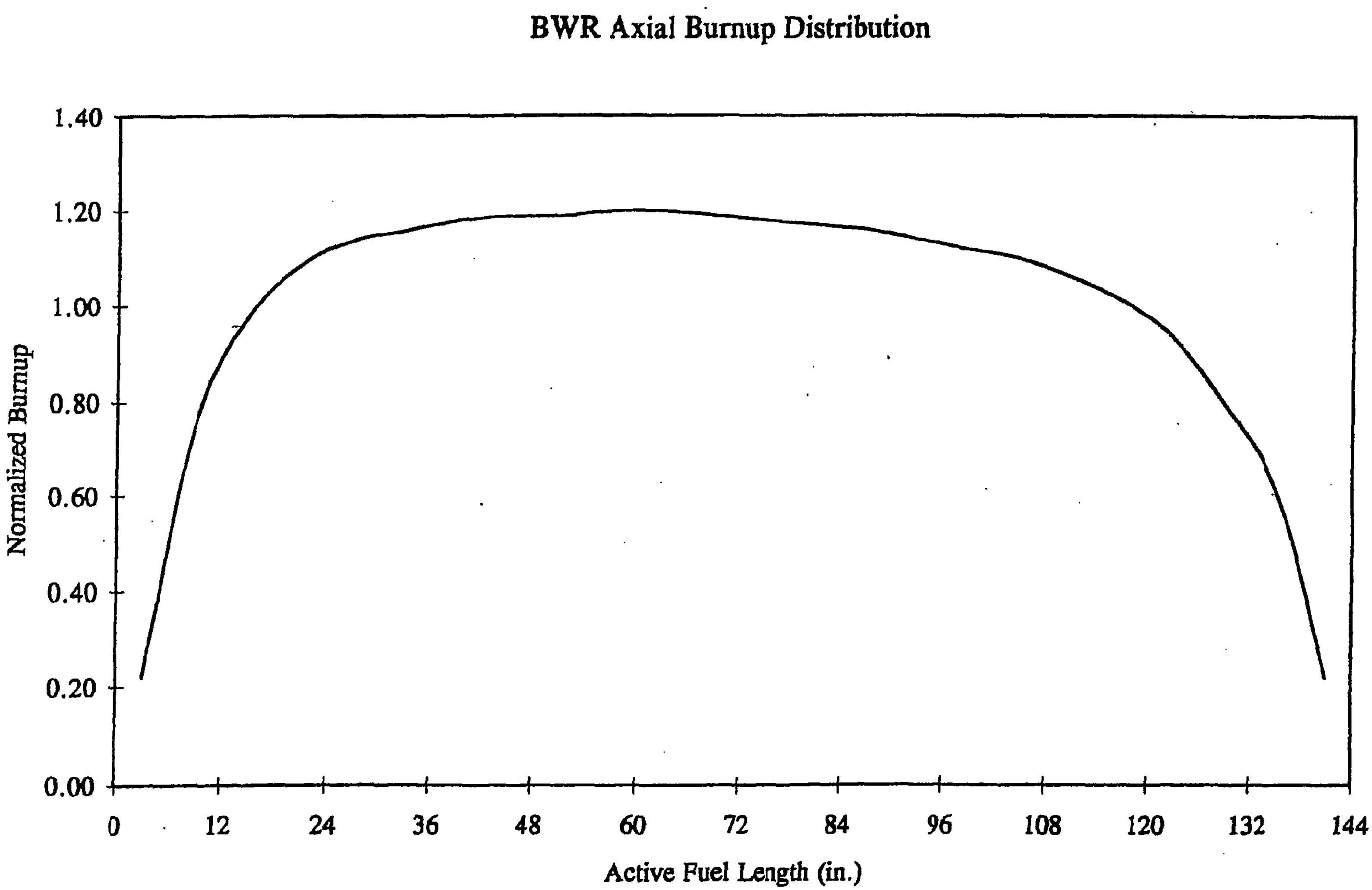

Figure 2.1.4; BWR Axial Burnup Profile with Normalized Distribution

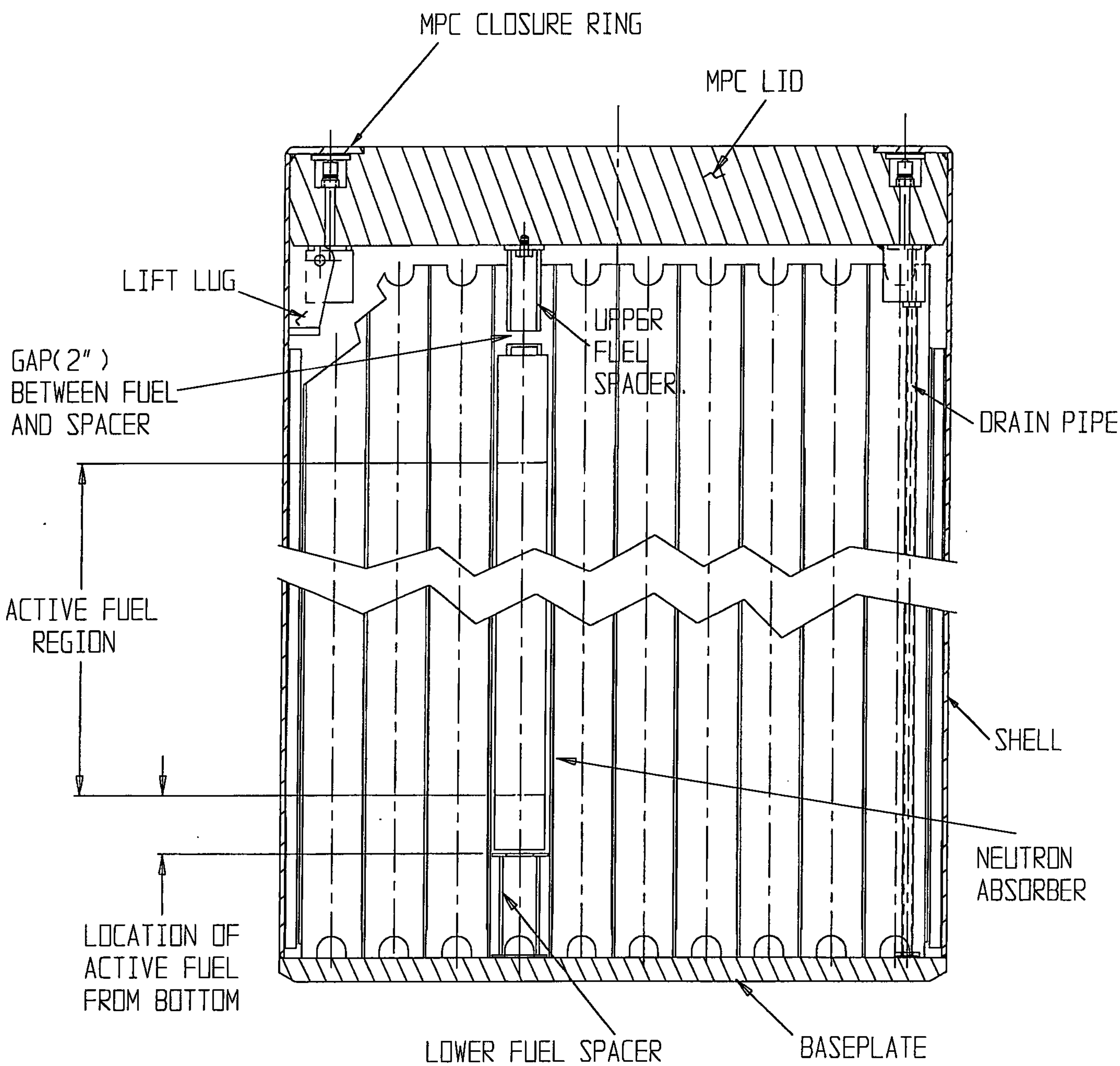

FIGURE 2.1.5; MPC WITH UPPER AND LOWER FUEL SPACERS

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FIGURE 2.1.6

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FIGURE 2.1.7; DELETED

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FIGURE 2.1.8; DELETED

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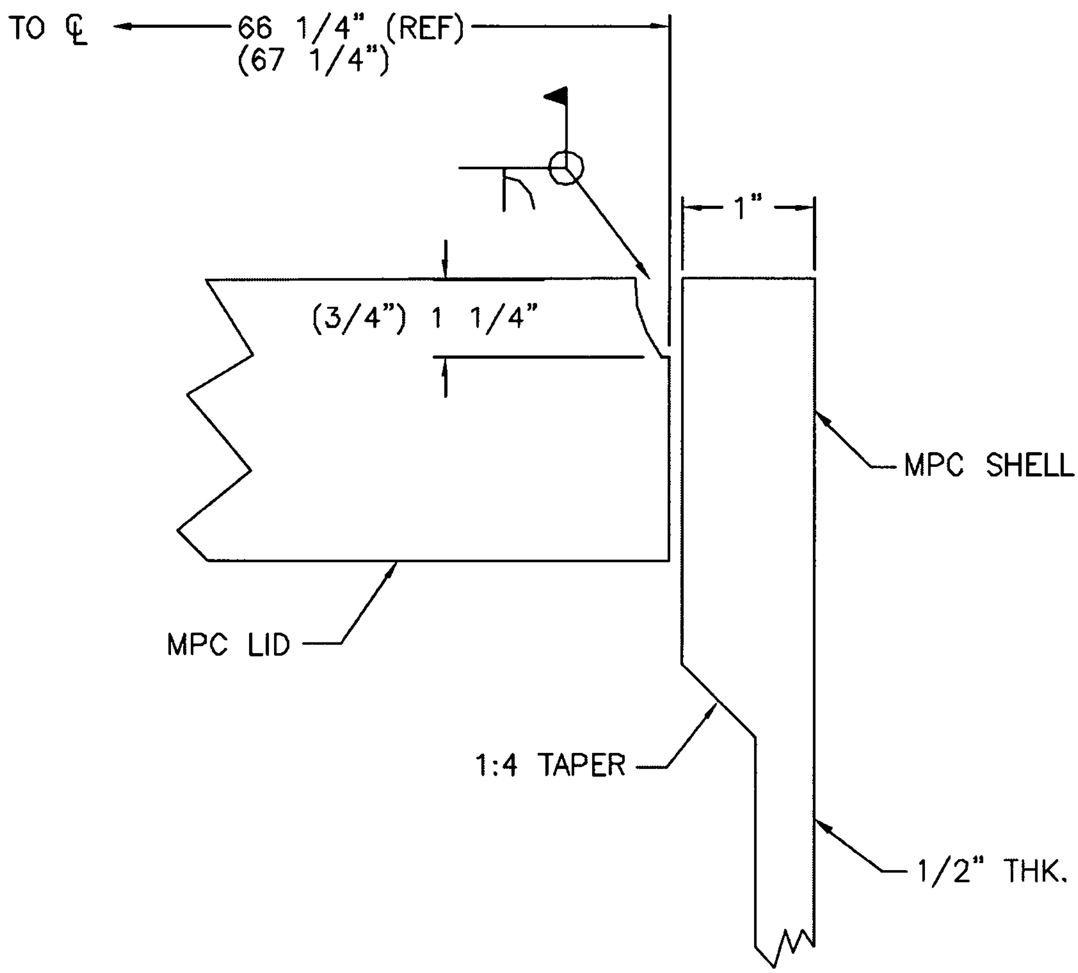

NOTES: 1. Standard MPC dimensions in parentheses.
2. Standard MPC shell thickness is 1/2" along its entire length.
3. Figure is not to scale.

Figure 2.1.9; Fuel Debris MPC ("F" Model)

2.2 HI-STORM 100 DESIGN CRITERIA

The HI-STORM 100 System is engineered for unprotected outside storage for the duration of its design life. Accordingly, the cask system is designed to withstand normal, off-normal, and environmental phenomena and accident conditions of storage. Normal conditions include the conditions that are expected to occur regularly or frequently in the course of normal operation. Off-normal conditions include those infrequent events that could reasonably be expected to occur during the lifetime of the cask system. Environmental phenomena and accident conditions include events that are postulated because their consideration establishes a conservative design basis.

Normal condition loads act in combination with all other loads (off-normal or environmental phenomena/accident). Off-normal condition loads and environmental phenomena and accident condition loads are not applied in combination. However, loads that occur as a result of the same phenomena are applied simultaneously. For example, the tornado winds loads are applied in combination with the tornado missile loads.

In the following subsections, the design criteria are established for normal, off-normal, and accident conditions for storage. Loads that require consideration under each condition are identified and the design criteria discussed. Based on consideration of the applicable requirements of the system, the following loads are identified:

Normal (Long-Term Storage) Condition: Dead Weight, Handling, Pressure, Temperature, Snow

Off-Normal Condition: Pressure, Temperature, Leakage of One Seal, Partial Blockage of Air Inlets, Off-Normal Handling of HI-TRAC, Supplemental Cooling System Power Failure

Accident Condition: Handling Accident, Tip-Over, Fire, Partial Blockage of MPC Basket Vent Holes, Tornado, Flood, Earthquake, Fuel Rod Rupture, Confinement Boundary Leakage, Explosion, Lightning, Burial Under Debris, 100% Blockage of Air Inlets, Extreme Environmental Temperature, Supplemental Cooling System Operational Failure

Short-Term Operations: This loading condition is defined to accord with ISG-11, Revision 3 guidance [2.0.8]. This 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 transfer cask.

Each of these conditions and the applicable loads are identified with applicable design criteria established. Design criteria are deemed to be satisfied if the specified allowable limits are not exceeded.

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2.2.1 Normal Condition Design Criteria

2.2.1.1 Dead Weight

The HI-STORM 100 System must withstand the static loads due to the weights of each of its components, including the weight of the HI-TRAC with the loaded MPC atop the storage overpack.

2.2.1.2 Handling

The HI-STORM 100 System must withstand loads experienced during routine handling. Normal handling includes:

- i. vertical lifting and transfer to the ISFSI of the HI-STORM overpack with loaded MPC
- ii. lifting, upending/downending, and transfer to the ISFSI of the HI-TRAC with loaded MPC in the vertical or horizontal position
- iii. lifting of the loaded MPC into and out of the HI-TRAC, HI-STORM, or HI-STAR overpack

The loads shall be increased by 15% to include any dynamic effects from the lifting operations as directed by CMAA #70 [2.2.16].

Handling operations of the loaded HI-TRAC transfer cask or HI-STORM overpack are limited to working area ambient temperatures greater than or equal to 0°F. This limitation is specified to ensure that a sufficient safety margin exists before brittle fracture might occur during handling operations. Subsection 3.1.2.3 provides the demonstration of the adequacy of the HI-TRAC transfer cask and the HI-STORM overpack for use during handling operations at a minimum service temperature of 0° F.

Lifting attachments and special lifting devices shall meet the requirements of ANSI N14.6† [2.2.3].

2.2.1.3 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.

† 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. To ensure consistency between the design and fabrication of a lifting component, compliance with ANSI N14.6 in this FSAR implies that the guidelines of ASME Section III, Subsection NF for Class 3 structures are followed for material procurement and testing, fabrication, and for NDE during manufacturing.

Table 2.2.1 provides the design pressures for the HI-STORM 100 System.

For the storage of damaged fuel assemblies or fuel debris in a damaged fuel container, it is 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) released for both normal and off-normal conditions. For PWR assemblies stored with non-fuel hardware, it is assumed that 100% of the gasses in the non-fuel hardware (e.g., BPRAs) is also released. This condition is bounded by the pressure calculation for design basis intact fuel with 100% of the fuel rods ruptured in all of the fuel assemblies. It is shown in Chapter 4 that the accident condition design pressure is not exceeded with 100% of the fuel rods ruptured in all of the design basis fuel assemblies. Therefore, rupture of 100% of the fuel rods in the damaged fuel assemblies or fuel debris will not cause the MPC internal pressure to exceed the accident design pressure.

The MPC internal design pressure under accident conditions is discussed in Subsection 2.2.3.

The HI-STORM overpack and MPC external pressure is a function of environmental conditions, which may produce a pressure loading. The normal and off-normal condition external design pressure is set at ambient standard pressure (1 atmosphere).

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

The HI-TRAC is not capable of retaining internal pressure due to its open design and, therefore, ambient and hydrostatic pressures are the only pressures experienced. Due to the thick steel walls of the HI-TRAC transfer cask, it is evident that the small hydrostatic pressure can be easily withstood; no analysis is required or provided for the HI-TRAC internal pressure. However, the HI-TRAC water jacket does experience internal pressure due to the heat-up of the water contained in the water jacket. Analysis is presented in Chapter 3 that demonstrates that the design pressure in Table 2.2.1 can be withstood by the water jacket and Chapter 4 demonstrates by analysis that the water jacket design pressure will not be exceeded. To provide an additional layer of safety, a pressure relief device set at the design pressure is provided, which ensures the pressure will not be exceeded.

2.2.1.4 Environmental Temperatures

To evaluate the long-term effects of ambient temperatures on the HI-STORM 100 System, an upper bound value on the annual average ambient temperatures for the continental United States is used. The normal temperature specified in Table 2.2.2 is bounding for all reactor sites in the contiguous United States. The "normal" temperature set forth in Table 2.2.2 is intended to ensure that it is greater than the annual average of ambient temperatures at any location in the continental United States. In the northern region of the U.S., the design basis "normal" temperature used in this FSAR will be exceeded only for brief periods, whereas in the southern U.S, it may be straddled daily in summer months. Inasmuch 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

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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 2.2.2 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 2.2.2 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. The annual average temperature is combined with insolation in accordance with 10CFR71.71 averaged over 24 hours to establish the normal condition temperatures in the HI-STORM 100 System.

2.2.1.5 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 100 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, we refer to this temperature as the "Design Temperature for Normal Conditions". Conservative calculations of the steady-state temperature field in the HI-STORM 100 System, under assumed environmental normal temperatures with the maximum decay heat load, result in HI-STORM component temperatures at or below the normal condition design temperatures for the HI-STORM 100 System defined in Table 2.2.3.

Maintaining fuel rod cladding integrity is also a design consideration. The fuel rod peak cladding temperature (PCT) limits for the long-term storage and short-term normal operating conditions meet the intent of the guidance in ISG-11, Revision 3 [2.0.8]. For moderate burnup fuel, the previously licensed PCT limit of 570°C (1058°F) may be used [2.0.9] (see also Section 4.5).

2.2.1.6 Snow and Ice

The HI-STORM 100 System must be capable of withstanding pressure loads due to snow and ice. ASCE 7-88 (formerly ANSI A58.1) [2.2.2] provides empirical formulas and tables to compute the effective design pressure on the overpack due to the accumulation of snow for the contiguous U.S. and Alaska. Typical calculated values for heated structures such as the HI-STORM 100 System range from 50 to 70 pounds per square foot. For conservatism, the snow pressure loading is set at a level in Table 2.2.8 which bounds the ASCE 7-88 recommendation.

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2.2.2 Off-Normal Conditions Design Criteria

As the HI-STORM 100 System is passive, loss of power and instrumentation failures are not defined as off-normal conditions. The off-normal condition design criteria are defined in the following subsections.

A discussion of the effects of each off-normal condition is provided in Section 11.1. Section 11.1 also provides the corrective action for each off-normal condition. The location of the detailed analysis for each event is referenced in Section 11.1.

2.2.2.1 Pressure

The HI-STORM 100 System must withstand loads due to off-normal pressure. The off-normal condition MPC internal design pressure bounds the cumulative effects of the maximum fill gas volume, off-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 in accordance with NUREG-1536.

2.2.2.2 Environmental Temperatures

The HI-STORM 100 System must withstand off-normal environmental temperatures. The off-normal environmental temperatures are specified in Table 2.2.2. The lower bound temperature occurs with no solar loads and the upper bound temperature occurs with steady- state insolation. Each bounding temperature is assumed to persist for a duration sufficient to allow the system to reach steady-state temperatures.

Limits on the peaks in the time-varying ambient temperature at an ISFSI site is 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 2.2.2 are intended to cover all ISFSI sites in the continent 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 100 storage system which reduces the effect of undulations in instantaneous temperature on the internals of the multi-purpose canister.

2.2.2.3 Design Temperatures

In addition to the normal condition design temperatures, which apply to long-term storage and short-term normal operating conditions (e.g., MPC drying operations and onsite transport operations), we also define an "off-normal/accident condition temperature" pursuant to the provisions of NUREG-1536 and Regulatory Guide 3.61. This is, in effect, the temperature, which may exist during a transient event (examples of such instances are the overpack blocked air duct off-normal event and fire accident). The off-normal/accident design temperatures of Table 2.2.3 are set down to bound the maximax (maximum in time and space) value of the thru-thickness average temperature of the pre 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 design 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 data in published references [2.2.12 and 2.2.13]. This ensures that the material will not fail due to creep rupture during these short duration transient events.

2.2.2.4 Leakage of One Seal

The MPC enclosure vessel is designed to have no credible leakage under all normal, off-normal, and hypothetical accident conditions of storage.

The confinement boundary is defined by the MPC shell, baseplate, MPC lid, port cover plates, closure ring, and associated welds. MPC shell welds and shell to baseplate weld are subject to helium leakage testing. 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 liquid penetrant examination, the MPC lid-to-shell weld is pressure tested, and volumetrically examined or multi-pass liquid penetrant examined. The vent and drain port cover plates are subject to liquid penetrant examination and helium leakage testing. These inspection and testing techniques are performed to verify the integrity of the confinement boundary.

2.2.2.5 Partial Blockage of Air Inlets

The HI-STORM 100 System must withstand the partial blockage of the overpack air inlets. This event is defined in Table 2.0.2 as 50% blockage of the four air inlets. Because the overpack air inlets and outlets are covered by screens, located 90° apart, and inspected routinely (or alternatively, exit vent air temperature monitored), significant blockage of all vents by blowing debris, animals, etc. is very unlikely. To demonstrate the inherent thermal stability of the HI-STORM 100 System all four air inlets are assumed to be 50% blocked.

2.2.2.6 Off-Normal HI-TRAC Handling

During upending and/or downending of the HI-TRAC 100 or HI-TRAC 125 transfer cask, the total lifted weight is distributed among both the upper lifting trunnions and the lower pocket trunnions. Each of the four trunnions on the HI-TRAC therefore supports approximately one-quarter of the total weight. This even distribution of the load would continue during the entire rotation operation. The HI-TRAC 100D and 125D transfer cask designs do not include pocket trunnions. Therefore, the entire load is held by the lifting trunnions.

If the lifting device cables begin to "go slack" while upending or downending the HI-TRAC 100 or HI-TRAC 125, the eccentricity of the pocket trunnions would immediately cause the cask to pivot, restoring tension on the cables. Nevertheless, the pocket trunnions are conservatively analyzed to
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support one-half of the total weight, doubling the load per trunnion. This condition is analyzed to demonstrate that the pocket trunnions in the standard HI-TRAC design possess sufficient strength to support the increased load under this off-normal condition.

2.2.3 Environmental Phenomena and Accident Condition Design Criteria

Environmental phenomena and accident condition design criteria are defined in the following subsections.

The minimum acceptance criteria for the evaluation of the accident conditions are that the MPC confinement boundary maintains radioactive material confinement, the MPC fuel basket structure maintains the fuel contents subcritical, the stored SNF can be retrieved by normal means, and the system provides adequate shielding.

A discussion of the effects of each environmental phenomenon and accident condition is provided in Section 11.2. The consequences of each accident or environmental phenomenon are evaluated against the requirements of 10CFR72.106 and 10CFR20. Section 11.2 also provides the corrective action for each event. The location of the detailed analysis for each event is referenced in Section 11.2.

2.2.3.1 Handling Accident

The HI-STORM 100 System must withstand loads due to a handling accident. Even though the loaded HI-STORM 100 System will be lifted in accordance with approved, written procedures and may use special lifting devices which complies with ANSI N14.6-1993 [2.2.3], certain drop events are considered herein to demonstrate the defense-in-depth features of the design.

The loaded HI-STORM overpack will be lifted so that the bottom of the cask is at a height less than the vertical lift limit (see Table 2.2.8) above the ground. For conservatism, the postulated drop event assumes that the loaded HI-STORM 100 overpack falls freely from the vertical lift limit height before impacting a thick reinforced concrete pad. The deceleration of the cask must be maintained below 45 g's. Additionally, the overpack must continue to suitably shield the radiation emitted from the loaded MPC. The use of special lifting devices designed in accordance with ANSI N14.6 having redundant drop protection features to lift the loaded overpack will eliminate the lift height limit. The lift height limit is dependent on the characteristics of the impacting surface, which are specified in Table 2.2.9. For site-specific conditions, which are not encompassed by Table 2.2.9, the licensee shall evaluate the site-specific conditions to ensure that the drop accident loads do not exceed 45 g's. The methodology used in this alternative analysis shall be commensurate with the analyses in Appendix 3.A and shall be reviewed by the Certificate Holder.

The loaded HI-TRAC will be lifted so that the lowest point on the transfer cask (i.e., the bottom edge of the cask/lid assemblage) is at a height less than the calculated horizontal lift height limit (see Table 2.2.8) above the ground, when lifted horizontally outside of the reactor facility. For conservatism, the postulated drop event assumes that the loaded HI-TRAC falls freely from the horizontal lift height limit before impact.

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Analysis is provided that demonstrates that the HI-TRAC continues to suitably shield the radiation emitted from the loaded MPC, and that the HI-TRAC end plates (top lid and transfer lid for HI-TRAC 100 and HI-TRAC 125 and the top lid and pool lid for HI-TRAC 100D and 125D) remain attached. Furthermore, the HI-TRAC inner shell is demonstrated by analysis to not deform sufficiently to hinder retrieval of the MPC. The horizontal lift height limit is dependent on the characteristics of the impacting surface, which are specified in Table 2.2.9. For site-specific conditions, which are not encompassed by Table 2.2.9, the licensee shall evaluate the site-specific conditions to ensure that the drop accident loads do not exceed 45 g's. The methodology used in this alternative analysis shall be commensurate with the methodology described in this FSAR and shall be reviewed by the Certificate Holder. The use of lifting devices designed in accordance with ANSI N14.6 having redundant drop protection features during horizontal lifting of the loaded HI-TRAC outside of the reactor facilities eliminate the need for a horizontal lift height limit.

The loaded HI-TRAC, when lifted in the vertical position outside of the Part 50 facility shall be lifted with devices designed in accordance with ANSI N14.6 and having redundant drop protection features unless a site-specific analysis has been performed to determine a lift height limit. For vertical lifts of HI-TRAC with suitably designed lift devices, a vertical drop is not a credible accident for the HI-TRAC transfer cask and no vertical lift height limit is required to be established. Likewise, while the loaded HI-TRAC is positioned atop the HI-STORM 100 overpack for transfer of the MPC into the overpack (outside the Part 50 facility), the lifting equipment will remain engaged with the lifting trunnions of the HI-TRAC transfer cask or suitable restraints will be provided to secure the HI-TRAC. This ensures that a tip-over or drop from atop the HI-STORM 100 overpack is not a credible accident for the HI-TRAC transfer cask. The design criteria and conditions of use for MPC transfer operations from the HI-TRAC transfer cask to the HI-STORM 100 overpack at a Cask Transfer Facility are specified in Subsection 2.3.3.1 of this FSAR.

The loaded MPC is lowered into the HI-STORM or HI-STAR overpack or raised from the overpack using the HI-TRAC transfer cask and a MPC lifting system designed in accordance with ANSI N14.6 and having redundant drop protection features. Therefore, the possibility of a loaded MPC falling freely from its highest elevation during the MPC transfer operations into the HI-STORM or HI-STAR overpacks is not credible.

The magnitude of loadings imparted to the HI-STORM 100 System due to drop events is heavily influenced by the compliance characteristics of the impacted surface. Two "pre-approved" concrete pad designs for storing the HI-STORM 100 System are presented in Table 2.2.9. Other ISFSI pad designs may be used provided the designs are reviewed by the Certificate Holder to ensure that impactive and impulsive loads under accident events such as cask drop and non-mechanistic tip-over are less than the design basis limits when analyzed using the methodologies established in this FSAR.

2.2.3.2 Tip-Over

The free-standing HI-STORM 100 System is demonstrated by analysis to remain kinematically stable under the design basis environmental phenomena (tornado, earthquake, etc.). However, the pre

HI-STORM 100 overpack and MPC shall also withstand impacts due to a hypothetical tip-over event. The structural integrity of a loaded HI-STORM 100 System after a tip-over onto a reinforced concrete pad is demonstrated by analysis. The cask tip-over is not postulated as an outcome of any environmental phenomenon or accident condition. The cask tip-over is a non-mechanistic event.

The ISFSI pad for deploying a free-standing HI-STORM overpack must possess sufficient structural stiffness to meet the strength limits set forth in the ACI Code selected by the ISFSI owner. At the same time, the pad must be sufficiently compliant such that the maximum deceleration under a tip-over event is below the limit set forth in Table 3.1.2 of this FSAR.

During original licensing for the HI-STORM 100 System, a single set of ISFSI pad and subgrade design parameters (now labeled Set A) was established. Experience has shown that achieving a maximum concrete compressive strength (at 28 days) of 4,200 psi can be difficult. Therefore, a second set of ISFSI pad and subgrade design parameters (labeled Set B) has been developed. The Set B ISFSI parameters include a thinner concrete pad and less stiff subgrade, which allow for a higher concrete compressive strength. Cask deceleration values for all design basis drop and tipover events with the HI-STORM 100, HI-STORM 100S, and HI-STORM 100S Version B overpacks have been verified to be less than or equal to the design limit of 45 g's for both sets of ISFSI pad parameters.

The original set and the new set (Set B) of acceptable ISFSI pad and subgrade design parameters are specified in Table 2.2.9. Users may design their ISFSI pads and subgrade in compliance with either parameter Set A or Set B. Alternatively, users may design their site-specific ISFSI pads and subgrade using any combination of design parameters resulting in a structurally competent pad that meets the provisions of ACI-318 and also limits the deceleration of the cask to less than or equal to 45 g's for the design basis drop and tip-over events for the HI-STORM 100, HI-STORM 100S, and HI-STORM 100S Version B overpacks. The structural analyses for site-specific ISFSI pad design shall be performed using methodologies consistent with those described in this FSAR, as applicable.

If the HI-STORM 100 System is deployed in an anchored configuration (HI-STORM 100A), then tip-over of the cask is structurally precluded along with the requirement of target compliance, which warrants setting specific limits on the concrete compressive strength and subgrade Young's Modulus. Rather, at the so-called high seismic sites (ZPAs greater than the limit set forth in the CoC for free standing casks), the ISFSI pad must be sufficiently rigid to hold the anchor studs and maintain the integrity of the fastening mechanism embedded in the pad during the postulated seismic event. The ISFSI pad must be designed to minimize a physical uplift during extreme environmental event (viz., tornado missile, DBE, etc.). The requirements on the ISFSI pad to render the cask anchoring function under long-term storage are provided in Section 2.0.4.

2.2.3.3 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 100 overpack or HI-TRAC transfer cask while it is being moved to the ISFSI.
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The HI-STORM 100 System must withstand temperatures due to a fire event. The HI-STORM overpack and HI-TRAC transfer cask fire accidents for storage are conservatively postulated to be the result of the spillage and ignition of 50 gallons of combustible transporter fuel. The HI-STORM overpack and HI-TRAC transfer cask surfaces are considered to receive an incident radiation and forced convection heat flux from the fire. Table 2.2.8 provides the fire durations for the HI-STORM overpack and HI-TRAC transfer cask based on the amount of flammable materials assumed. The temperature of fire is assumed to be 1475° F in accordance with 10CFR71.73.

The accident condition design temperatures for the HI-STORM 100 System and the fuel rod cladding limits are specified in Table 2.2.3. The specified fuel cladding temperature limits are based on the temperature limits specified in ISG-11, Rev. 3 [2.0.9].

2.2.3.4 Partial Blockage of MPC Basket Vent Holes

The HI-STORM 100 System is designed to withstand reduction of flow area due to partial blockage of the MPC basket vent holes. As the MPC basket vent holes are internal to the confinement barrier, the only events that could partially block the vents are fuel cladding failure and debris associated with this failure, or the collection of crud at the base of the stored SNF assembly. The HI-STORM 100 System maintains the SNF in an inert environment with fuel rod cladding temperatures below accepted values (Table 2.2.3). Therefore, there is no credible mechanism for gross fuel cladding degradation during storage in the HI-STORM 100. For the storage of damaged BWR fuel assemblies or fuel debris, the assemblies and fuel debris will be 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 vent holes. In addition, each MPC will be loaded once for long-term storage and, therefore, buildup of crud in the MPC due to numerous loadings is precluded. Using crud quantities reported in an Empire State Electric Energy Research Corporation Report [2.2.6], a layer of crud of conservative depth is assumed to partially block the MPC basket vent holes. The crud depths for the different MPCs are listed in Table 2.2.8.

2.2.3.5 Tornado

The HI-STORM 100 System must withstand pressures, wind loads, and missiles generated by a tornado. The prescribed design basis tornado and wind loads for the HI-STORM 100 System are consistent with NRC Regulatory Guide 1.76 [2.2.7], ANSI 57.9 [2.2.8], and ASCE 7-88 [2.2.2]. Table 2.2.4 provides the wind speeds and pressure drops which the HI-STORM 100 overpack must withstand while maintaining kinematic stability. The pressure drop is bounded by the accident condition MPC external design pressure.

The kinematic stability of the HI-STORM overpack, and continued integrity of the MPC confinement boundary, while within the storage overpack or HI-TRAC transfer cask, must be demonstrated under impact from tornado-generated missiles in conjunction with the wind loadings. Standard Review Plan (SRP) 3.5.1.4 of NUREG-0800 [2.2.9] stipulates that the postulated missiles include at least three objects: a massive high kinetic energy missile that deforms on impact (large missile); a rigid missile to test penetration resistance (penetrant missile); and a small rigid missile of

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a size sufficient to pass through any openings in the protective barriers (micro-missile). SRP 3.5.1.4 suggests an automobile for a large missile, a rigid solid steel cylinder for the penetrant missile, and a solid sphere for the small rigid missile, all impacting at 35% of the maximum horizontal wind speed of the design basis tornado. Table 2.2.5 provides the missile data used in the analysis, which is based on the above SRP guidelines. The effects of a large tornado missile are considered to bound the effects of a light general aviation airplane crashing on an ISFSI facility.

During horizontal handling of the loaded HI-TRAC transfer cask outside the Part 50 facility, tornado missile protection shall be provided to prevent tornado missiles from impacting either end of the HI-TRAC. The tornado missile protection shall be designed such that the large tornado missile cannot impact the bottom or top of the loaded HI-TRAC, while in the horizontal position. Also, the missile protection for the top of the HI-TRAC shall be designed to preclude the penetrant missile and micro-missile from passing through the penetration in the HI-TRAC top lid, while in the horizontal position. With the tornado missile protection in place, the impacting of a large tornado missile on either end of the loaded HI-TRAC or the penetrant missile or micro-missile entering the penetration of the top lid is not credible. Therefore, no analyses of these impacts are provided.

2.2.3.6 Flood

The HI-STORM 100 System must withstand pressure and water forces associated with a flood. Resultant loads on the HI-STORM 100 System consist of buoyancy effects, static pressure loads, and velocity pressure due to water velocity. The flood is assumed to deeply submerge the HI-STORM 100 System (see Table 2.2.8). The flood water depth is based on the hydrostatic pressure which is bounded by the MPC external pressure stated in Table 2.2.1.

It must be shown that the MPC does not collapse, buckle, or allow water in-leakage under the hydrostatic pressure from the flood.

The flood water is assumed to be nonstagnant. The maximum allowable flood water velocity is determined by calculating the equivalent pressure loading required to slide or tip over the HI-STORM 100 System. The design basis flood water velocity is stated in Table 2.2.8. Site-specific safety reviews by the licensee must confirm that flood parameters do not exceed the flood depth, slide, or tip-over forces.

If the flood water depth exceeds the elevation of the top of the HI-STORM overpack inlet vents, then the cooling air flow would be blocked. The flood water may also carry debris which may act to block the air inlets of the overpack. Blockage of the air inlets is addressed in Subsection 2.2.3.13.

Most reactor sites are hydrologically characterized as required by Paragraph 100.10(c) of 10CFR100 and further articulated in Reg. Guide 1.59, "Design Basis Floods for Nuclear Power Plants" and Reg. Guide 1.102, "Flood Protection for Nuclear Power Plants." It is assumed that a complete characterization of the ISFSI's hydrosphere including the effects of hurricanes, floods, seiches and tsunamis is available to enable a site-specific evaluation of the HI-STORM 100 System for

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kinematic stability. An evaluation for tsunamis† for certain coastal sites should also be performed to demonstrate that sliding or tip-over will not occur and that the maximum flood depth will not be exceeded.

Analysis for each site for such transient hydrological loadings must be made for that site. It is expected that the plant licensee will perform this evaluation under the provisions of 10CFR72.212.

2.2.3.7 Seismic Design Loadings

The HI-STORM 100 System must withstand loads arising due to a seismic event and must be shown not to tip over during a seismic event. Subsection 3.4.7 contains calculations based on conservative static "incipient tipping" calculations which demonstrate static stability. The calculations in Section 3.4.7 result in the values reported in Table 2.2.8, which provide the maximum horizontal zero period acceleration (ZPA) versus vertical acceleration multiplier above which static incipient tipping would occur. This conservatively assumes the peak acceleration values of each of the two horizontal earthquake components and the vertical component occur simultaneously. The maximum horizontal ZPA provided in Table 2.2.8 is the vector sum of two horizontal earthquakes.

For anchored casks, the limit on zero period accelerations (ZPA) is set by the structural capacity of the sector lugs and anchoring studs. Table 2.2.8 provides the limits for HI-STORM 100A for the maximum vector sum of two horizontal earthquake peak ZPA's along with the coincident limit on the vertical ZPA.

2.2.3.8 100% Fuel Rod Rupture

The HI-STORM 100 System must withstand loads due to 100% fuel rod rupture. For conservatism, 100 percent of the fuel rods are assumed to rupture with 100 percent 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 in analyzing this event.

2.2.3.9 Confinement Boundary Leakage

No credible scenario has been identified that would cause failure of the confinement system. Section 7.1 provides a discussion as to why leakage of any magnitude from the MPC is not credible, based on the materials and methods of fabrication and inspection.

2.2.3.10 Explosion

The HI-STORM 100 System must withstand loads due to an explosion. The accident condition MPC external pressure and overpack pressure differential specified in Table 2.2.1 bounds all credible

† A tsunami is an ocean wave from seismic or volcanic activity or from submarine landslides. A tsunami may be the result of nearby or distant events. A tsunami loading may exist in combination with wave splash and spray, storm surge and tides.

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external explosion events. There are no credible internal explosive events since all materials are compatible with the various operating environments, as discussed in Section 3.4.1, or appropriate preventive measures are taken to preclude internal explosive events (see Section 1.2.1.3.1.1). The MPC is composed of stainless steel, neutron absorber material, and prior to CoC Amendment 2, possibly optional aluminum alloy 1100 heat conduction elements. For these materials, and considering the protective measures taken during loading and unloading operations there is no credible internal explosive event.

2.2.3.11 Lightning

The HI-STORM 100 System must withstand loads due to lightning. The effect of lightning on the HI-STORM 100 System is evaluated in Chapter 11.

2.2.3.12 Burial Under Debris

The HI-STORM 100 System must withstand burial under debris. Such debris may result from floods, wind storms, or mud slides. Mud slides, blowing debris from a tornado, or debris in flood water may result in duct blockage, which is addressed in Subsection 2.2.3.13. The thermal effects of burial under debris on the HI-STORM 100 System are evaluated in Chapter 11. Siting of the ISFSI pad shall ensure that the storage location is not located near shifting soil. Burial under debris is a highly unlikely accident, but is analyzed in this FSAR.

2.2.3.13 100% Blockage of Air Inlets

For conservatism, this accident is defined as a complete blockage of all four bottom air inlets. Such a blockage may be postulated to occur during accident events such as a flood or tornado with blowing debris. The HI-STORM 100 System must withstand the temperature rise as a result of 100% blockage of the air inlets and outlets. The fuel cladding temperature must be shown to remain below the off-normal/accident temperature limit specified in Table 2.2.3.

2.2.3.14 Extreme Environmental Temperature

The HI-STORM 100 System must withstand extreme environmental temperatures. The extreme accident level temperature is specified in Table 2.2.2. The extreme accident level temperature occurs with steady-state insolation. This temperature is assumed to persist for a duration sufficient to allow the system to reach steady-state temperatures. The HI-STORM overpack and MPC have a large thermal inertia. Therefore, this temperature is assumed to persist over three days (3-day average).

2.2.3.15 Bounding Hydraulic, Wind, and Missile Loads for HI-STORM 100A

In the anchored configuration, the HI-STORM 100A System is clearly capable of withstanding much greater lateral loads than a free-standing overpack. Coastal sites in many areas of the world, particularly the land mass around the Pacific Ocean, may be subject to severe fluid inertial loads. Several publications [2.2.10, 2.2.11] explain and quantify the nature and source of such environmental hazards.

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It is recognized that a lateral fluid load may also be accompanied by an impact force from a fluid borne missile (debris). Rather than setting specific limits for these loads on an individual basis, a limit on the static overturning base moment on the anchorage is set. This bounding overturning moment is given in Table 2.2.8 and is set at a level that ensures that structural safety margins on the sector lugs and on the anchor studs are essentially equal to the structural safety margins of the same components under the combined effect of the net horizontal and vertical seismic load limits in Table 2.2.8.The ISFSI owner bears the responsibility to establish that the lateral hydraulic, wind, and missile loads at his ISFSI site do not yield net overturning moments, when acting separately or together, that exceed the limit value in Table 2.2.8. If loadings are increased above those values for free-standing casks, their potential effect on the other portions of the cask system must be considered.

2.2.4 Applicability of Governing Documents

The ASME Boiler and Pressure Vessel Code (ASME Code), 1995 Edition, with Addenda through 1997 [2.2.1], is the governing code for the structural design of the MPC, the metal structure of the HI-STORM 100 overpack, and the HI-TRAC transfer cask, except for Sections V and IX. The latest effective editions of ASME Section V and IX may be used, provided a written reconciliation of the later edition against the 1995 Edition, including addenda, is performed by the certificate holder. The MPC enclosure vessel and fuel basket are designed in accordance with Section III, Subsections NB Class 1 and NG Class 1, respectively. The metal structure of the overpack and the HI-TRAC transfer cask are designed in accordance with Section III, Subsection NF Class 3. The ASME Code is applied to each component consistent with the function of the component.

ACI 349 is the governing code for the plain concrete in the HI-STORM 100 overpack. ACI 318.1-85(92) is the applicable code utilized to determine the allowable compressive strength of the plain concrete credited during structural analysis. Appendix 1.D provides the sections of ACI 349 and ACI 318.1-85(92) applicable to the plain concrete.

Table 2.2.6 provides a summary of each structure, system and component (SSC) of the HI-STORM 100 System that is identified as important to safety, along with its function and governing Code. Some components perform multiple functions and in those cases, the most restrictive Code is applied. In accordance with NUREG/CR-6407, "Classification of Transportation Packaging and Dry Spent Fuel Storage System Components", and according to importance to safety, components of the HI-STORM 100 System are classified as A, B, C, or NITS (not important to safety) in Table 2.2.6. Section 13.1 provides the criteria used to classify each item. The classification of necessary auxiliary equipment is provided in Table 8.1.6.

Table 2.2.7 lists the applicable governing Code for material procurement, design, fabrication and inspection of the components of the HI-STORM 100 System. The ASME Code section listed in the design column is the section used to define allowable stresses for structural analyses.

Table 2.2.15 lists the alternatives to the ASME Code for the HI-STORM 100 System and the justification for those alternatives.

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The MPC enclosure vessel and certain fuel basket designs utilized in the HI-STORM 100 System are identical to the MPC components described in the SARs for the HI-STAR 100 System for storage (Docket 72-1008) and transport (Docket 71-9261). To avoid unnecessary repetition of the large numbers of stress analyses, this document refers to those SARs, as applicable, if the MPC loadings for storage in the HI-STORM 100 System do not exceed those computed in the HI-STAR documents. Many of the loadings in the HI-STAR applications envelope the HI-STORM loadings on the MPC, and, therefore, a complete re-analysis of the MPC is not provided in the FSAR. Certain individual MPC analyses may have been required to license a particular MPC fuel basket design for HI-STORM that was not previously licensed for HI-STAR. These unique analyses are summarized in the appropriate location in this FSAR.

Table 2.2.16 provides a summary comparison between the loading elements. Table 2.2.16 shows that most of the loadings remain unchanged and several are less than the HI-STAR loading conditions. In addition to the magnitude of the loadings experienced by the MPC, the application of the loading must also be considered. Therefore, it is evident from Table 2.2.16 that the MPC stress limits can be ascertained to be qualified a priori if the HI-STAR analyses and the thermal loadings under HI-STORM storage are not more severe compared to previously analyzed HI-STAR conditions. In the analysis of each of the normal, off-normal, and accident conditions, the effect on the MPC is evaluated and compared to the corresponding condition analyzed in the HI-STAR 100 System SARs [2.2.4 and 2.2.5]. If the HI-STORM loading is greater than the HI-STAR loading or the loading is applied differently, the analysis of its effect on the MPC is evaluated in Chapter 3.

2.2.5 Service Limits

In the ASME Code, plant and system operating conditions are commonly referred to as normal, upset, emergency, and faulted. Consistent with the terminology in NRC documents, this FSAR utilizes the terms normal, off-normal, and accident conditions.

The ASME Code defines four service conditions in addition to the Design Limits for nuclear components. They are referred to as Level A, Level B, Level C, and Level D service limits, respectively. Their definitions are provided in Paragraph NCA-2142.4 of the ASME Code. The four levels are used in this FSAR as follows:

a. Level A Service Limits: Level A Service Limits are used to establish allowables for normal condition load combinations.

b. Level B Service Limits: Level B Service Limits are used to establish allowables for off-normal condition load combinations.

c. Level C Service Limits: Level C Service Limits are not used.

d. Level D Service Limits: Level D Service Limits are used to establish allowables for accident condition load combinations.

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The ASME Code service limits are used in the structural analyses for definition of allowable stresses and allowable stress intensities. Allowable stresses and stress intensities for structural analyses are tabulated in Chapter 3. These service limits are matched with normal, off-normal, and accident condition loads combinations in the following subsections.

The MPC confinement boundary is required to meet Section III, Class 1, Subsection NB stress intensity limits. Table 2.2.10 lists the stress intensity limits for the Levels A, B, C, and D service limits for Class 1 structures extracted from the ASME Code (1995 Edition). The limits for the MPC fuel basket, required to meet the stress intensity limits of Subsection NG of the ASME Code, are listed in Table 2.2.11. Table 2.2.12 lists allowable stress limits for the steel structure of the HI-STORM overpack and HI-TRAC which are analyzed to meet the stress limits of Subsection NF, Class 3. Only service levels A, B, and D requirements, normal, off-normal, and accident conditions, are applicable.

2.2.6 Loads

Subsections 2.2.1, 2.2.2, and 2.2.3 describe the design criteria for normal, off-normal, and accident conditions, respectively. Table 2.2.13 identifies the notation for the individual loads that require consideration. The individual loads listed in Table 2.2.13 are defined from the design criteria. Each load is assigned a symbol for subsequent use in the load combinations.

The loadings listed in Table 2.2.13 fall into two broad categories; namely, (i) those that primarily affect kinematic stability, and (ii) those that produce significant stresses. The loadings in the former category are principally applicable to the overpack. Tornado wind (W'), earthquake (E), and tornado-borne missile (M) are essentially loadings which can destabilize a cask. Analyses reported in Chapter 3 show that the HI-STORM 100 overpack structure will remain kinematically stable under these loadings. Additionally, for the missile impact case (M), analyses that demonstrate that the overpack structure remains unbreached by the postulated missiles are provided in Chapter 3.

Loadings in the second category produce global stresses that must be shown to comply with the stress intensity or stress limits, as applicable. The relevant loading combinations for the fuel basket, the MPC, the HI-TRAC and the HI-STORM overpack are different because of differences in their function. For example, the fuel basket does not experience a pressure loading because it is not a pressure vessel. The specific load combination for each component is specified in Subsection 2.2.7.

2.2.7 Load Combinations

To demonstrate compliance with the design requirements for normal, off-normal, and accident conditions of storage, the individual loads, identified in Table 2.2.13, are combined into load combinations. In the formation of the load combinations, it is recognized that the number of combinations requiring detailed analyses is reduced by defining bounding loads. Analyses performed using bounding loads serve to satisfy the requirements for analysis of a multitude of separately identified loads in combination.

For example, the values established for internal and external pressures (P_i and P_o) are defined such
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that they bound other surface-intensive loads, namely snow (S), tornado wind (W'), flood (F), and explosion (E^*). Thus, evaluation of pressure in a load combination established for a given storage condition enables many individual load effects to be included in a single load combination.

Table 2.2.14 identifies the combinations of the loads that are required to be considered in order to ensure compliance with the design criteria set forth in this chapter. Table 2.2.14 presents the load combinations in terms of the loads that must be considered together. A number of load combinations are established for each ASME Service Level. Within each loading case, there may be more than one analysis that is required to demonstrate compliance. Since the breakdown into specific analyses is most applicable to the structural evaluation, the identification of individual analyses with the applicable loads for each load combination is found in Chapter 3. Tables 3.1.3 through 3.1.5 define the particular evaluations of loadings that demonstrate compliance with the load combinations of Table 2.2.14.

For structural analysis purposes, Table 2.2.14 serves as an intermediate classification table between the definition of the loads (Table 2.2.13 and Section 2.2) and the detailed analysis combinations (Tables 3.1.3 through 3.1.5).

Finally, it should be noted that the load combinations identified in NUREG-1536 are considered as applicable to the HI-STORM 100 System. The majority of load combinations in NUREG-1536 are directed toward reinforced concrete structures. Those load combinations applicable to steel structures are directed toward frame structures. As stated in NUREG-1536, Page 3-35 of Table 3-1, "Table 3-1 does not apply to the analysis of confinement casks and other components designed in accordance with Section III of the ASME B&PV Code." Since the HI-STORM 100 System is a metal shell structure, with concrete primarily employed as shielding, the load combinations of NUREG-1536 are interpreted within the confines and intent of the ASME Code.

2.2.8 Allowable Stresses

The stress intensity limits for the MPC confinement boundary for the design condition and the service conditions are provided in Table 2.2.10. The MPC confinement boundary stress intensity limits are obtained from ASME Code, Section III, Subsection NB. The stress intensity limits for the MPC fuel basket are presented in Table 2.2.11 (governed by Subsection NG of Section III). The steel structure of the overpack and the HI-TRAC meet the stress limits of Subsection NF of ASME Code, Section III for plate and shell components. Limits for the Level D condition are obtained from Appendix F of ASME Code, Section III for the steel structure of the overpack. The ASME Code is not applicable to the HI-TRAC transfer cask for accident conditions, service level D conditions. The HI-TRAC transfer cask has been shown by analysis to not deform sufficiently to apply a load to the MPC, have any shell rupture, or have the top lid, pool lid, or transfer lid (as applicable) detach.

The following definitions of terms apply to the tables on stress intensity limits; these definitions are the same as those used throughout the ASME Code:

S_m: Value of Design Stress Intensity listed in ASME Code Section II, Part D, Tables 2A, 2B and 4

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S_y: Minimum yield strength at temperature

S_u: Minimum ultimate strength at temperature

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Table 2.2.1

DESIGN PRESSURES

Pressure Location	Condition	Pressure (psig)
MPC Internal Pressure	Normal	100
	Off-Normal	110
	Accident	200
MPC External Pressure	Normal	(0) Ambient
	Off-Normal	(0) Ambient
	Accident	60
Overpack External Pressure	Normal	(0) Ambient
	Off-Normal	(0) Ambient
	Accident	10 (differential pressure for 1 second maximum)* or 5 (differential pressure steady state)
HI-TRAC Water Jacket	Normal	60
	Off-normal	60
	Accident	N/A (Under accident conditions, the water jacket is assumed to have lost all water thru the pressure relief valves)

* The overpack is also qualified to sustain without tip-over a lateral impulse load of 60 psi (differential pressure for 85 milliseconds maximum) [3.4.5].

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Table 2.2.2

ENVIRONMENTAL TEMPERATURES

Condition	Temperature (°F)	Comments
HI-STORM 100 Overpack		
Normal Ambient (Bounding Annual Average)	80	
Normal Soil Temperature (Bounding Annual Average)	77	
Off-Normal Ambient (3-Day Average)	-40 and 100	-40°F with no insolation 100°F with insolation
Extreme Accident Level Ambient (3-Day Average)	125	125°F with insolation starting at steady-state off-normal high environment temperature
HI-TRAC Transfer Cask		
Normal (Bounding Annual Average)	80	

Note:

1. Handling operations with the loaded HI-STORM overpack and HI-TRAC transfer cask are limited to working area ambient temperatures greater than or equal to 0°F as specified in Subsection 2.2.1.2.

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Table 2.2.3

DESIGN TEMPERATURES

HI-STORM 100 Component	Long Term, Normal Condition Design Temperature Limits (Long-Term Events) (° F)	Off-Normal and Accident Condition Temperature Limits (Short-Term Events)† (° F)
MPC shell	500	775
MPC basket	725	950
MPC Neutron Absorber	800	1000
MPC lid	550	775
MPC closure ring	400	775
MPC baseplate	400	775
HI-TRAC inner shell	400	800
HI-TRAC pool lid/transfer lid	350	800
HI-TRAC top lid	400	800
HI-TRAC top flange	400	700
HI-TRAC pool lid seals	350	N/A
HI-TRAC bottom lid bolts	350	800
HI-TRAC bottom flange	350	800
HI-TRAC top lid neutron shielding	300	350
HI-TRAC radial neutron shield	307	N/A
HI-TRAC radial lead gamma shield	350	600
Remainder of HI-TRAC	350	800
Fuel Cladding	752	752 or 1058 (Short Term Operations)†† 1058 (Off-Normal and Accident Conditions)
Overpack concrete	300	350
Overpack Lid Top and Bottom Plate	450	800
Remainder of overpack steel structure	350	800

† For accident conditions that involve heating of the steel structures and no mechanical loading (such as the blocked air duct accident), the permissible metal temperature of the steel parts is defined by Table 1A of ASME Section II (Part D) for Section III, Class 3 materials as 700°F. For the ISFSI fire event, the maximum temperature limit for ASME Section 1 equipment is appropriate (850°F in Code Table 1A).

†† Normal short term operations includes MPC drying and onsite transport per Reference [2.0.8]. The 1058°F temperature limit applies to MPCs containing all moderate burnup fuel as discussed in Reference [2.0.9]. The limit for MPCs containing one or more high burnup fuel assemblies is 752°F. See also Section 4.3.

Table 2.2.4

TORNADO CHARACTERISTICS

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

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Table 2.2.5

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

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TABLE 2.2.6

MATERIALS AND COMPONENTS OF THE HI-STORM 100 SYSTEM
MPC [1,2]

Primary Function	Component [3]	Safety Class [4]	Codes/Standards (as applicable to component)	Material	Strength (ksi)	Special Surface Finish/Coating	Contact Matl. (if dissimilar)
Confinement	Shell	A	ASME Section III; Subsection NB	Alloy X [5]	See Appendix 1.A	NA	NA
Confinement	Baseplate	A	ASME Section III; Subsection NB	Alloy X	See Appendix 1.A	NA	NA
Confinement	Lid (One-piece design and top portion of optional two-piece design)	A	ASME Section III; Subsection NB	Alloy X	See Appendix 1.A	NA	NA
Confinement	Closure Ring	A	ASME Section III; Subsection NB	Alloy X	See Appendix 1.A	NA	NA
Confinement	Port Cover Plates	A	ASME Section III; Subsection NB	Alloy X	See Appendix 1.A	NA	NA
Criticality Control	Basket Cell Plates	A	ASME Section III; Subsection NG core support structures (NG-1121)	Alloy X	See Appendix 1.A	NA	NA
Criticality Control	Neutron Absorber	A	Non-code	NA	NA	NA	Aluminum/SS
Shielding	Drain and Vent Shield Block	C	Non-code	Alloy X	See Appendix 1.A	NA	NA
Shielding	Plugs for Drilled Holes	NITS	Non-code	SA 193B8 (or equivalent)	See Appendix 1.A	NA	NA

Notes:
1) There are no known residuals on finished component surfaces
2) All welding processes used in welding the components shall be qualified in accordance with the requirements of ASME Section IX. All welds shall be made using welders qualified in accordance with ASME Section IX. Weld material shall meet the requirements of ASME Section II and the applicable Subsection of ASME Section III.
3) Component nomenclature taken from Bill of Materials in Chapter 1.
4) A, B, and C denote important to safety classifications as described in the Holtec QA Program. NITS stands for Not Important to Safety.
5) For details on Alloy X material, see Appendix 1.A.
6) Must be Type 304, 304LN, 316, or 316 LN with tensile strength ≥ 75 ksi, yield strength ≥ 30 ksi and chemical properties per ASTM A554.

TABLE 2.2.6

MATERIALS AND COMPONENTS OF THE HI-STORM 100 SYSTEM
MPC [1,2]

Primary Function	Component [3]	Safety Class [4]	Codes/Standards (as applicable to component)	Material	Strength (ksi)	Special Surface Finish/Coating	Contact Matl. (if dissimilar)
Shielding	Bottom portion of optional two-piece MPC lid design	B	Non-code	Alloy X or Carbon Steel	See Appendix 1.A for Alloy X, Table 3.3.6 for Carbon Steel	Stainless Steel coating when using Carbon Steel	Stainless Steel when using Carbon Steel
Structural Integrity	Upper Fuel Spacer Column	B	ASME Section III; Subsection NG (only for stress analysis)	Alloy X	See Appendix 1.A	NA	NA
Structural Integrity	Sheathing	A	Non-code	Alloy X	See Appendix 1.A	Aluminum/SS	NA
Structural Integrity	Shims	NITS	Non-code (shims, welded directly to angle or parallel plate basket supports, are ASME Section II)	Alloy X	See Appendix 1.A	NA	NA
Structural Integrity	Basket Supports (Angled Plate or Parallel Plates with connecting end shim)	A	ASME Section III; Subsection NG internal structures (NG-1122)	Alloy X	See Appendix 1.A	NA	NA
Structural Form	Basket Supports (Flat Plates)	NITS	Non-Code	Alloy X	See Appendix 1.A	NA	NA
Structural Integrity	Lift Lug	C	NUREG-0612	Alloy X	See Appendix 1.A	NA	NA
Structural Integrity	Lift Lug Baseplate	C	Non-code	Alloy X	See Appendix 1.A	NA	NA

Notes:
1) There are no known residuals on finished component surfaces
2) All welding processes used in welding the components shall be qualified in accordance with the requirements of ASME Section IX. All welds shall be made using welders qualified in accordance with ASME Section IX. Weld material shall meet the requirements of ASME Section II and the applicable Subsection of ASME Section III.
3) Component nomenclature taken from Bill of Materials in Chapter 1.
4) A, B, and C denote important to safety classifications as described in the Holtec QA Program. NITS stands for Not Important to Safety.
5) For details on Alloy X material, see Appendix 1.A.
6) Must be Type 304, 304LN, 316, or 316 LN with tensile strength $\geq$ 75 ksi, yield strength $\geq$ 30 ksi and chemical properties per ASTM A554.

TABLE 2.2.6

MATERIALS AND COMPONENTS OF THE HI-STORM 100 SYSTEM
MPC [1,2]

Primary Function	Component [3]	Safety Class [4]	Codes/Standards (as applicable to component)	Material	Strength (ksi)	Special Surface Finish/Coating	Contact Matl. (if dissimilar)
Structural Integrity	Upper Fuel Spacer Bolt	NITS	Non-code	A193-B8 (or equiv.)	Per ASME Section II	NA	NA
Structural Integrity	Upper Fuel Spacer End Plate	B	Non-code	Alloy X	See Appendix 1.A	NA	NA
Structural Integrity	Lower Fuel Spacer Column	B	ASME Section III; Subsection NG (only for stress analysis)	Stainless Steel. See Note 6	See Appendix 1.A	NA	NA
Structural Integrity	Lower Fuel Spacer End Plate	B	Non-code	Alloy X	See Appendix 1.A	NA	NA
Structural Integrity	Vent Shield Block Spacer	C	Non-code	Alloy X	See Appendix 1.A	NA	NA
Operations	Vent and Drain Tube	C	Non-code	S/S	Per ASME Section II	Thread area surface hardened	NA
Operations	Vent & Drain Cap	C	Non-code	S/S	Per ASME Section II	NA	NA
Operations	Vent & Drain Cap Seal Washer	NITS	Non-code	Aluminum	NA	NA	Aluminum/SS
Operations	Vent & Drain Cap Seal Washer Bolt	NITS	Non-code	Aluminum	NA	NA	NA
Operations	Reducer	NITS	Non-code	Alloy X	See Appendix 1.A	NA	NA
Operations	Drain Line	NITS	Non-code	Alloy X	See Appendix 1.A	NA	NA

Notes:
1) There are no known residuals on finished component surfaces
2) All welding processes used in welding the components shall be qualified in accordance with the requirements of ASME Section IX. All welds shall be made using welders qualified in accordance with ASME Section IX. Weld material shall meet the requirements of ASME Section II and the applicable Subsection of ASME Section III.
3) Component nomenclature taken from Bill of Materials in Chapter 1.
4) A, B, and C denote important to safety classifications as described in the Holtec QA Program. NITS stands for Not Important to Safety.
5) For details on Alloy X material, see Appendix 1.A.
6) Must be Type 304, 304LN, 316, or 316 LN with tensile strength $\geq$ 75 ksi, yield strength $\geq$ 30 ksi and chemical properties per ASTM A554.

TABLE 2.2.6

MATERIALS AND COMPONENTS OF THE HI-STORM 100 SYSTEM
MPC [1,2]

Primary Function	Component [3]	Safety Class [4]	Codes/Standards (as applicable to component)	Material	Strength (ksi)	Special Surface Finish/Coating	Contact Matl. (if dissimilar)
Operations	Damaged Fuel Container	C	ASME Section III; Subsection NG	S/S (Primarily 304 S/S)	See Appendix 1.A	NA	NA
Operations	Drain Line Guide Tube	NITS	Non-code	S/S	NA	NA	NA
Operations	Vent and Drain Tube, Optional	C	Non-code	S/S	Per ASME Section II	Thread area surface hardened	N/A
Operations	Threaded Disc, Plug Adjustment	C	Non-code	S/S	Per ASME Section II	N/A	N/A
Operations	Vent and Drain Plug	C	Non-code	Aluminum	N/A	N/A	N/A
Operations	Thread Shield Cap	NITS	Non-code	Aluminum	N/A	N/A	N/A
Operations	Retaining Ring	NITS	Non-code	S/S	N/A	N/A	N/A

Notes:
1) There are no known residuals on finished component surfaces
2) All welding processes used in welding the components shall be qualified in accordance with the requirements of ASME Section IX. All welds shall be made using welders qualified in accordance with ASME Section IX. Weld material shall meet the requirements of ASME Section II and the applicable Subsection of ASME Section III.
3) Component nomenclature taken from Bill of Materials in Chapter 1.
4) A, B, and C denote important to safety classifications as described in the Holtec QA Program. NITS stands for Not Important to Safety.
5) For details on Alloy X material, see Appendix 1.A.
6) Must be Type 304, 304LN, 316, or 316 LN with tensile strength $\geq$ 75 ksi, yield strength $\geq$ 30 ksi and chemical properties per ASTM A554.

TABLE 2.2.6

MATERIALS AND COMPONENTS OF THE HI-STORM 100 SYSTEM OVERPACK [1,2]

Primary Function	Component [3]	Safety Class [4]	Codes/Standards (as applicable to component)	Material	Strength (ksi)	Special Surface Finish/Coating	Contact Matl. (if dissimilar)
Shielding	Radial Shield	B	ACI 349, App. 1.D	Concrete	See Table 1.D.1	NA	NA
Shielding	Shield Block Ring (100)	B	See Note 6	SA516-70	See Table 3.3.2	See Note 5	NA
Shielding	Lid Shield Ring (100S and 100S Version B) and Shield Block Shell (100S)	B	ASME Section III; Subsection NF	SA516-70 or SA515-70 (SA515-70 not permitted for 100S Version B)	See Table 3.3.2	See Note 5	NA
Shielding	Shield Block Shell (100)	B	See Note 6	SA516-70 or SA515-70	See Table 3.3.2	See Note 5	NA
Shielding	Pedestal Shield	B	ACI 349, App. 1-D	Concrete	See Table 1.D.1	NA	NA
Shielding	Lid Shield	B	ACI 349, App. 1-D	Concrete	See Table 1.D.1	NA	NA
Shielding	Shield Shell (eliminated from design 6/01)	B	See Note 6	SA516-70	See Table 3.3.2	NA	NA
Shielding	Shield Block	B	ACI 349, App. 1-D	Concrete	See Table 1.D.1	NA	NA
Shielding	Gamma Shield Cross Plates & Tabs	C	Non-code	SA240-304	NA	NA	NA

Notes:
1) There are no known residuals on finished component surfaces
2) All welding processes used in welding the components shall be qualified in accordance with the requirements of ASME Section IX. All welds shall be made using welders qualified in accordance with ASME Section IX. Weld material shall meet the requirements of ASME Section II and the applicable Subsection of ASME Section III.
3) Component nomenclature taken from Bills of Material and drawings in Chapter 1. All components are "as applicable" based in the overpack drawing/BOM unless otherwise noted.
4) A, B, and C denote important to safety classifications as described in the Holtec QA Program. NITS stands for Not Important to Safety.
5) All exposed steel surfaces (except threaded holes) to be painted in accordance with Appendix 1.C, to the extent practical.
6) Welds will meet AWS D1.1 requirements for prequalified welds, except that welder qualification and weld procedures of ASME Code Section IX may be substituted.

TABLE 2.2.6

MATERIALS AND COMPONENTS OF THE HI-STORM 100 SYSTEM OVERPACK [1,2]

Primary Function	Component [3]	Safety Class [4]	Codes/Standards (as applicable to component)	Material	Strength (ksi)	Special Surface Finish/Coating	Contact Matl. (if dissimilar)
Structural Integrity	Baseplate	B	ASME Section III; Subsection NF	SA516-70	See Table 3.3.3	See Note 5	NA
Structural Integrity	Outer Shell	B	ASME Section III; Subsection NF	SA516-70	See Table 3.3.2	See Note 5	NA
Structural Integrity	Inner Shell	B	ASME Section III; Subsection NF	SA516-70	See Table 3.3.2	See Note 5	NA
Concrete Form	Pedestal Shell	B	See Note 6	SA516-70	See Table 3.3.2	See Note 5	NA
Concrete Form	Pedestal Plate (100) Pedestal Baseplate (100S)	B	See Note 6	SA516-70 or SA515-70	See Table 3.3.2	See Table 3.3.2	NA
Structural Integrity	Lid Bottom Plate	B	ASME Section III; Subsection NF	SA516-70	See Table 3.3.2	See Note 5	NA
Structural Integrity	Lid Shell	B	ASME Section III; Subsection NF	SA516-70	See Table 3.3.2	See Note 5	NA
Structural Integrity	Inlet Vent Vertical & Horizontal Plates	B	ASME Section III; Subsection NF	SA516-70	See Table 3.3.2	See Note 5	NA
Thermal	Exit Vent Horizontal Plate (100)	B	See Note 6	SA516-70	See Table 3.3.2	See Note 5	NA
Thermal	Exit Vent Vertical/Side Plate	B	See Note 6	SA516-70 or SA515-70	See Table 3.3.2	See Note 5	NA

Notes:
1) There are no known residuals on finished component surfaces
2) All welding processes used in welding the components shall be qualified in accordance with the requirements of ASME Section IX. All welds shall be made using welders qualified in accordance with ASME Section IX. Weld material shall meet the requirements of ASME Section II and the applicable Subsection of ASME Section III.
3) Component nomenclature taken from Bills of Material and drawings in Chapter 1. All components are "as applicable" based in the overpack drawing/BOM unless otherwise noted.
4) A, B, and C denote important to safety classifications as described in the Holtec QA Program. NITS stands for Not Important to Safety.
5) All exposed steel surfaces (except threaded holes) to be painted in accordance with Appendix 1.C, to the extent practical.
6) Welds will meet AWS D1.1 requirements for prequalified welds, except that welder qualification and weld procedures of ASME Code Section IX may be substituted.

TABLE 2.2.6

MATERIALS AND COMPONENTS OF THE HI-STORM 100 SYSTEM OVERPACK [1,2]

Primary Function	Component [3]	Safety Class [4]	Codes/Standards (as applicable to component)	Material	Strength (ksi)	Special Surface Finish/Coating	Contact Matl. (if dissimilar)
Thermal	Heat Shield	B	N/A	C/S	N/A	See Note 5	N/A
Thermal	Heat Shield Ring	B	N/A	C/S	N/A	See Note 5	N/A
Structural Integrity	Top Plate, including shear ring	B	ASME Section III; Subsection NF	SA516-70	See Table 3.3.2	See Note 5	NA
Structural Integrity	Lid Top (Cover) Plate, including shear ring (100 and 100S)	B	ASME Section III; Subsection NF	SA516-70	See Table 3.3.2	See Note 5	NA
Structural Integrity	Radial Plate	B	ASME Section III; Subsection NF	SA516-70	See Table 3.3.2	See Note 5	NA
Structural Integrity	Lid Stud & Nut	B	ASME Section II	SA564-630 or SA 193-B7 (stud) SA 194-2H (nut)	See Table 3.3.4 (stud) Per ASME Section II (nut)	Threads to have cadmium coating (or similar lubricant for corrosion protection)	NA
Structural Integrity	100S Lid Washer	B	Non-Code	SA240-304	Per ASME Section II	NA	NA
Structural Integrity	Bolt Anchor Block	B	ASME Section III; Subsection NF ANSI N14.6	SA350-LF3, SA350-LF2, or SA203E	See Table 3.3.3	See Note 5	NA

Notes:
1) There are no known residuals on finished component surfaces
2) All welding processes used in welding the components shall be qualified in accordance with the requirements of ASME Section IX. All welds shall be made using welders qualified in accordance with ASME Section IX. Weld material shall meet the requirements of ASME Section II and the applicable Subsection of ASME Section III.
3) Component nomenclature taken from Bills of Material and drawings in Chapter 1. All components are "as applicable" based in the overpack drawing/BOM unless otherwise noted.
4) A, B, and C denote important to safety classifications as described in the Holtec QA Program. NITS stands for Not Important to Safety.
5) All exposed steel surfaces (except threaded holes) to be painted in accordance with Appendix 1.C, to the extent practical.
6) Welds will meet AWS D1.1 requirements for prequalified welds, except that welder qualification and weld procedures of ASME Code Section IX may be substituted.

TABLE 2.2.6

MATERIALS AND COMPONENTS OF THE HI-STORM 100 SYSTEM OVERPACK [1,2]

Primary Function	Component [3]	Safety Class [4]	Codes/Standards (as applicable to component)	Material	Strength (ksi)	Special Surface Finish/Coating	Contact Matl. (if dissimilar)
Structural Integrity	Channel	B	ASME Section III; Subsection NF	SA516-70 (galvanized) or SA240-304	See Table 3.3.2 or Table 3.3.1	See Note 5	NA
Structural Integrity	Channel Mounts	B	ASME Section III; Subsection NF	SA36 or equivalent	Per ASME Section II	See Note 5	NA
Shielding	Pedestal Platform	B	Non-Code	SA36 or equivalent	NA	See Note 5	NA
Operations	Storage Marking Nameplate	NITS	Non-code	SA240-304	NA	NA	NA
Operations	Exit Vent Screen Sheet	NITS	Non-code	SA240-304	NA	NA	NA
Operations	Drain Pipe	NITS	Non-code	C/S or S/S	NA	See Note 5	NA
Operations	Exit & Inlet Screen Frame	NITS	Non-code	SA240-304	NA	NA	NA
Operations	Temperature Element & Associated Temperature Monitoring Equipment	C	Non-code	NA	NA	NA	NA
Operations	Screen	NITS	Non-code	Mesh Wire	NA	NA	NA
Operations	Paint	NITS	Non-code	Per Appendix 1.C	NA	NA	NA

Notes:
1) There are no known residuals on finished component surfaces
2) All welding processes used in welding the components shall be qualified in accordance with the requirements of ASME Section IX. All welds shall be made using welders qualified in accordance with ASME Section IX. Weld material shall meet the requirements of ASME Section II and the applicable Subsection of ASME Section III.
3) Component nomenclature taken from Bills of Material and drawings in Chapter 1. All components are "as applicable" based in the overpack drawing/BOM unless otherwise noted.
4) A, B, and C denote important to safety classifications as described in the Holtec QA Program. NITS stands for Not Important to Safety.
5) All exposed steel surfaces (except threaded holes) to be painted in accordance with Appendix 1.C, to the extent practical.
6) Welds will meet AWS D1.1 requirements for prequalified welds, except that welder qualification and weld procedures of ASME Code Section IX may be substituted.

TABLE 2.2.6

MATERIALS AND COMPONENTS OF THE HI-STORM 100 SYSTEM OVERPACK [1,2]

Primary Function	Component [3]	Safety Class [4]	Codes/Standards (as applicable to component)	Material	Strength (ksi)	Special Surface Finish/Coating	Contact Matl. (if dissimilar)
Structural Integrity	100S Version B Base Bottom Plate	B	ASME III; Subsection NF	Carbon Steel	See Table 3.3.6	See Note 5	NA
Structural Integrity	100S Version B Base Spacer Block	B	Non-code	Carbon Steel	See Table 3.3.6	See Note 5	NA
Shielding	100S Version B Base Shield Block	B	Non-code	Carbon Steel	NA	See Note 5	NA
Structural Integrity	100S Version B Base Top Plate	B	ASME III; Subsection NF	SA 516-70	See Table 3.3.2	See Note 5	NA
Structural Integrity	100S Version B Base MPC Support	B	Non-code	Carbon Steel	See Table 3.3.6	See Note 5	NA
Shielding	100S Version B Lid Outer Ring	B	ASME III; Subsection NF	SA516-70 or SA36	See Table 3.3.2 or Table 3.3.6	See Note 5	NA
Operations	100S Version B Lid Vent Duct	NITS	Non-code	Carbon Steel	NA	See Note 5	NA
Structural Integrity	100S Version B Lid Inner Ring	B	ASME III; Subsection NF	Carbon Steel	See Table 3.3.6	See Note 5	NA
Operations	100S Version B Lid Stud Pipe	NITS	Non-code	Carbon Steel	NA	See Note 5	NA
Operations	100S Version B Lid Stud Spacer	NITS	Non-code	Carbon Steel	NA	See Note 5	NA

Notes:
1) There are no known residuals on finished component surfaces
2) All welding processes used in welding the components shall be qualified in accordance with the requirements of ASME Section IX. All welds shall be made using welders qualified in accordance with ASME Section IX. Weld material shall meet the requirements of ASME Section II and the applicable Subsection of ASME Section III.
3) Component nomenclature taken from Bills of Material and drawings in Chapter 1. All components are "as applicable" based in the overpack drawing/BOM unless otherwise noted.
4) A, B, and C denote important to safety classifications as described in the Holtec QA Program. NITS stands for Not Important to Safety.
5) All exposed steel surfaces (except threaded holes) to be painted in accordance with Appendix 1.C, to the extent practical.
6) Welds will meet AWS D1.1 requirements for prequalified welds, except that welder qualification and weld procedures of ASME Code Section IX may be substituted.

TABLE 2.2.6

MATERIALS AND COMPONENTS OF THE HI-STORM 100 SYSTEM OVERPACK [1,2]

Primary Function	Component [3]	Safety Class [4]	Codes/Standards (as applicable to component)	Material	Strength (ksi)	Special Surface Finish/Coating	Contact Matl. (if dissimilar)
Operations	100S Version B Lid Lift Block	B	ASME III; Subsection NF	SA36	See Table 3.3.6	See Note 5	NA
Shielding	100S Version B Lid Vent Shield	B	Non-code	Carbon Steel	NA	See Note 5	NA
Operations	100S Version B Lid Stud Washer	C	Non-code	Stainless Steel	NA	See Note 5	NA
Operations	100S Version B Lid Stud Cap	NITS	Non-code	PVC	NA	See Note 5	NA
Structural Integrity	100S Version B Radial Gusset	B	ASME III; Subsection NF	SA 516-70	See Table 3.3.2	See Note 5	NA
Structural Integrity	100S Version B Lid Closure Bolt and Closure Bolt Handle	B (bolt) NITS (bolt Handle)	ASME Section II	SA 193-B7 (bolt) C/S (bolt handle)	See Table 3.3.4 (bolt) NA (bolt handle)	Threads to have cadmium coating (or similar lubricant for corrosion protection)	NA
Structural Integrity	100S Version B Lid Top (Cover) Plate	B	ASME Section III; Subsection NF	SA516-70 or SA36	See Table 3.3.2 or Table 3.3.6	See Note 5	NA
Structural Integrity	100S Version B Shear Ring	B	ASME Section III; Subsection NF	SA516-70	See Table 3.3.2	See Note 5	NA

Notes:
1) There are no known residuals on finished component surfaces
2) All welding processes used in welding the components shall be qualified in accordance with the requirements of ASME Section IX. All welds shall be made using welders qualified in accordance with ASME Section IX. Weld material shall meet the requirements of ASME Section II and the applicable Subsection of ASME Section III.
3) Component nomenclature taken from Bills of Material and drawings in Chapter 1. All components are "as applicable" based in the overpack drawing/BOM unless otherwise noted.
4) A, B, and C denote important to safety classifications as described in the Holtec QA Program. NITS stands for Not Important to Safety.
5) All exposed steel surfaces (except threaded holes) to be painted in accordance with Appendix 1.C, to the extent practical.
6) Welds will meet AWS D1.1 requirements for prequalified welds, except that welder qualification and weld procedures of ASME Code Section IX may be substituted.

TABLE 2.2.6

MATERIALS AND COMPONENTS OF THE HI-STORM 100 SYSTEM
HI-TRAC TRANSFER CASK (1,2)

Primary Function	Component (3)	Safety Class (4)	Codes/Standards (as applicable to component)	Material	Strength (ksi)	Special Surface Finish/Coating	Contact Matl. (if dissimilar)
Shielding	Radial Lead Shield	B	Non-code	Lead	NA	NA	NA
Shielding	Pool Lid Lead Shield	B	Non-code	Lead	NA	NA	NA
Shielding	Top Lid Shielding	B	Non-code	Holtite	NA	NA	NA
Shielding	Plugs for Lifting Holes	NITS	Non-code	C/S or S/S	NA	NA	
Structural Integrity	Outer Shell	B	ASME Section III; Subsection NF	SA516-70	See Table 3.3.2	See Note 5	NA
Structural Integrity	Inner Shell	B	ASME Section III; Subsection NF	SA516-70	See Table 3.3.2	See Note 5	NA
Structural Integrity	Radial Ribs	B	ASME Section III; Subsection NF	SA516-70	See Table 3.3.2	See Note 5	NA
Structural Integrity	Water Jacket Enclosure Shell Panels (HI-TRAC 100 and 125)	B	ASME Section III; Subsection NF	SA516-70	See Table 3.3.2	See Note 5	NA
Structural Integrity	Water Jacket Enclosure Shell Panels (HI-TRAC 100D and 125D)	B	ASME Section III; Subsection NF	SA516-70 or SA515-70	See Table 3.3.2	See Note 5	NA
Structural Integrity	Water Jacket End Plate	B	ASME Section III; Subsection NF	SA516-70	See Table 3.3.2	See Note 5	NA
Structural Integrity	Top Flange	B	ASME Section III; Subsection NF	SA350-LF3	See Table 3.3.3	See Note 5	NA
Structural Integrity	Lower Water Jacket Shell	B	ASME Section III; Subsection NF	SA516-70	See Table 3.3.2	See Note 5	NA

Notes:
1) There are no known residuals on finished component surfaces
2) All welding processes used in welding the components shall be qualified in accordance with the requirements of ASME Section IX. All welds shall be made using welders qualified in accordance with ASME Section IX. Weld material shall meet the requirements of ASME Section II and the applicable Subsection of ASME Section III.
3) Component nomenclature taken from Bill of Materials in Chapter 1.
4) A, B, and C denote important to safety classifications as described in the Holtec QA Program. NITS stands for Not Important to Safety.
5) All surfaces to be painted in accordance with Appendix 1.C, as applicable.

TABLE 2.2.6

MATERIALS AND COMPONENTS OF THE HI-STORM 100 SYSTEM
HI-TRAC TRANSFER CASK [1,2]

Primary Function	Component [3]	Safety Class [4]	Codes/Standards (as applicable to component)	Material	Strength (ksi)	Special Surface Finish/Coating	Contact Matl. (if dissimilar)
Structural Integrity	Pool Lid Outer Ring	B	ASME Section III; Subsection NF	SA516-70 or SA 203E or SA350-LF3	See Table 3.3.2 or Table 3.3.3	See Note 5	NA
Structural Integrity	Pool Lid Top Plate	B	ASME Section III; Subsection NF	SA516-70	See Table 3.3.2	See Note 5	NA
Structural Integrity	Top Lid Outer Ring	B	ASME Section III; Subsection NF	SA516-70	See Table 3.3.2	See Note 5	NA
Structural Integrity	Top Lid Inner Ring	B	ASME Section III; Subsection NF	SA516-70	See Table 3.3.2	See Note 5	NA
Structural Integrity	Top Lid Top Plate	B	ASME Section III; Subsection NF	SA516-70	See Table 3.3.2	See Note 5	NA
Structural Integrity	Top Lid Bottom Plate	B	ASME Section III; Subsection NF	SA516-70	See Table 3.3.2	See Note 5	NA
Structural Integrity	Fill Port Plugs	C	ASME Section III; Subsection NF	Carbon Steel	See Table 3.3.2	See Note 5	NA

Notes:
1) There are no known residuals on finished component surfaces
2) All welding processes used in welding the components shall be qualified in accordance with the requirements of ASME Section IX. All welds shall be made using welders qualified in accordance with ASME Section IX. Weld material shall meet the requirements of ASME Section II and the applicable Subsection of ASME Section III.
3) Component nomenclature taken from Bill of Materials in Chapter 1.
4) A, B, and C denote important to safety classifications as described in the Holtec QA Program. NITS stands for Not Important to Safety.
5) All surfaces to be painted in accordance with Appendix 1.C, as applicable.

TABLE 2.2.6

MATERIALS AND COMPONENTS OF THE HI-STORM 100 SYSTEM
HI-TRAC TRANSFER CASK [1,2]

Primary Function	Component [3]	Safety Class [4]	Codes/Standards (as applicable to component)	Material	Strength (ksi)	Special Surface Finish/Coating	Contact Matl. (if dissimilar)
Structural Integrity	Pool Lid Bolt	B	ASME Section III; Subsection NF	SA193-B7	See Table 3.3.4	NA	NA
Structural Integrity	Lifting Trunnion Block	B	ASME Section III; Subsection NF	SA350-LF3	See Table 3.3.3	See Note 5	NA
Structural Integrity	Lifting Trunnion	A	ANSI N14.6	SB637 (N07718) or SA564-630H1100 (For HI-TRAC125D only)	See Table 3.3.4	NA	NA
Structural Integrity	Pocket Trunnion (HI-TRAC 100 and HI-TRAC 125 only)	B	ASME Section III; Subsection NF ANSI N14.6	SA350-LF3	See Table 3.3.3	See Note 5	NA
Structural Integrity	Dowel Pins	B	ASME Section III; Subsection NF	SA564-630	See Table 3.3.4	NA	SA350-LF3
Structural Integrity	Water Jacket End Plate	B	ASME Section III; Subsection NF	SA516-70	See Table 3.3.2	See Note 5	NA
Structural Integrity	Pool Lid Bottom Plate	B	ASME Section III; Subsection NF	SA516-70	See Table 3.3.2	See Note 5	NA
Structural Integrity	Top Lid Lifting Block	C	ASME Section III; Subsection NF	SA516-70	See Table 3.3.2	See Note 5	NA

Notes:
1) There are no known residuals on finished component surfaces
2) All welding processes used in welding the components shall be qualified in accordance with the requirements of ASME Section IX. All welds shall be made using welders qualified in accordance with ASME Section IX. Weld material shall meet the requirements of ASME Section II and the applicable Subsection of ASME Section III.
3) Component nomenclature taken from Bill of Materials in Chapter 1.
4) A, B, and C denote important to safety classifications as described in the Holtec QA Program. NITS stands for Not Important to Safety.
5) All surfaces to be painted in accordance with Appendix 1.C, as applicable.

TABLE 2.2.6

MATERIALS AND COMPONENTS OF THE HI-STORM 100 SYSTEM
HI-TRAC TRANSFER CASK [1,2]

Primary Function	Component [3]	Safety Class [4]	Codes/Standards (as applicable to component)	Material	Strength (ksi)	Special Surface Finish/Coating	Contact Matl. (if dissimilar)
Structural Integrity	Bottom Flange Gussets (HI-TRAC 100D and 125D only)	B	ASME Section III; Subsection NF	SA516-70	See Table 3.3.2	See Note 5	NA
Operations	Top Lid Stud or bolt	B	ASME Section III; Subsection NF	SA193-B7	See Table 3.3.4	NA	NA
Operations	Top Lid Nut	B	ASME Section III; Subsection NF	SA194-2H	Per ASME Section II	NA	NA
Operations	Pool Lid Gasket	NITS	Non-code	Elastomer	NA	NA	NA
Operations	Lifting Trunnion End Cap (HI-TRAC 100 and HI-TRAC 125 only)	C	Non-code	SA516-70	See Table 3.3.2	See Note 5	NA
Operations	End Cap Bolts (HI-TRAC 100 and HI-TRAC 125 only)	NITS	Non-code	SA193-B7	See Table 3.3.4	NA	NA
Operations	Drain Pipes	NITS	Non-code	SA106	NA	NA	NA
Operations	Drain Bolt	NITS	Non-code	SA193-B7	See Table 3.3.4	NA	NA
Operations	Couplings, Valves and Vent Plug	NITS	Non-code	Commercial	NA	NA	NA

Notes:
1) There are no known residuals on finished component surfaces
2) All welding processes used in welding the components shall be qualified in accordance with the requirements of ASME Section IX. All welds shall be made using welders qualified in accordance with ASME Section IX. Weld material shall meet the requirements of ASME Section II and the applicable Subsection of ASME Section III.
3) Component nomenclature taken from Bill of Materials in Chapter 1.
4) A, B, and C denote important to safety classifications as described in the Holtec QA Program. NITS stands for Not Important to Safety.
5) All surfaces to be painted in accordance with Appendix 1.C, as applicable.

TABLE 2.2.6

MATERIALS AND COMPONENTS OF THE HI-STORM 100 SYSTEM
HI-TRAC TRANSFER LID (HI-TRAC 100 and HI-TRAC 125 ONLY) (1,2)

Primary Function	Component (3)	Safety Class (4)	Codes/Standards (as applicable to component)	Material	Strength (ksi)	Special Surface Finish/Coating	Contact Matl. (if dissimilar)
Shielding	Side Lead Shield	B	Non-code	Lead	NA	NA	NA
Shielding	Door Lead Shield	B	Non-code	Lead	NA	NA	
Shielding	Door Shielding	B	Non-code	Holtite	NA	NA	NA
Structural Integrity	Lid Top Plate	B	ASME Section III; Subsection NF	SA516-70	See Table 3.3.2	See Note 5	NA
Structural Integrity	Lid Bottom Plate	B	ASME Section III; Subsection NF	SA516-70	See Table 3.3.2	See Note 5	NA
Structural Integrity	Lid Intermediate Plate	B	ASME Section III; Subsection NF	SA516-70	See Table 3.3.2	See Note 5	NA
Structural Integrity	Lead Cover Plate	B	ASME Section III; Subsection NF	SA516-70	See Table 3.3.2	See Note 5	NA
Structural Integrity	Lead Cover Side Plate	B	ASME Section III; Subsection NF	SA516-70	See Table 3.3.2	See Note 5	NA
Structural Integrity	Door Top Plate	B	ASME Section III; Subsection NF	SA516-70	See Table 3.3.2	See Note 5	NA
Structural Integrity	Door Middle Plate	B	ASME Section III; Subsection NF	SA516-70	See Table 3.3.2	See Note 5	NA
Structural Integrity	Door Bottom Plate	B	ASME Section III; Subsection NF	SA516-70	See Table 3.3.2	See Note 5	NA
Structural Integrity	Door Wheel Housing	B	ASME Section III; Subsection NF	SA516-70 (SA350-LF3)	See Table 3.3.2 (Table 3.3.3)	See Note 5	NA
Structural Integrity	Door Interface Plate	B	ASME Section III; Subsection NF	SA516-70	See Table 3.3.2	See Note 5	NA

Notes:
1) There are no known residuals on finished component surfaces
2) All welding processes used in welding the components shall be qualified in accordance with the requirements of ASME Section IX. All welds shall be made using welders qualified in accordance with ASME Section IX. Weld material shall meet the requirements of ASME Section II and the applicable Subsection of ASME Section III.
3) Component nomenclature taken from Bill of Materials in Chapter 1.
4) A, B, and C denote important to safety classifications as described in the Holtec QA Program. NITS stands for Not Important to Safety.
5) All surfaces to be painted in accordance with Appendix 1.C, as applicable.

TABLE 2.2.6

MATERIALS AND COMPONENTS OF THE HI-STORM 100 SYSTEM
HI-TRAC TRANSFER LID (HI-TRAC 100 and HI-TRAC 125 ONLY) (1,2)

Primary Function	Component (3)	Safety Class (4)	Codes/Standards (as applicable to component)	Material	Strength (ksi)	Special Surface Finish/Coating	Contact Matl. (if dissimilar)
Structural Integrity	Door Side Plate	B	ASME Section III; Subsection NF	SA516-70	See Table 3.3.2	See Note 5	NA
Structural Integrity	Wheel Shaft	C	ASME Section III; Subsection NF	SA 193-B7	36 (yield)	See Note 5	NA
Structural Integrity	Lid Housing Stiffener	B	ASME Section III; Subsection NF	SA516-70	See Table 3.3.2	See Note 5	NA
Structural Integrity	Door Lock Bolt	B	ASME Section III; Subsection NB	SA193-B7	See Table 3.3.4	NA	NA
Structural Integrity	Door End Plate	B	ASME Section III; Subsection NF	SA516-70	See Table 3.3.2	See Note 5	NA
Structural Integrity	Lifting Lug and Pad	B	ASME Section III; Subsection NF	SA516-70	See Table 3.3.2	See Note 5	NA
Operations	Wheel Track	C	ASME Section III; Subsection NF	SA-36	36 (yield)	See Note 5	NA
Operations	Door Handle	NITS	Non-code	C/S or S/S	NA	See Note 5	NA
Operations	Door Wheels	NITS	Non-code	Forged Steel	NA	NA	NA
Operations	Door Stop Block	C	Non-code	SA516-70	See Table 3.3.2	See Note 5	NA
Operations	Door Stop Block Bolt	C	Non-code	SA193-B7	See Table 3.3.4	NA	NA

Notes:
1) There are no known residuals on finished component surfaces
2) All welding processes used in welding the components shall be qualified in accordance with the requirements of ASME Section IX. All welds shall be made using welders qualified in accordance with ASME Section IX. Weld material shall meet the requirements of ASME Section II and the applicable Subsection of ASME Section III.
3) Component nomenclature taken from Bill of Materials in Chapter 1.
4) A, B, and C denote important to safety classifications as described in the Holtec QA Program. NITS stands for Not Important to Safety.
5) All surfaces to be painted in accordance with Appendix 1.C, as applicable.

Table 2.2.7

HI-STORM 100 ASME BOILER AND PRESSURE VESSEL CODE APPLICABILITY

HI-STORM 100 Component	Material Procurement	Design	Fabrication	Inspection
Overpack steel structure	Section II, Section III, Subsection NF, NF-2000	Section III, Subsection NF, NF-3200	Section III, Subsection NF, NF-4000	Section III, Subsection NF, NF-5350, NF-5360 and Section V
Anchor Studs for HI-STORM 100A	Section II, Section III, Subsection NF, NF-2000*	Section III, Subsection NF, NF- 3300	NA	NA
MPC confinement boundary	Section II, Section III, Subsection NB, NB-2000	Section III, Subsection NB, NB-3200	Section III, Subsection NB, NB-4000	Section III, Subsection NB, NB-5000 and Section V
MPC fuel basket	Section II, Section III, Subsection NG, NG-2000; core support structures (NG-1121)	Section III, Subsection NG, NG-3300 and NG-3200; core support structures (NG-1121)	Section III, Subsection NG, NG-4000; core support structures (NG-1121)	Section III, Subsection NG, NG-5000 and Section V; core support structures (NG-1121)
HI-TRAC Trunnions	Section II, Section III, Subsection NF, NF-2000	ANSI N14.6	Section III, Subsection NF, NF-4000	See Chapter 9
MPC basket supports (Angled Plates)	Section II, Section III, Subsection NG, NG-2000; internal structures (NG-1122)	Section III, Subsection NG, NG-3300 and NG-3200; internal structures (NG-1122)	Section III, Subsection NG, NG-4000; internal structures (NG-1122)	Section III, Subsection NG, NG-5000 and Section V; internal structures (NG-1122)
HI-TRAC steel structure	Section II, Section III, Subsection NF, NF-2000	Section III, Subsection NF, NF-3300	Section III, Subsection NF, NF-4000	Section III, Subsection NF, NF-5360 and Section V
Damaged fuel container	Section II, Section III, Subsection NG, NG-2000	Section III, Subsection NG, NG-3300 and NG-3200	Section III, Subsection NG, NG-4000	Section III, Subsection NG, NG-5000 and Section V
Overpack concrete	ACI 349 as specified by Appendix 1.D	ACI 349 and ACI 318.1-89(92) as specified by Appendix 1.D	ACI 349 as specified by Appendix 1.D	ACI 349 as specified by Appendix 1.D

* Except impact testing shall be determined based on service temperature and material type.

Table 2.2.8

ADDITIONAL DESIGN INPUT DATA FOR NORMAL, OFF-NORMAL, AND ACCIDENT CONDITIONS

Item	Condition	Value
Snow Pressure Loading (lb./ft^2)	Normal	100
Constriction of MPC Basket Vent Opening By Crud Settling (Depth of Crud, in.)	Accident	0.85 (MPC-68) 0.36 (MPC-24 and MPC-32)
Cask Environment During the Postulated Fire Event (Deg. F)	Accident	1475
HI-STORM Overpack Fire Duration (seconds)	Accident	217
HI-TRAC Transfer Cask Fire Duration (minutes)	Accident	4.8
Maximum submergence depth due to flood (ft)	Accident	125
Flood water velocity (ft/s)	Accident	15
Interaction Relation for Horizontal & Vertical acceleration for HI-STORM	Accident	$G_H + 0.53G_V = 0.53$[††] (HI-STORM 100, 100S, and 100S Version B) $G_H = 2.12$; $G_V = 1.5$ (HI-STORM 100A)
Net Overturning Moment at base of HI-STORM 100A (ft-lb)	Accident	$18.7x10^6$
HI-STORM 100 Overpack Vertical Lift Height Limit (in.)	Accident	11[†††] (HI-STORM 100 and 100S), OR By Users (HI-STORM 100A)
HI-TRAC Transfer Cask Horizontal Lift Height Limit (in.)	Accident	42[†††]

†† See Subsection 3.4.7.1 for definition of G_H and G_V. The coefficient of friction may be increased above 0.53 based on testing described in Subsection 3.4.7.1

††† For ISFSI and subgrade design parameter Sets A and B. Users may also develop a site-specific lift height limit.

Table 2.2.9

EXAMPLES OF ACCEPTABLE ISFSI PAD DESIGN PARAMETERS

PARAMETER	PARAMETER SET "A" †	PARAMETER SET "B"
Concrete thickness, t_p, (inches)	$\leq$ 36	$\leq$ 28
Concrete Compressive Strength (at 28 days), f_c', (psi)	$\leq$ 4,200	$\leq$ 6,000 psi
Reinforcement Top and Bottom (both directions)	Reinforcing bar shall be 60 ksi Yield Strength ASTM Material	Reinforcing bar shall be 60 ksi Yield Strength ASTM Material
Subgrade Effective Modulus of Elasticity†† (measured prior to ISFSI pad installation), E, (psi)	$\leq$ 28,000	$\leq$ 16,000

NOTE: A static coefficient of friction of 0.53 between the ISFSI pad and the bottom of the overpack shall be used. If for a specific ISFSI a higher value of the coefficient of friction is used, it shall be verified by test. The test procedure shall follow the guidelines included in the Sliding Analysis in Subsection 3.4.7.1.

† The characteristics of this pad are identical to the pad considered by Lawrence Livermore Laboratory (see Appendix 3.A).

†† An acceptable method of defining the soil effective modulus of elasticity applicable to the drop and tipover analysis is provided in Table 13 of NUREG/CR-6608 with soil classification in accordance with ASTM-D2487 Standard Classification of Soils for Engineering Purposes (Unified Soil Classification System USCS) and density determination in accordance with ASTM-D1586 Standard Test Method for Penetration Test and Split/Barrel Sampling of Soils.

Table 2.2.10
MPC CONFINEMENT BOUNDARY STRESS INTENSITY LIMITS
FOR DIFFERENT LOADING CONDITIONS (ELASTIC ANALYSIS PER NB-3220)†

STRESS CATEGORY	DESIGN	LEVELS A & B	LEVEL D††
Primary Membrane, P_m	S_m	N/A†††	AMIN ($2.4S_m$, $.7S_u$)
Local Membrane, P_L	$1.5S_m$	N/A	150% of P_m Limit
Membrane plus Primary Bending	$1.5S_m$	N/A	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.
††† No Specific stress limit applicable.
†††† Governed by NB-3227.2 or F-1331.1(d).

Table 2.2.11

MPC BASKET STRESS INTENSITY LIMITS
FOR DIFFERENT LOADING CONDITIONS (ELASTIC ANALYSIS PER NG-3220)

STRESS CATEGORY	DESIGN	LEVELS A & B	LEVEL D†
Primary Membrane, P_m	S_m	S_m	AMIN ($2.4S_m$, $.7S_u$)††
Primary Membrane plus Primary Bending	$1.5S_m$	$1.5S_m$	150% of P_m Limit
Primary Membrane plus Primary Bending plus Secondary	N/A†††	$3S_m$	N/A

† Governed by Appendix F, Paragraph F-1331 of the ASME Code, Section III.
†† Governed by NB-3227.2 or F-1331.1(d).
††† No specific stress intensity limit applicable.

Table 2.2.12
STRESS LIMITS FOR DIFFERENT
LOADING CONDITIONS FOR THE STEEL STRUCTURE OF THE OVERPACK AND HI-TRAC
(ELASTIC ANALYSIS PER NF-3260)

		SERVICE CONDITION	
STRESS CATEGORY	**DESIGN + LEVEL A**	**LEVEL B**	**LEVEL D†**
Primary Membrane, P_m	S	1.33S	AMAX (1.2S_y, 1.5S_m) but < .7S_u
Primary Membrane, P_m, plus Primary Bending, P_b	1.5S	1.995S	150% of P_m
Shear Stress (Average)	0.6S	0.6S	<0.42S_u

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 Strength

† Governed by Appendix F, Paragraph F-1332 of the ASME Code, Section III.

Table 2.2.13

NOTATION FOR DESIGN LOADINGS FOR NORMAL, OFF-NORMAL, AND ACCIDENT CONDITIONS

NORMAL CONDITION	
LOADING	**NOTATION**
Dead Weight	D
Handling Loads	H
Design Pressure (Internal)	P_i
Design Pressure (External)†	P_o
Snow	S
Operating Temperature	T
OFF-NORMAL CONDITION	
Loading	Notation
Off-Normal Pressure (Internal)	P_i’
Off-Normal Pressure (External)†	P_o
Off-Normal Temperature	T’
Off-Normal HI-TRAC Handling	H’

Table 2.2.13 (continued)

NOTATION FOR DESIGN LOADINGS FOR NORMAL, OFF-NORMAL, AND ACCIDENT CONDITIONS

ACCIDENT CONDITIONS	
LOADING	**NOTATION**
Handling Accident	H'
Earthquake	E
Fire	T^*
Tornado Missile	M
Tornado Wind	W'
Flood	F
Explosion	E^*
Accident Pressure (Internal)	P_i^*
Accident Pressure (External)	P_o^*

Table 2.2.14

APPLICABLE LOAD CASES AND COMBINATIONS FOR EACH CONDITION AND COMPONENT†, ††

CONDITION	LOADING CASE	MPC	OVERPACK	HI-TRAC
Design (ASME Code Pressure Compliance)	1	P_i, P_o	N/A	N/A
Normal (Level A)	1	D, T, H, P_i	D, T, H	D, T†††, H, $P_{i\,(water\ jacket)}$
	2	D, T, H, P_o	N/A	N/A
Off-Normal (Level B)	1	D, T', H, P_i'	D, T', H	N/A††† (H' pocket trunnion)
	2	D, T', H, P_o	N/A	N/A
Accident (Level D)	1	D, T, P_i, H'	D, T, H'	D, T, H'
	2	D, T^*, P_i^*	N/A	N/A
	3	D, T, P_o^*††††	D, T, P_o^*††††	D, T, P_o^*††††
	4	N/A	D, T, (E, M, F, W')†††††	D, T, (M, W')†††††

† The loading notations are given in Table 2.2.13. Each symbol represents a loading type and may have different values for different components. The different loads are assumed to be additive and applied simultaneously.

†† N/A stands for "Not Applicable."

††† T (normal condition) for the HI-TRAC is 100°F and $P_{i(water\ jacket)}$ is 60 psig and, therefore, there is no off-normal temperature or load combination because Load Case 1, Normal (Level A), is identical to Load Case 1, Off-Normal (Level B). Only the off-normal handling load on the pocket trunnion is analyzed separately.

†††† P_o^* bounds the external pressure due to explosion.

††††† (E, M, F, W') means loads are considered separately in combination with D, T. E and F not applicable to HI-TRAC.

Table 2.2.15
LIST OF ASME CODE ALTERNATIVES FOR HI-STORM 100 SYSTEM

Component	Reference ASME Code Section/Article	Code Requirement	Alternative, Justification & Compensatory Measures
MPC, MPC basket assembly, HI-STORM overpack steel structure, and HI-TRAC transfer cask steel structure.	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, overpack, and transfer cask are not ASME Code stamped vessels, 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 HI-STORM 100 System 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 various articles of Subsections NB, NG, and NF of 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 2.2.15 (continued)
LIST OF ASME CODE ALTERNATIVES FOR HI-STORM 100 SYSTEM

Component	**Reference ASME Code Section/Article**	**Code Requirement**	**Alternative, Justification & Compensatory Measures**
MPC	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 nonpressure - 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 MPC basket supports (nonpressure - retaining structural attachment) and lift lugs (nonstructural attachments (relative to the function of lifting a loaded MPC) 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 basket supports and associated attachment welds are designed to satisfy the stress limits of Subsection NG and the lift lugs and associated attachment welds are designed to satisfy the stress limits of Subsection NF, as a minimum. These attachments and their welds are shown by analysis to meet the respective stress limits for their service conditions. Likewise, non-structural items, such as shield plugs, spacers, etc. if used, can be attached to pressure-retaining parts in the same manner.

Table 2.2.15 (continued)
LIST OF ASME CODE ALTERNATIVES FOR HI-STORM 100 SYSTEM

Component	Reference ASME Code Section/Article	Code Requirement	Alternative, Justification & Compensatory Measures
MPC	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.
MPC, MPC basket assembly, HI-STORM overpack, and HI-TRAC transfer cask	NB-3100 NG-3100 NF-3100	Provides requirements for determining design loading conditions, such as pressure, temperature, and mechanical loads.	These requirements are not applicable. The HI-STORM FSAR, serving as the Design Specification, establishes the service conditions and load combinations for the storage system.
MPC	NB-3350	NB-3352.3 requires, for Category C joints, that the minimum dimensions of the welds and throat thickness shall be as shown in Figure NB-4243-1.	Due to MPC basket-to-shell interface requirements, the MPC shell-to-baseplate weld joint design (designated Category C) does not include a reinforcing fillet weld or a bevel in the MPC baseplate, which makes it different than any of the representative configurations depicted in Figure NB-4243-1. The transverse thickness of this weld is equal to the thickness of the adjoining shell (1/2 inch). The weld is designed as a full penetration weld that receives VT and RT or UT, as well as final surface PT examinations. Because the MPC shell design thickness is considerably larger than the minimum thickness required by the Code, a reinforcing fillet weld that would intrude into the MPC cavity space is not included. Not including this fillet weld provides for a higher quality radiographic examination of the full penetration weld. From the standpoint of stress analysis, the fillet weld serves to reduce the local bending stress (secondary stress) produced by the gross structural discontinuity defined by the flat plate/shell junction. In the MPC design, the shell and baseplate thicknesses are well beyond that required to meet their respective membrane stress intensity limits.

Table 2.2.15 (continued)
LIST OF ASME CODE ALTERNATIVES FOR HI-STORM 100 SYSTEM

Component	Reference ASME Code Section/Article	Code Requirement	Alternative, Justification & Compensatory Measures
MPC, MPC basket assembly, HI-STORM overpack steel structure, and HI-TRAC transfer cask steel structure	NB-4120 NG-4120 NF-4120	NB-4121.2, NG-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, coating, and pouring of lead are not, unless explicitly stated by the Code, defined as heat treatment operations. For the steel parts in the HI-STORM 100 System components, the duration for which a part exceeds the off-normal temperature limit defined in Chapter 2 of the FSAR shall be limited to 24 hours in a particular manufacturing process (such as the HI-TRAC lead pouring process).
MPC, HI-STORM overpack steel structure, HI-TRAC transfer cask steel structure	NB-4220 NF-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 2.2.15 (continued)
LIST OF ASME CODE ALTERNATIVES FOR HI-STORM 100 SYSTEM

Component	Reference ASME Code Section/Article	Code Requirement	Alternative, Justification & Compensatory Measures
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. Additionally, a weld efficiency factor of 0.45 has been applied to the analyses of these welds.
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 Shell Weld	NB-5230	Radiographic (RT) or ultrasonic (UT) examination required.	Only UT or multi-layer liquid penetrant (PT) examination is permitted. If PT examination alone is used, at a minimum, it 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 9. Accessibility for leakage inspections precludes a Code compliant pressure test. Since the shell welds of the MPC cannot be checked for leakage during this pressure test, the shop leakage test to 10^{-7} ref cc/sec (as described in Chapter 9) provides reasonable assurance as to its leak tightness. All MPC vessel welds (except closure ring and vent/drain cover plate) are inspected by volumetric examination, except the MPC lid-to-shell weld shall be verified by volumetric or multi-layer PT examination. If PT alone is used, at a minimum, it must include the root and final layers and each approximately 3/8 inch of weld depth. For either UT or PT, the maximum undetectable flaw size must be determined in accordance with ASME Section XI methods. The critical flaw size shall not cause the primary stress limits of NB-3000 to be exceeded. The inspection results, including relevant findings

Table 2.2.15 (continued)
LIST OF ASME CODE ALTERNATIVES FOR HI-STORM 100 SYSTEM

Component	Reference ASME Code Section/Article	Code Requirement	Alternative, Justification & Compensatory Measures
			(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 requirements of ASME Code Section III, NB-5350 for PT or NB-5332 for UT.
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 100 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.
MPC Basket Assembly	NG-2000	Requires materials to be supplied by ASME approved Material Supplier.	Materials will be supplied by Holtec approved supplier with CMTRs in accordance with NG-2000 requirements.

Table 2.2.15 (continued)
LIST OF ASME CODE ALTERNATIVES FOR HI-STORM 100 SYSTEM

Component	Reference ASME Code Section/Article	Code Requirement	Alternative, Justification & Compensatory Measures
MPC Basket Assembly	NG-4420	NG-4427(a) requires a fillet weld in any single continuous weld may be less that the specified fillet weld dimension by not more than 1/16 inch, provided that the total undersize portion of the weld does not exceed 10 percent of the length of the weld. Individual undersize weld portions shall not exceed 2 inches in length.	Modify the Code requirement (intended for core support structures) with the following text prepared to accord with the geometry and stress analysis imperatives for the fuel basket: For the longitudinal MPC basket fillet welds, the following criteria apply: 1) The specified fillet weld throat dimension must be maintained over at least 92 percent of the total weld length. All regions of undersized weld must be less than 3 inches long and separated from each other by at least 9 inches. 2) Areas of undercuts and porosity beyond that allowed by the applicable ASME Code shall not exceed 1/2 inch in weld length. The total length of undercut and porosity over any 1-foot length shall not exceed 2 inches. 3) The total weld length in which items (1) and (2) apply shall not exceed a total of 10 percent of the overall weld length. The limited access of the MPC basket panel longitudinal fillet welds makes it difficult to perform effective repairs of these welds and creates the potential for causing additional damage to the basket assembly (e.g., to the neutron absorber and its sheathing) if repairs are attempted. The acceptance criteria provided in the foregoing have been established to comport with the objectives of the basket design and preserve the margins demonstrated in the supporting stress analysis. From the structural standpoint, the weld acceptance criteria are established to ensure that any departure from the ideal, continuous fillet weld seam would not alter the primary bending stresses on which the design of the fuel baskets is predicated. Stated differently, the permitted weld discontinuities are limited in size to ensure that they remain classifiable as local stress elevators ("peak stress", F, in the ASME Code for which specific stress intensity limits do not apply).

Table 2.2.15 (continued)
LIST OF ASME CODE ALTERNATIVES FOR HI-STORM 100 SYSTEM

Component	Reference ASME Code Section/Article	Code Requirement	Alternative, Justification & Compensatory Measures
MPC Basket Assembly	NG-8000	States requirements for nameplates, stamping and reports per NCA-8000.	The HI-STORM 100 System is to be marked and identified in accordance with 10CFR71 and 10CFR72 requirements. No Code stamping is required. The MPC basket data package is to be in conformance with Holtec's QA program.
Overpack Steel Structure	NF-2000	Requires materials to be supplied by ASME approved Material Supplier.	Materials will be supplied by Holtec approved supplier with CMTRs in accordance with NF-2000 requirements.
HI-TRAC Steel Structure	NF-2000	Requires materials to be supplied by ASME approved Material Supplier.	Materials will be supplied by Holtec approved supplier with CMTRs in accordance with NF-2000 requirements.
Overpack Baseplate and Lid Top Plate	NF-4441	Requires special examinations or requirements for welds where a primary member thickness of 1" or greater is loaded to transmit loads in the through thickness direction.	The margins of safety in these welds under loads experienced during lifting operations or accident conditions are quite large. The overpack baseplate welds to the inner shell, pedestal shell, and radial plates are only loaded during lifting conditions and have large safety factors during lifting. Likewise, the top lid plate to lid shell weld has a large structural margin under the inertia loads imposed during a non-mechanistic tipover event.

Table 2.2.15 (continued)
LIST OF ASME CODE ALTERNATIVES FOR HI-STORM 100 SYSTEM

Component	Reference ASME Code Section/Article	Code Requirement	Alternative, Justification & Compensatory Measures
Overpack Steel Structure	NF-3256 NF-3266	Provides requirements for welded joints.	Welds for which no structural credit is taken are identified as "Non-NF" welds in the design drawings by an "*". These non-structural welds are specified in accordance with the pre-qualified welds of AWS D1.1. These welds shall be made by welders and weld procedures qualified in accordance with AWS D1.1 or ASME Section IX. Welds for which structural credit is taken in the safety analyses shall meet the stress limits for NF-3256.2, but are not required to meet the joint configuration requirements specified in these Code articles. The geometry of the joint designs in the cask structures are based on the fabricability and accessibility of the joint, not generally contemplated by this Code section governing supports.
HI-STORM Overpack and HI-TRAC Transfer Cask	NF-3320 NF-4720	NF-3324.6 and NF-4720 provide requirements for bolting	These Code requirements are applicable to linear structures wherein bolted joints carry axial, shear, as well as rotational (torsional) loads. The overpack and transfer cask bolted connections in the structural load path are qualified by design based on the design loadings defined in the FSAR. Bolted joints in these components see no shear or torsional loads under normal storage conditions. Larger clearances between bolts and holes may be necessary to ensure shear interfaces located elsewhere in the structure engage prior to the bolts experiencing shear loadings (which occur only during side impact scenarios). Bolted joints that are subject to shear loads in accident conditions are qualified by appropriate stress analysis. Larger bolt-to-hole clearances help ensure more efficient operations in making these bolted connections, thereby minimizing time spent by operations personnel in a radiation area. Additionally, larger bolt-to-hole clearances allow interchangeability of the lids from one particular fabricated cask to another.

Table 2.2.16

COMPARISON BETWEEN HI-STORM MPC LOADINGS WITH HI-STAR MPC LOADINGS†

Loading Condition	Difference Between MPC Loadings Under HI-STAR and HI-STORM Conditions
Dead Load	Unchanged
Design Internal Pressure (normal, off-normal, & accident)	Unchanged
Design External Pressure (normal, off-normal, & accident)	HI-STORM normal and off-normal external pressure is ambient which is less than the HI-STAR 40 psig. The accident external pressure is unchanged.
Thermal Gradient (normal, off-normal, & accident)	Determined by analysis in Chapters 3 and 4
Handling Load (normal)	Unchanged
Earthquake (accident)	Inertial loading increased less than 0.1g's (for free-standing overpack designs).
Handling Load (accident)	HI-STORM vertical and horizontal deceleration loadings are less than those in HI-STAR, but the HI-STORM cavity inner diameter is different and therefore the horizontal loading on the MPC is analyzed in Chapter 3.

† HI-STAR MPC loadings are those specified in the HI-STAR SAR under docket number 71-9261, which does not impose any off-normal condition loadings.

2.3 SAFETY PROTECTION SYSTEMS

2.3.1 General

The HI-STORM 100 System is engineered to provide for the safe long-term storage of spent nuclear fuel (SNF). The HI-STORM 100 will withstand all normal, off-normal, and postulated accident conditions without any uncontrolled 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 operating conditions. The design considerations, which have been incorporated into the HI-STORM 100 System to ensure safe long-term fuel storage are:

1. The MPC confinement barrier is an enclosure vessel designed in accordance with the ASME Code, Subsection NB with confinement welds inspected by radiography (RT) or ultrasonic testing (UT). Where RT or UT is not possible, a redundant closure system is provided with field welds, which are pressure tested and/or inspected by the liquid penetrant method (see Section 9.1).

2. The MPC confinement barrier is surrounded by the HI-STORM overpack which provides for the physical protection of the MPC.

3. The HI-STORM 100 System is designed to meet the requirements of storage while maintaining the safety of the SNF.

4. The SNF once initially loaded in the MPC does not require opening of the canister for repackaging to transport the SNF.

5. The decay heat emitted by the SNF is rejected from the HI-STORM 100 System through passive means. No active cooling systems are employed.

It is recognized that a rugged design with large safety margins is essential, but that is not sufficient to ensure acceptable performance over the service life of any system. A carefully planned oversight and surveillance plan, which does not diminish system integrity but provides reliable information on the effect of passage of time on the performance of the system is essential. Such a surveillance and performance assay program will be developed to be compatible with the specific conditions of the licensee's facility where the HI-STORM 100 System is installed. The general requirements for the acceptance testing and maintenance programs are provided in Chapter 9. Surveillance requirements are specified in the Technical Specifications in Appendix A to the CoC. .

The structures, systems, and components of the HI-STORM 100 System designated as important to safety are identified in Table 2.2.6. Similar categorization of structures, systems, and components, which are part of the ISFSI, but not part of the HI-STORM 100 System, will be the responsibility of the 10CFR72 licensee. For HI-STORM 100A, the ISFSI pad is designated ITS, Category C as discussed in Subsection 2.0.4.1.

2.3.2 Protection by Multiple Confinement Barriers and Systems

2.3.2.1 Confinement Barriers and Systems

The radioactivity which the HI-STORM 100 System must confine originates from the spent fuel assemblies and, to a lesser extent, the contaminated water in the fuel pool. This radioactivity is confined by multiple confinement barriers.

Radioactivity 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 pool lid prevent the fuel pool water from contacting the exterior of the MPC and interior of the HI-TRAC while submerged for fuel loading. The fuel pool water is drained from the interior of the MPC and the MPC internals are dried. The exterior of the HI-TRAC has a painted surface which is decontaminated to acceptable levels. Any residual radioactivity deposited by the fuel pool water is confined by the MPC confinement boundary along with the spent nuclear fuel.

The HI-STORM 100 System is designed with several confinement barriers for the radioactive fuel contents. Intact fuel assemblies have cladding which provides the first boundary preventing release of the fission products. Fuel assemblies classified as damaged fuel or fuel debris are placed in a damaged fuel container which restricts the release of fuel debris. The MPC is a seal welded enclosure which provides the confinement boundary. The MPC confinement boundary is defined by the MPC baseplate, shell, lid, closure ring, and port cover plates.

The MPC confinement boundary has been designed to withstand any postulated off-normal operations, internal change, or external natural phenomena. The MPC is designed to endure normal, off-normal, and accident conditions of storage with the maximum decay heat loads without loss of confinement. Designed in accordance with the ASME Code, Section III, Subsection NB, with certain NRC-approved alternatives, the MPC confinement boundary provides assurance that there will be no release of radioactive materials from the cask under all postulated loading conditions. 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. MPC field weld examinations, helium leakage testing and pressure testing are performed to verify the confinement function. Fabrication inspections and tests are also performed, as discussed in Chapter 9, to verify the confinement boundary.

2.3.2.2 Cask Cooling

To facilitate the passive heat removal capability of the HI-STORM 100, several thermal design criteria are established for normal and off-normal conditions. They are as follows:

- The heat rejection capacity of the HI-STORM 100 System is deliberately understated by conservatively determining the design basis fuel that maximizes thermal resistance (see Section 2.1.6). Additional margin is built into the calculated cask cooling rate by using the design basis fuel assembly that offers maximum resistance to MPC internal helium circulation.

- The MPC fuel basket is formed by a honeycomb structure of stainless steel plates with full-length edge-welded intersections, which allows the unimpaired conduction of heat.

- The MPC confinement boundary ensures that the 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 2.2.3 and Table 2.2.1, respectively.

- The MPC thermal design maintains the fuel rod cladding temperatures below the values stated in Chapter 4 such that fuel cladding is not degraded during the long term storage period.

- The HI-STORM is optimally designed with cooling vents and an MPC to overpack annulus which maximize air flow, while providing superior radiation shielding. The vents and annulus allow cooling air to circulate past the MPC removing the decay heat.

2.3.3 Protection by Equipment and Instrumentation Selection

2.3.3.1 Equipment

Design criteria for the HI-STORM 100 System are described in Section 2.2. The HI-STORM 100 System may include use of ancillary or support equipment for ISFSI implementation. Ancillary equipment and structures utilized outside of the reactor facility's 10CFR Part 50 structures 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, "Classification of Transportation Packaging and Dry Spent Fuel Storage System Components According to Importance to Safety", provides guidance for the determination of a component's safety classification. Certain ancillary equipment (such as trailers, rail cars, skids, portable cranes, transporters, or air pads) are not required to be designated as ITS for most ISFSI implementations, if the HI-STORM 100 is designed to withstand the failure of these components.

The listing and ITS designation of ancillary equipment in Table 8.1.6 follows NUREG/CR-6407. Ancillary equipment is classified as the highest ITS classification of any of its constituent parts/components. The ITS classification of the ancillary equipment consituent parts/components are determined and documented in the quality program documents such as purchase specifications. ITS ancillary equipment utilized in activities that occur outside the 10CFR Part 50 structure shall be engineered to meet all functional, strength, service life, and operational safety requirements to ensure that the design and operation of the ancillary equipment is consistent with the intent of this Safety Analysis Report. The design for these components shall consider the following information, as applicable:

1. Functions and boundaries of the ancillary equipment
2. The environmental conditions of the ISFSI site, including tornado-borne missile, tornado wind, seismic, fire, lightning, explosion, ambient humidity limits, flood, tsunami and any other environmental hazards unique to the site.
3. Material requirements including impact testing requirements
4. Applicable codes and standards
5. Acceptance testing requirements
6. Quality assurance requirements
7. Foundation type and permissible loading
8. Applicable loads and load combinations
9. Pre-service examination requirements
10. In-use inspection and maintenance requirements
11. Number and magnitude of repetitive loading significant to fatigue
12. Insulation and enclosure requirements (on electrical motors and machinery)
13. Applicable Reg. Guides and NUREGs.
14. Welding requirements
15. Painting, marking, and identification requirements
16. Design Report documentation requirements
17. Operational and Maintenance (O&M) Manual information requirements

All design documentation shall be subject to a review, evaluation, and safety assessment process in accordance with the provisions of the QA program described in Chapter 13.

Users may effectuate the inter-cask transfer of the MPC between the HI-TRAC transfer cask and either the HI-STORM 100 or the HI-STAR 100 overpack in a location of their choice, depending upon site-specific needs and capabilities. For those users choosing to perform the MPC inter-cask transfer using devices not integral to structures governed by the regulations of 10 CFR Part 50 (e.g., fuel handling or reactor building), a Cask Transfer Facility (CTF) is required. The CTF may be any of the following types to effectuate the cask manipulations and MPC transfers:

1. Stand-alone, aboveground
2. Underground, combined with a mobile lifting device
3. Underground, combined with a cask transporter (e.g., crawler)

The detailed design criteria which must be followed for the design and operation of the CTF are set down in Paragraphs A through R below.

The inter-cask transfer operations consist of the following potential scenarios of MPC transfer:

- Transfer between a HI-TRAC transfer cask and a HI-STORM overpack
- Transfer between a HI-TRAC transfer cask and a HI-STAR 100 overpack

In both scenarios, the standard design HI-TRAC is mounted on top of the overpack (HI-STAR 100, HI-STORM 100, HI-STORM 100S) and the MPC transfer is carried out by opening the transfer lid doors located at the bottom of the HI-TRAC transfer cask and by moving the MPC vertically to the cylindrical cavity of the recipient cask. For the HI-TRAC 100D and 125D designs, the MPC transfer is carried out in a similar fashion, except that there is no transfer lid involved - the pool lid is removed while the transfer cask is mounted atop the HI-STORM overpack with the HI-STORM mating device located between the two casks (see Figure 1.2.18). However, the devices utilized to lift the HI-TRAC cask to place it on the overpack and to vertically transfer the MPC may be of stationary or mobile type.

The specific requirements for the CTF employing stationary and mobile lifting devices are somewhat different. The requirements provided in the following specification for the CTF apply to both types of lifting devices, unless explicitly differentiated in the text. The numbers in brackets {} after each design criterion indicate which of the 3 types of CTF design they apply to.

A General Specifications:

i. The cask handling functions which may be required of the Cask Transfer Facility include:

a. Upending and downending of a HI-STAR 100 overpack on a flatbed rail car or other transporter (see Figure 2.3.1 for an example). {1, 2}

b. Upending and downending of a HI-TRAC transfer cask on a heavy-haul transfer trailer or other transporter (see Figure 2.3.2 for an example). {1, 2}

c. Raising and placement of a HI-TRAC transfer cask on top of a HI-STORM 100 overpack for MPC transfer operations (see Figure 2.3.3 for an example of the cask arrangement with the standard design HI-TRAC transfer cask. The HI-TRAC 100D and 125D designs would include the mating device and no transfer lid). {1, 2, 3}

d. Raising and placement of a HI-TRAC transfer cask on top of a HI-STAR 100 overpack for MPC transfer operations (see Figure 2.3.4 for an example of the cask arrangement with the standard design HI-TRAC transfer cask. The HI-TRAC 100D and 125D designs would include the mating device and no transfer lid). {1, 2, 3}

e. MPC transfer between the HI-TRAC transfer cask and the HI-STORM overpack. {1, 2, 3}

f. MPC transfer between the HI-TRAC transfer cask and the HI-STAR 100 overpack. {1, 2, 3}

ii. Other Functional Requirements:

The CTF should possess facilities and capabilities, as applicable, to support cask operations such as:

a. Devices and areas to support installation and removal of the HI-STORM overpack lid. {1, 2, 3}

b. Devices and areas to support installation and removal of the HI-STORM 100 overpack vent shield block inserts. {1, 2, 3}

c. Devices and areas to support installation and removal of the HI-STAR 100 closure plate. {1, 2, 3}

d. Devices and areas to support installation and removal of the HI-STAR 100 transfer collar. {1, 2, 3}

e. Features to support positioning and alignment of the HI-STORM overpack and the HI-TRAC transfer cask. {1, 2, 3}

f. Features to support positioning and alignment of the HI-STAR 100 overpack and the HI-TRAC transfer cask. {1, 2, 3}

g. Areas to support jacking of a loaded HI-STORM overpack for insertion of a translocation device underneath. {1, 2, 3}

h. Devices and areas to support placement of an empty MPC in the HI-TRAC transfer cask or HI-STAR 100 overpack. {1, 2, 3}

i. Devices and areas to support receipt inspection of the MPC, HI-TRAC transfer cask, HI-STORM overpack, and HI-STAR overpack. {1, 2, 3}

j. Devices and areas to support installation and removal of the HI-STORM mating device (HI-TRAC 100D and 125D only). {1, 2, 3}

iii. Definitions:

The components of the CTF covered by this specification consist of all structural members, lifting devices, and foundations which bear all or a significant portion of the dead load of the transfer cask or the multi-purpose canister during MPC transfer operations. The definitions of typical terms not defined elsewhere in this FSAR and used in this specification are provided below. Not all parts defined in this paragraph apply to all CTF designs.

- Connector Brackets: The mechanical part used in the load path which connects to the cask trunnions. A fabricated weldment, slings, and turnbuckles are typical examples of connector brackets. {1, 2, 3}

- CTF structure: The CTF structure is the stationary, anchored portion of the CTF which provides the required structural function to support MPC transfer operations, including lateral stabilization of the HI-TRAC transfer cask and, if required, the overpack, to protect against seismic events. The MPC lifter, if used in the CTF design, is integrated into the CTF structure (see Lifter Mount). {1}

- HI-TRAC lifter(s): The HI-TRAC lifter is the mechanical lifting device, typically consisting of jacks or hoists, that is utilized to lift a loaded or unloaded HI-TRAC to the required elevation in the CTF so that it can be mounted on the overpack.† {1, 2, 3}

- Lifter Mount: A beam-like structure (part of the CTF structure) that supports the HI-TRAC and MPC lifter(s). {1}

- Lift Platform: The lift platform is the intermediate structure that transfers the vertical load of the HI-TRAC transfer cask to the HI-TRAC lifters. {1}

- Mobile lifting devices: A mobile lifting device is a device defined in ASME B30.5-1994, Mobile and Locomotive Cranes. A mobile lifting device may be used in lieu of the HI-TRAC lifter and/or an MPC lifter provided all requirements set forth in this subsection are satisfied. {2}

- MPC lifter: The MPC lifter is a mechanical lifting device, typically consisting of jacks or hoists, that is utilized to vertically transfer the MPC between the HI-TRAC transfer cask and the overpack. {1}

- Pier: The portion of the reinforced concrete foundation which projects above the concrete floor of the CTF. {1}

- Single-Failure-Proof (SFP): A single-failure-proof handling device is one wherein all directly loaded tension and compression members are engineered to satisfy the enhanced safety criteria given in of NUREG-0612 and/or is designed in accordance with ANSI N14.6 and employs redundant drop protection features. {1, 2, 3}

- Translocation Device: A low vertical profile device used to laterally position an overpack such that the bottom surface of the overpack is fully supported by the top surface of the device. Typical translocation devices are air pads and Hillman rollers. {1,2}

- Vertical Cask Transporter: A device which is capable of performing the CTF functions as well as transporting the transfer

† The term overpack is used in this specification as a generic term for the HI-STAR 100 and the various HI-STORM overpacks.

cask and overpack to and from the CTF. A vertical cask transporter may be used in lieu of the CTF structure, HI-TRAC lifter, and/or an MPC lifter provided all requirements set forth in this subsection are satisfied. {3}

iv. Important to Safety Designation:

All components and structures which comprise the CTF shall be given an ITS category designation in accordance with a written procedure which is consistent with NUREG/CR-6407 and the Holtec quality assurance program. {1,2,3}

B. Environmental and Design Conditions

i. Lowest Service Temperature (LST): Unless otherwise specified, the LST for the CTF is 0°F (consistent with the specification for the HI-TRAC transfer cask in Subsection 3.1.2.3). Based on its local meteorological data, a host nuclear site may use a higher LST value for the Cask Transfer Facility.{1, 2, 3}

ii. Snow and Ice Load, S: The CTF structure shall be designed to withstand the dead weight of snow and ice for unheated structures as set forth in ASCE 7-88 [2.2.2] for the specific ISFSI site. {1}

iii. Tornado Missile, M, and Tornado Wind, W': The tornado wind and tornado-generated missile data applicable to the HI-STORM 100 System (Tables 2.2.4 and 2.2.5) will be used in the design of the CTF unless existing site design basis data or a probabilistic risk assessment (PRA) for the CTF site with due consideration of short operation durations indicates that a less severe tornado missile impact or wind loading on the CTF can be postulated. The PRA analysis can be performed in the manner of the EPRI Report NP-2005, "Tornado Missile Simulation and Design Methodology Computer Code Manual". USNRC Reg. Guide 1.117 and Section 2.2.3 of NUREG-800 may be used for guidance in establishing the appropriate tornado missile and wind loading for the CTF.

The following additional clarifications apply to the large tornado missile (4,000 lb. automobile) in Tables 2.2.4 and 2.2.5 in the CTF analysis:

- The missile has a planform area of 20 sq. ft. and impact force characteristics consistent with the HI-TRAC missile impact analysis.

- The large missile can strike the CTF in any orientation up to an elevation of 15 feet.

If the site tornado missile data developed by the ISFSI owner suggests that tornado missiles of greater kinetic energies than that postulated in this FSAR (Table 2.2.4 and 2.2.5) should be postulated for CTF during its use, then the integrity analysis of the CTF shall be carried out under the site-specific tornado missiles. This situation would also require the HI-TRAC transfer cask and the overpack to be re-evaluated under the provisions of 10CFR72.212 and 72.48.

The wind speed specified in this FSAR (Tables 2.2.4 and 2.2.5), likewise, shall be evaluated for their applicability to the site. Lower or higher site-specific wind velocity, compared to the design basis values cited in this FSAR shall be used if justified by appropriate analysis, which may include PRA.

Intermediate penetrant missile and small missiles postulated in this FSAR are not considered to be a credible threat to the functional integrity of the CTF and, therefore, need not be considered. {1, 2, 3}

iv. Flood: The CTF will be assumed to be flooded to the highest elevation for the CTF facility determined from the local meteorological data. The flood velocity shall be taken as the largest value defined for the ISFSI site. {1, 2, 3}

v. Lightning: Meteorological data for the region surrounding the ISFSI site shall be used to specify the applicable lightning input to the CTF for personnel safety evaluation purposes. {1, 2, 3}

vi. Water Waves (Tsunami, Y): Certain coastal CTF sites may be subject to sudden, short duration waves of water, denoted in the literature by various terms, such as tsunami. If the applicable meteorological data for the CTF site indicates the potential of such water-borne loadings on the CTF, then such a loading, with due consideration of the short duration of CTF operations, shall be defined for the CTF. {1, 2, 3}

vii. Design Basis Earthquake (DBE), E: The DBE event applicable to the

CTF facility pursuant to 10CFR100, Appendix A, shall be specified. The DBE should be specified as a set of response spectra or acceleration time-histories for use in the CTF structural and impact consequence analyses. {1, 2, 3}

viii. Design Temperature: Unless a lower value can be justified for a specific site, all material properties used in the stress analysis of the CTF structure shall utilize a reference design temperature of 150°F. {1, 2, 3}

C. Heavy Load Handling:

i. Apparent dead load, D*: The dead load of all components being lifted shall be increased in the manner set forth in Subsection 3.4.3 to define the Apparent Dead Load, D*. {1, 2, 3}

ii. NUREG-0612 Conformance:

The Connector Bracket, HI-TRAC lifter, and MPC lifter shall comply with the guidance provided in NUREG-0612 (1980) for single failure proof devices. Where the geometry of the lifting device is different from the configurations contemplated by NUREG-0612, the following exceptions apply:

a. Mobile lifting devices at the CTF shall conform to the guidelines of Section 5.1.1 of NUREG-0612 with the exception that mobile lifting devices shall meet the requirements of ANSI B30.5, "Mobile and Locomotive Cranes", in lieu of the requirements of ANSI B30.2, "Overhead and Gantry Cranes". The mobile lifting device used shall have a minimum safety factor of two over the allowable load table for the lifting device in accordance with Section 5.1.6(1)(a) of NUREG-0612, and shall be capable of stopping and holding the load during a DBE event. {2}

b. Section 5.1.6(2) of NUREG-0612 specifies that new cranes should be designed to meet the requirements of NUREG-0554. For mobile lifting devices, the guidance of Section 5.1.6(2) of NUREG-0612 does not apply. {2}

c. Vertical cask transporters shall be designed in accordance with ANSI N14.6 and shall employ redundant drop protection features. {3}

iii. Defense-in-Depth Measures:

a. The lift platform and the lifter mount shall be designed to ensure that the stresses produced under the apparent dead load, D*, are less than the Level A (normal condition) stress limits for ASME Section III, Subsection NF, Class 3, linear structures. {1}

b. The CTF structure shall be designed to ensure that the stresses produced in it under the apparent dead load, D*, are less than the Level A (normal condition) stress limits for ASME Section III, Subsection NF, Class 3, linear structures. {1}

c. Maximum deflection of the lift platform and the lifter mount under the apparent dead load shall comply with the limits set forth in CMAA-70. {1}

d. When the HI-TRAC transfer cask is stacked on the overpack, HI-TRAC shall be either held by the lifting device or laterally restrained by the CTF structure. Furthermore, when the HI-TRAC transfer cask is placed atop the overpack, the overpack shall be laterally restrained from uncontrolled movement, if required by the analysis specified in Subsection 2.3.3.1.N. {1}

e. The design of the lifting system shall ensure that the lift platform (or lift frame) is held essentially horizontal at all times and that the symmetrically situated axial members are symmetrically loaded. {1,3}

f. In order to minimize occupational radiation exposure to ISFSI personnel, design of the MPC lifting attachment (viz., sling) should not require any human activity inside the HI-TRAC cylindrical space. {1, 2, 3}

g. The HI-TRAC lifter and MPC lifter shall possess design features to avoid excessive side-sway of the payload during lifting operations. {1, 2, 3}

h. The lifter (HI-TRAC and MPC) design shall ensure that any electrical malfunction in the motor or the power supply will not lead to an uncontrolled lowering of the load. {1, 2, 3}

i. The kinematic stability of HI-TRAC or HI-STORM standing upright in an unrestrained configuration (if such a condition exists during the use of the CTF) shall be analytically evaluated and ensured under all postulated extreme environmental phenomena loadings for the CTF facility. {1, 2, 3}

iv. Shielding Surety:

The design of the HI-TRAC and MPC lifters shall preclude the potential for the MPC to be removed, completely or partially, from the cylindrical space formed by the HI-TRAC and the underlying overpack. {1, 2, 3}

v. Specific Requirements for Mobile Lifting Devices and Vertical Cask Transporters:

A mobile lifting device, if used in the CTF in the role of the HI-TRAC lifter or MPC lifter is governed in part by ANSI/ASME N45.2.15 with technical requirements specified in ANSI B30.5 (1994). {2}

When lifting the MPC from an overpack to the HI-TRAC transfer cask, limit switches or load limiters shall be set to ensure that the lifted load does not exceed 110% of the loaded MPC weight. {2,3}

An analysis of the consequences of a potential MPC vertical drop which conforms to the guidelines of Appendix A to NUREG-0612 shall be performed. The analysis shall demonstrate that a postulated drop would not result in the MPC developing a thru-wall breach resulting in loss of confinement or experiencing a deceleration in excess of its design basis deceleration specified in this FSAR. {2}

vi. Lift Height Limitation: The HI-TRAC lift heights shall be governed by the Technical Specifications. {1,2,3}

vii. Control of Side Sway: Procedures shall provide provisions to ensure that the load is lifted essentially vertically with positive control of the load. Key cask lifting and transfer procedures, as determined by the user, should be reviewed by the Certificate Holder before their use. {1, 2, 3}

D. Loads and Load Combinations for the CTF Structure

The applicable loadings for the CTF have been summarized in paragraph B in the preceding. A stress analysis of the CTF structure shall be performed to demonstrate compliance with the Subsection NF stress limits for Class 3 linear structures for the service condition germane to each load combination. Table 2.3.2 provides the load combinations (the symbols in Table 2.3.2 are defined in the preceding text and in Table 2.2.13). {1}

E. Materials and Failure Modes

i. Acceptable Materials and Material Properties: All materials used in the design of the CTF shall be ASME or ASTM approved or equal, consistent with the ITS category of the part (see discussion in subsection 2.I.0). Reinforced concrete, if used, shall comply with the provisions of ACI 318 (89). The material property and allowable stress values for all steel structures shall be taken from the ASME and B&PV Code, Section II, wherever such data is available; otherwise, the data provided in the ASTM standards shall be used. {1, 2, 3}

ii. Brittle Fracture: All materials used for structural components of the CTF structure and the lift platform, designated as primary load bearing, shall meet the fracture toughness requirements for ASME Section III, Subsection NF, and Class 3 structures (NF-2300). If required, Charpy impact test temperature shall be equal to the designated LST or lower. {1, 2, 3}

iii. Fatigue: Fatigue failure modes of primary structural members in the CTF structure whose failure may result in uncontrolled lowering of the HI-TRAC transfer cask or the MPC (critical members) shall be evaluated. A minimum factor of safety of 2 on the number of permissible loading cycles on the critical members shall apply. {1, 2, 3}

iv. Buckling: For all critical members in the CTF structure (defined above), potential failure modes through buckling under axial compression shall be considered. The margin of safety against buckling shall comply with the provisions of ASME Section III, Subsection NF, for Class 3 linear structures. {1, 2, 3}

F. CTF Pad

A reinforced concrete pad in conformance with the specification for the ISFSI pad set forth in this FSAR (see Table 2.2.9) may be used in the region of the CTF where the overpack and HI-TRAC are stacked for MPC transfer. Alternatively, the pad may be designed using the guidelines of ACI-318(89). {1, 2, 3}

G. Miscellaneous Components

Hoist rings, turnbuckles, slings, and other appurtenances which are in the load path during heavy load handling at the CTF shall have enhanced margin of safety per ANSI N14.6 or be single-failure-proof. {1, 2, 3}

H. Structural Welds

All primary structural welds in the CTF structure shall comply with the specifications of ASME Section III for Class 3 NF linear structures. {1}

I. Foundation

The design of the CTF structure foundation and piers, including load combinations, shall be in accordance with ACI-318(89). {1}

J. Rail Access

The rail lines that enter the Cask Transfer Facility shall be set at grade level with no exposed rail ties or hardware other than the rail itself. {1,2}

K. Vertical Cask Crawler/Translocation Device Access (If Required)

i. The cask handling bay in the CTF shall allow access of a vertical cask crawler or translocation device carrying a transfer cask or overpack. The building floor shall be equipped with a smooth transition to the cask travel route such that the vertical cask crawler tracks do not have to negotiate sharp lips or slope transitions and the translocation devices have a smooth transition. Grading of exterior aprons shall be no more than necessary to allow water drainage. {1}

ii. If roll-up doors are used, the roll up doors shall have no raised threshold that could damage the vertical cask crawler tracks (if a crawler is used). {1}

iii. Exterior aprons shall be of a material that will not be damaged by the vertical cask crawler tracks, if a crawler is used. {1}

L. Facility Floor

i. The facility floor shall be sufficiently flat to allow optimum handling of casks with a translocation device. {1}

ii. Any floor penetrations, in areas where translocation device operations may occur, shall be equipped with flush inserts. {1}

iii. The rails, in areas where translocation device operations may occur shall be below the finish level of the floor. Flush inserts, if necessary, shall be sized for installation by hand. {1}

M. Cask Connector Brackets

i. Primary lifting attachments between the cask and the lifting platform are the cask connector brackets. The cask connector brackets may be lengthened or shortened to allow for differences in the vehicle deck height of the cask delivery vehicle and the various lifting operations. The connector brackets shall be designed to perform cask lifting, upending and downending functions. The brackets shall be designed in accordance with ANSI N14.6 [Reference 2.2.3] and load tested at 300% of the load applied to them during normal handling. {1, 2, 3}

ii. The connector brackets shall be equipped with a positive engagement to ensure that the cask lifting attachments do not become inadvertently disconnected during a seismic event and during normal cask handling operations. {1, 2, 3}

iii. The design of the connector brackets shall ensure that the HI-TRAC transfer cask is fully secured against slippage during MPC transfer operations. {1, 2, 3}

N. Cask Restraint System

A time-history analysis of the stacked overpack/HI-TRAC transfer cask assemblage under the postulated ISFSI Level D events in Table 2.3.2 shall be performed to demonstrate that a minimum margin of safety of 1.1 against overturning or kinematic instability exists and that the CTF structure complies with the applicable stress limits (Table 2.3.2) and that the maximum permissible deceleration loading specified in the FSAR is not exceeded. If required to meet the minimum margin of safety of 1.1, a cask restraining system shall be incorporated into the design of the Cask Transfer Facility to provide lateral restraint to the overpack (HI-STORM or HI-STAR 100). If the HI-STORM/HI-TRAC stack is laterally supported such that the fundamental natural frequency of the beam mode vibration of the stack is in the rigid range of the horizontal acceleration time histories (or the corresponding response spectra), then the dynamic time history solution converges to the static solution using the ZPA (see Glossary, Table 1.0.1) of the corresponding time history. In such a case, a time history analysis or a static analysis may be performed since the maximum predicted responses from both solutions are identical. {1, 2, 3}

O. Design Life

The Cask Transfer Facility shall be constructed to have a minimum design life of 40 years.{1}

P. Testing Requirements

In addition to testing recommended in NUREG-0612 (1980), a structural adequacy test of the CTF structure at 125% of its operating load prior to its first use in a cask loading campaign shall be performed. This test should be performed in accordance with the guidance provided in the CMAA Specification 70 [2.2.16]. {1}

Q. Quality Assurance Requirements

All components of the CTF shall be manufactured in full compliance with the quality assurance requirements applicable to the ITS category of the component as set forth in the Holtec QA program. {1, 2, 3}

R. Documentation Requirements

i. O&M Manual: An Operations and Maintenance Manual shall be prepared which contains, at minimum, the following items of information: {1, 2, 3}

- Maintenance Drawings
- Operating Procedures

ii. Design Report: if required by the safety classification, a QA-validated design report documenting full compliance with the provisions of this specification shall be prepared and archived for future reference in accordance with the provisions of the Holtec QA program. {1, 2, 3}

2.3.3.2 Instrumentation

As a consequence of the passive nature of the HI-STORM 100 System, instrumentation which is important to safety is not necessary. No instrumentation is required or provided for HI-STORM 100 storage operations, other than normal security service instruments and TLDs.

However, in lieu of performing the periodic inspection of the HI-STORM overpack vent screens, temperature elements may be installed in two of the overpack exit vents to continuously monitor the air temperature. If the temperature elements and associated temperature monitoring instrumentation are used, they shall be designated important to safety as specified in Table 2.2.6.

The temperature elements and associated temperature monitoring instrumentation provided to monitor the air outlet temperature shall be suitable for a temperature range of -40°F to 500°F. At a minimum, the temperature elements and associated temperature monitoring instrumentation shall be calibrated for the temperatures of 32°F (ice point), 212°F (boiling point), and 449°F (melting point of tin) with an accuracy of +/- 4°F.

2.3.4 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.

2.3.4.1 Control Methods for Prevention of Criticality

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

a. Incorporation of permanent neutron absorbing material in the MPC fuel basket walls.

b. Favorable geometry provided by the MPC fuel basket

Additional control methods used to prevent criticality for the MPC-24, MPC-24E, and MPC-24EF (all with higher enriched fuel), and the MPC-32 and MPC-32F are the following:

a. Loading of PWR fuel assemblies must be performed in water with a minimum boron content as specified in Table 2.1.14 or 2.1.16, as applicable.

b. Prevention of fresh water entering the MPC internals.

Administrative controls and shall be used to ensure that fuel placed in the HI-STORM 100 System meets the requirements described in Chapters 2 and 6. All appropriate criticality analyses are presented in Chapter 6.

2.3.4.2 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.

2.3.4.3 Verification Analyses

In Chapter 6, 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.

2.3.5 Radiological Protection

2.3.5.1 Access Control

As required by 10CFR72, uncontrolled access to the ISFSI is prevented through physical protection means. A peripheral fence with an appropriate locking and monitoring system is a standard approach to limit access. 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 100 System.

2.3.5.2 Shielding

The shielding design is governed by 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 2.3.1 for normal, off-normal, and accident conditions.

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. 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 overpack are important in consideration of occupational exposure. Conservative evaluations of dose rate have been performed and are described in Chapter 5 based on the contents of the BWR and PWR MPCs permitted for storage as described in Section 2.1.9. Actual dose rates in operation will be lower than those reported in Chapter 5 for the following reasons:

- The shielding evaluation model has a number of conservatisms, as discussed in Chapter 5.

- No single cask will likely contain design basis fuel in each fuel storage location and the full compliment of non-fuel hardware allowed by Section 2.1.9.

- No single cask will contain fuel and non-fuel hardware at the limiting burnups and cooling times allowed by Section 2.1.9.

Consistent with 10 CFR 72, there is no single dose rate limit established for the HI-STORM 100 System. Compliance with the regulatory limits on occupational and controlled area doses is performance-based, as demonstrated by dose monitoring performed by each cask A design objective for the maximum average radial surface dose rate has been established as 300 mrem/hr. Areas adjacent to the inlet and exit vents which pass through the radial shield are limited to 175 mrem/hr. The average dose rate at the top of the overpack is limited to below 60 mrem/hr. Chapter 5 of this FSAR presents the analyses and evaluations to establish HI-STORM 100 compliance with these design objectives.

Because of the passive nature of the HI-STORM 100 System, human activity related to the system is infrequent and of short duration. Personnel exposures due to operational and maintenance activities are discussed in Chapter 10. Chapter 10 also provides information concerning temporary shielding which may be utilized to reduce the personnel dose during loading, unloading, transfer, and handling operations. The estimated occupational doses for personnel comply with the requirements of 10CFR20.

For the loading and unloading of the HI-STORM overpack with the MPC, several transfer cask designs are provided (i.e., HI-TRAC 125, HI-TRAC 100, HI-TRAC 100D and HI-TRAC 125D). The two 125 ton HI-TRAC provide better shielding than the HI-TRAC 100D and 125D due to the increased shielding thickness and corresponding greater weight. Provided the licensee is capable of utilizing the 125 ton HI-TRAC, ALARA considerations would normally dictate that the 125 ton HI-TRAC should be used. However, sites may not be capable of utilizing the 125 ton HI-TRAC due to crane capacity limitations, floor loading limitations, or other site-specific considerations. As with other dose reduction-based plant activities, individual users who cannot accommodate the 125 ton HI-TRAC should perform a cost-benefit analysis of the actions (e.g., plant modifications) that would be necessary to use the 125 ton HI-TRAC. The cost of the action(s) would be weighed against the value of the projected reduction in radiation exposure and a decision made based on each plant's particular ALARA implementation philosophy.

Dose rates at the restricted area and site boundaries shall be in accordance with applicable regulations. Licensees shall demonstrate compliance with 10CFR72.104 and 10CFR72.106 for the actual fuel being stored, the ISFSI storage array, and the controlled area boundary distances.

The analyses presented in Chapters 5, 10, and 11 demonstrate that the HI-STORM 100 System is capable of meeting the above radiation dose limits.

2.3.5.3 Radiological Alarm System

There are no credible events that could result in release of radioactive materials or increases in direct radiation above the requirements of 10CFR72.106.

2.3.6 Fire and Explosion Protection

There are no combustible or explosive materials associated with the HI-STORM 100 System. No such materials would be stored within an ISFSI. However, for conservatism we have analyzed a hypothetical fire accident as a bounding condition for HI-STORM 100. An evaluation of the HI-STORM 100 System in a fire accident is discussed in Chapter 11.

Small overpressures may result from accidents involving explosive materials which are stored or transported near the site. Explosion is an accident loading condition considered in Chapter 11.

Table 2.3.1

RADIOLOGICAL SITE BOUNDARY REQUIREMENTS

BOUNDARY OF CONTROLLED AREA (m) (minimum)	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 2.3.2

Load Combinations[†] and Service Condition Definitions for the CTF Structure

Load Combination	Service Condition for Section III of the ASME Code for Definition of Allowable Stress	Comment
D*	Level A	All primary load bearing members must satisfy Level A stress limits.
D+S	Level A	
D+M[††]+W' D+F D+E or D+Y	Level D	Factor of safety against overturning shall be ≥ 1.1

† The reinforced concrete portion of the CTF structure shall also meet factored combinations of the above loads set forth in ACI-318(89).

†† This load may be reduced or eliminated based on a PRA for the CTF site.

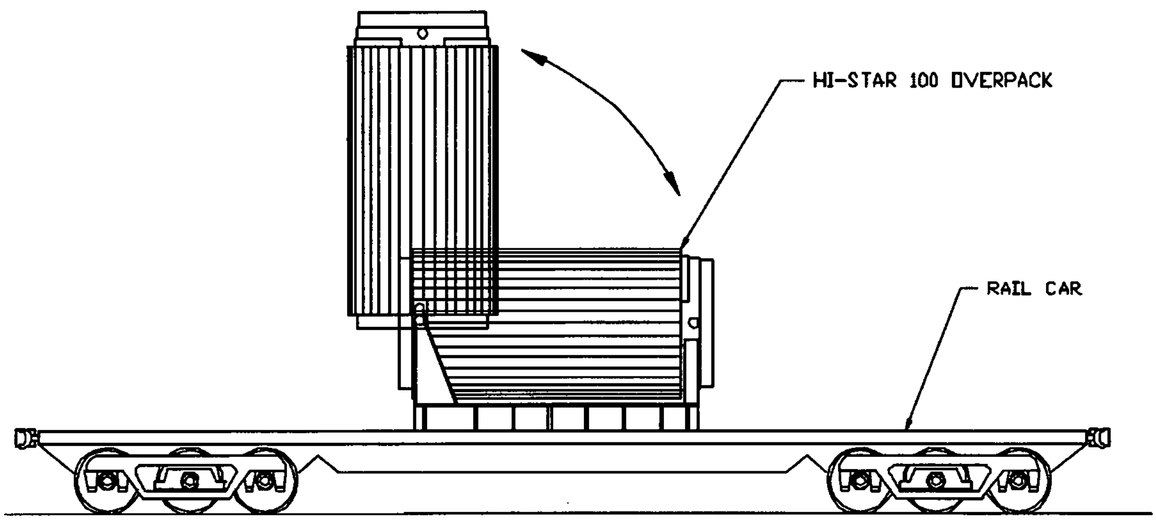

FIGURE 2.3.1; HI-STAR 100 UPENDING AND DOWNENDING ON A RAIL CAR

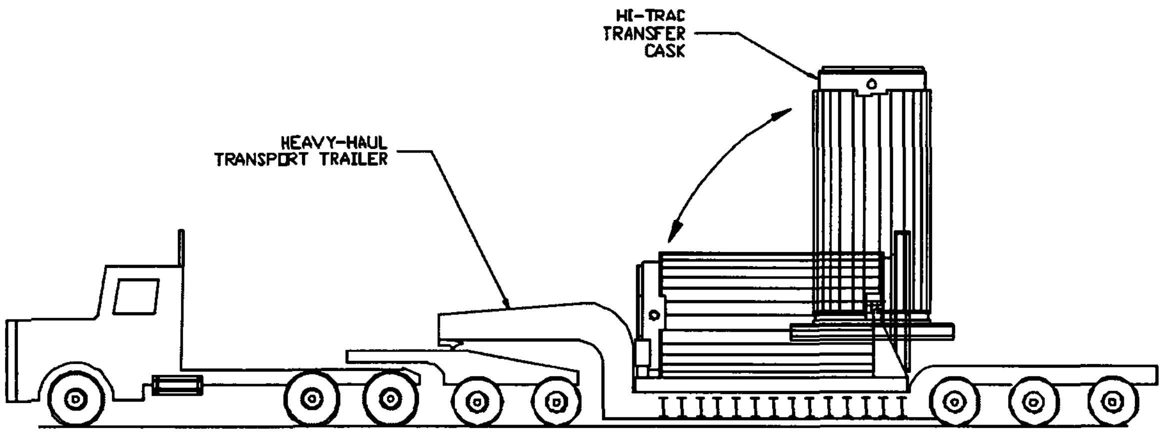

FIGURE 2.3.2; HI-TRAC UPENDING AND DOWNENDING ON A HEAVY-HAUL TRANSPORT TRAILER

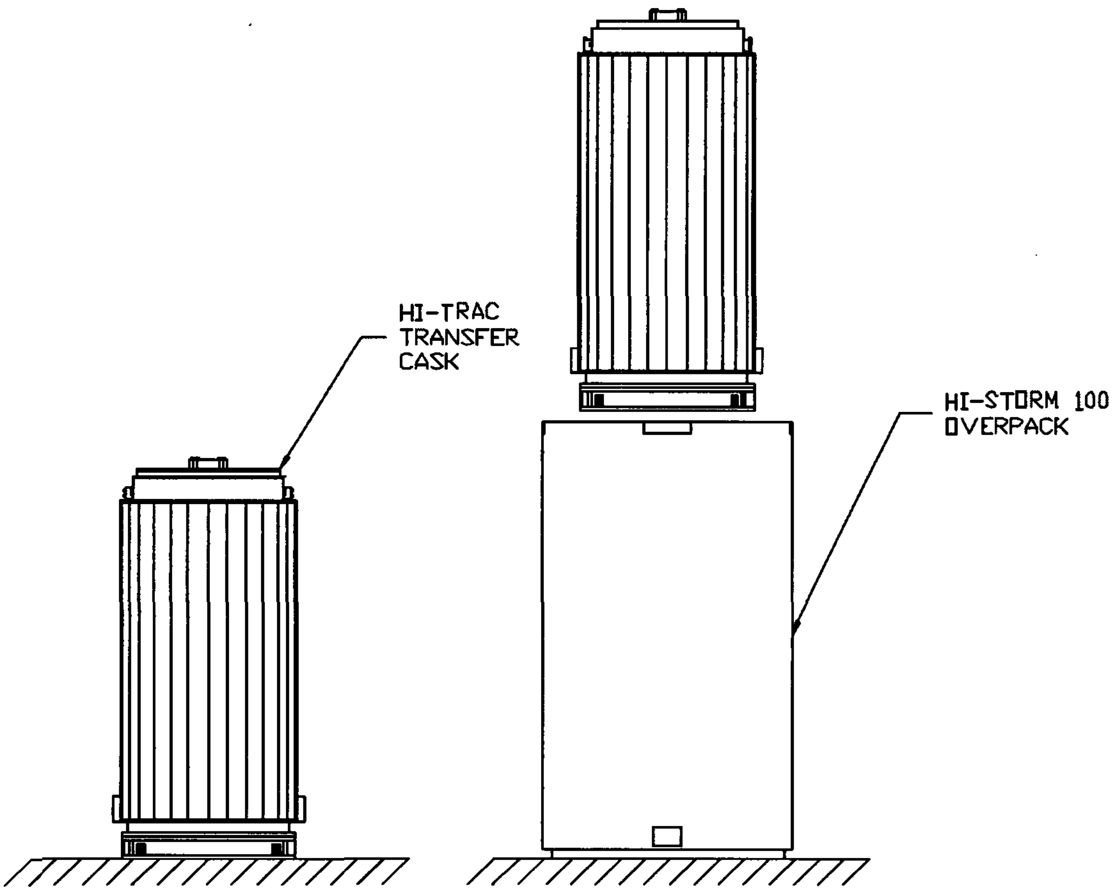

FIGURE 2.3.3; HI-TRAC PLACEMENT ON HI-STORM 100 FOR MPC TRANSFER OPERATIONS

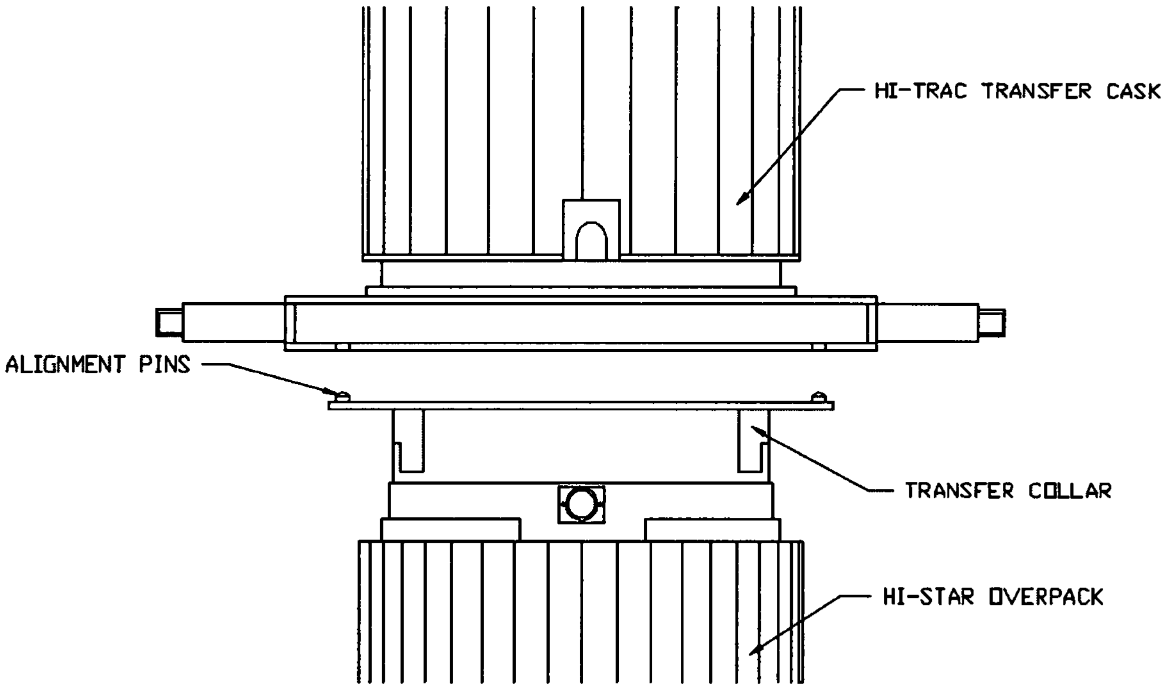

FIGURE 2.3.4; HI-TRAC PLACEMENT ON HI-STAR 100 FOR MPC TRANSFER OPERATIONS

2.4 DECOMMISSIONING CONSIDERATIONS

Efficient decommissioning of the ISFSI is a paramount objective of the HI-STORM 100 System. The HI-STORM 100 System is ideally configured to facilitate rapid, safe, and economical decommissioning of the storage site.

The MPC is being licensed for transport off-site in the HI-STAR 100 dual-purpose cask system (Reference Docket No. 71-9261). No further handling of the SNF stored in the MPC is required prior to transport to a licensed centralized storage facility or licensed 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 should 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) boring of the MPC lid to provide access to the MPC vent and drain. The circumferential welds of the MPC lid closure ring can be removed by semiautomatic or remotely actuated means, providing access to the SNF.

Likewise, the overpack consists of steel and concrete rendering it suitable for permanent burial. Alternatively, the MPC can be removed from the overpack, and the latter reused for storage of other MPCs.

In either case, the overpack 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 MPC needs to be opened and separated from the SNF before the fuel is placed into the MGDS, the MPC interior metal surfaces will be decontaminated using existing mechanical or chemical methods. This will be facilitated by the MPC fuel basket and interior structures' 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.

It is also likely that both the overpack and MPC, or extensive portions of both, can be further decontaminated to allow recycle or reuse options. After decontamination, the only radiological hazard the HI-STORM 100 System may pose is slight activation of the HI-STORM 100 materials caused by irradiation over a 40-year storage period.

Due to the design of the HI-STORM 100 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 overpack is removed.

To evaluate the effects on the MPC and HI-STORM overpack caused by irradiation over a 40-year storage period, the following analysis is provided. Table 2.4.1 provides the conservatively determined quantities of the major nuclides after 40 years of irradiation. The calculation of the material activation is based on the following:

- Beyond design basis fuel assemblies (B&W 15x15, 4.8% enrichment, 70,000 MWD/MTU, and five-year cooling time) stored for 40 years. A constant source term for 40 years was used with no decrease in the neutron source term. This bounds the source term associated with the limiting PWR burnup of 68,200 MWD/MTU.

- Material quantities based on the drawings in Section 1.5.

- A constant flux equal to the initial loading condition is conservatively assumed for the full 40 years.

- Material activation is based on MCNP-4A calculations.

As can be seen from the material activation results presented in Table 2.4.1, the MPC and HI-STORM overpack activation is very low, even including the very conservative assumption of a constant flux for 40 years. The results for the concrete in the HI-STORM overpack can be conservatively applied to the ISFSI pad. This is extremely conservative because the overpack shields most of the flux from the fuel and, therefore, the ISFSI pad will experience a minimal flux.

In any case, the HI-STORM 100 System would not impose any additional decommissioning requirements on the licensee of the ISFSI facility per 10CFR72.30, since the HI-STORM 100 System could eventually be shipped from the site.

Table 2.4.1

MPC ACTIVATION

Nuclide	Activity After 40-Year Storage (Ci/m^3)
^{54}Mn	2.20e-3
^{55}Fe	3.53e-3
^{59}Ni	2.91e-6
^{60}Co	3.11e-4
^{63}Ni	9.87e-5
Total	6.15e-3

HI-STORM OVERPACK ACTIVATION

Nuclide	Activity After 40-Year Storage (Ci/m^3)
Overpack Steel	
^{54}Mn	3.62e-4
^{55}Fe	6.82e-3
Total	7.18e-3
Overpack Concrete	
^{39}Ar	3.02e-6
^{41}Ca	2.44e-7
^{54}Mn	1.59e-7
^{55}Fe	2.95e-5
Total	3.43e-5

2.5 REGULATORY COMPLIANCE

Chapter 2 provides the principal design criteria related to structures, systems, and components important to safety. These criteria include specifications regarding the fuel, as well as, external conditions that may exist in the operating environment during normal and off-normal operations, accident conditions, and natural phenomena events. The chapter has been written to provide sufficient information to allow verification of compliance with 10CFR72, NUREG-1536, and Regulatory Guide 3.61. A more detailed evaluation of the design criteria and an assessment of compliance with those criteria is provided in Chapters 3 through 13.

2.6 REFERENCES

[2.0.1] American Concrete Institute, "Building Code Requirements for Structural Plain Concrete (ACI 318.1-89) (Revised 1992) and Commentary - ACI 318.1R-89 (Revised 1992)".

[2.0.2] American Concrete Institute, "Code Requirements for Nuclear Safety Related Concrete Structures", ACI 349-85, ACI, Detroit, Michigan†

[2.0.3] Deleted.

[2.0.4] NRC Regulatory Guide 7.10, "Establishing Quality Assurance Programs for Packaging Used in the Transport of Radioactive Material," USNRC, Washington, D.C. Rev. 1 (1986).

[2.0.5] J.W. McConnell, A.L. Ayers, and M.J. Tyacke, "Classification of Transportation Packaging and Dry Spent Fuel Storage System Component According to Important to Safety," Idaho Engineering Laboratory, NUREG/CR-6407, INEL-95-0551, 1996.

[2.0.6] NUREG-1567, Standard Review Plan for Spent Fuel Dry Storage Facilities, March 2000.

[2.0.7] ASME Code, Section III, Subsection NF and Appendix F, and Code Section II, Part D, Materials, 1995, with Addenda through 1997.

[2.0.8] "Cladding Considerations for the Transportation and Storage of Spent Fuel," USNRC Interim Staff Guidance-11, Revision 3, November 17, 2003.

[2.0.9] USNRC Memorandum from Christopher L. Brown to M. Wayne Hodges, "Scoping Calculations for Cladding Hoop Stresses in Low Burnup Fuel," dated January 29, 2004.

[2.1.1] ORNL/TM-10902, "Physical Characteristics of GE BWR Fuel Assemblies", by R.S. Moore and K.J. Notz, Martin Marietta (1989).

[2.1.2] U.S. DOE SRC/CNEAF/96-01, Spent Nuclear Fuel Discharges from U.S. Reactors 1994, Feb. 1996.

[2.1.3] Deleted.

† The 1997 edition of ACI-349 is specified for embedment design for deployment of the anchored HI-STORM 100A and HI-STORM 100SA.

[2.1.4] Deleted.

[2.1.5] NUREG-1536, SRP for Dry Cask Storage Systems, USNRC, Washington, DC, January 1997.

[2.1.6] DOE Multi-Purpose Canister Subsystem Design Procurement. Specification.

[2.1.7] S.E. Turner, "Uncertainty Analysis - Axial Burnup Distribution Effects," presented in "Proceedings of a Workshop on the Use of Burnup Credit in Spent Fuel Transport Casks", SAND-89-0018, Sandia National Laboratory, Oct., 1989.

[2.1.8] Commonwealth Edison Company, Letter No. NFS-BND-95-083, Chicago, Illinois.

[2.2.1] ASME Boiler & Pressure Vessel Code, American Society of Mechanical Engineers, 1995 with Addenda through 1997.

[2.2.2] ASCE 7-88 (formerly ANSI A58.1), "Minimum Design Loads for Buildings and Other Structures", American Society of Civil Engineers, New York, NY, 1990.

[2.2.3] ANSI N14.6-1993, "Special Lifting Devices for Shipping Containers Weighing 10,000 Pounds (4500 Kg) or More", June 1993.

[2.2.4] Holtec Report HI-2012610, "Final Safety Analysis Report for the HI-STAR 100 Cask System", NRC Docket No. 72-1008, latest revision.

[2.2.5] Holtec Report HI-951251, "Safety Analysis Report for the HI-STAR 100 Cask System", NRC Docket No. 71-9261, latest revision.

[2.2.6] "Debris Collection System for Boiling Water Reactor Consolidation Equipment", EPRI Project 3100-02 and ESEERCO Project EP91-29, October 1995.

[2.2.7] Design Basis Tornado for Nuclear Power Plants, Regulatory Guide 1.76, U.S. Nuclear Regulatory Commission, April 1974.

[2.2.8] ANSI/ANS 57.9-1992, "Design Criteria for an Independent Spent Fuel Storage Installation (dry type)", American Nuclear Society, LaGrange Park, Illinois.

[2.2.9] NUREG-0800, SRP 3.5.1.4, USNRC, Washington, DC.

[2.2.10] United States Nuclear Regulatory Commission Regulatory Guide 1.59, "Design Basis Floods for Nuclear Power Plants", August 1973 and Rev. 1, April 1976.

[2.2.11] "Estimate of Tsunami Effect at Diablo Canyon Nuclear Generating Station, California." B.W. Wilson, PG&E (September 1985, Revision 1).

[2.2.12] D. Peckner and I.M. Bernstein, "Handbook of Stainless Steels," McGraw-Hill Book Company, 1977.

[2.2.13] "Nuclear Systems Materials Handbook," Oak Ridge National Laboratory, TID 26666, Volume 1.

[2.2.14] Deleted.

[2.2.15] Deleted.

[2.2.16] Crane Manufacturer's Association of America (CMAA), Specification #70, 1988, Section 3.3.

APPENDIX 2.A

GENERAL DESIGN AND CONSTRUCTION REQUIREMENTS FOR THE ISFSI PAD FOR HI-STORM 100A

2.A.1 General Comments

As stated in Section 2.0.4, an ISFSI slab that anchors a spent fuel storage cask should be classified as "important to safety." This classification of the slab follows from the provisions of 10CFR72, which require that the cask system retain its capacity to store spent nuclear fuel in a safe configuration subsequent to a seismic or other environmental event. Since the slab for anchored HI-STORM deployment is designated as ITS, the licensee is required to determine whether the reactor site parameters, including earthquake intensity and large missiles, are enveloped by the cask design bases. The intent of the regulatory criteria is to ensure that the slab meets all interface requirements of the cask design and the geotechnical characteristics of the ISFSI site.

This appendix provides general requirements for design and construction of the ISFSI concrete pad as an ITS structure, and also establishes the framework for ensuring that the ISFSI design bases are clearly articulated. The detailed design of the ISFSI pad for anchored HI-STORM deployment shall comply with the technical provisions set forth in this appendix.

2.A.2 General Requirements for ISFSI Pad

1. Consistent with the provisions of NUREG-1567 [2.0.6], all concrete work shall comply with the requirements of ACI-349-85 [2.0.2].

2. All reinforcing steel shall be manufactured from high strength billet steel conforming to ASTM designation A615 Grade 60.

3. The ISFSI owner shall develop appropriate mixing, pouring, reinforcing steel placement, curing, testing, and documentation procedures to ensure that all provisions of ACI 349-85 [2.0.2] are met.

4. The placement, depth, and design and construction of the slab shall take into account the depth of the frost line at the ISFSI location. The casks transmit a very small amount of heat into the cask pad through conduction. The American Concrete Institute guidelines on reinforced concrete design of ground level slabs to minimize thermal and shrinkage induced cracking shall be followed.

5. General Requirements for Steel Embedment: The steel embedment, excluding the pre-tensioned anchorage studs, is required to follow the provisions stipulated in ACI 349-85 [2.0.2], Appendix B "Steel Embedment" and the associated Commentary on Appendix B, as applicable. Later editions of this Code may be used provided a written reconciliation is performed. An example of one acceptable embedment configuration is provided in Figure 2.A.1. Site-specific embedment designs may vary from this example, depending on the geotechnical characteristics of the site-specific foundation. The embedment designer shall consider any current, relevant test data in designing the pad embedment for HI-STORM 100A and HI-STORM 100SA.

6. The ISFSI owner shall ensure that pad design analyses, using interface loads provided in this report, demonstrate that all structural requirements of NUREG-1567 and ACI-349-85 are satisfied.

7. Unless the load handling device is designed in accordance with ANSI N14.6 and incorporates redundant drop protection features, the ISFSI owner shall ensure that a permissible cask carry height is computed for the site-specific pad/foundation configuration such that the design basis deceleration set forth in this FSAR are not exceeded in the event of a handling accident involving a vertical drop.

8. The ISFSI owner shall ensure that the pad/foundation configuration provides sufficient safety margins for overall kinematic stability of the cask/pad/foundation assemblage.

9. The ISFSI owner shall ensure that the site-specific seismic inputs, established at the top surface of the ISFSI pad, are bounded by the seismic inputs used as the design basis for the attachment components. If required, the ISFSI owner shall perform additional analyses to ensure that the site-specific seismic event or durations greater than the design basis event duration analyzed in this report, do not produce a system response leading to structural safety factors (defined as allowable stress (load) divided by calculated stress (load)) less than 1.0. Table 2.0.5 and Table 2.2.8 provide the limiting values of ZPAs in the three orthogonal directions that must not be exceeded at an ISFSI site (on the pad top surface) to comply with the general CoC for the HI-STORM 100A (and 100SA) System.

10. An ISFSI pad used to support anchored HI-STORM overpacks, unlike the case of free standing overpacks, may experience tensile (vertically upward) anchorage forces in addition to compression loads. The reinforcing steel (pattern and quantity) must be selected to meet the demands of the anchorage forces under seismic and other environmental conditions that involve destabilizing loadings (such as the large tornado missile defined in this FSAR).

2.A.3 Steel Embedment for Anchored Casks

Figure 2.A.1 shows a typical fastening arrangement for the HI-STORM 100A System. The details of the rebars in the pad (which are influenced by the geotechnical characteristics of the foundation and its connection to the underlying continuum) are not shown in Figure 2.A.1. Representative dimensions of the embedment and anchorage system are provided in Table 2.A.1.

The embedment detail illustrated in Figure 2.A.1 is designed to resist a load equal to the ASME Code, Section III Appendix F Level D load capacity of the cask anchor studs. The figure does not show the additional reinforcement required to ensure that tensile cracking of concrete is inhibited (see Figure B-4 in the Commentary ACI-349R-97) as this depends on the depth chosen for the ITS ISFSI pad concrete. The ACI Code contemplates ductile failure of the embedment steel and requires that the ultimate load capacity of the steel embedment be less than the limit pullout strength of the concrete surrounding the embedment that resists the load transferred from the cask anchor stud. If this criterion cannot be assured, then additional reinforcement must be added to inhibit concrete cracking (per Subsection B.4.4 of Appendix B of ACI-349-97).

The anchor stud receptacle described in Figure 2.A.1 is configured so that the cask anchor studs (which interface with the overpack baseplate as well as the pad embedment per Table 2.0.5 and are designed in accordance with ASME Section III, Subsection NF stress limits), sits flush with the ISFSI top surface while the cask is being positioned. Thus, a translocation device such as an "air pad" (that requires a flat surface) can be used to position the HI-STORM overpack at the designated location. Subsequent to positioning of the cask, the cask anchor stud is raised, the anchor stud nut installed, and the anchor stud preload applied. The transfer of load from the cask anchor stud to the embedment is through the bearing surface of the lower head of the cask anchor stud and the upper part of the anchor stud receptacle shown in the figure. The members of the anchoring system illustrated in Figure 2.A.1, as well as other geometries developed by the ISFSI designer, must meet the following criteria:

i. The weakest structural link in the system shall be in the ductile member. In other words, the tension capacity of the anchor stud/anchor receptacle group (based on the material ultimate strengths) shall be less than the concrete pull-out strength (computed with due recognition of the rebars installed in the pad).

ii. The maximum ratio of embedment plus cask anchor stud effective tensile stiffness to the effective compressive stiffness of the embedment plus concrete shall not exceed 0.25 in order to ensure the effectiveness of the pre-load.

iii. The maximum axial stress in the cask anchor studs under normal and seismic conditions shall be governed by the provisions of ASME Section III Subsection NF (1995).

iv. The load-bearing members of the HI-STORM 100A anchorage system shall be considered important-to-safety. This includes the following components shown in Figure 2.A.1: anchor stud and nut, top ring, upper collar, anchor receptacle, and anchor ring.

For sites with lower ZPA DBE events, compared to the limiting ZPAs set down in this FSAR, the size of the anchor studs and their number can be appropriately reduced. However, the above three criteria must be satisfied in all cases.

Table 2.A.1

Typical Embedment and Anchoring Data*

Nominal diameter of the anchor stud, (inch)	2
Thickness of the embedment ring, (inch)	2
I.D. of the embedment ring, (inch)	130
Anchor receptacle: Upper Position O.D. and I.D. (inch) Lower portion O.D. and I.D. (inch)	 O.D.: 2.5 / I.D.: 2.125 (min.) O.D.: 4.875 / I.D.: 3.625 (min.)
Depth of anchor receptacle collar, d, (inch)	2.5
Free fall height of the anchor stud, h_e,(inch)	8
Representative Materials of Construction are as follows:[†]	
Anchor Studs:	Per Table 2.0.4
Anchor Receptacle:	Low carbon steel such as A-36, A-105
Top Ring, Upper Collar, Anchor Ring:	Low carbon steel such as A-36, SA-516-Gr. 70

* Refer to Figure 2.A.1

[†] The ISFSI designer shall ensure that all permanently affixed embedment parts (such as the anchor receptacle) made from materials vulnerable to deleterious environmental effects (e.g. low carbon steel) are protected through the use of suitably engineered corrosion barrier. Alternatively, the selected material of construction must be innately capable of withstanding the long term environmental conditions at the ISFSI site.

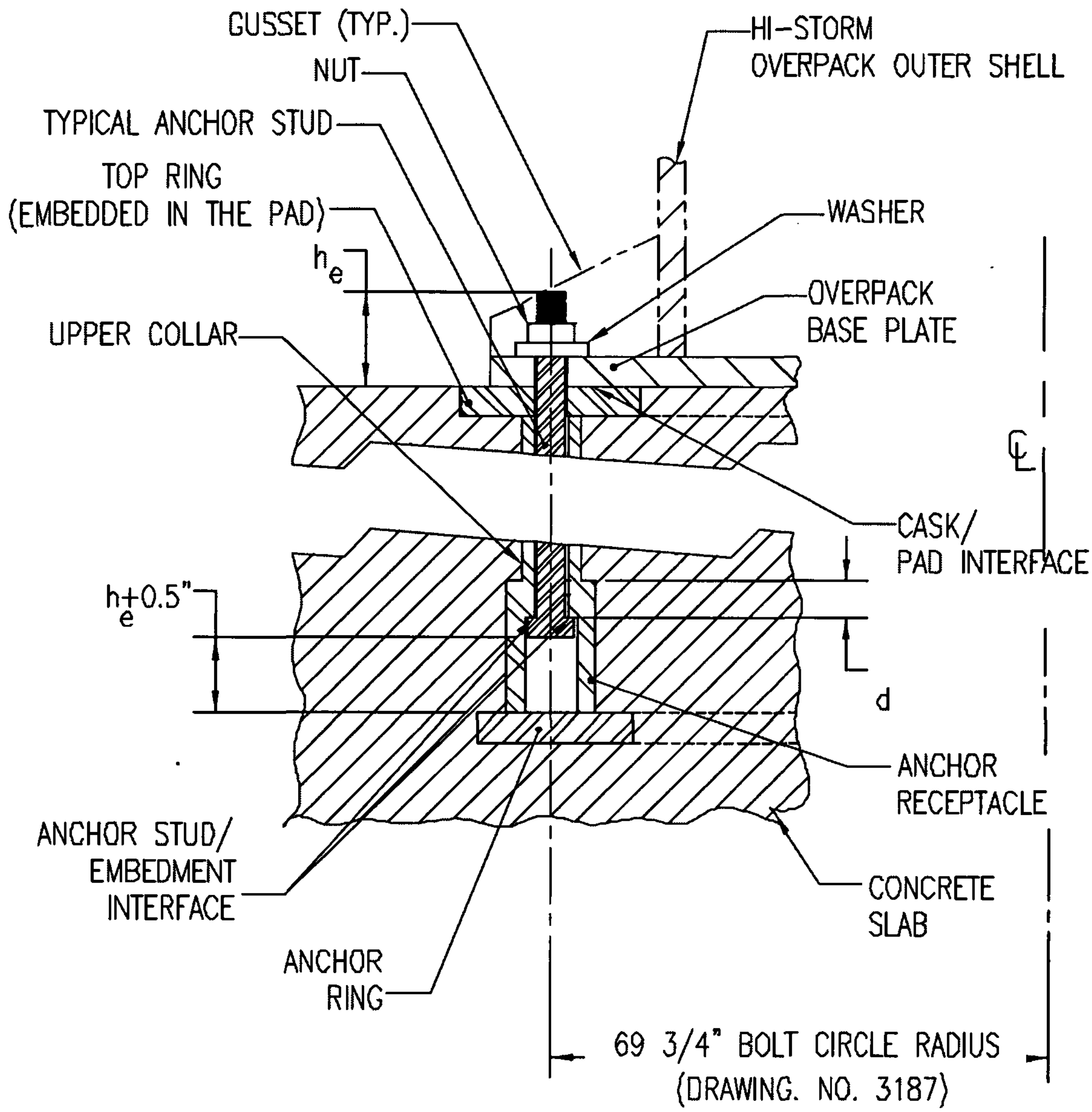

Figure 2.A.1;
Typical HI-STORM/ISFSI pad Fastening Detail

Note: Rebars in the ISFSI pad and sub-surface soil/rock continuum not shown.

Appendix 2.B The Forced Helium Dehydration (FHD) System

2.B.1 System Overview

The Forced Helium Dehydration (FHD) system is 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 blowdown operation. The FHD system is required to be used for MPCs containing at least one high burnup fuel assembly. 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, shall utilize helium gas as the working substance.

The FHD system, schematically illustrated in Figure 2.B.1, can be viewed as an assemblage of four thermal modules, namely, (i) the condensing module, (ii) the demoisturizer module, (iii) the helium circulator module and (iv) the pre-heater module. The condensing module serves to cool the helium/vapor mixture exiting the MPC to a temperature well below its dew point such that water may be extracted from the helium stream. The condensing module is equipped with suitable instrumentation to provide a direct assessment of the extent of condensation that takes place in the module during the operation of the FHD system. The demoisturizer module, engineered to receive partially cooled helium exiting the condensing module, progressively chills the recirculating helium gas to a temperature that is well below the temperature corresponding to the partial pressure of water vapor at 3 torr.

The motive energy to circulate helium is provided by the helium circulator module, which is sized to provide the pressure rise necessary to circulate helium at the requisite rate. The last item, labeled the pre-heater module, serves to pre-heat the flowing helium to the desired temperature such that it is sufficiently warm to boil off any water present in the MPC cavity.

The pre-heater module, in essence, serves to add supplemental heat energy to the helium gas (in addition to the heat generated by the stored SNF in the MPC) so as to facilitate rapid conversion of water into vapor form. The heat input from the pre-heater module can be adjusted in the manner of a conventional electric heater so that the recirculating helium entering the MPC is sufficiently dry and hot to evaporate water, but not unduly hot to place unnecessary thermal burden on the condensing module.

The FHD system described in the foregoing performs its intended function by continuously removing water entrained in the MPC through successive cooling, moisture removal and reheating of the working substance in a closed loop. In a classical system of the FHD genre, the moisture removal operation occurs in two discrete phases. In the beginning of the FHD system's operation (Phase 1), the helium exiting the MPC is laden with water vapor produced by boiling of the entrained bulk water. The condensing module serves as the principal device to condense out the water vapor from the helium stream in Phase 1. Phase 1 ends when all of the bulk water in the MPC cavity is vaporized. At this point, the operation of the FHD system moves on to steadily lowering the relative humidity and bulk temperature of the circulating helium gas (Phase 2). The demoisturizer module, equipped with the facility to chill flowing helium, plays the principal role in the dehydration process in Phase 2.

2.B.2 Design Criteria

The design criteria set forth below are intended to ensure that design and operation of the FHD system will drive the partial pressure of the residual vapor in the MPC cavity to ≤ 3 torr if the gas has met the specified temperature or dew point value and duration criteria. The FHD system shall be 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.

ii. The pressure in the MPC cavity space shall be less than or equal to 60.3 psig (75 psia).

iii. 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.

iv. The partial pressure of the water vapor in the MPC cavity will not exceed 3 torr. The limit will be met if the gas temperature at the demoisturizer outlet is verified by measurement to remain ≤ 21°F for ≥ 30 minutes or if the dew point of the gas exiting the MPC is verified by measurement to remain ≤ 22.9°F for ≥ 30 minutes.

In addition to the above system design criteria, the individual modules shall be designed in accordance with the following criteria:

i. The condensing module shall be designed to de-vaporize the recirculating helium gas to a dew point of 120°F or less.

ii. The demoisturizer module shall be configured to be introduced into its helium conditioning function <u>after</u> the condensing module has been operated for the required length of time to assure that the bulk moisture vaporization in the MPC (defined as Phase 1 in Section 2.B.1) has been completed.

iii. The helium circulator shall be sized to effect the minimum flow rate of circulation required by the system design criteria described above.

iv. The pre-heater module shall be engineered to ensure that the temperature of the helium gas in the MPC meets the system design criteria described above.

2.B.3 Analysis Requirements

The design of the FHD system shall be subject to the confirmatory analyses listed below to ensure that the system will accomplish the performance objectives set forth in this FSAR.

i. System thermal analysis in Phase 1: Characterize the rate of condensation in the condensing module and helium temperature variation under Phase 1 operation (i.e., the scenario where there is some unevaporated water in the MPC) using a classical thermal-hydraulic model wherein the incoming helium is assumed to fully mix with the moist helium inside the MPC.

ii. System thermal analysis in Phase 2: Characterize the thermal performance of the closed loop system in Phase 2 (no unvaporized moisture in the MPC) to predict the rate of condensation and temperature of the helium gas exiting the condensing and the demoisturizer modules. Establish that the system design is capable to ensure that partial pressure of water vapor in the MPC will reach ≤ 3 torr if the temperature of the helium gas exiting the demoisturizer is predicted to be at a maximum of 21°F for 30 minutes.

iii. Fuel Cladding Temperature Analysis: A steady-state thermal analysis of the MPC under the forced helium flow scenario shall be performed using the methodology described in HI-STORM 100 FSAR Subsections 4.4.1.1.1 through 4.4.1.1.4 with due recognition of the forced convection process during FHD system operation. This analysis shall demonstrate that the peak temperature of the fuel cladding under the most adverse condition of FHD system operation (design maximum heat load, no moisture, and maximum helium inlet temperature), is below the peak cladding temperature limit for normal conditions of storage for the applicable fuel type (PWR or BWR) and cooling time at the start of dry storage.

2.B.4 Acceptance Testing

The first FHD system designed and built for the MPC drying function required by HI-STORM's technical specifications shall be subject to confirmatory testing as follows:

a. A representative quantity of water shall be placed in a manufactured MPC (or equivalent mock-up) and the closure lid and RVOAs installed and secured to create a hermetically sealed container.

b. The MPC cavity drying test shall be conducted for the worst case scenario (no heat generation within the MPC available to vaporize water).

c. The drain and vent line RVOAs on the MPC lid shall be connected to the terminals located in the pre-heater and condensing modules of the FHD system.

d. The FHD system shall be operated through the moisture vaporization (Phase 1) and subsequent dehydration (Phase 2). The FHD system operation will be stopped after the temperature of helium exiting the demoisturizer module has been at or below 21°F for thirty minutes (nominal). Thereafter, a sample of the helium gas from the MPC will be extracted and tested to determine the partial pressure of the residual water vapor in it. The FHD system will be deemed to have passed the acceptance testing if the partial pressure in the extracted helium sample is less than or equal to 3 torr.

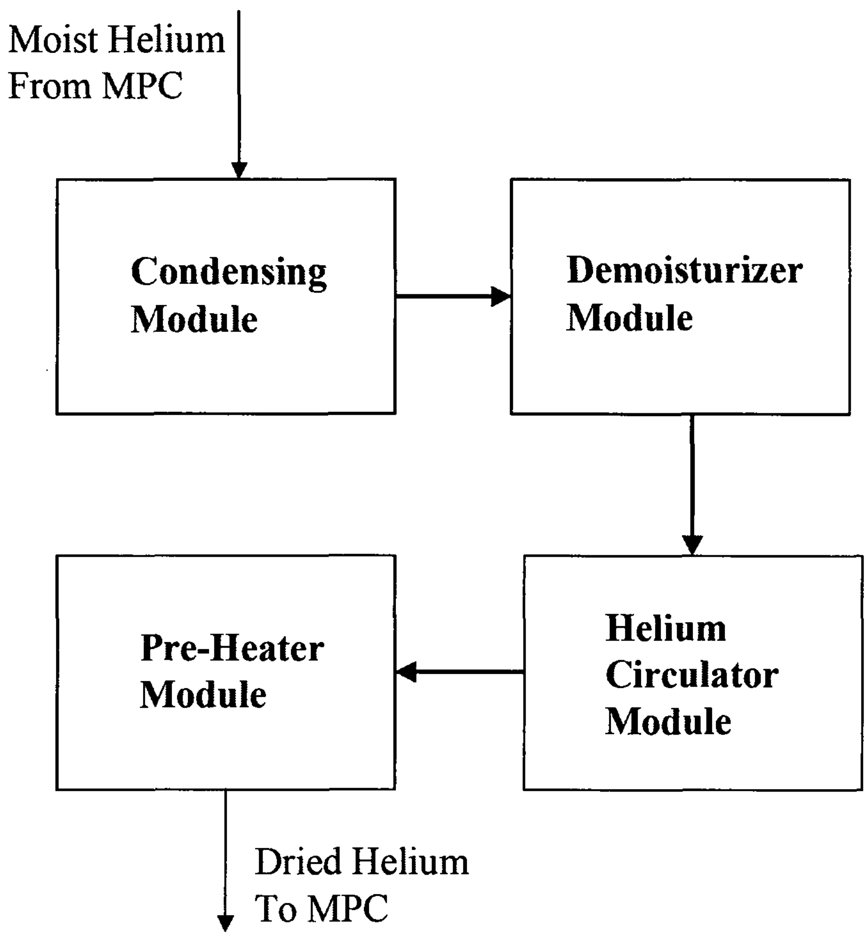

FIGURE 2.B.1: SCHEMATIC OF THE FORCED HELIUM DEHYDRATION SYSTEM

Appendix 2.C

The Supplemental Cooling System

2.C.1 Purpose

The Supplemental Cooling System (SCS) will be utilized, as necessary, to maintain the peak fuel cladding temperature below the limit set forth in Chapter 2 of the FSAR during normal short-term operations (as defined in Section 2.2).

2.C.2 General Description and Requirements

The SCS is a system for cooling the MPC inside the HI-TRAC transfer cask during on-site transport. During normal SCS operation, heat is removed by a coolant from the HI-TRAC annulus and rejected to the heat sink (ambient air). The SCS shall be designed to meet the following criteria:

(i) If the system uses water as the coolant, the system is sized to limit the coolant temperature to below 180°F under steady-state conditions for the design basis heat load at an ambient air temperature of 100°F. Active components (i.e., pump or air-cooler fan) are powered by electric motors with a backup power supply for uninterrupted operation.

(ii) The system will utilize a contamination-free fluid medium in contact with the external surfaces of the MPC and inside surfaces of the HI -TRAC transfer cask to minimize corrosion. Figure 2.C.1 shows a typical P&ID for a SCS.

(iii) The number of active components in the SCS will be minimized.

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

2.C.3 Thermal/Hydraulic Design Criteria

(i) The heat dissipation capacity of the SCS shall be equal to or greater than the minimum necessary to ensure that the peak cladding temperature of High-Burnup fuel assemblies is below the ISG-11, Rev. 3 limit of 400°C (752°F). All heat transfer surfaces in any heat exchangers shall be assumed to be fouled to the maximum limits specified in a widely used heat exchange equipment standard such as the Standards of Tubular Exchanger Manufacturers Association.

(ii) The coolant utilized to extract heat from the MPC shall be either high purity water or air. Anti-freeze may be used to prevent water from freezing if warranted by operating conditions.

2.C.4 Mechanical Requirements

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

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

(iii) Prohibited Materials

The following materials will not be in contact with the system coolant in the SCS.

- Lead
- Mercury
- Sulfur
- Saran
- Silastic L8-53
- Cadmium
- Tin
- Antimony
- Bismuth
- Mischmetal
- Neoprene or similar gasket materials made of halogen containing elastomers
- Phosphorus
- Zinc
- Copper and Copper Alloys
- Rubber-bonded asbestos
- Nylon
- Magnesium oxide (e.g., insulation)
- Materials that contain halogens in amounts exceeding 75 ppm

(iv) Not Used.

(v) The SCS skid shall be equipped with appropriate lifting lugs to permit its handling by the plant's lifting devices in full compliance with NUREG-0612 provisions.

2.C.5 Regulatory Requirements

The SCS is classified as Important-to-Safety Category B.

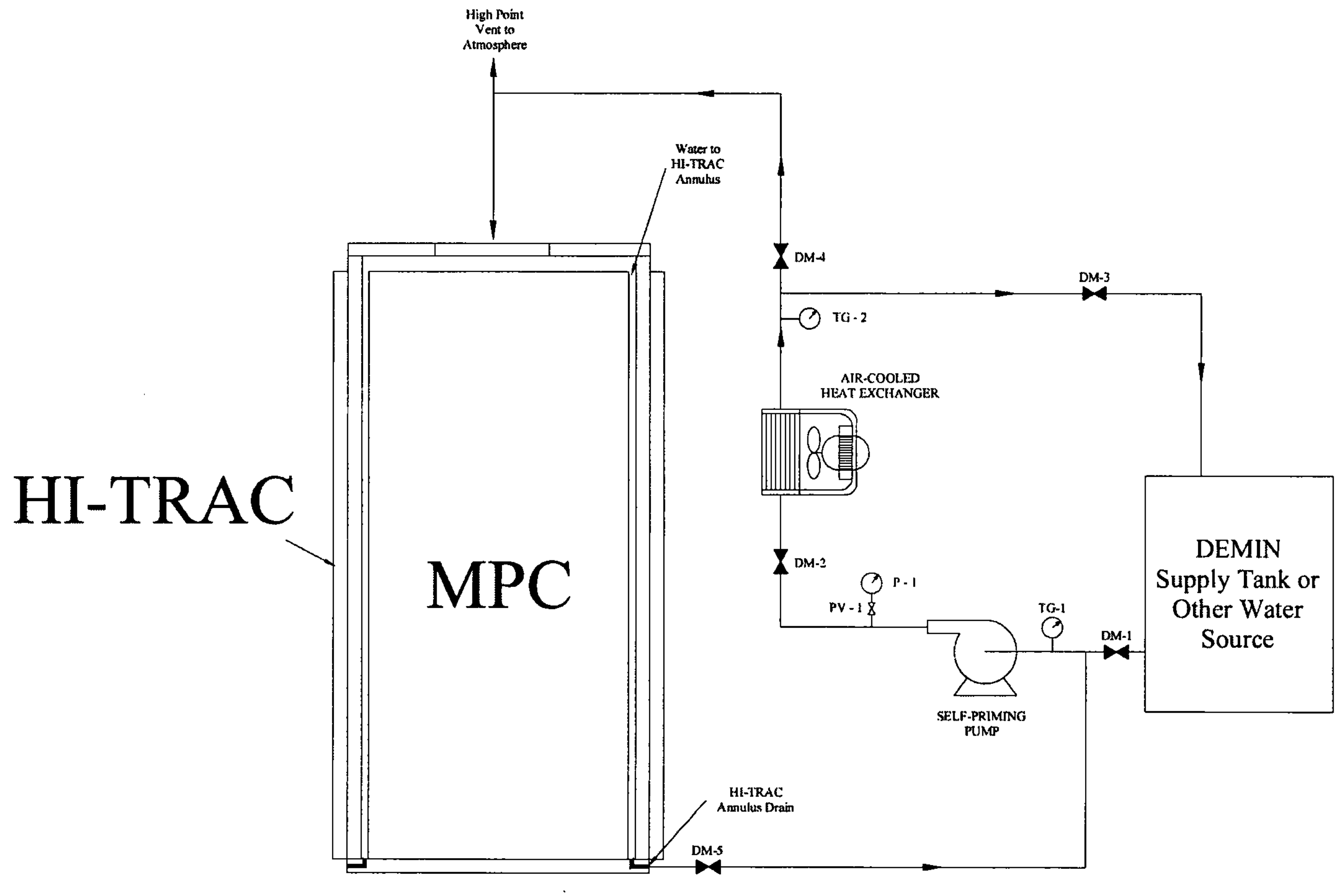

FIGURE 2.C.1: SUPPLEMENTAL COOLING SYSTEM EXAMPLE P&I DIAGRAM

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

2.I.0 OVERVIEW OF THE PRINCIPAL DESIGN CRITERIA

General

A description of the HI-STORM 100U VVM is provided in Supplement 1.I. Because the HI-STORM 100U System uses the same MPCs, transfer cask, and ancillary equipment as the aboveground systems, the design criteria presented in Table 2.0.1 for the MPC, and Table 2.0.3 for the HI-TRAC provide the basis for setting down the applicable criteria in this supplement with due recognition of the advances in the analysis methodologies over the past decade. The applicable loads, the affected parts under each loading condition, and the applicable structural acceptance criteria are compiled in this supplement to provide a complete framework for the required qualifying analyses in Supplement 3.I. Information consistent with the regulatory requirements related to shielding, thermal performance, confinement, radiological, and operational considerations is also provided. Drawings of the VVM are provided in Section 1.I.5.

Structural

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

The surrounding subgrade, the Support Foundation on which the VVM is founded, and the VVM Interface Pad are categorized as "interfacing SSCs", while the Top Surface Pad is categorized as a "proximate structure". These structures are also classified as important-to-safety (ITS) (see Table 2.I.8) and are included in the analyses in Supplement 3.I, and in other supplements as applicable. The current supplement defines the critical characteristics (Table 2.I.2) and design data (Table 2.I.7) for these structures. ACI-318 (2005) is specified as the governing code for the design and construction of the Foundation Pad, VVM Interface Pad , and the Top Surface Pad. The methodology to perform the seismic qualification of the storage system is illustrated in Chapter 3 using the reference design data for the ISFSI. A site specific seismic analysis following the method presented in Chapter 3 is required for all sites where the underground storage system will be deployed.

The values of the *critical characteristics* data on the interfacing SSCs and the Top Surface Pad, set down in this supplement, help ensure that the structural and shielding performance of the VVM will meet or exceed the requirements of 10CFR72 at all ISFSI sites (criticality, radiological, and thermal performance are unaffected by the interfacing SSCs and the Top Surface Pad).

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

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

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

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

Table 2.I.10 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:

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

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

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

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

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

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

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

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

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

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

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

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

Further, recognizing that each ISFSI is apt to have its own unique layout and quantity of VVMs, site-specific seismic inputs, and unique substrates (both around and under a VVM), a site-specific analysis is necessary to quantify the design margins under the limiting extreme environmental phenomena (viz., the site Design Basis Earthquake). To ensure that each site uses a consistent approach to the VVM structural qualification, an acceptable analysis methodology, grounded on a three-dimensional non-linear time-history solution procedure, is set down in Supplement 3.I and is applied to a representative configuration. This methodology is incorporated by reference into the Technical Specification (TS).

To serve their intended functions, the CEC and Closure Lid shall ensure confinement integrity and subcriticality, and allow the retrieval of the MPC under all conditions of storage (72.122(l)). Because the VVM is located under ground, drops and tipover of the VVM are not credible events and, therefore, do not warrant analysis. The load combinations (cases) germane to establishing the structural adequacy of the VVM pursuant to 72.24(c) are compiled in Table 2.I.5. The physical characteristics of the MPCs, which are intended for storage in the VVM, are presented in the main body of Chapter 1.

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

Thermal

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

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

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

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

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

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

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

Shielding

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

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

The dose rate calculations presented in Chapter 5 conservatively use a much smaller subgrade density than is specified in the system Technical Specification. For dose rate calculation at a particular ISFSI, the spatial average of the actual subgrade density shall be used.

Criticality

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

Confinement

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

Operations

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

Acceptance Tests and Maintenance

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

Decommissioning

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

2.I.1 SPENT FUEL TO BE STORED

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

2.I.2 HI-STORM 100U VVM SUB-COMPONENTS AND INTERFACING SSCs

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

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

i. The MPC Cavity Enclosure Container (CEC), and
ii. The Closure Lid

The CEC is comprised of the following subcomponents:

1. Container Shell (a cylindrical enclosure shell)
2. Bottom Plate

3. Container Flange (a top ring flange)
4. Divider Shell (and MPC Guides)
5. MPC bearing pads

The Closure Lid consists of:

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

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

The five SSCs that interface with the VVM and the one proximate structure germane to the design of a HI-STORM 100U ISFSI are:

i) The VVM Support Foundation (including the undergirding substrate) that supports the weight of the loaded VVM.

ii) The ISFSI pad consists of the VVM Interface Pad (provides a water seepage barrier against rainwater and melting snow and also acts as a missile barrier) and the Top Surface Pad (the proximate structure) that serves as a water seepage barrier as well as the riding surface for the transporter.

iii) The lateral subgrade (natural or engineered fill) surrounding the CEC.

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

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

Each of these SSCs is discussed below:

i. <u>The VVM Support Foundation</u>

The structural requirements on the VVM Support Foundation are focused on providing a robust support to the CEC structure (for shear and compression), and to limit the long-term settlement of the Support Foundation. The minimum structural requirements on the VVM Support Foundation are provided in Table 2.I.2. The evaluations of the CEC structure that include the VVM Support Foundation utilize these typical foundation strength values as applicable.

To meet the requirements set forth in Table 2.I.2, it may be necessary at "soft soil" sites to utilize a reinforced concrete Support Foundation undergirded by pilings, Soilcrete™ columns, and the like. ACI 318-05 is the prescribed Code for Support Foundation design for the HI-STORM 100U System where a reinforced concrete slab is utilized.

ii. VVM Interface Pad and Top Surface Pad

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

Because the VVM Interface Pad and the Top Surface Pad constitute a physical interfacing and proximate structure around the CEC, respectively, their performance mission must be set down in this FSAR. A set of design data, derived from Holtec's experience with pad designs, is summarized in Table 2.I.7. The design objective is to ensure that the self-supporting VVM Interface Pad provides a leak tight interface and the Top Surface Pad provides a sufficiently inflexible surface for the loaded transporter.

iii. Lateral Subgrade

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

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

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

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

During the movement of the cask transporter, loaded with the transfer cask (see Chapter 8 for operational details), the vertical load of the cask transporter results in a lateral pressure on the upper part of the Container Shell. Although the lateral pressure is apt to be quite small due to the physical restriction on how close to the Container Shell the transporter can ride, mandatory limits on the lateral separation and subgrade properties are necessary to ensure a design with adequate safety margins.

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

iv. Impressed Current Cathodic Protection System (ICCPS)

If an ICCPS is required by the technical specifications, it shall be implemented in accordance with the requirements in Supplement 3.I, Subsection 3.I.4 and appropriate references. The following general design procedure may be followed:

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

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

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

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

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

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

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

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

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

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

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

v. <u>Concrete Encasement</u>

If concrete encasement is used, it shall be implemented in accordance with the requirements in

Supplement 3.I, Subsection 3.I.4 and appropriate references.

The following points shall also be taken into consideration:

- The effect of the concrete encasement on the ICCPS, if an ICCPS is also implemented. The concrete encasement should not interfere with the settlement of the concrete pad providing the transporter support surface without appropriate evaluation.

2.I.3 Service Conditions and Applicable Loads

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

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

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

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

The design basis magnitudes of the above loads, as applicable, are provided in Tables 2.I.1 and 2.I.4, and are discussed further in the following subsections. Applicable loads for an MPC contained in a VVM or for a HI-TRAC that services a VVM are identical to those already identified in the main body of Chapter 2 and, therefore, are not repeated or discussed within this supplement. However, recognizing that the support of an MPC in a VVM is different from the support provided in an above ground HI-STORM, the design basis dynamic analysis model includes the fuel assemblies, the fuel basket, and the enclosure vessel so that the loads described above are properly distributed within the VVM.

2.I.4 Normal Condition Operating Parameters and Loads

i. Dead Weight

The HI-STORM 100U System must withstand the static loads due to the weight of each of its components. If any support provided by the subgrade and the VVM Interface Pad is neglected, then the dead weight of the Closure Lid bears on the Container Flange and the

Container Shell; the load to the VVM Support Foundation is transferred through a direct bearing action.

ii. Handling Loads

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

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

iii. Live Load

a. Subgrade Pressure Due to Transporter Movement

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

b. MPC Transfer Operation

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

iv. Ambient Temperature

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

v. Snow

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

vi. Differential settlement

The effect of long term differential settlement on the Support Foundation pad (mat) shall be considered as a concurrent load with dead weight.

2.I.5 Off-Normal Condition Design Criteria

i. Elevated Ambient Air Temperature

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

ii. Partial Blockage of Inlet Air Ducts

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

2.I.6 Environmental Phenomena and Accident Condition Criteria

The extreme environmental phenomena and accident conditions specific to the HI-STORM 100U System are defined in the following discussion. No additional structural load condition is identified on the HI-STORM 100U system.

i. Handling Accidents (Drops and Tipover)

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

ii. Fire

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

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

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

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

iii. Tornado

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

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

iv. Flood

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

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

v. Earthquake

The MPC Enclosure Vessel and fuel basket have been qualified to a 60g deceleration limit in the HI-STAR 100 (Docket Nos. 72-1008, 71-9261); this deceleration exceeds the expected deceleration from a seismic event. However, to ensure an accurate structural evaluation of the VVM, the evaluation of the response of the VVM to the design basis seismic event shall include a detailed model of the MPC, the fuel basket, and the contained fuel; this model should capture impacts between the fuel and the fuel basket, between the fuel basket and the MPC, and between the MPC and applicable components of the VVM.

There are two criteria that must be considered when establishing that a site can deploy the HI-STORM 100U System. These are: a) the strength of the input seismic event and, b) the stiffness of the surrounding and undergirding subgrade. Each of these is considered below.

a) As required by 10CFR72.102(f), the Design Basis Earthquake for the ISFSI must be specified. The Design Basis Earthquake (DBE) at a plant site is variously stated in terms of the so-called "free field" acceleration or the "top-of-rock" acceleration, etc. The accelerations are typically specified in two orthogonal horizontal directions, and in the vertical direction. While the vertical acceleration is largely unaffected by the presence of a massive underground structure, such as the vertical ventilated module (VVM), the effect on the horizontal acceleration components may be significant.

The underlying premise adopted for deployment of the HI-STORM 100U System is that the user shall perform a site-specific dynamic analysis, using the methodology prescribed in Supplement 3.I and incorporated by reference into the Technical Specification. The dynamic analysis model includes a single isolated VVM, a surrounding substrate of sufficient extent to preclude the free-field behavior from being altered by the presence of a VVM, and the undergirding pad, substrate, and any additional structure below the pad. The ZPA values for the underground VVM in Table 2.I.4 are used solely to demonstrate the robustness of a representative system analyzed in Subsection 3.I.4.7 using the specified methodology. The dynamic model referenced in the Technical Specification is demonstrated to provide a conservative portrayal of the response of the VVM under earthquakes in Section 3.I.4. This model is referred to as the Design Basis Seismic Model (DBSM).

vi. Explosion

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

vii. Lightning

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

viii. Burial Under Debris

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

ix. 100% Blockage of Air Inlets

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

x. Extreme Environmental Temperature

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

xi. 100% Fuel Rod Rupture

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

xii. Construction Accident Proximate to the ISFSI

As shown in the licensing drawings (Section 1.5) a radiation protection space (RPS) around a loaded ISFSI is specified within which any activity that may disturb the substrate lateral to the VVM is forbidden. The extent of the protected region defined in the licensing drawings is set down to ensure, with sufficient margin of safety, that the ISFSI will continue to meet all relevant safety criteria under all applicable conditions of storage including normal, off-normal, extreme environmental phenomena and accident conditions. Thus, for example, the RPS must be sufficiently wide to insure that the design basis projectiles (large, medium, and penetrant missiles) defined in Chapter 2 under extreme environmental phenomena loadings, will not access an MPC stored in a VVM cavity. As explained in Supplement 3.I, the incident missile is assumed to act when a deep cavity has been excavated contiguous to the protected space and the direction of action of the missile is oriented to achieve maximum penetration of the substrate towards the CEC shell. The *minimum* ground buffer requirement around the ISFSI must be evaluated under the provisions of 10CFR72.212 for an ISFSI site for the site-specific conditions for the ISFSI. Because the earth around an operating ISFSI serves a principal shielding function, it is essential that any excavation activity adjacent to the ISFSI (to build an extension of the ISFSI, for example), must not disturb the soil in the Radiation Protection Space (RPS) (see subsection 1.I.4). If the soil column in the RPS is not adequately secured, then (since the soil is not integral to the VVM) it is susceptible to being stripped from the RPS as a result of human error during construction activities involving excavation, or as a result of a coincident seismic event.

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

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

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

ACI 318-05 [2.I.5] is the applicable reference code to establish applicable limits on unreinforced concrete (in the Closure Lid), which is subject to secondary structural loadings. Appendix 1.D contains the design, construction, and testing criteria applicable to the plain concrete in the VVM's Closure Lid. Applicable sections of [2.I.5] should be used in the design of the interfacing and proximate SSCs.

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

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

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

2.I.8 Service Limits

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

2.I.9 Loads and Acceptance Criteria

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

Bounding load cases that are significant to the structural performance of the VVM and require evaluation are compiled in Table 2.I.5 using information provided in Sections 2.I.4, 2.I.5, and 2.I.6.

Supplement 3.I contains a description of the evaluations, establishes the evaluation methodology, and provides evaluation results that demonstrate compliance of the VVM to the applicable load cases and acceptance criteria described below. The load cases and acceptance criteria are explained in subsequent paragraphs and summarized in Table 2.I.5. Table 2.I.6 summarizes the acceptance criteria for extreme environmental events.

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

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

Load Case 01: Buoyant Force

This loading case pertains to the scenario wherein a VVM has been built, but the Closure Lid and MPC are not yet installed. Strictly speaking, this condition is not important to storage safety because the MPC is not present. However, considerations of long-term service life warrant that a minimum weight CEC, subject to the maximum buoyant force of water under an assumed hypothetical condition of submergence in water with a head equal to the length of the CEC, does not float. This evaluation sets a minimum additional weight (usually on a temporary cover) that will be set in place during construction to protect the CEC from construction debris, to provide for construction worker safety, and to insure that the CEC does not suffer uplift from buoyant forces. In addition, the Bottom Plate of the CEC must have sufficient flexural strength such that under a buoyant uplift pressure, its primary bending stress intensity remains below the ASME Level D allowable stress intensity at the reference metal temperature (assumed to be 125°F (extreme environmental condition temperature) in Table 2.I.5).

Load Case 02: Dead Load plus Design Basis Explosion Pressure

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

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

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

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

Load Case 03: Tornado Missile Impact

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

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

Load Case 04: Design Basis Seismic Event

The effect of a seismic event on a loaded VVM is influenced by a number of parameters such as the structural characteristics of the surrounding and undergirding substrate, the presence of other VVMs, the properties of the interfacing structures (i.e., the Support Foundation and VVM Interface Pad), the type of MPC stored, and the harmonic content of the earthquake. An array of analyses documented in Section 3.I provides the quantitative information to help define an analysis methodology that has been termed the Design Basis Seismic Model (DBSM) in Section 2.I.6. The details of the DBSM are provided in Subsection 3.I.4.7 and are set down as the prescribed method in the Technical Specification. The array of ISFSI parameters, significant to the seismic behavior of the storage system and used in the qualifying analysis in Chapter 3, are used to define their minimum acceptable reference value in the Technical Specification. All HI-STORM 100U ISFSIs must be analyzed to demonstrate their structural compliance to the criteria set forth in this FSAR under all applicable site specific loads. The Design Basis Seismic Event is classified as an extreme environmental phenomenon, and as such, the Level D service condition limits are applicable to the Code components, such as the MPC Enclosure Vessel.

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 confinement, and that the system remains subcritical. This is accomplished by demonstrating that after the seismic event, permanent ovalization of the Container Shell and/or Divider Shell does not result in a geometry that precludes removal of an MPC.

The Divider shell's sole function is to direct the airflow inside the CEC cavity and to hold MPC Guides that serve to restrain the MPC from excessive rattling motion during an earthquake event. The guides are subject to in-plane compressive impacts from the "hard points" on the MPC (the approximately 2.5-inch thick baseplate at the bottom and the 9.5-inch thick lid at the top). The ratio of the buckling load or the ultimate load for the MPC Guides to the calculated maximax (maximum in time and space) in-plane load is the factor of safety for this item.

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

The limits on the primary stresses in the MPC components, stated above for the DBE condition, are also applicable to other Level D (faulted) events consistent with the dynamic analysis using a 3-D detailed model of the MPC, the internal fuel basket, and the fuel assemblies inside the basket. In particular, the local strain in the Confinement Boundary due to the impact between the MPC and the MPC guides under the Design Basis Earthquake for the site requires evaluation.

Table 2.I.6 summarizes the above discussion in tabular form.

Load Case 05: Closure Lid Handling

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

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

Load Case 06: Design Basis Fire Event

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

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

Load Case 07: CEC Loading From Surrounding Subgrade

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

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

In evaluating the structural safety margins in Supplement 3.I for the load cases described above, design data for the interfacing SSCs presented in Table 2.I.7 is used as applicable.

2.I.10 Safety Protection Systems

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

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

2.I.11 Decommissioning Considerations

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

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

2.I.12 Regulatory Compliance

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

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

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

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

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

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

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

2.I.13 References

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

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

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

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

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

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

Table 2.I.1

LOADS, CRITERIA, APPLICABLE REGULATIONS, REFERENCE CODES, AND STANDARDS FOR THE VVM

Type	Criteria or Value and Reference Location in the FSAR	Basis, Regulation and Reference Code/Standard
Life:		
Design Life	40 yrs, Section 3.I.4	-
License Life	20 yrs, Section 3.I.4	10CFR72.42(a) & 10CFR72.236(g)
Structural:		
Design & Fabrication Codes: Foundation Pad; VVM Interface Pad and Top Surface Pad	ACI 318 (2005)	10CFR 72.24
Unreinforced Concrete Stress Limits (Closure Lid)	Applicable Sections of ACI 318 (2005)	10CFR72.24(c)(4)
Structural Steel	Section 2.I.7, Tables 2.I.5, 2.I.6	10CFR72.24(c)(4)
VVM Closure Lid Dead Weight†:	Table 3.I.1	R.G. 3.61
Design Internal Pressure	Atmospheric, Supplement 1.I	Ventilated Module
Response and Degradation Limits	Section 3.I.4	10CFR72.122(b), (c)
Corrosion Allowance	1/8" on surfaces directly in contact with subgrade	Standard industry practice
Thermal:		
Maximum Design Temperatures:		
Closure Lid Concrete		
Through-Thickness Section Average (Normal)	Table 1.D.1	ACI 349-85, Appendix A, (Paragraph A.4.3)
Through-Thickness Section Average (Off-Normal and Accident)	Table 1.D.1	ACI 349-85, Appendix A, (Paragraph A.4.2)
Structural Steel	Table 2.I.8	ASME Code, Section II, Part D
VVM Divider Shell Thermal Insulation	Heat transfer resistance ≥ 4 hr-ft^2-°F/Btu. Must be stable at temperatures ≤ 800°F	N/A
Confinement:	N/A, Provided by MPC; Supplement 7.I	10CFR72.128(a)(3) and 10CFR72.236(d) & (e)
Retrievability: Normal/Off-Normal/Accident	No damage that precludes MPC retrieval or threatens subcriticality of fuel. MPC maintains confinement,	10CFR72.122(f), (h), (1), & (l)

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

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

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

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

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

Type	Criteria or Value and Reference Location in the FSAR	Basis, Regulation and Reference Code/Standard
Off-Normal Design Event Conditions:		
Ambient Temperature:	Subsection 2.I.5	-
Minimum	-40°F; Subsection 2.2.2.2	ANSI/ANS 57.9
Maximum	100°F; Subsection 2.2.2.2	ANSI/ANS 57.9
Partial Blockage of Air Inlets	50% blockage of air inlet flow area; Supplement 4.I	-
Design Basis Accident Events and Conditions:		
Drop Cases:		
End Drop	Not credible; Subsection 2.I.6	In-ground VVM is not lifted
Tipover	Not credible; Subsection 2.I.6	In-ground VVM is constrained by subgrade and foundation
Fire:	-	-
Duration	217 seconds; Supplement 11.I	10CFR72.122(c)
Temperature	1475°F; Supplement 11.I	10CFR72.122(c)
Fuel Rod Rupture	See Table 2.0.1; Subsection 2.2.3.8	-
Air Flow Blockage	100% blockage of air inlet flow area; Subsection 2.I.6	10CFR72.128(a)(4)
Explosive Overpressure External Differential Pressure	10 psi steady state; Subsection 2.I.6 and Table 2.2.1	10CFR72.128(a)(4)
Extreme Environmental Phenomenon Events and Conditions:		
Flood:	Subsection 2.I.6	-
Height	125 ft	R.G. 1.59
Velocity	N/A; Supplement 1.I	In-ground VVM is not subject to tipover or sliding. Loads on the Closure Lid are bounded by missile impact loads.
Max. Earthquake	Table 2.I 4; Subsection 2.I.6 and Supplement 3.I	10CFR72.102(f)
Tornado:	Subsection 2.I.6	-
Tornado-Borne Missiles:		
i. Automobile	Ensure confinement, subcriticality and retrievability Subsection 2.I.6 and Supplement 3.I	NUREG-1536
▪ Weight	Table 2.2.5	NUREG-0800

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

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

Table 2.I.2
CRITICAL CHARACTERISTICS FOR INTERFACING SSCs, MPC GUIDES, AND VVM SPACING

	Item	Value	Symbol	Comment
1.	Minimum value for nominal vertical stiffness of the Support Foundation Undergirding Subgrade (lb/inch)	97.9E6	K	This stiffness value is equivalent to that of a homogeneous substrate subject to vertical loading from a rigid punch having diameter equal to that of the CEC bottom plate, and homogeneous best estimate properties corresponding to a shear wave speed of 3500 ft./sec., and a Poisson's Ratio of 0.4. (see Note 1)
2.	Minimum thickness of the VVM Interface Pad (inch)	28	T	This thickness is used in shielding analysis in Supplement 5.I; use of a larger value will enhance shielding even further.
3.	Minimum density of the VVM Interface Pad concrete (lb/ft^3)	140	ϒ	This density is used in shielding analysis in Supplement 5.I; use of a different value will results in a change in the computed dose results.
4.	Minimum density of subgrade adjacent to CEC (spatial average) (lb/ft^3)	120	Υ_s	A lower average density value may be used in shielding analysis in Supplement 5.I for conservatism.
5	Minimum Number of Upper/Lower MPC Guides	4 / 6	Ng	The MPC Guides transfer impact loads from the MPC to the Divider Shell.
6	Minimum VVM Pitch (ft.)	See Licensing Drawing in Subsection 1.I.5	-	-

Note 1: The resistance of a homogeneous elastic material to load from a rigid punch of diameter D (see Theory of Elasticity, Timoshenko and Goodier, 3rd Edition, McGraw Hill, Chapter 12) can be written in the form:

$$K = \frac{2G\sqrt{A}}{0.96(1-\nu)}$$

G is the subgrade shear modulus, ν is the subgrade Poisson's Ratio (assumed to be 0.4), and A is the area of the circular punch in contact with the subgrade. Since G is related to subgrade mass density and the wave speed, a direct relation is obtained between subgrade stiffness and subgrade shear wave speed.

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

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

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

Table 2.I.4

SEISMIC AND SUBSTRATE DATA FOR THE HI-STORM 100U SYSTEM IN THE REPRESENTATIVE SOLUTIONS

Direction	Value
Net Horizontal ZPA at specified bedrock depth (g)	0.50
Zero Period Vertical Acceleration at specified bedrock depth (g)	0.33
Substrate Weight Density below Support Foundation Pad (lb/cu.ft.)	140
Substrate Weight Density above Support Foundation Pad (lb/cu.ft.)	120

Note 1: Site-Specific values shall be used for qualification at a specific location.

Note 2: Time histories are derived from Reg. Guide 1.60 spectra set with a 20 second duration. Acceleration time histories developed from the Reg Guide 1.60 spectra meet the enveloping and statistical independence requirements of SRP 3.7.1 of NUREG-0800 (1980).

Note 3: The reference surface for the input spectra used in the sample evaluations is approximately 51' below TOG as shown in the drawings in Section 1.I.5.

Table 2.I.5

BOUNDING LOADINGS, AFFECTED SUB-COMPONENTS, APPLICABLE DATA, ACCEPTANCE CRITERION

Case I.D.	Bounding Loading	Affected Sub-Component	Applicable Data		Acceptance Criterion
			Magnitude of Loading (Ref. Table I.D.)	Value of Coincident Metal Temperature used (Deg. F)	
01	Condition with no MPC or Closure Lid installed; buoyancy from a water head equal to the distance between TOG and TOF.	• Temporary Cover • CEC Bottom Plate	Buoyant Force From CEC Displaced Volume < 8 psi	125 125	The minimum weight of the anti-buoyancy cover is 16,000lb. Maximum primary bending stress intensity in the CEC Bottom Plate must be below Level D limit.
02	Normal operation condition; dead load plus design basis explosion pressure	• Container Shell structure • Closure Lid	2.I.1; 3.I.1 2.I.1	125 350	Primary stresses do not exceed applicable Level A stress limits of ASME Subsection NF (or Level D limits with explosion)
03	Design basis missile	Closure Lid	2.I.1 and 2.2.5	350	Closure Lid does not collapse, is not dislodged from the cavity, and is not perforated by the missile.
04	Design basis earthquake	Container Shell	Site-specific (Table 2.I.4 used for sample evaluation)	125	After the event, MPC retrievability, subcriticality and confinement must not be compromised. Additional criteria for the CEC and its contents are defined in Table 2.I.6.
05	Closure lid handling	Lid Lift Lugs; all metal structure in Lid	1.15 x Closure Lid Weight (From Table 3.I.1)	125	ANSI 14.6 limits based on yield or ultimate strength including magnified inertia loads. Meet Reg. Guide 3.61 and Level A limits as applicable. (See Section 2.I.9)

Table 2.I.5 (continued)

BOUNDING LOADINGS, AFFECTED SUB-COMPONENTS, APPLICABLE DATA, ACCEPTANCE CRITERION

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

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

Table 2.I.6
Acceptance Criteria for the HI-STORM 100U CEC and Internals under Extreme Environmental Conditions

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

Table 2.I.7

MINIMUM DATA FOR THE DESIGN OF INTERFACING SSCs and TOP SURFACE PAD

	Interfacing SSC	Reference Design Data
1.	Support Foundation	30" thick reinforced concrete pad founded on subgrade. Concrete density = 145 lb/ft^3 Minimum concrete compressive strength @ ≤ 28 days = 4,000 psi Grade 60 Rebar - Minimum yield strength of rebar = 60,000 psi; rebar is #10@9" (each face, each direction) Minimum concrete cover on rebar per section 7.7.1 of ACI 318 (2005)
2.	Subgrade Under Support Foundation	Minimum Shear Wave Speed = 3500 fps (see Note 1); Density from Table 2.I.4
3.	Subgrade Surrounding VVMs	Minimum Shear Wave Speed = 800 fps (see Note 1); Density from Table 2.I.2
4.	VVM Interface Pad (See Licensing Dwg. In Section 1.I.5)	Reinforced Concrete Thickness per Table 2.I.2 Concrete density per Table 2.I.2 Minimum concrete compressive strength @ ≤ 28 days = 4,000 psi Grade 60 Rebar - Minimum yield strength of rebar = 60,000 psi; rebar is #10@9" (each face, each direction) Minimum Concrete cover on rebar per section 7.7.1 of ACI 318 (2005)
5.	Top Surface Pad	24" thick reinforced concrete pad; other parameters same as VVM Interface Pad. Minimum width of TSP beams are: 6' (along direction of transporter path); 4' (perpendicular to direction of transporter path)

Note 1: The substrate low strain shear wave speed, corresponding to best estimate elastic properties averaged over the region 30' below the base of the Support Foundation or down to bedrock (whichever is less) and to the substrate surrounding the VVM (averaged over a distance of 5 CEC shell diameters) is specified above. Should these conditions not be satisfied, then substrate remediation is required prior to installation of the HI-STORM 100U facility. Design analyses shall also account for uncertainties in substrate properties in accordance with ASCE 4-98 [3.I.28].

Table 2.I.8

PERMISSIBLE MATERIALS FOR HI-STORM 100U VVM SUB-COMPONENTS

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

Note: Equivalent materials have their critical characteristics defined in Table 2.I.9.

Table 2.I.8 (continued)

PERMISSIBLE MATERIALS FOR HI-STORM 100U VVM SUB-COMPONENTS

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

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

Table 2.I.9

CRITICAL CHARACTERISTICS OF EQUIVALENT MATERIALS USED IN THE VVM

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

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

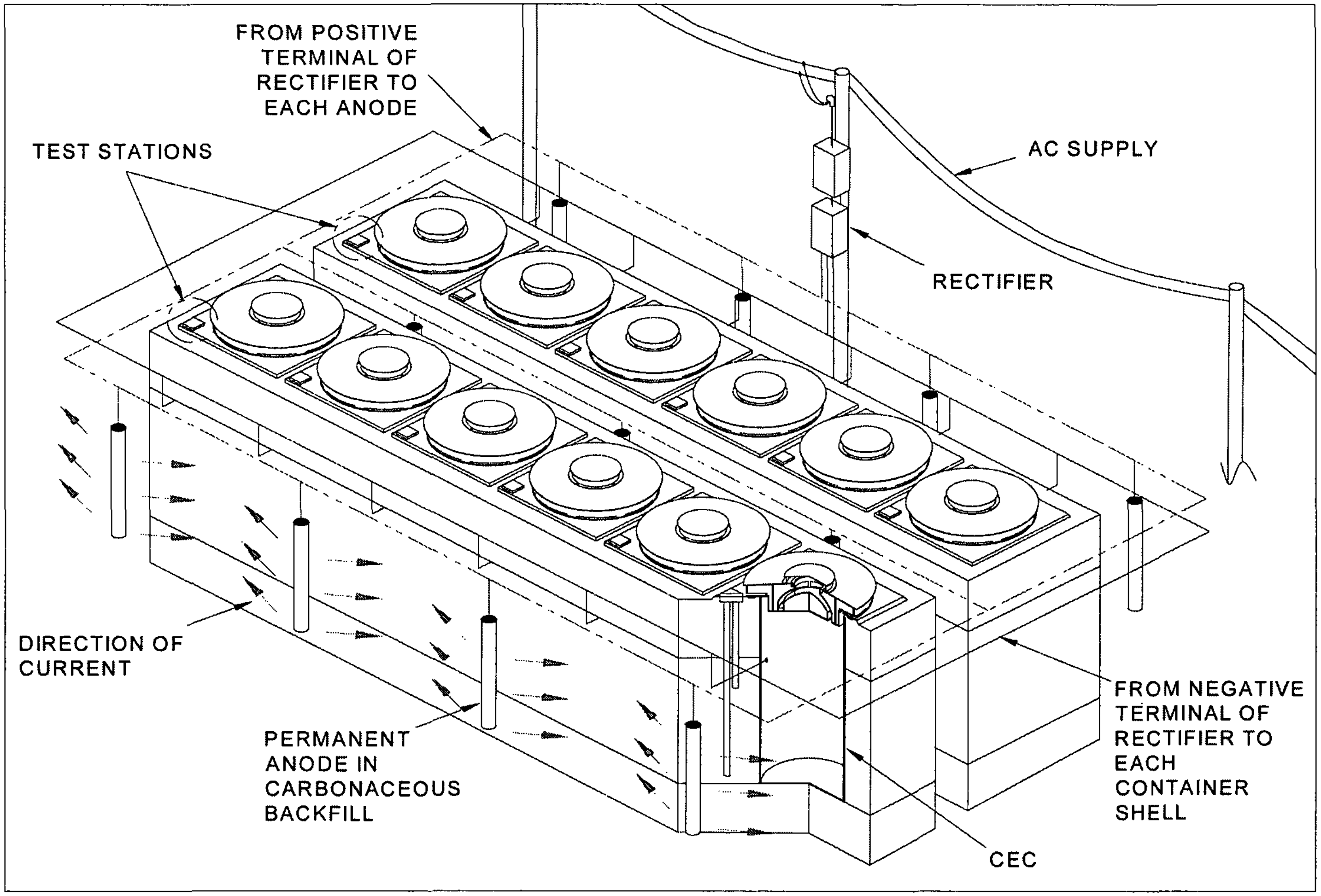

FIGURE 2.I.1: HI-STORM 100U SYSTEM EXAMPLE ICCPS DESIGN – 2 X 6 ARRAY DESIGN LAYOUT*

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

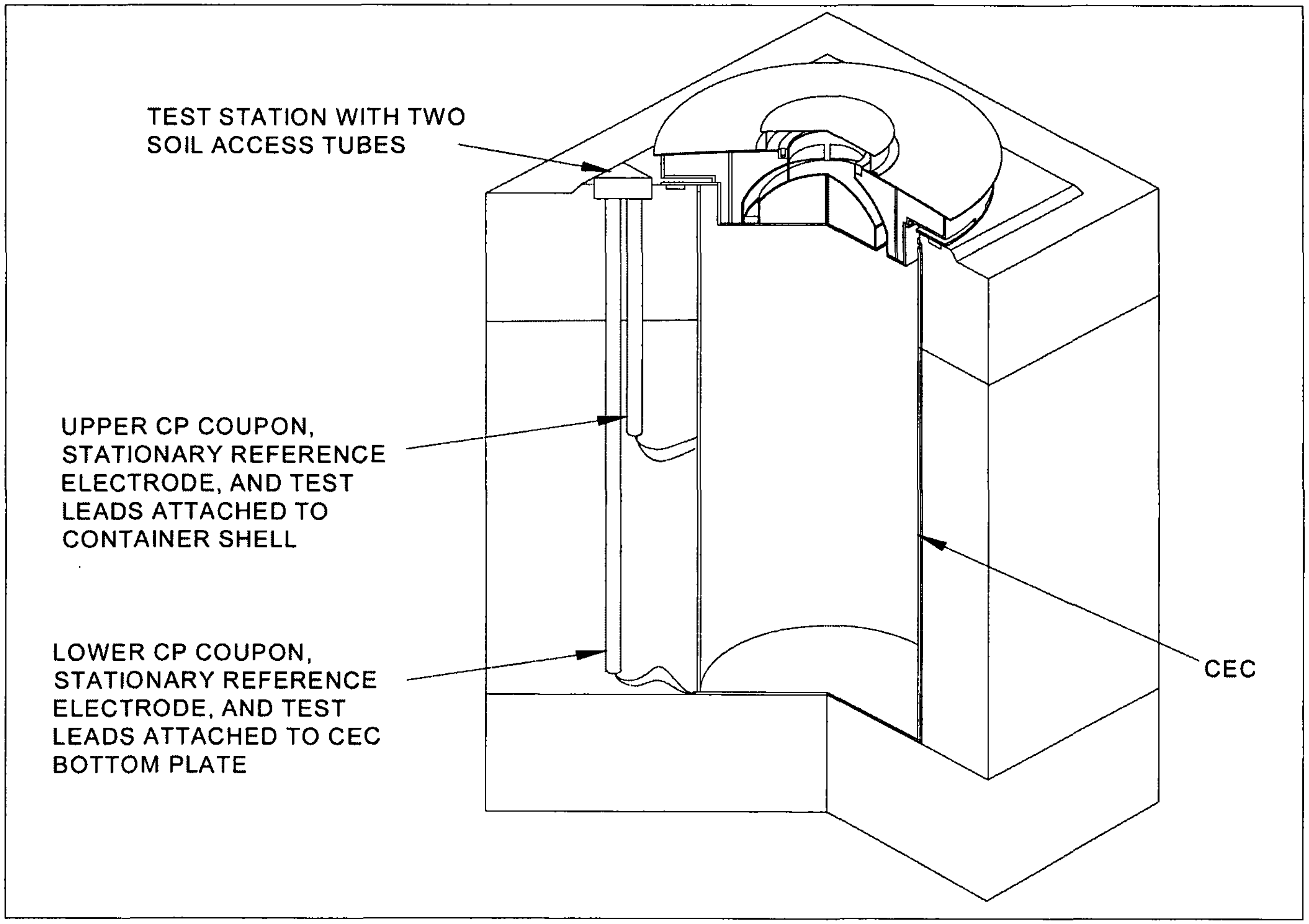

FIGURE 2.I.2: HI-STORM 100U SYSTEM EXAMPLE ICCPS DESIGN – TEST STATION*

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

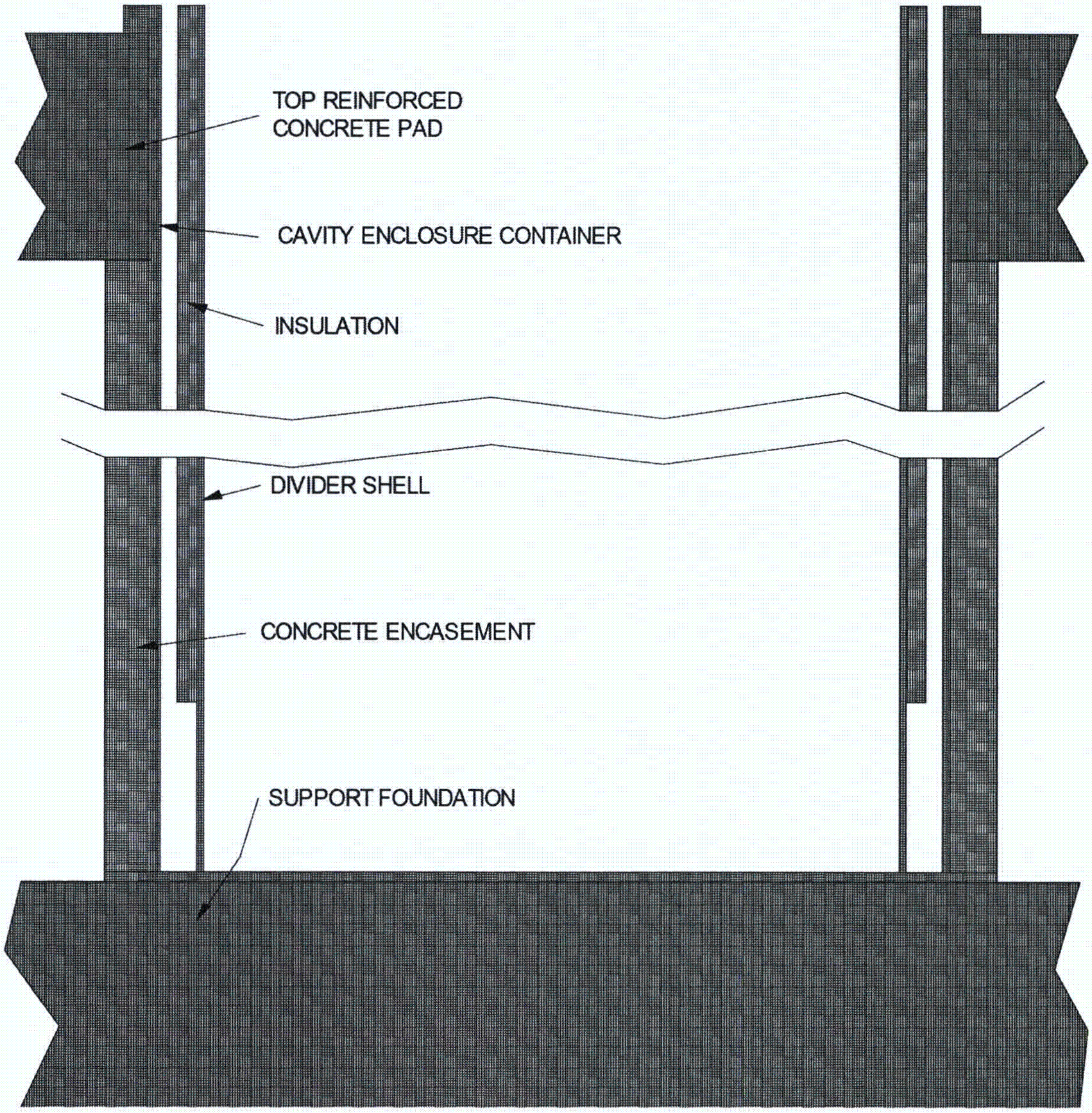

FIGURE 2.I.3: TYPICAL CONCRETE ENCASEMENT OF THE CEC

SUPPLEMENT 2.III

PRINCIPAL DESIGN CRITERIA FOR THE MPC-68M

2.III.0 OVERVIEW OF THE PRINCIPAL DESIGN CRITERIA

A general description of the MPC-68M is provided in Supplement 1.III. This supplement specifies the loading conditions and associated design criteria applicable to the MPC-68M fuel basket. The loads, loading conditions, and design criteria presented in Chapter 2 are applicable to the HI-STORM 100 System using the MPC-68M unless otherwise specified in this supplement. The drawing package for the MPC-68M fuel basket is provided in Section 1.5. The safety classifications of Metamic-HT basket and basket shims are ITS-A and NITS, respectively.

The design criteria pertaining to the HI-STORM overpack and the HI-TRAC transfer cask are completely unaffected by the incorporation of the MPC-68M. Likewise, the structural demands on the MPC Enclosure Vessel (whose design remains unchanged) are also unaffected. The design criteria in this supplement pertain to the loading conditions that bear upon the fuel basket's function and performance.

2.III.0.1 MPC-68M Design Criteria

i. Structural

The fuel basket is designed to meet a more stringent displacement limit under mechanical loadings than those implicit in the stress limits of the ASME code (see Section 2.III.2). The basket shims are designed to remain below the yield limit of the selected aluminum alloy. Fuel basket welds are designed and fabricated in accordance with Supplement 9.III and the drawing package in Section 1.5. Fuel basket structural welds are designed to the minimum weld strength specified in the drawing package in Section 1.5. Metamic-HT is a Holtec proprietary (non-ASME code) material. The *critical characteristics* and the attainment of the required critical characteristics through a comprehensive qualification process and production testing are discussed in Appendix A to Supplement 1.III with acceptance criteria established in Supplement 9.III.

All normal and off-normal conditions (including pressures) for the MPC-68M are the same as those described in Section 2.2. All loads on the HI-STORM 100 overpack and HI-TRAC transfer cask described in Section 2.2 remain applicable when using the MPC-68M.

The main acceptance criterion for the evaluation of accident conditions on the MPC-68M fuel basket is for the basket structure to maintain the fuel contents in a subcritical configuration. The structural design criteria for the MPC-68M basket are provided in Table 2.III.4.

The fuel basket material is subject to the requirements in Appendix 1.III.A and is designed to a specific (lateral) deformation limit of its walls under accident conditions of loading (credible and non-mechanistic). The basis for the lateral deflection limit in the active fuel region, θ, is provided in [2.III.6.1] as

$$\theta = \frac{\delta}{w}$$

where δ is defined as the maximum total deflection sustained by the basket panels under the loading event and *w* is the nominal inside (width) dimension of the storage cell. The limiting value of θ is provided in Table 2.III.4. The above deflection-based criterion has been used previously in the HI-STAR 180 Transportation Package [2.III.6.2] to qualify similar Metamic-HT fuel baskets.

ii. Thermal

The design and operation of the HI-STORM 100 System with the MPC-68M must meet the intent of the review guidance contained in ISG-11, Revision 3 [2.0.8] as described in Subsection 2.0.1.

All applicable material design temperature limits in Section 2.2 and 4.3 continue to apply to the MPC-68M. Temperature limits of MPC-68M fuel basket and basket shim materials are specified in Table 4.III.2.

The MPC-68M is designed for both uniform and regionalized fuel loading strategies as described in Subsection 2.0.1. The regions for the MPC-68M are given in Table 2.III.1.

iii. Shielding

Same as Subsection 2.0.1.

iv. Criticality

Same as Subsection 2.0.1 with the clarifications herein.

Criticality control is maintained by the geometric spacing of the fuel assemblies and spatially distributed B-10 isotope in the Metamic-HT. No soluble boron is required in the MPC-68M water. The minimum specified boron concentration in the Metamic-HT purchasing specification must be met in every lot of the material manufactured. No credit is taken for burnup. Enrichment limits are delineated in Table 2.III.2.

v. Confinement

Same as Subsection 2.0.1

vi. Operations

Same as Subsection 2.0.1. Generic operating procedures for the HI-STORM 100 System with MPC-68M are provided in Chapter 8 with certain limitations and clarifications provide in Supplement 8.III.

vii. Acceptance Tests and Maintenance

Same as Subsection 2.0.1. The acceptance criteria for the HI-STORM 100 System with MPC-68M are provided in Chapter 9 and Supplement 9.III.

vi. 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 of the HI-STORM 100 System is addressed in Section 2.III.4.

2.III.1 SPENT FUEL TO BE STORED

Table 2.1.22 and the limitations/clarification in this supplement provide the limits for material to be stored in the MPC-68M. All BWR fuel assembly array/classes which are authorized for the MPC-68 are authorized in the MPC-68M except fuel assembly array/classes 6x6A, 6x6B, 6x6C, 7x7A, 8x8A, 10x10D, and 10x10E. Table 2.1.4 in Chapter 2 provides the acceptable fuel characteristics for the fuel array/class authorized for storage in the MPC-68M, however fuel with planar-average initial enrichments up to 4.8 wt.% U-235 are authorized in the MPC-68M. The maximum planar-average initial enrichments acceptable for loading in the MPC-68M, for each fuel assembly array/class given in Table 2.1.4, are provided in Table 2.III.2. Table 2.III.3 provides the description of two new fuel assembly array/classes which are added as acceptable contents to the MPC-68M only, 10x10F and 10x10G. No credit is taken for fuel burnup or integral poisons such as gadolinia for any fuel assembly array/class. The maximum allowable initial enrichment for fuel assemblies are consistent with the criticality analysis described in Supplement 6.III. See Table 2.1.29 for assembly cooling time-dependent coefficients for 10x10F and 10x10G.

Fuel classified as damaged fuel assemblies or fuel debris will be loaded into damaged fuel containers (DFCs) for storage in the MPC-68M. The appropriate thermal and criticality analyses have been performed to account for damaged fuel and fuel debris and are described in Supplements 4.III and 6.III, respectively. The restrictions on the number and location of damaged fuel containers authorized for loading in the MPC-68M is the same as MPC-68 (see Section 1.III.2.3 and Figure 1.III.2). Non-fuel hardware is not applicable to all the BWR fuel classes/arrays.

The heat generation rate, axial burnup distribution, and all other bounding radiological, thermal, and criticality parameters specified for MPC-68 are used to ensure the performance of the HI-STORM SYSTEM with the MPC-68M.

2.III.2 MPC-68M DESIGN LOADINGS

Design loadings in Section 2.2 apply to the HI-STORM 100 System using the MPC-68M.

2.III.3 SAFETY PROTECTION SYSTEMS

Same as Section 2.3.

2.III.4 DECOMMISSIONING CONSIDERATION

Same as Section 2.4.

2.III.5 REGULATORY COMPLIANCE

Same as Section 2.5.

2.III.6 REFERENCES

[2.III.6.1] Holtec Proprietary Position Paper DS-331, "Structural Acceptance Criteria for the Metamic-HT Fuel Basket", (USNRC Docket No. 71-9325).

[2.III.6.2] HI-STAR 180 Transportation Package, USNRC Docket No. 71-9325.

Table 2.III.1: MPC-68M FUEL STORAGE REGIONS

Number of Storage Cells		Storage Cell IDs*	
Inner Region (n_1)	Outer Region (n_2)	Inner Region	Outer Region
32	36	11 through 14, 18 through 23, 27 through 32, 37 through 42, 46 through 51, 55 through 58	All other locations
* See Figure 1.III.2 for storage cell numbering			

Table 2.III.2: BWR FUEL ASSEMBLY INITIAL ENRICHMENTS FOR LOADING IN MPC-68M (Note 1)

Fuel Assembly Array and Class	**Maximum Planar-Average Initial Enrichment (wt.% ^{235}U) (Note 3)**
7x7 B	4.8
8x8 B	4.8
8x8 C	4.8
8x8 D	4.8
8x8 E	4.8
8x8 F	4.5 (Note 2)
9x9 A	4.8
9x9 B	4.8
9x9 C	4.8
9x9 D	4.8
9x9 E	4.5 (Note 2)
9x9 F	4.5 (Note 2)
9x9 G	4.8
10x10 A	4.8
10x10 B	4.8
10x10 C	4.8

Notes:

1. All other fuel assembly array/class specifications from Table 2.1.4 apply.
2. Fuel assemblies classified as damaged fuel assemblies are limited to 4.0 wt.% U-235.
3. For MPC-68M loaded with both intact fuel assemblies and damaged fuel assemblies or fuel debris, the maximum planar average initial enrichment for the intact fuel assemblies is limited to the enrichment of the damaged assembly.

Table 2.III.3: BWR FUEL ASSEMBLY CHARACTERISTICS FOR LOADING IN MPC-68M (Note 1)

Fuel Assembly Array and Class	**10x10F**	**10x10G**
Clad Material (Note 2)	Zr	Zr
Design Initial U (kg/assy.) (Note 3)	≤ 192	≤ 188
Maximum Planar-Average Initial Enrichment (wt.% ^{235}U) (Note 8)	4.7 (Note 7)	4.6 (Note 7)
Initial Rod Maximum Enrichment (wt.% ^{235}U)	≤ 5.0	≤ 5.0
No. of Fuel Rod Locations	92/78 (Note 4)	96/84
Fuel Clad O.D. (in.)	≥ 0.4035	≥ 0.387
Fuel Clad I.D. (in.)	≤ 0.3570	≤ 0.340
Fuel Pellet Dia. (in.)	≤ 0.3500	≤ 0.334
Fuel Rod Pitch (in.)	≤ 0.510	≤ 0.512
Design Active Fuel Length (in.)	≤ 150	≤ 150
No. of Water Rods (Note 6)	2	5 (Note 5)
Water Rod Thickness (in.)	≥ 0.030	≥ 0.031
Channel Thickness (in.)	≤ 0.120	≤ 0.060

Table 2.III.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. See Table 1.0.1 for the definition of "ZR."

3. Design initial uranium weight is the nominal uranium weight specified for each assembly by the fuel manufacturer or reactor user. For each BWR fuel assembly, the total uranium weight limit specified in this table may be increased up to 1.5 percent for comparison with users' fuel records to account for manufacturer tolerances.

4. This assembly contains 92 total fuel rods; 78 full length rods and 14 partial length rods.

5. One diamond-shaped water rod replacing the four center fuel rods and four rectangular water rods dividing the assembly into four quadrants.

6. These rods may also be sealed at both ends and contain ZR material in lieu of water.

7. Fuel assemblies classified as damaged fuel assemblies are limited to 4.6 wt.% 235U for the 10x10F array/class and 4.0 wt.% 235U for the 10x10G array/class.

8. For MPC-68M loaded with both intact fuel assemblies and damaged fuel assemblies or fuel debris, the maximum planar average initial enrichment for the intact fuel assemblies is limited to the enrichment of the damaged assembly.

Table 2.III.4

STRUCTURAL DESIGN CRITERIA FOR THE FUEL BASKET

PARAMETER	ALLOWABLE VALUE
Minimum service temperature	-40°F
Maximum total (lateral) deflection in the active fuel region, θ (dimensionless)	0.005

CHAPTER 3: STRUCTURAL EVALUATION†

3.0 OVERVIEW

In this chapter, the structural components of the HI-STORM 100 System that are important to safety (ITS) are identified and described. The objective of the structural analyses is to ensure that the integrity of the HI-STORM 100 System is maintained under all credible loads for normal, off-normal, and design basis accident/natural phenomena. The chapter results support the conclusion that the confinement, criticality control, radiation shielding, and retrievability criteria set forth by 10CFR72.236(l), 10CFR72.124(a), 10CFR72.104, 10CFR72.106, and 10CFR72.122(l) are met. In particular, the design basis information contained in the previous two chapters and in this chapter provides sufficient data to permit structural evaluations to demonstrate compliance with the requirements of 10CFR72.24. To facilitate regulatory review, the assumptions and conservatisms inherent in the analyses are identified along with a complete description of the analytical methods, models, and acceptance criteria. A summary of other material considerations, such as corrosion and material fracture toughness is also provided. Design calculations for the HI-TRAC transfer cask are included where appropriate to comply with the guidelines of NUREG-1536.

The organization of technical information in this chapter follows the format and content guidelines of USNRC Regulatory Guide 3.61 (February 1989). The FSAR ensures that the responses to the review requirements listed in NUREG-1536 (January 1997) are complete and comprehensive. The areas of NRC staff technical inquiries, with respect to structural evaluation in NUREG-1536, span a wide array of technical topics within and beyond the material in this chapter. To facilitate the staff's review to ascertain compliance with the stipulations of NUREG-1536, Table 3.0.1 "Matrix of NUREG-1536 Compliance - Structural Evaluation", is included in this chapter. A comprehensive cross-reference of the topical areas set forth in NUREG-1536, and the location of the required compliance information is contained in Table 3.0.1.

Section 3.7 describes in detail HI-STORM 100 System's compliance to NUREG-1536 Structural Evaluation Requirements.

The HI-STORM 100 System matrix of compliance table given in this section is developed with the supposition that the storage overpack is designated as a steel structure that falls within the purview of subsection 3.V.3 "Other Systems Components Important to Safety" (page 3-28 of NUREG-1536), and therefore, does not compel the use of reinforced concrete. (Please refer to Table 1.0.3 for an explicit statement of exception on this matter). The concrete mass installed in the HI-STORM 100 overpack is accordingly equipped with "plain concrete" for which the sole applicable industry code is ACI 318.1 (92). Plain concrete, in contrast to reinforced concrete, is the preferred shielding

† This chapter has been prepared in the format and section organization set forth in Regulatory Guide 3.61. However, the material content of this chapter also fulfills the requirements of NUREG-1536. Pagination and numbering of sections, figures, and tables are consistent with the convention set down in Chapter 1, Section 1.0, herein. Finally, all terms-of-art used in this chapter are consistent with the terminology of the glossary (Table 1.0.1) and component nomenclature of the Bill-of-Materials (Section 1.5).

material HI-STORM 100 because of three key considerations:

(i) Plain concrete is more amenable to a void free pour than reinforced concrete in narrow annular spaces typical of ventilated vertical storage casks.

(ii) The tensile strength bearing capacity of reinforced concrete is not required to buttress the steel weldment of the HI-STORM 100 overpack.

(iii) The compression and bearing strength capacity of plain concrete is unaffected by the absence of rebars. A penalty factor, on the compression strength, pursuant to the provisions of ACI-318.1 is, nevertheless, applied to insure conservatism. However, while plain concrete is the chosen shielding embodiment for the HI-STORM 100 storage overpack, all necessary technical, procedural Q.C., and Q.A. provisions to insure nuclear grade quality will be implemented by utilizing the relevant sections from ACI-349 (85) as specified in Appendix 1.D.

In other words, guidelines of NUREG 1536 pertaining to reinforced concrete are considered to insure that the material specification, construction quality control and quality assurance of the shielding concrete comply with the provisions of ACI 349 (85). These specific compliance items are listed in the compliance matrix.

TABLE 3.0.1
MATRIX OF NUREG-1536 COMPLIANCE ITEMS – STRUCTURAL EVALUATION †

PARAGRAPH IN NUREG-1536	NUREG-1536 COMPLIANCE ITEM	LOCATION IN FSAR CHAPTER 3	LOCATION OUTSIDE OF FSAR CHAPTER 3
IV.1.a	ASME B&PV Compliance		
	NB	3.1.1	Tables 2.2.6,2.2.7
	NG	3.1.1	Tables 2.2.6,2.2.7
IV.2	Concrete Material Specification		Appendix 1.D
IV.4	Lifting Devices	3.1; 3.4	
V.	Identification of SSC that are ITS		Table 2.2.6
"	Applicable Codes/Standards	3.6.1	Table 2.2.6
"	Loads		Table 2.2.13
"	Load Combinations	3.1.2.1.2; Tables 3.1.1-3.1.5	Table 2.2.14
"	Summary of Safety Factors	3.4.3; 3.4.4.2; 3.4.4.3.1-3 3.4.6-3.4.9; Tables 3.4.3-3.4.9	
"	Design/Analysis Procedures	Chapter 3	
"	Structural Acceptance Criteria		Tables 2.2.10-2.2.12

TABLE 3.0.1 (CONTINUED)
MATRIX OF NUREG-1536 COMPLIANCE ITEMS – STRUCTURAL EVALUATION †

PARAGRAPH IN NUREG-1536	NUREG-1536 COMPLIANCE ITEM	LOCATION IN FSAR CHAPTER 3	LOCATION OUTSIDE OF FSAR CHAPTER 3
"	Material/QC/Fabrication	Table 3.4.2	Chap. 9; Chap. 13
"	Testing/In-Service Surveillance		Chap. 9; Chap. 12
"	Conditions for Use		Table 1.2.6; Chaps. 8,9,12
V.1.a	Description of SSC	3.1.1	1.2
V.1.b.i.(2)	Identification of Codes & Standards		Tables 2.2.6, 2.2.7
V.1.b.ii	Drawings/Figures		1.5
"	Identification of Confinement Boundary		1.5; 2.3.2; 7.1; Table 7.1.1
"	Boundary Weld Specifications	3.3.1.4	1.5; Table 7.1.2
"	Boundary Bolt Torque	NA	
"	Weights and C.G. Location	Tables 3.2.1-3.2.4	
"	Chemical/Galvanic Reactions	3.4.1; Table 3.4.2	
V.1.c	Material Properties	3.3; Tables 3.3.1-3.3.5	1.A; 1.C; 1.D
"	Allowable Strengths	Tables 3.1.6-3.1.17	Tables 2.2.10-2.2.12; 1.D
"	Suitability of Materials	3.3; Table 3.4.2	1.A; 1.B; 1.D
"	Corrosion	3.3	
"	Material Examination before Fabrication		9.1.1

TABLE 3.0.1 (CONTINUED)
MATRIX OF NUREG-1536 COMPLIANCE ITEMS – STRUCTURAL EVALUATION †

PARAGRAPH IN NUREG-1536	NUREG-1536 COMPLIANCE ITEM	LOCATION IN FSAR CHAPTER 3	LOCATION OUTSIDE OF FSAR CHAPTER 3
"	Material Testing and Analysis		9.1; Table 9.1.1; 1.D
"	Material Traceability		9.1.1
"	Material Long Term Performance	3.3; 3.4.11; 3.4.12	9.2
"	Materials Appropriate to Load Conditions		Chap. 1
"	Restrictions on Use		Chap. 12
"	Temperature Limits	Table 3.1.17	Table 2.2.3
"	Creep/Slump	3.4.4.3.3.2	
"	Brittle Fracture Considerations	3.1.2.3; Table 3.1.18	
"	Low Temperature Handling		2.2.1.2
V.1.d.i.(1)	Normal Load Conditions		2.2.1; Tables 2.2.13,2.2.14
"	Fatigue	3.1.2.4	
"	Internal Pressures/Temperatures for Hot and Cold Conditions	3.4.4.1	2.2.2; Tables 2.2.1,2.2.3
"	Required Evaluations		
"	Weight+Pressure	3.4.4.3.1.2	
"	Weight/Pressure/Temp.	3.4.4.3.1.2	
"	Free Thermal Expansion	3.4.4.2	4.4.6; Table 4.4.10

TABLE 3.0.1 (CONTINUED)
MATRIX OF NUREG-1536 COMPLIANCE ITEMS – STRUCTURAL EVALUATION †

PARAGRAPH IN NUREG-1536	NUREG-1536 COMPLIANCE ITEM	LOCATION IN FSAR CHAPTER 3	LOCATION OUTSIDE OF FSAR CHAPTER 3
V.1.d.i.(2)	Off-Normal Conditions		2.2.2; Tables 2.2.13, 2.2.14; 11.1
V.1.d.i.(3)	Accident Level Events and Conditions	Tables 3.1.1, 3.1.2	2.2.3; Tables 2.2.13, 2.2.14; 11.2
V.1.d.i.(3).(a)	Storage Cask Vertical Drop	3.1.2.1.1.2; 3.4.10; 3.A	2.2.3.1
"	Storage Cask Tipover	3.1.2.1.1.1; 3.4.10; 3.A	2.2.3.2
"	Transfer Cask Horizontal Drop	3.4.9	2.2.3.1
V.1.d.i.(3).(b)	Explosive Overpressure	3.1.2.1.1.4	2.2.3.10
V.1.d.i.(3).(c)	Fire		
"	Structural Evaluations	3.4.4.2	2.2.3.3
"	Material Properties		11.2
"	Material Suitability	3.1.2.2; 3.3.1.1	Table 2.2.3; 11.2
V.1.d.i.(3).(d)	Flood		
"	Identification	3.1.2.1.1.3; 3.4.6	2.2.3.6
"	Cask Tipover	3.4.6	
"	Cask Sliding	3.4.6	
"	Hydrostatic Loading	3.1.2.1.1.3; 3.4.6	72-1008(3.H)
"	Consequences		11.2
V.1.d.i.(3).(e)	Tornado Winds		
"	Specification	3.1.2.1.1.5	2.2.3.5; Table 2.2.4
"	Drag Coefficients	3.4.8	
"	Load Combination	3.4.8	

TABLE 3.0.1 (CONTINUED)
MATRIX OF NUREG-1536 COMPLIANCE ITEMS – STRUCTURAL EVALUATION †

PARAGRAPH IN NUREG-1536	NUREG-1536 COMPLIANCE ITEM	LOCATION IN FSAR CHAPTER 3	LOCATION OUTSIDE OF FSAR CHAPTER 3
"	Overturning –Transfer	NA	
V.1.d.i.(3).(f)	Tornado Missiles		
"	Missile Parameters	3.1.2.1.1.5	Table 2.2.5
"	Tipover	3.4.8	
"	Damage	3.4.8.1; 3.4.8.2	
"	Consequences	3.4.8.1; 3.4.8.2	11.2
V.1.d.i.(3).(g)	Earthquakes		
"	Definition of DBE	3.1.2.1.1.6; 3.4.7	2.2.3.7; Table 2.2.8
"	Sliding	3.4.7	
"	Overturning	3.4.7	
"	Structural Evaluations	3.4.7	11.2
V.1.d.i.(4).(a)	Lifting Analyses		
"	Trunnions		
"	Requirements	3.1.2.1.2; 3.4.3.1; 3.4.3.2	72-1008(3.4.3); 2.2.1.2
"	Analyses	3.4.3.1; 3.4.3.2	72-1008(3.4.3)
"	Other Lift Analyses	3.4.3.7-3.4.3.9	
V.1.d.i.(4).(b)	Fuel Basket		
"	Requirements	3.1.2.1.2; Table 3.1.3	
"	Specific Analyses	3.4.4.2; 3.4.4.3; 3.6.3	72-1008(3.4.4.3.1.2; 3.4.4.3.1.6; 3.M; 3.H; 3.I)

TABLE 3.0.1 (CONTINUED)
MATRIX OF NUREG-1536 COMPLIANCE ITEMS – STRUCTURAL EVALUATION †

PARAGRAPH IN NUREG-1536	NUREG-1536 COMPLIANCE ITEM	LOCATION IN FSAR CHAPTER 3	LOCATION OUTSIDE OF FSAR CHAPTER 3
"	Dynamic Amplifiers	3.4.4.4.1	
"	Stability	3.4.4.3; 3.4.4.4	72-1008(Figures 3.4.27-32)
V.1.d.i.(4).(c)	Confinement Closure Lid Bolts		
"	Pre-Torque	NA	
"	Analyses	NA	
"	Engagement Length	NA	
"	Miscellaneous Bolting		
"	Pre-Torque	3.4.3.7; 3.4.3.8	
"	Analyses	3.4.4.3.2.2	
"	Engagement Length	3.4.3.5; 3.4.3.7; 3.4.3.8	
V.1.d.i.(4)	Confinement		
"	Requirements	3.1.2.1.2; Table 3.1.4	Chap. 7
"	Specific Analyses	3.6.3; Tables 3.4.3, 3.4.4	72-1008(3.E; 3.K; 3.I)
"	Dynamic Amplifiers	3.4.4.1	
"	Stability	3.4.4.3.1	72-1008(3.H)
"	Overpack		
"	Requirements	3.1.2.1.2; Tables 3.1.1, 3.1.5	
"	Specific Analyses	3.6.3; 3.4.4.3	

TABLE 3.0.1 (CONTINUED)
MATRIX OF NUREG-1536 COMPLIANCE ITEMS – STRUCTURAL EVALUATION †

PARAGRAPH IN NUREG-1536	NUREG-1536 COMPLIANCE ITEM	LOCATION IN FSAR CHAPTER 3	LOCATION OUTSIDE OF FSAR CHAPTER 3
"	Dynamic Amplifiers	3.4.4.3.2	
"	Stability	3.4.4.3; Table 3.1.1; 3.4.4.5	
"	Transfer Cask		
"	Requirements	3.1.2.1.2; Table 3.1.5	
"	Specific Analyses	3.4.4.3; 3.6.3	
"	Dynamic Amplifiers	3.4.4.4.1	
"	Stability	NA	2.2.3.1

† Legend for Table 3.0.1

Per the nomenclature defined in Chapter 1, the first digit refers to the chapter number, the second digit is the section number within the chapter; an alphabetic character in the second place means it is an appendix to the chapter.

72-1008	HI-STAR 100 Docket Number where the referenced item is located
NA	Not Applicable for this item

3.1 STRUCTURAL DESIGN

3.1.1 Discussion

The HI-STORM 100 System consists of three principal components: the Multi-Purpose Canister (MPC), the storage overpack, and the transfer cask. The MPC is a hermetically sealed, welded structure of cylindrical profile with flat ends and a honeycomb fuel basket. A complete description is provided in Subsection 1.2.1.1 wherein the anatomy of the MPC and its fabrication details are presented with the aid of figures. The MPCs utilized in the HI-STORM 100 System are identical to those for the HI-STAR 100 System submitted under Dockets 72-1008 and 71-9261. The evaluation of the MPCs presented herein draws upon the work described in those earlier submittals. In this section, the discussion is confined to characterizing and establishing the structural features of the MPC, the storage overpack, and the HI-TRAC transfer cask. Since a detailed discussion of the HI-STORM 100 Overpack and HI-TRAC transfer cask geometries is presented in Section 1.2, attention is focused here on structural capabilities and their inherent margins of safety for housing the MPC. Detailed design drawings for the HI-STORM 100 System are provided in Section 1.5.

The design of the MPC seeks to attain three objectives that are central to its functional adequacy, namely:

- Ability to Dissipate Heat: The thermal energy produced by the stored spent fuel must be transported to the outside surface of the MPC such that the prescribed temperature limits for the fuel cladding and for the fuel basket metal walls are not exceeded.

- Ability to Withstand Large Impact Loads: The MPC, with its payload of nuclear fuel, must be sufficiently robust to withstand large impact loads associated with the postulated handling accident events. Furthermore, the strength of the MPC must be sufficiently isotropic to meet structural requirements under a variety of handling and tip-over accidents.

- Restraint of Free End Expansion: The membrane and bending stresses produced by restraint of free-end expansion of the fuel basket are categorized as primary stresses. In view of the concentration of heat generation in the fuel basket, it is necessary to ensure that structural constraints to its external expansion do not exist.

Where the first two criteria call for extensive inter-cell connections, the last criterion requires the opposite. The design of the MPC seeks to realize all of the above three criteria in an optimal manner.

From the description presented in Chapter 1, the MPC enclosure vessel is the confinement vessel designed to meet ASME Code, Section III, Subsection NB stress limits. The enveloping canister shell, the baseplate, and the lid system form a complete confinement boundary for the stored fuel that is referred to as the "enclosure vessel". Within this cylindrical shell confinement vessel is an integrally welded assemblage of cells of square cross sectional openings for fuel storage, referred to herein as the fuel basket. The fuel basket is analyzed under the provisions of Subsection NG of Section III of the ASME Code. All multi-purpose canisters designed for deployment in the HI-

STORM 100 and HI-STAR 100 systems are exactly alike in their external dimensions. The essential difference between the MPCs lies in the fuel baskets. Each fuel storage MPC is designed to house fuel assemblies with different characteristics. Although all fuel baskets are configured to maximize structural ruggedness through extensive inter-cell connectivity, they are sufficiently dissimilar in structural details to warrant separate evaluations. Therefore, analyses for each of the MPC types were carried out to ensure structural compliance. Inasmuch as no new MPC designs are introduced in this application, and all MPC designs were previously reviewed by the USNRC under Docket 72-1008, the MPC analyses submitted under Docket Numbers 72-1008 and 71-9261 for the HI-STAR 100 System are not reproduced herein unless they need to be modified by HI-STORM 100 conditions or geometry differences. Analyses provided in the HI-STAR 100 System safety analysis reports that are applicable to the HI-STORM 100 System are referenced in this FSAR by docket number and subsection or appendix.

Components of the HI-STORM 100 System that are important to safety and their applicable design codes are defined in Chapter 2.

Some of the key structural functions of the MPC in the storage mode are:

1. To position the fuel in a subcritical configuration, and

2. To provide a confinement boundary.

Some of the key structural functions of the overpack in the storage mode are:

1. To serve as a missile barrier for the MPC,

2. To provide flow paths for natural convection,

3. To ensure stability of the HI-STORM 100 System, and

4. To maintain the position of the radiation shielding.

5. To allow movement of the overpack with a loaded MPC inside.

Some structural features of the MPCs that allow the system to perform these functions are summarized below:

- There are no gasketed ports or openings in the MPC. The MPC does not rely on any sealing arrangement except welding. The absence of any gasketed or flanged joints makes the MPC structure immune from joint leaks. The confinement boundary contains no valves or other pressure relief devices.

- The closure system for the MPCs consists of two components, namely, the MPC lid and the closure ring. The MPC lid can be either a single thick circular plate continuously welded to the MPC shell along its circumference or two dual lids welded around their common periphery. The MPC closure system is shown in the design drawings in Section 1.5. The MPC lid is equipped with vent and drain ports which are utilized for evacuating moisture and air from the MPC following fuel loading, and subsequent backfilling with an inert gas (helium) at a specified mass. The vent and drain ports are covered by a cover plate and welded before the closure ring is installed. The closure ring is a circular annular plate edge-welded to the MPC lid and shell. The two closure members are interconnected by welding around the inner diameter of the ring. Lift points for the MPC are provided in the MPC lid.

- The MPC fuel baskets consist of an array of interconnecting plates. The number of storage cells formed by this interconnection process varies depending on the type of fuel being stored. Basket designs containing cell configurations for PWR and BWR fuel have been designed and are explained in detail in Section 1.2. All baskets are designed to fit into the same MPC shell. Welding of the basket plates along their edges essentially renders the fuel basket into a multiflange beam. Figure 3.1.1 provides an isometric illustration of a fuel basket for the MPC-68 design.

- The MPC basket is separated from its supports by a gap. The gap size decreases as a result of thermal expansion (depending on the magnitude of internal heat generation from the stored spent fuel). The provision of a small gap between the basket and the basket support structure is consistent with the natural thermal characteristics of the MPC. The planar temperature distribution across the basket, as shown in Section 4.4, approximates a shallow parabolic profile. This profile will create high thermal stresses unless structural constraints at the interface between the basket and the basket support structure are removed.

- The MPCs will be loaded with fuel with widely varying heat generation rates. The basket/basket support structure gap tends to be reduced for higher heat generation rates due to increased thermal expansion rates. Gaps between the fuel basket and the basket support structure are specified to be sufficiently large such that a gap exists around the periphery after any thermal expansion.

- In some early vintage MPCs, a small number of flexible thermal conduction elements (thin aluminum tubes) are interposed between the basket and the MPC shell. The elements are designed to be resilient. They do not provide structural support for the basket, and thus their resistance to thermal growth is negligible.

It is quite evident from the geometry of the MPC that a critical loading event pertains to the drop condition when the MPC is postulated to undergo a handling side drop (the longitudinal axis of the MPC is horizontal) or tip-over. Under the side drop or tip-over condition the flat panels of the fuel basket are subject to an equivalent pressure loading that simulates the deceleration-magnified inertia load from the stored fuel and the MPC's own metal mass.

The MPC fuel basket maintains the spent nuclear fuel in a subcritical arrangement. Its safe operation is assured by maintaining the physical configuration of the storage cell cavities intact in the aftermath of a drop event. This requirement is considered to be satisfied if the MPC fuel basket meets the stress intensity criteria set forth in the ASME Code, Section III, Subsection NG. Therefore, the demonstration that the fuel basket meets Subsection NG limits ensures that there is no impairment of ready retrievability (as required by NUREG-1536), and that there is no unacceptable effect on the subcritical arrangement.

The MPC confinement boundary contains no valves or other pressure relief devices. The MPC enclosure vessel is shown to meet the stress intensity criteria of the ASME Code, Section III, Subsection NB for all service conditions. Therefore, the demonstration that the enclosure vessel meets Subsection NB limits ensures that there is no unacceptable release of radioactive materials.

The HI-STORM 100 storage overpack is a steel cylindrical structure consisting of inner and outer low carbon steel shells, a lid, and a baseplate. Between the two shells is a thick cylinder of un-reinforced (plain) concrete. Additional regions of fully confined (by enveloping steel structure) unreinforced concrete are attached to the lid and to the baseplate depending on the specific configuration (see applicable figures in previous chapters). The storage overpack serves as a missile and radiation barrier, provides flow paths for natural convection, provides kinematic stability to the system, and acts as a cushion for the MPC in the event of a tip-over accident. The storage overpack is not a pressure vessel since it contains cooling vents that do not allow for a differential pressure to develop across the overpack wall. The structural steel components of the HI-STORM 100 Overpack are designed to meet the stress limits of the ASME Code, Section III, Subsection NF, Class 3. Short versions of the HI-STORM 100 overpack, designated as the HI-STORM 100S, and the HI-STORM 100S Version B, are included in this revision. To accommodate nuclear plants with limited height access, the HI-STORM 100S has a re-configured lid and a lower overall height. There are minor weight redistributions but the overall bounding weight of the system is unchanged. The HI-STORM 100S Version B incorporates other improvements and modifications designed to improve fabricability and enhance some margins. Structural analyses are revisited if and only if the modified configuration cannot be demonstrated to be bounded by the original calculation. New or modified calculations focused on the HI-STORM 100S and the HI-STORM 100S Version B are clearly identified within the text of this chapter. Unless otherwise designated, general statements using the terminology "HI-STORM 100" also apply to the HI-STORM 100S and to the HI-STORM 100S Version B. The HI-STORM 100S overpacks can carry all MPCs and transfer casks that can be carried in the HI-STORM 100.

As discussed in Chapters 1 and 2, and Section 3.0, the principal shielding material utilized in the HI-STORM 100 Overpack is plain concrete. Plain concrete was selected for the HI-STORM 100 Overpack in lieu of reinforced concrete, because there is no structural imperative for incorporating tensile load bearing strength into the contained concrete. From a purely practical standpoint, the absence of rebars facilitate pouring and curing of concrete with minimal voids, which is an important consideration in light of its shielding function in the HI-STORM 100 Overpack. Plain concrete, however, acts essentially identical to reinforced concrete under compressive and bearing loads, even though ACI standards apply a penalty factor on the compressive and bearing strength of concrete in the absence of rebars (vide ACI 318.1).

Accordingly, the plain concrete in the HI-STORM 100 is considered as a structural material only to the extent that it may participate in supporting direct compressive loads. The allowable compression/bearing resistance is defined and quantified in the ACI318.1-89(92) Building Code for Structural Plain Concrete.

In general, strength analysis of the HI-STORM 100 Overpack and its confined concrete is carried out only to demonstrate that the concrete is able to perform its radiation protection function and that retrievability of the MPC subsequent to any postulated accident condition of storage or handling is maintained.

A discrete ITS component in the HI-STORM 100 System is the HI-TRAC transfer cask. The HI-TRAC serves to provide a missile and radiation barrier during transport of the MPC from the fuel pool to the HI-STORM 100 Overpack. The HI-TRAC body is a double-walled steel cylinder that constitutes its structural system. Contained between the two steel shells is an intermediate lead cylinder. Attached to the exterior of the HI-TRAC body outer shell is a water jacket that acts as a radiation barrier. The HI-TRAC is not a pressure vessel since it contains a penetration in the HI-TRAC top lid that does not allow for a differential pressure to develop across the HI-TRAC wall. Nevertheless, in the interest of conservatism, structural steel components of the HI-TRAC are subject to the stress limits of the ASME Code, Section III, Subsection NF, Class 3.

Since both the HI-STORM 100 and HI-TRAC may serve as an MPC carrier, their lifting attachments are designed to meet the design safety factor requirements of NUREG-0612 [3.1.1] and ANSI N14.6-1993 [3.1.2] for single-failure-proof lifting equipment.

Table 2.2.6 provides a listing of the applicable design codes for all structures, systems, and components which are designated as ITS. Since no structural credit is required for the weld between the adjustable basket support pieces (i.e., shims and basket support flat plates), the adjustable basket supports are classified as NITS.

3.1.2 Design Criteria

Principal design criteria for normal, off-normal, and accident/environmental events are discussed in Section 2.2. In this section, the loads, load combinations, and allowable stresses used in the structural evaluation of the HI-STORM 100 System are presented in more detail.

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 100 System possesses sufficient structural capability to withstand normal and off-normal loads and the worst case loads under natural phenomenon or accident events. Withstanding such loadings enables the HI-STORM 100 System to successfully preclude the following negative consequences:

- 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 100 System can be particularized for individual components as follows:

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

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

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

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

  1. Tornado-generated missiles do not compromise the integrity of the MPC confinement boundary.

  2. The overpack can safely provide for on-site transfer of the loaded MPC and ensure adequate support to the HI-TRAC transfer cask during loading and unloading of the MPC.

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

  4. The flow path for the cooling airflow shall remain available under normal and off-normal conditions of storage and after a natural phenomenon or accident event.

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

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

7. A freestanding storage overpack can safely withstand a non-mechanistic tip-over event with a loaded MPC within the overpack. The HI-STORM 100A is specifically engineered to be permanently attached to the ISFSI pad. The ISFSI pad engineered for the anchored cask is designated as "Important to Safety". Therefore, the non-mechanistic tipover is not applicable to the HI-STORM 100A.

8. The inter-cask transfer of a loaded MPC can be carried out without exceeding the structural capacity of the HI-STORM 100 Overpack, provided all required auxiliary equipment and components specific to an ISFSI site comply with their design criteria set forth in this FSAR and the handling operations are in full compliance with operational limits and controls prescribed in this FSAR.

- The objective of the structural analysis of the HI-TRAC transfer cask is to demonstrate that:

  1. Tornado generated missiles do not compromise the integrity of the MPC confinement boundary while the MPC is contained within HI-TRAC.

  2. No geometry changes occur under any postulated handling or storage conditions that may preclude ready retrievability of the contained MPC.

  3. The structural components perform their intended function during lifting and handling with the loaded MPC.

  4. The radiation shielding remains properly positioned under all applicable handling service conditions for HI-TRAC.

  5. The lead shielding, top lid, and transfer lid doors remain properly positioned during postulated handling accidents.

The aforementioned objectives are deemed to be satisfied for the MPC, the overpack, and the HI-TRAC, if stresses (or stress intensities, as applicable) calculated by the appropriate structural analyses are less than the allowables defined in Subsection 3.1.2.2, and if the diametral change in the storage overpack (or HI-TRAC), if any, after any event of structural consequence to the overpack (or transfer cask), does not preclude ready retrievability of the contained MPC.

Stresses arise in the components of the HI-STORM 100 System due to various loads that originate under normal, off-normal, or accident conditions. These individual loads are combined to form load combinations. Stresses and stress intensities resulting from the load combinations are compared to their respective allowable stresses and stress intensities. The following subsections present loads, load combinations, and the allowable limits germane to them for use in the structural analyses of the MPC, the overpack, and the HI-TRAC transfer cask.

3.1.2.1 Loads and Load Combinations

The individual loads applicable to the HI-STORM 100 System and the HI-TRAC cask are defined in Section 2.2 of this report (Table 2.2.13). Load combinations are developed by assembling the individual loads that may act concurrently, and possibly, synergistically (Table 2.2.14). In this subsection, the individual loads are further clarified as appropriate and the required load combinations are identified. Table 3.1.1 contains the load combinations for the storage overpack where kinematic stability is of primary importance. The load combinations where stress or load level is of primary importance are set forth in Table 3.1.3 for the MPC fuel basket, in Table 3.1.4 for the MPC confinement boundary, and in Table 3.1.5 for the storage overpack and the HI-TRAC transfer cask. Load combinations are applied to the mathematical models of the MPCs, the overpack, and the HI-TRAC. Results of the analyses carried out under bounding load combinations are compared with their respective allowable stresses (or stress intensities, as applicable). The analysis results from the bounding load combinations are also assessed, where warranted, to ensure satisfaction of the functional performance criteria discussed in the preceding subsection.

3.1.2.1.1 Individual Load Cases

The individual loads that address each design criterion applicable to the structural design of the HI-STORM 100 System are catalogued in Table 2.2.13. Each load is given a symbol for subsequent use in the load combination listed in Table 2.2.14.

Accident condition and natural phenomena-induced events, collectively referred to as the "Level D" condition in Section III of the ASME Boiler & Pressure Vessel Codes, in general, do not have a universally prescribed limit. For example, the impact load from a tornado-borne missile, or the overturning load under flood or tsunami, cannot be prescribed as design basis values with absolute certainty that all ISFSI sites will be covered. Therefore, as applicable, allowable magnitudes of such loadings are postulated for the HI-STORM 100 System. The allowable values are drawn from regulatory and industry documents (such as for tornado missiles and wind) or from an intrinsic limitation in the system (such as the permissible "drop height" under a postulated handling accident). In the following, the essential characteristic of each "Level D" type loading is explained.

3.1.2.1.1.1 Tip-Over

It is required to demonstrate that the free-standing HI-STORM 100 storage overpack, containing a loaded MPC, will not tip over as a result of a postulated natural phenomenon event, including tornado wind, a tornado-generated missile, a seismic or a hydrological event (flood). However, to demonstrate the defense-in-depth features of the design, a non-mechanistic tip-over scenario per NUREG-1536 is analyzed. Since the HI-STORM 100S and the HI-STORM 100S Version B have an overall length that is less than the regular HI-STORM 100, the maximum impact velocity of the overpack will be reduced. Therefore, the results of the tipover analysis for the HI-STORM 100 (reported in Appendix 3.A) are bounding for the HI-STORM 100S and HI-STORM 100S Version B. The potential of the HI-STORM 100 Overpack tipping over during the lowering (or raising) of the loaded MPC into (or out of) it with the HI-TRAC cask mounted on it is ruled out because of the safeguards and devices mandated by this FSAR for such operations (Subsection 2.3.3.1 and Technical Specification 4.9). The physical and procedural barriers under the MPC handling operations have been set down in the FSAR to preclude overturning of the HI-STORM/HI-TRAC assemblage with an extremely high level of certainty. Much of the ancillary equipment needed for the MPC transfer operations must be custom engineered to best accord with the structural and architectural exigencies of the ISFSI site. Therefore, with the exception of the HI-TRAC cask, their design cannot be prescribed, a priori, in this FSAR. However, carefully drafted Design Criteria and conditions of use set forth in this FSAR eliminate the potential of weakening of the safety measures contemplated herein to preclude an overturning event during MPC transfer operations. Subsection 2.3.3.1 contains a comprehensive set of design criteria for the ancillary equipment and components required for MPC transfer operations to ensure that the design objective of precluding a kinematic instability event during MPC transfer operations is met. Further information on the steps taken to preclude system overturning during MPC transfer operations may be found in Chapter 8, Section 8.0.

In the HI-STORM 100A configuration, wherein the overpack is physically anchored to the ISFSI pad, the potential for a tip-over is a' priori precluded. Therefore, the ISFSI pad need not be engineered to be sufficiently compliant to limit the peak MPC deceleration to Table 2.2.8 values. The stiffness of the pad, however, may be controlled by the ISFSI structural design and, therefore, may result in a reduced "carry height" from that specified for a freestanding cask. If a non-single failure proof lifting device is employed to carry the cask over the pad, determination of maximum carry height must be performed by the ISFSI owner once the ISFSI pad design is formalized.

3.1.2.1.1.2 Handling Accident

A handling accident during transport of a loaded HI-STORM 100 storage overpack is assumed to result in a vertical drop. The HI-STORM 100 storage overpack will not be handled in a horizontal position while containing a loaded MPC. Therefore, a side drop is not considered a credible event.

HI-TRAC can be carried in a horizontal orientation while housing a loaded MPC. Therefore, a handling accident during transport of a loaded HI-TRAC in a horizontal orientation is considered to be a credible accident event.

As discussed in the foregoing, the vertical drop of the HI-TRAC and the tip-over of the assemblage of a loaded HI-TRAC on the top of the HI-STORM 100 storage overpack during MPC transfer operations do not need to be considered.

3.1.2.1.1.3 Flood

The postulated flood event results into two discrete scenarios which must be considered; namely,

1. stability of the HI-STORM 100 System due to flood water velocity, and
2. structural effects of hydrostatic pressure and water velocity induced lateral pressure.

The maximum hydrostatic pressure on the cask in a flood where the water level is conservatively set at 125 feet is calculated as follows:

Using

p = the maximum hydrostatic pressure on the system (psi),
γ = weight density of water = 62.4 lb/ft^3
h = the height of the water level = 125 ft;

The maximum hydrostatic pressure is

$$p = \gamma h = (62.4\ \text{lb/ft}^3)(125\ \text{ft})(1\ \text{ft}^2/144\ \text{in}^2) = 54.2\ \text{psi}$$

The accident condition design external pressure for the MPC (Table 2.2.1) bounds the maximum hydrostatic pressure exerted by the flood.

3.1.2.1.1.4 Explosion

The potential for explosive materials shall be evaluated based on site specific conditions as required in the HI-STORM 100 Technical Specification.

Pressure waves from an explosive blast in a property near the ISFSI site result in an impulsive aerodynamic loading on the stored HI-STORM 100 Overpacks. Depending on the rapidity of the pressure build-up, the inside and outside pressures on the HI-STORM METCON™ shell may not equalize, leading to a net lateral loading on the upright overpack as the pressure wave traverses the overpack. The magnitude of the dynamic pressure wave is conservatively set to a value below the magnitude of the pressure differential that would cause a tip-over of the cask if the pulse duration were set at one second. With the maximum design basis pressure pulse established (by setting the design basis pressure differential sufficiently low that cask tip-over is not credible due to the travelling pressure wave), the stress state under this condition requires analysis. The lateral pressure difference, applied over the overpack full height, causes axial and circumferential stresses and strains to develop. Level D stress limits must not be exceeded under this state of stress. It must also be demonstrated that no permanent ovalization of the cross section occurs that leads to loss of clearance to remove the MPC after the explosion.

Once the pressure wave traverses the cask body, then an elastic stability evaluation is warranted. An all-enveloping pressure from the explosion may threaten safety by buckling the overpack outer shell.

In contrast to the overpack, the MPC is a closed pressure vessel. Because of the enveloping overpack around it, the explosive pressure wave would manifest as an external pressure on the external surface of the MPC.

The maximum overpressure on the MPC resulting from an explosion is limited to the accident condition design external pressure specified in Table 2.2.1. The maximum external pressure differential on the overpack is limited to the accident condition design pressure differential specified in Table 2.2.1.

3.1.2.1.1.5 Tornado

The three components of a tornado load are:

1. pressure changes,
2. wind loads, and
3. tornado-generated missiles.

Wind speeds and tornado-induced pressure drop are specified in Table 2.2.4. Tornado missiles are listed in Table 2.2.5. A central functional objective of a storage overpack is to maintain the integrity of the "confinement boundary", namely, the multi-purpose canister stored inside it. This operational imperative requires that the mechanical loadings associated with a tornado at the ISFSI do not jeopardize the physical integrity of the loaded MPC. Potential consequences of a tornado on the cask system are:

- Instability (tip-over) due to tornado missile impact plus either steady wind or impulse from the pressure drop (only applicable for free-standing cask).
- Stress in the overpack induced by the lateral force caused by the steady wind or missile impact.
- Loadings applied on the MPC transmitted to the inside of the overpack through its openings or as a secondary effect of loading on the enveloping overpack structure.
- Excessive storage overpack permanent deformation that may prevent ready retrievability of the MPC.
- Excessive storage overpack permanent deformation that may significantly reduce the shielding effectiveness of the storage overpack.

Analyses must be performed to ensure that, due to the tornado-induced loadings:

- The loaded overpack does not become kinematically unstable (only applicable for free-standing cask).

- The overpack does not deform plastically such that the retrievability of the stored MPC is threatened.

- The MPC does not sustain an impact from an incident missile.

- The MPC is not subjected to inertia loads (acceleration or deceleration) in excess of its design basis limit set forth in Chapter 2 herein.

- The overpack does not deform sufficiently due to tornado-borne missiles such that the shielding effectiveness of the overpack is significantly affected.

The results obtained for the HI-STORM 100 bound the corresponding results for the HI-STORM 100S versions because of the reduced height. In the anchored configuration (HI-STORM 100A), the kinematic stability requirement stated above is replaced with the requirement that the stresses in the anchor studs do not exceed level D stress limits for ASME Section III, Class 3, Subsection NF components.

3.1.2.1.1.6 Earthquake

Subsections 2.2.3.7 and 3.4.7 contain the detailed specification of the seismic inputs applied to the HI-STORM 100 System. The design basis earthquake is assumed to be at the top of the ISFSI pad. Potential consequences of a seismic event are sliding/overturning of a free-standing cask, overstress of the sector lugs and anchor studs for the anchored HI-STORM 100A, and lateral force on the overpack causing excessive stress and deformation of the storage overpack.

In the anchored configuration (HI-STORM 100A), a seismic event results in a fluctuation in the state of stress in the anchor bolts and a local bending action on the sector lugs.

Analyses must be performed to ensure that:

- The maximum axial stress in the anchor bolts remains below the Level D stress limits for Section III Class 3 Subsection NF components.

- The maximum primary membrane plus bending stress intensity in the sector lugs during the DBE event satisfies Level D stress limits of the ASME Code, Subsection NF.

- The anchor bolts will not sustain fatigue failure due to pulsation in their axial stress during the DBE event.

- The stress in the weld line joining the sector lugs to the HI-STORM 100 weldment is within Subsection NF limits for Level D condition.

3.1.2.1.1.7 Lightning

The HI-STORM 100 Overpack contains over 25,000 lb of highly conductive carbon steel with over 700 square feet of external surface area. Such a large surface area and metal mass is adequate to dissipate any lightning that may strike the HI-STORM 100 System. There are no combustible materials on the HI-STORM 100 surface. Therefore, lightning will not impair the structural performance of components of the HI-STORM 100 System that are important to safety.

3.1.2.1.1.8 Fire

The potential structural consequences of a fire are: the possibility of an interference developing between the storage overpack and the loaded MPC due to free thermal expansion; and, the degradation of material properties to the extent that their structural performance is affected during a subsequent recovery action. The fire condition is addressed to the extent necessary to demonstrate that these adverse structural consequences do not materialize.

3.1.2.1.1.9 100% Fuel Rod Rupture

The effect on structural performance by 100% fuel rod rupture is felt as an increase in internal pressure. The accident internal pressure limit set in Chapter 2 bounds the pressure from 100% fuel rod rupture. Therefore, no new load condition has been identified.

3.1.2.1.2 Load Combinations

Load combinations are created by summing the effects of several individual loads. The load combinations are selected for the normal, off-normal, and accident conditions. The loadings appropriate for HI-STORM 100 under the various conditions are presented in Table 2.2.14. These loadings are combined into meaningful combinations for the various HI-STORM 100 System components in Tables 3.1.1, and 3.1.3-3.1.5. Table 3.1.1 lists the load combinations that address overpack stability. Tables 3.1.3 through 3.1.5 list the applicable load combinations for the fuel basket, the enclosure vessel, and the overpack and HI-TRAC, respectively.

As discussed in Subsection 2.2.7, the number of discrete load combinations for each situational condition (i.e., normal, off-normal, etc.) is consolidated by defining bounding loads for certain groups of loadings. Thus, the accident condition pressure P_o^* bounds the surface loadings arising from accident and extreme natural phenomenon events, namely, tornado wind W', flood F, and explosion E^*.

As noted previously, certain loads, namely earthquake E, flowing water under flood condition F, force from an explosion pressure pulse F*, and tornado missile M, act to destabilize a cask. Additionally, these loads act on the overpack and produce essentially localized stresses at the HI-STORM 100 System to ISFSI interface. Table 3.1.1 provides the load combinations that are relevant to the stability analyses of freestanding casks. The site ISFSI DBE zero period acceleration (ZPA) must be bounded by the design basis seismic ZPA defined by the Load Combination C of Table 3.1.1 to demonstrate that the margin against tip-over during a seismic event is maintained.

The major constituents in the HI-STORM 100 System are: (i) the fuel basket, (ii) the enclosure vessel, (iii) the HI-STORM 100 (or HI-STORM 100S versions) Overpack, and (iv) the HI-TRAC transfer cask. The fuel basket and the enclosure vessel (EV) together constitute the multi-purpose canister. The multi-purpose canister (MPC) is common to HI-STORM 100 and HI-STAR 100, and as such, has been extensively analyzed in the storage FSAR and transport SAR (Dockets 72-1008 and 71-9261) for HI-STAR 100. Many of the loadings on the MPC (fuel basket and enclosure vessel) are equal to or bounded by loadings already considered in the HI-STAR 100 SAR documents. Where such analyses have been performed, their location in the HI-STAR 100 SAR documents is indicated in this HI-STORM 100 SAR for continuity in narration. A complete account of analyses and results for all load combinations for all four constituents parts is provided in Section 3.4 as required by Regulatory Guide 3.61.

In the following, the loadings listed as applicable for each situational condition in Table 2.2.14 are addressed in meaningful load combinations for the fuel basket, enclosure vessel, and the overpack. Each component is considered separately.

<u>Fuel Basket</u>

Table 3.1.3 summarizes all loading cases (derived from Table 2.2.14) that are germane to demonstrating compliance of the fuel baskets to Subsection NG when these baskets are housed within HI-STORM 100 or HI-TRAC.

The fuel basket is not a pressure vessel; therefore, the pressure loadings are not meaningful loads for the basket. Further, the basket is structurally decoupled from the enclosure vessel. The gap between the basket and the enclosure vessel is sized to ensure that no constraint of free-end thermal expansion of the basket occurs. The demonstration of the adequacy of the basket-to -enclosure vessel (EV) gap to ensure absence of interference is a physical problem that must be analyzed.

The normal handling loads on the fuel basket in an MPC within the HI-STORM 100 System or the HI-TRAC transfer cask are identical to or bounded by the normal handling loads analyzed in the HI-STAR 100 FSAR Docket Number 72-1008.

Three accident condition scenarios must be considered: (i) drop with the storage overpack axis vertical; (ii) drop with the HI-TRAC axis horizontal; and (iii) storage overpack tipover. The vertical drop scenario is considered in the HI-STAR 100 FSAR.

The horizontal drop and tip-over must consider multiple orientation of the fuel basket, as the fuel basket is not radially symmetric. Therefore, two horizontal drop orientations are considered which are referred to as the 0 degree drop and 45 degree drop, respectively. In the 0 degree drop, the basket drops with its panels oriented parallel and normal to the vertical (see Figure 3.1.2). The 45-degree drop implies that the basket's honeycomb section is rotated meridionally by 45 degrees (Figure 3.1.3).

Enclosure Vessel

Table 3.1.4 summarizes all load cases that are applicable to structural analysis of the enclosure vessel to ensure integrity of the confinement boundary.

The enclosure vessel is a pressure vessel consisting of a cylindrical shell, a thick circular baseplate at the bottom, and a thick circular lid at the top. This pressure vessel must be shown to meet the primary stress intensity limits for ASME Section III Class 1 at the design temperature and primary plus secondary stress intensity limits under the combined action of pressure plus thermal loads.

Normal handling of the enclosure vessel is considered in Docket 72-1008; the handling loads are independent of whether the enclosure vessel is within HI-STAR 100, HI-STORM 100, or HI-TRAC.

The off-normal condition handling loads are identical to the normal condition and, therefore, a separate analysis is not required.

Analyses presented in this chapter are intended to demonstrate that the maximum decelerations in drop and tip-over accident events are limited by the bounding values in Table 3.1.2. The vertical drop event is considered in the HI-STAR 100 FSAR Docket 72-1008.

The deceleration loadings developed in the enclosure vessel during a horizontal drop event are combined with those due to P_i (internal pressure) acting alone. The accident condition pressure is bounded by P_i^*. The design basis deceleration for the MPC in the HI-STAR 100 System is 60g's, whereas the design basis deceleration for the MPC in the HI-STORM 100 System is 45g's. The design pressures are identical. The fire event (T^* loading) is considered for ensuring absence of interference between the enclosure vessel and the fuel basket and between the enclosure vessel and the overpack.

It is noted that the MPC basket-enclosure vessel thermal expansion and stress analyses are reconsidered in this submittal to reflect the different MPC-to-overpack gaps that exist in the HI-STORM 100 Overpack versus the HI-STAR 100 overpack, coupled with the different design basis decelerations.

Storage Overpack

Table 3.1.5 identifies the load cases to be considered for the overpack. These are in addition to the kinematic criteria listed in Table 3.1.1. Within these load cases and kinematic criteria, the following items must be addressed:

Normal Conditions

- The dead load of the HI-TRAC with the heaviest loaded MPC (dry) on top of the HI-STORM 100 Overpack must be shown to be able to be supported by the metal-concrete (METCON™) structure consisting of the two concentric steel shells and the radial ribs.

- The dead load of the HI-STORM 100 Overpack itself must be supportable by the steel structure with no credit for concrete strength other than self-support in compression.

- Normal handling loads must be accommodated without taking any strength credit from the contained concrete other than self-support in compression.

Accident Conditions

- Maximum flood water velocity for the overpack with an empty MPC must be specified to ensure that no sliding or tip-over occurs.

- Tornado missile plus wind on an overpack with an empty MPC must be specified to demonstrate that no cask tip-over occurs.

- Tornado missile penetration analysis must demonstrate that the postulated large and penetrant missiles cannot contact the MPC. The small missile must be shown not to penetrate the MPC pressure vessel boundary, since it can enter the overpack cavity through the vent ducts.

- Under seismic conditions, a fully loaded, free-standing HI-STORM 100 overpack must be demonstrated to not tip over under the maximum ZPA event. The maximum sliding of the overpack must demonstrate that casks will not impact each other.

- Under a non-mechanistic postulated tip-over of a fully loaded, freestanding HI-STORM 100 overpack, the overpack lid must not dislodge.

- Accident condition stress levels must not be exceeded in the steel and compressive stress levels in the concrete must remain within allowable limits.

- Accident condition induced gross general deformations of the storage overpack must be limited to values that do not preclude ready retrievability of the MPC.

As noted earlier, analyses performed using the HI-STORM 100 generally provide results that are identical to or bound results for the shorter HI-STORM 100S versions; therefore, analyses are not repeated specifically for the HI-STORM 100S unless the specific geometry changes significantly influence the safety factors.

HI-TRAC Transfer Cask

Table 3.1.5 identifies load cases applicable to the HI-TRAC transfer cask.

The HI-TRAC transfer cask must provide radiation protection, must act as a handling cask when carrying a loaded MPC, and in the event of a postulated accident must not suffer permanent deformation to the extent that ready retrievability of the MPC is compromised. This submittal includes four types of transfer casks: a 125-ton HI-TRAC (referred to as the HI-TRAC 125), a modified version of the HI-TRAC 125 called the HI-TRAC 125D, a 100-ton HI-TRAC (referred to as the HI-TRAC 100), and a modified version of the HI-TRAC 100 called the HI-TRAC 100D. The details of these four transfer casks are provided in the design drawings in Section 1.5. The same steel structures (i.e., shell thicknesses, lid thicknesses, etc.) are maintained with the only major differences being in the amount of lead shielding, the water jacket configuration, the bottom flange, and the lower dead weight loading. Therefore, all structural analyses performed for the HI-TRAC 125 are repeated for the HI-TRAC 125D, the HI-TRAC 100, and the HI-TRAC 100D only if it cannot be clearly demonstrated that the HI-TRAC 125 calculation is bounding.

3.1.2.2 Allowables

The important to safety components of the HI-STORM 100 System are listed in Table 2.2.6. Allowable stresses, as appropriate, are tabulated for these components for all service conditions.

In Subsection 2.2.5, the applicable service level from the ASME Code for determination of allowables is listed. Table 2.2.14 provides a tabulation of normal, off-normal, and accident conditions and the service levels defined in the ASME Code, along with the applicable loadings for each service condition.

Allowable stresses and stress intensities are calculated using the data provided in the ASME Code and Tables 2.2.10 through 2.2.12. Tables 3.1.6 through 3.1.16 contain numerical values of the stresses/stress intensities for all MPC, overpack, and HI-TRAC load bearing 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 analyses are extracted from the ASME Code (Figure NB-3222-1, for example) as follows:

Symbol	Description	Notes
P_m	Average primary stress across a solid section	Excludes effects of discontinuities and concentrations. Produced by pressure and mechanical loads.
P_L	Average stress across any solid section	Considers effects of discontinuities but not concentrations. Produced by pressure and mechanical loads, including earthquake inertial effects.
P_b	Primary bending stress	Component of primary stress proportional to the distance from the centroid of a solid section. Excludes the effects of

Symbol	Description	Notes
		discontinuities and concentrations. Produced by pressure and mechanical loads, including earthquake inertial effects.
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.)
Q	Secondary membrane plus bending stress	Self-equilibrating stress necessary to satisfy continuity of structure. Occurs at structural discontinuities. Can be caused by pressure, mechanical loads, or differential thermal expansion.
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. This value is not used in the tables.

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 100 component.

It is recognized that the planar temperature distribution in the fuel basket and the overpack under the maximum heat load condition is the highest at the cask center and drops monotonically, reaching its lowest value at the outside surface. Strictly speaking, the allowable stresses/stress intensities at any location in the basket, the enclosure vessel, or the overpack should be based on the coincident metal temperature under the specific operating condition. However, in the interest of conservatism, reference temperatures are established for each component, which are upper bounds on the metal temperature for each situational condition. Table 3.1.17 provides the reference temperatures for the fuel basket and the MPC canister utilizing Tables 3.1.6 through 3.1.16, and provides conservative numerical limits for the stresses and stress intensities for all loading cases. Reference temperatures for the MPC baseplate and the MPC lid are 400 degrees F and 550 degrees F, respectively, as specified in Table 2.2.3.

Finally, the lift devices in the HI-STORM 100 Overpack and HI-TRAC casks and the multi-purpose canisters, collectively referred to as "trunnions", are subject to specific limits set forth by NUREG-0612: the primary stresses in a trunnion must be less than the smaller of 1/10 of the material ultimate strength and 1/6 of the material yield strength under a normal handling condition (Load Case 01 in Table 3.1.5). The load combination D+H in Table 3.1.5 is equivalent to 1.15D. This is further explained in Subsection 3.4.3.

The region around the trunnions is part of the NF structure in HI-STORM 100 and HI-TRAC and NB pressure boundary in the MPC, and as such, must satisfy the applicable stress (or stress intensity) limits for the load combination. In addition to meeting the applicable Code limits, it is further required that the primary stress required to maintain equilibrium at the defined trunnion/mother structure interface must not exceed the material yield stress at three times the handling condition load

(1.15D). This criterion, mandated by Regulatory Guide 3.61, Section 3.4.3, insures that a large safety factor exists on non-local section yielding at the trunnion/mother structure interface that would lead to unacceptable section displacement and rotation.

3.1.2.3 Brittle Fracture

The MPC canister and basket are constructed from a series of stainless steels termed Alloy X. These stainless steel materials do not undergo a ductile-to-brittle transition in the minimum temperature range of the HI-STORM 100 System. Therefore, brittle fracture is not a concern for the MPC components. Such an assertion can not 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 requirements for the HI-STORM overpack and the HI-TRAC transfer cask are 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 overpack and the transfer cask, 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 HI-STORM handling operations, the applicable lowest service temperature is 0°F (which is the threshold ambient temperature below which lifting and handling of the HI-STORM 100 Overpack or the HI-TRAC cask is not permitted by the Technical Specification). Therefore, two distinct LSTs are applicable to load bearing metal parts within the HI-STORM 100 Overpack and the HI-TRAC 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 storage mode).

Parts used to lift the overpack or the transfer cask, which include the anchor block in the HI-STORM 100 overpack, and the pocket trunnions, the lifting trunnions and the lifting trunnion block in HI-TRAC, will henceforth be referred to as "significant-to-handling" (STH) parts. The applicable design code for these elements of the structure is ANSI N14.6. 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° below the LST. Therefore, the required NDT temperature for all STH parts is -40°F.

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. For example, according to Burgreen [3.1.3], 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 lowers the NDT from 10°C to -50°C [3.1.3]. 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 (which is a principal NF material in the HI-STORM 100 Overpack) 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 which 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 100 Overpack (NF and STH) is -40°F. Likewise, the NDT temperature for all NF parts in HI-TRAC (except for STH parts) is set equal to 0°F.

The STH components (HI-STORM bolt anchor block, HI-TRAC lifting trunnion, HI-TRAC lifting trunnion block, and HI-TRAC pocket trunnion) have thicknesses greater than 2". SA350-LF3 has been selected as the material for these items (except for the lifting trunnions) due to its capability to maintain acceptable fracture toughness at low temperatures (see Table 5 in SA350 of ASME Section IIA). Additionally, material for the HI-TRAC top flange, pool lid (100 ton) and pool lid outer ring (125 ton) has been defined as SA350-LF3, SA350-LF2, or SA203E (see Table A1.15 of ASME Section IIA) in order to achieve low temperature fracture toughness. The HI-TRAC lifting trunnion is fabricated from SB-637 Grade N07718, a high strength nickel alloy material. This material has a high resistance to fracture at low temperatures. All other steel structural materials in the HI-STORM 100 overpack and HI-TRAC cask are made of SA516 Gr. 70, SA515 Gr. 70, or SA36 (with some components having an option for SA203E or SA350-LF3 depending on material availability).

Either as-rolled or normalized SA516 Gr. 70 plate can be used to fabricate the overpack and the transfer cask. If the SA516 Gr. 70 plate is normalized, then it is exempt from impact testing per NF-2311(b). The specific reasons are:

1. The LST for handling operations is above the Minimum Design Temperature of SA516 Gr. 70 normalized plate (for thickness less than 2-1/2") per Figure NF-2311(b)-1, and;

2. During non-handling operations (i.e., normal 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 material is used for the following HI-STORM components: inner and outer shells, top plate, lid shear ring, lid shield ring, lid outer ring (for 100S Version B), and lid cover plate (for 100S Version B) and Base-Bottom Plate (for 100S Version B). The material for these components is exempt from impact testing per NF-2311(b)(7) since the maximum stress under normal conditions, including handling operations, does not exceed 6,000 psi tension or is compressive.

Even though SA516 Gr. 70 normalized plate is exempt from impact testing per the above, certain components of the HI-STORM 100A overpack, namely the lug support ring, the gussets, and the baseplate, are impact tested, as a defense-in-depth measure, because they are potentially subject to high tensile stress levels (i.e., greater than 6,000 psi) during an earthquake.

Table 3.1.18 provides a summary of impact testing requirements to satisfy the requirements for prevention of brittle fracture.

3.1.2.4 Fatigue

In storage, the HI-STORM 100 System is not subject to significant cyclic loads. Failure due to fatigue is not a concern for the HI-STORM 100 System.

In an anchored installation, however, the anchor studs sustain a pulsation in the axial load during the seismic event. The amplitude of axial stress variation under the DBE event is computed in this chapter and a significant margin of safety against fatigue failure during the DBE event is demonstrated.

The system is subject to cyclic temperature fluctuations. These fluctuations result in small changes of thermal expansions and pressures in the MPC. The loads resulting from these changes are small and do not significantly contribute to the "usage factor" of the cask.

Inspection of the HI-TRAC trunnions specified in Chapter 9 will preclude use of a trunnion that exhibits visual damage.

3.1.2.5 Buckling

Certain load combinations subject structural sections with relatively large slenderness ratios (such as the enclosure vessel shell) to compressive stresses that may actuate buckling instability before the allowable stress is reached. Tables 3.1.4 and 3.1.5 list load combinations for the enclosure vessel and the HI-STORM 100/HI-TRAC structures; the cases which warrant stability (buckling) check are listed therein (note that a potential buckling load has already been identified as a consequence of a postulated explosion).

TABLE 3.1.1

LOAD COMBINATIONS SIGNIFICANT TO HI-STORM 100 OVERPACK KINEMATIC STABILITY ANALYSIS

Loading Case	Combinations†	Comment	Analysis of this Load Case Presented in:
A	D + F	This case establishes flood water flow velocity with a minimum safety factor of 1.1 against overturning and sliding.	Subsection 3.4.6
B	D + M + W'	Demonstrate that the HI-STORM 100 Overpack with minimum SNF stored (minimum D) will not tip over.	Subsection 3.4.8
C	D + E	Establish the value of ZPA†† that will not cause the overpack to tip over.	Subsection 3.4.7

† Loading symbols are defined in Table 2.2.13

†† ZPA is zero period acceleration

TABLE 3.1.2

DESIGN BASIS DECELERATIONS FOR THE DROP EVENTS

Case	Value[†] (in multiples of acceleration due to gravity)
Vertical axis drop (HI-STORM 100 Overpack only)	45
Horizontal axis (side) drop (HI-TRAC only)	45

† The design basis value is set from the requirements of the HI-STORM 100 System, as its components are operated as a storage system. The MPC is designed to higher loadings (60g's vertical and horizontal) when in a HI-STAR 100 overpack. Analysis of the MPC in a HI-STAR 100 overpack under a 60g loading is provided in HI-STAR 100 Docket Numbers 71-9261 and 72-1008.

TABLE 3.1.3

LOADING CASES FOR THE FUEL BASKET

Load Case I.D.	Loading†	Notes	Location Where this Case is Evaluated
F1	T, T'	Demonstrate that the most adverse of the temperature distributions in the basket will not cause fuel basket to expand and contact the enclosure vessel wall. Compute the secondary stress intensity and show that it is small.	Subsection 3.4.4.2
F2 (Note 1)	D + H	Conservatively add the stresses in the basket due to vertical and horizontal orientation handling to form a bounding stress intensity.	Table 3.4.9 of HI-STAR FSAR (Docket 72-1008)
F3			
F3.a (Note 2)	D + H'	Vertical axis drop event	HI-STAR FSAR, Subsection 3.4.4.3.1.3
F3.b (Note 3)	D + H'	Side Drop, 0 degree orientation (Figure 3.1.2)	Table 3.4.6
F3.c (Note 3)	D + H'	Side Drop, 45 degree orientation (Figure 3.1.3)	Table 3.4.6

Notes:

1. Load Case F2 for the HI-STORM 100 System is identical to Load Case F2 for the HI-STAR 100 System in Docket Number 72-1008, Table 3.1.3.

2. Load Case F3.a is bounded by the 60g deceleration analysis performed for the HI-STAR 100 System in Docket Number 72-1008, Subsection 3.4.4.3.1.3. The HI-STORM 100 vertical deceleration loading is limited to 45g.

3. Load Cases F3.b and F3.c are analyzed here for a 45g deceleration, while the MPC is housed within a HI-STORM 100 Overpack or a HI-TRAC transfer cask. The initial clearance at the interface between the MPC shell and the HI-STORM 100 Overpack or HI-TRAC transfer cask is greater than or equal to the initial clearance between the MPC shell and the HI-STAR 100 overpack. This difference in clearance directly affects the stress field. The side drop analysis for the MPC in the HI-STAR 100 overpack under 60g's bounds the corresponding analysis of the MPC in HI-TRAC for 45 g's.

† The symbols used for the loadings are defined in Table 2.2.13.

TABLE 3.1.4

LOADING CASES FOR THE ENCLOSURE VESSEL (CONFINEMENT BOUNDARY)

Load Case I.D.	**Load Combination**†	**Notes**	**Comments and Location Where this Case is Analyzed**
E1 (Note 1) E1.a	Design internal pressure, P_i	Primary stress intensity limits in the shell, baseplate, and closure ring	E1.a Lid Docket 72-1008 3.E.8.1.1 Baseplate Docket 72-1008 3.1.8.1 Shell 3.4.4.3.1.2 Supports N/A
E1.b	Design external pressure, P_o	Primary stress intensity limits, buckling stability	E1.b Lid P_i bounds Baseplate P_i bounds Shell Docket 72-1008 Buckling methodology in 3.H Supports N/A
E1.c	Design internal pressure, P_i, Plus Temperature, T	Primary plus secondary stress intensity under Level A condition	E1.c Lid, Baseplate, and Shell Section 3.4.4.3.1.2
E2	D + H + (P_i,P_o)††	Vertical lift, internal operating pressure conservatively assumed to be equal to the normal design pressure. Principal area of concern is the lid assembly.	Lid Docket 72-1008 3.E.8.1.2 Baseplate 3.4.3.6 Shell Docket 72-1008 Table 3.4.9 (stress) Docket 72-1008 Buckling methodology in 3.H Supports Docket 72-1008 Table 3.4.9

† The symbols used for the loadings are defined in Table 2.2.13.

†† The notation (P_i, P_o) means that both cases are checked with either P_o or P_i applied.

TABLE 3.1.4 (CONTINUED)

LOADING CASES FOR THE ENCLOSURE VESSEL (CONFINEMENT BOUNDARY)

Load Case I.D.	Load Combination†	Notes	Comments and Location Where this Case is Analyzed
E3 E3.a (Note 2)	$D + H' + (P_o, P_i)$	Vertical axis drop event	E3.a Lid: Docket 72-1008 3.E.8.2.1-2 Baseplate: Docket 72-1008 3.I.8.3 Shell: Docket 72-1008 Buckling methodology in 3.H Supports: N/A
E3.b (Note 3)	$D + H' + (P_i, P_o)$	Side drop, 0 degree orientation (Figure 3.1.2)	E3.b Lid: End drop bounds Baseplate: End drop bounds Shell: Table 3.4.6 Supports: Table 3.4.6
E3.c (Note 3)	$D + H' + (P_i, P_o)$	Side drop, 45 degree orientation (Figure 3.1.3)	E3.c Lid: End drop bounds Baseplate: End drop bounds Shell: Table 3.4.6 Supports: Table 3.4.6
E4	T	Demonstrate that interference with the overpack will not develop for T.	Section 3.4.4.2

† The symbols used for the loadings are defined in Table 2.2.13.

TABLE 3.1.4 (CONTINUED)

LOADING CASES FOR THE ENCLOSURE VESSEL (CONFINEMENT BOUNDARY)

Load Case I.D.	Load Combination†	Notes	Comments and Location Where this Case is Analyzed	
E5	P_i^* or P_o^* + D + T^*	Demonstrate compliance with level D stress limits – buckling stability.	Lid	3.4.4.3.1.10
			Baseplate	3.4.4.3.1.10
			Shell	Docket 72-1008 Buckling methodology in 3.H 3.4.4.3.1.2 (stress)
			Supports	N/A

Notes:

1. Load Cases E1.a, E1.b, and E2 are identical to the load cases presented in Docket Number 72-1008, Table 3.1.4. Design pressures and MPC weights are identical.

2. Load Case E3.a is bounded by the 60g deceleration analysis performed for the HI-STAR 100 System in Docket Number 72-1008. The HI-STORM 100 vertical deceleration loading is limited to 45g.

3. Load Cases E3.b and E3.c are analyzed in this HI-STORM 100 SAR for a 45g deceleration, while the MPC is housed within the HI-STORM 100 storage overpack. The interface between the MPC shell and storage overpack is not identical to the MPC shell and HI-STAR 100 overpack. The analysis for an MPC housed in HI-TRAC is not performed since results are bounded by those reported in the HI-STAR 100 TSAR for a 60g deceleration.

† The symbols used for the loadings are defined in Table 2.2.13.

TABLE 3.1.5

LOAD CASES FOR THE HI-STORM 100 OVERPACK/HI-TRAC TRANSFER CASK

Load Case I.D.	Loading[†]	Notes	Location in FSAR
01	$D + H + T + (P_o,P_i)$	Vertical load handling of HI-STORM 100 Overpack/HI-TRAC.	Overpack 3.4.3.5 HI-TRAC Shell 3.4.3.3, 3.4.3.4 Pool lid 3.4.3.8 Transfer lid 3.4.3.9
02			
02.a	$D + H' + (P_o,P_i)$	Storage Overpack: End drop; primary stress intensities must meet level D stress limits.	Overpack 3.4.4.3.2.3
02.b	$D + H' + (P_o,P_i)$	HI-TRAC: Horizontal (side) drop; meet level D stress limits for NF Class 3 components away from the impacted zone; show lids stay in-place. Show primary and secondary impact decelerations are within design basis. (This case is only applicable to HI-TRAC.)	HI-TRAC Shell 3.4.9.1 Transfer Lid 3.4.4.3.3.3 Slapdown 3.4.9.2
02.c	$D + H'$	Storage Overpack: Tip-over; any permanent deformations must not preclude ready retrieval of the MPC.	Overpack 3.4.10, 3.A

† The symbols used for the loadings are defined in Table 2.2.13

TABLE 3.1.5 (CONTINUED)

LOAD CASES FOR THE HI-STORM 100 OVERPACK/HI-TRAC TRANSFER CASK

Load Case I.D.	Loading†	Notes	Location in FSAR
03	D (water jacket)	Satisfy primary membrane plus bending stress limits for water jacket (This case is only applicable to HI-TRAC).	3.4.4.3.3.4
04	M (penetrant missiles)	Demonstrate that no thru-wall breach of the HI-STORM overpack or HI-TRAC transfer cask occurs, and the primary stress levels are not exceeded. Small and intermediate missiles are examined for HI-STORM and HI-TRAC. Large missile penetration is also examined for HI-TRAC.	Overpack 3.4.8.1 HI-TRAC 3.4.8.2.1, 3.4.8.2.2
05	P_o	Explosion: must not produce buckling or exceed primary stress levels in the overpack structure.	3.4.4.5.2, 3.4.7.2

Notes:

1. Under each of these load cases, different regions of the structure are analyzed to demonstrate compliance.

† The symbols used for the loadings are defined in Table 2.2.13

TABLE 3.1.6

DESIGN, LEVELS A AND B: STRESS INTENSITY

Code: ASME NB
Material: SA203-E
Service Conditions: Design, Levels A and B
Item: Stress Intensity

Temp. (Deg. F)	Classification and Value (ksi)					
	S_m	P_m †	P_L †	$P_L + P_b$ †	$P_L + P_b + Q$ ††	P_e ††
-20 to 100	23.3	23.3	35.0	35.0	69.9	69.9
200	23.3	23.3	35.0	35.0	69.9	69.9
300	23.3	23.3	35.0	35.0	69.9	69.9
400	22.9	22.9	34.4	34.4	68.7	68.7
500	21.6	21.6	32.4	32.4	64.8	64.8

Definitions:

S_m = Stress intensity values per ASME Code
P_m = Primary membrane stress intensity
P_L = Local membrane stress intensity
P_b = Primary bending stress intensity
P_e = Expansion stress
Q = Secondary stress
$P_L + P_b$ = Either primary or local membrane plus primary bending

Definitions for Table 3.1.6 apply to all following tables unless modified.

Notes:

1. Limits on values are presented in Table 2.2.10.

† Evaluation required for Design condition only.
†† Evaluation required for Levels A and B only. P_e not applicable to vessels.

TABLE 3.1.7

LEVEL D: STRESS INTENSITY

Code: ASME NB
Material: SA203-E
Service Condition: Level D
Item: Stress Intensity

Temp. (Deg. F)	Classification and Value (ksi)		
	P_m	P_L	$P_L + P_b$
-20 to 100	49.0	70.0	70.0
200	49.0	70.0	70.0
300	49.0	70.0	70.0
400	48.2	68.8	68.8
500	45.4	64.9	64.9

Notes:

1. Level D allowables per NB-3225 and Appendix F, Paragraph F-1331.
2. Average primary shear stress across a section loaded in pure shear may not exceed 0.42 S_u.
3. Limits on values are presented in Table 2.2.10.
4. P_m, P_L, and P_b are defined in Table 3.1.6.

TABLE 3.1.8

DESIGN, LEVELS A AND B: STRESS INTENSITY

Code: ASME NB
Material: SA350-LF3
Service Conditions: Design, Levels A and B
Item: Stress Intensity

Temp. (Deg. F)	Classification and Value (ksi)					
	S_m	P_m †	P_L †	$P_L + P_b$ †	$P_L + P_b + Q$ ††	P_e ††
-20 to 100	23.3	23.3	35.0	35.0	69.9	69.9
200	22.8	22.8	34.2	34.2	68.4	68.4
300	22.2	22.2	33.3	33.3	66.6	66.6
400	21.5	21.5	32.3	32.3	64.5	64.5
500	20.2	20.2	30.3	30.3	60.6	60.6
600	18.5	18.5	27.75	27.75	55.5	55.5
700	16.8	16.8	25.2	25.2	50.4	50.4

Notes:

1. Source for S_m is ASME Code
2. Limits on values are presented in Table 2.2.10.
3. S_m, P_m, P_L, P_b, Q, and P_e are defined in Table 3.1.6.

† Evaluation required for Design condition only.

†† Evaluation required for Levels A and B conditions only. P_e not applicable to vessels.

TABLE 3.1.9

LEVEL D, STRESS INTENSITY

Code: ASME NB
Material: SA350-LF3
Service Conditions: Level D
Item: Stress Intensity

Temp. (Deg. F)	Classification and Value (ksi)		
	P_m	P_L	$P_L + P_b$
-20 to 100	49.0	70.0	70.0
200	48.0	68.5	68.5
300	46.7	66.7	66.7
400	45.2	64.6	64.6
500	42.5	60.7	60.7
600	38.9	58.4	58.4
700	35.3	53.1	53.1

Notes:

1. Level D allowables per NB-3225 and Appendix F, Paragraph F-1331.
2. Average primary shear stress across a section loaded in pure shear may not exceed 0.42 S_u.
3. Limits on values are presented in Table 2.2.10.
4. P_m, P_L, and P_b are defined in Table 3.1.6.

TABLE 3.1.10

DESIGN AND LEVEL A: STRESS

Code: ASME NF
Material: SA516, Grade 70, SA350-LF3, SA203-E
Service Conditions: Design and Level A
Item: Stress

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

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. Limits on values are presented in Table 2.2.12.

TABLE 3.1.11

LEVEL B: STRESS

Code: ASME NF
Material: SA516, Grade 70, SA350-LF3, and SA203-E
Service Conditions: Level B
Item: Stress

Temp. (Deg. F)	Classification and Value (ksi)	
	Membrane Stress	Membrane plus Bending Stress
-20 to 650	23.3	34.9
700	22.1	33.1

Notes:

1. Limits on values are presented in Table 2.2.12 with allowables from Table 3.1.10.

TABLE 3.1.12

LEVEL D: STRESS INTENSITY

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

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

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. Limits on values are presented in Table 2.2.12.
4. P_m and P_b are defined in Table 3.1.6.

TABLE 3.1.13

DESIGN, LEVELS A AND B: STRESS INTENSITY

Code: ASME NB
Material: Alloy X
Service Conditions: Design, Levels A and B
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	18.7	18.7	28.1	28.1	56.1	56.1
500	17.5	17.5	26.3	26.3	52.5	52.5
600	16.4	16.4	24.6	24.6	49.2	49.2
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	14.9	14.9	22.4	22.4	44.7	44.7

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 temperature.
3. Stress classification per NB-3220.
4. Limits on values are presented in Table 2.2.10.
5. P_m, P_L, P_b, Q, and P_e are defined in Table 3.1.6.

† Evaluation required for Design condition only.

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

TABLE 3.1.14

LEVEL D: STRESS INTENSITY

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

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

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. Limits on values are presented in Table 2.2.10.
4. P_m, P_L, and P_b are defined in Table 3.1.6.

TABLE 3.1.15

DESIGN, LEVELS A AND B: STRESS INTENSITY

Code: ASME NG
Material: Alloy X
Service Conditions: Design, Levels A and B
Item: Stress Intensity

Temp. (Deg. F)	Classification and Value (ksi)				
	S_m	P_m	P_m+P_b	P_m+P_b +Q	P_e
-20 to 100	20.0	20.0	30.0	60.0	60.0
200	20.0	20.0	30.0	60.0	60.0
300	20.0	20.0	30.0	60.0	60.0
400	18.7	18.7	28.1	56.1	56.1
500	17.5	17.5	26.3	52.5	52.5
600	16.4	16.4	24.6	49.2	49.2
650	16.0	16.0	24.0	48.0	48.0
700	15.6	15.6	23.4	46.8	46.8
750	15.2	15.2	22.8	45.6	45.6
800	14.9	14.9	22.4	44.7	44.7

Notes:

1. S_m = Stress intensity values per Table 2A of ASME, Section II, Part D.
2. Alloy X S_m values are the lowest values for each of the candidate materials at temperature.
3. Classifications per NG-3220.
4. Limits on values are presented in Table 2.2.11.
5. P_m, P_b, Q, and P_e are defined in Table 3.1.6.

TABLE 3.1.16

LEVEL D: STRESS INTENSITY

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

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

Notes:

1. Level D stress intensities per ASME NG-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. Limits on values are presented in Table 2.2.11.
4. P_m, P_L, and P_b are defined in Table 3.1.6.

TABLE 3.1.17

REFERENCE TEMPERATURES AND STRESS LIMITS FOR THE VARIOUS LOAD CASES

Load Case I.D.	Material	Reference Temperature[†], °F	Stress Intensity Allowables, ksi		
			P_m	$P_L + P_b$	$P_L + P_b + Q$
F1	Alloy X	725	15.4	23.1	46.2
F2	Alloy X	725	15.4	23.1	46.2
F3	Alloy X	725	36.9	55.4	NL
E1	Alloy X	500	17.5	26.3	52.5
E2	Alloy X	500	17.5	26.3	52.5
E3	Alloy X	500	42.0	63.0	NL[††]
E4	Alloy X	500	17.5	26.3	52.5
E5	Alloy X	775	36.15	54.25	NL

Notes:

1. Q, P_m, P_L, and P_b are defined in Table 3.1.6.
2. Reference temperatures for Load Cases E1-E4 are for MPC shell; for MPC lid and MPC baseplate, reference temperatures are 550 deg. F and 400 deg. F, respectively (per Table 2.2.3) and stress intensity allowables should be adjusted accordingly.

† Values for reference temperatures are chosen to bound the thermal results in Chapter 4. Lower temperature values may be used provided that they are at least equal to the calculated temperature for the specific component and location or otherwise justified.

†† NL: No specified limit in the Code

TABLE 3.1.17 (CONTINUED)

REFERENCE TEMPERATURES AND STRESS LIMITS FOR THE VARIOUS LOAD CASES

Load Case I.D.	Material	Reference Temperature,†,†† °F	Stress Intensity Allowables, ksi		
			P_m	$P_L + P_b$	$P_L + P_b + Q$
O1	SA203-E	400	17.5	26.3	NL†††
	SA350-LF3	400	17.5	26.3	NL
	SA516 Gr. 70 SA515 Gr. 70	400	17.5	26.3	NL
O2	SA203-E	400	41.2	61.7	NL
	SA350-LF3	400	38.6	58.0	NL
	SA516 Gr. 70 SA515 Gr. 70	400	39.1	58.7	NL
O3	SA203-E	400	17.5	26.3	NL
	SA350-LF3	400	17.5	26.3	NL
	SA516 Gr. 70 SA515 Gr. 70	400	17.5	26.3	NL
O4	SA203-E	400	41.2	61.7	NL
	SA350-LF3	400	38.6	58.0	NL
	SA516 Gr. 70 SA515 Gr. 70	400	39.1	58.7	NL

Note:

1. P_m, P_L, P_b, and Q are defined in Table 3.1.6.
2. Load Cases 01 and 03 are for Normal Conditions; therefore the values listed refer to allowable stress, not allowable stress intensity

† Values for reference temperatures are chosen to bound the thermal results in Chapter 4. Lower temperature values may be used provided that they are at least equal to the calculated temperature for the specific component and location or otherwise justified.

†† For storage fire analysis, temperatures are defined by thermal solution

††† NL: No specified limit in the Code

TABLE 3.1.18
FRACTURE TOUGHNESS TEST REQUIREMENTS

Material	Test Requirement	Test Temperature	Acceptance Criterion
Bolting (SA193 B7)	Not required (per NF-2311(b)(13) and Note (e) to Figure NF-2311(b)-1)	-	-
Ferritic steel with nominal section thickness of 5/8" or less	Not required per NF-2311(b)(1)	-	-
SA36 (thickness greater than 5/8")	Not required per NF-2311(b)(7)	-	-
Normalized SA516 Gr. 70 (thickness greater than 5/8", but less than or equal to 2-1/2"), except when used for HI-STORM 100A baseplate, lug support ring, and gussets	Not required per NF-2311(b)(7), NF-2311(b)(13), and curve D in Figure NF-2311(b)-1	-	-
HI-STORM 100A baseplate, lug support ring, and gussets (See Note 2)	Per NF-2331	See Note 1. (Also must meet ASME Section IIA requirements)	Table NF-2331(a)-3 or Figure NF-2331(a)-2 (Also must meet ASME Section IIA requirements)
As-rolled SA516 Gr. 70, except when used for HI-STORM inner and outer shells, top plate, lid shear ring, lid shield ring, lid outer ring (for 100S Version B), and lid cover plate (for 100S Version B)	Per NF-2331	See Note 1. (Also must meet ASME Section IIA requirements)	Table NF-2331(a)-3 or Figure NF-2331(a)-2 (Also must meet ASME Section IIA requirements)
As-rolled SA516 Gr. 70 used for HI-STORM inner and outer shells, top plate, lid shear ring, lid shield ring, lid outer ring (for 100S Version B), and lid cover plate (for 100S Version B) and Base- Bottom Plate (for 100S Version B)	Not required per NF-2311(b)(7)	-	-
SA203, SA515 Gr. 70, SA350-LF2, SA350-LF3 (thickness greater than	Per NF-2331	See Note 1. (Also must meet ASME Section IIA requirements)	Table NF-2331(a)-3 or Figure NF-2331(a)-2

5/8")			(Also must meet ASME Section IIA requirements)
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 SA516 Gr. 70 with nominal section thickness greater than 5/8".	See Note 1	Per NF-2330

Notes:

1. Required NDT temperature = -40 deg. F for all materials in the HI-STORM 100 Overpack, -40 deg. F for HI-TRAC "STH" materials, and 0 deg. F for HI-TRAC "NF" materials.
2. In accordance with ASME Code Subsection NF, impact testing is not required for these components; specified testing is performed strictly for defense-in-depth.

TABLE 3.1.19

DESIGN AND LEVEL A: STRESS

Code: ASME NF
Material: SA36
Service Conditions: Design and Level A
Item: Stress

Temp. (Deg. F)	Classification and Value (ksi)		
	S	Membrane Stress	Membrane plus Bending Stress
-20 to 650	14.5	14.5	21.8
700	13.9	13.9	20.9

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. Limits on values are presented in Table 2.2.12.

TABLE 3.1.20

LEVEL B: STRESS

Code: ASME NF
Material: SA36
Service Conditions: Level B
Item: Stress

Temp. (Deg. F)	Classification and Value (ksi)	
	Membrane Stress	Membrane plus Bending Stress
-20 to 650	19.3	28.9
700	18.5	27.7

Notes:

1. Limits on values are presented in Table 2.2.12 with allowables from Table 3.1.19.

TABLE 3.1.21

LEVEL D: STRESS INTENSITY

Code: ASME NF
Material: SA36
Service Conditions: Level D
Item: Stress Intensity

Temp. (Deg. F)	Classification and Value (ksi)		
	S_m	P_m	$P_m + P_b$
-20 to 100	19.3	43.2	64.8
200	19.3	37.0	55.5
300	19.3	36.0	54.0
400	19.3	34.7	52.1
500	19.3	32.8	49.2
600	17.7	30.0	45.0
650	17.4	29.5	44.3
700	17.3	29.2	43.8

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. Limits on values are presented in Table 2.2.12.
4. P_m and P_b are defined in Table 3.1.6.

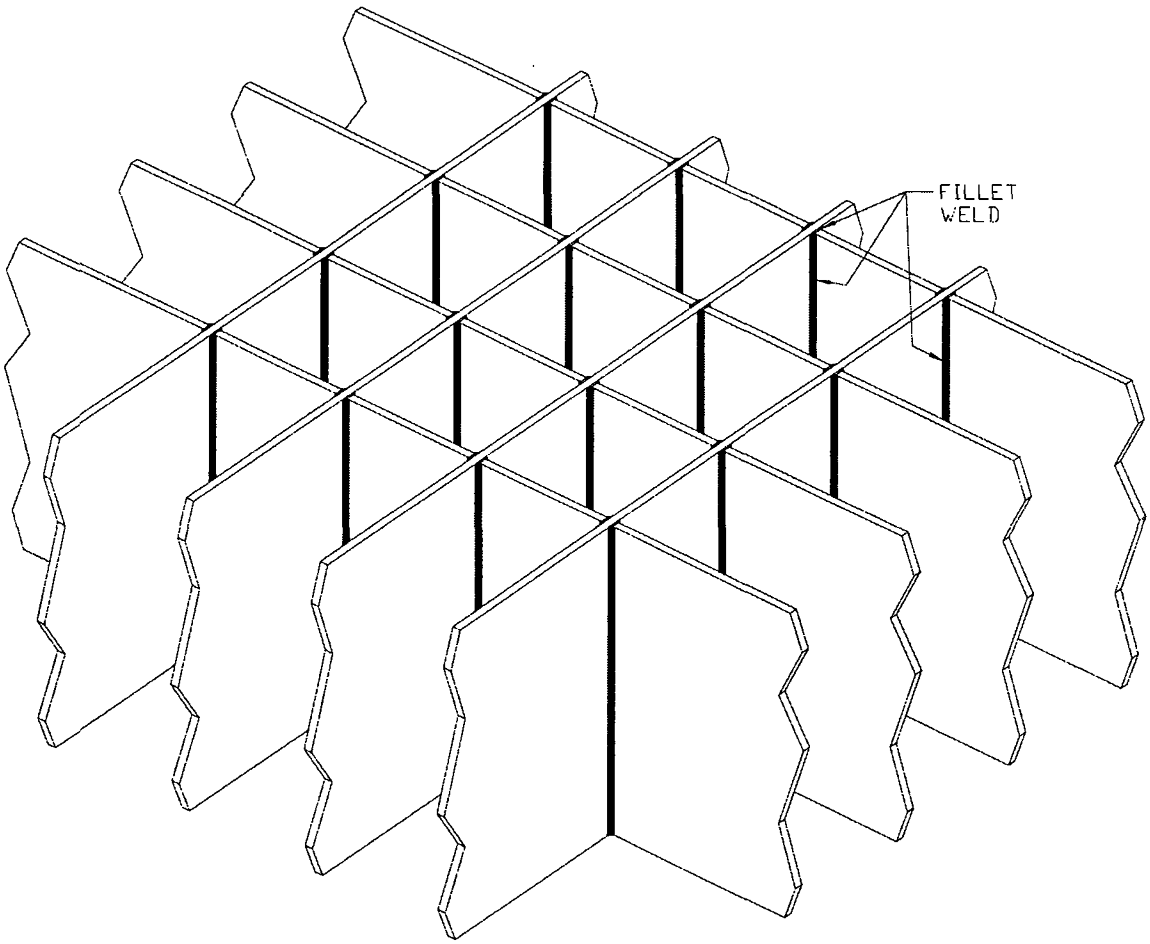

FIGURE 3.1.1; MPC-68 AND MPC-32 FUEL BASKET GEOMETRY

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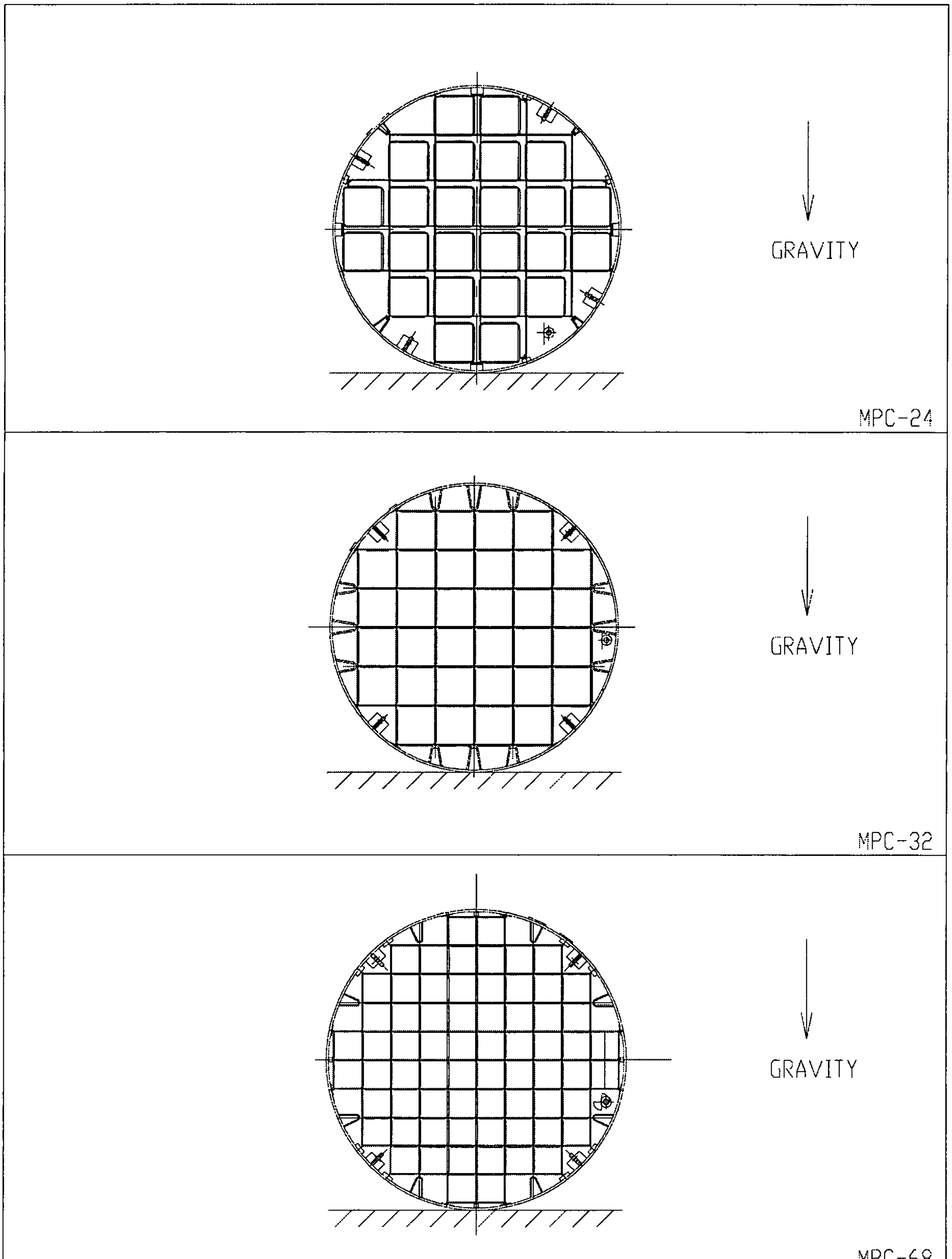

FIGURE 3.1.2; 0° DROP ORIENTATIONS FOR THE MPCs

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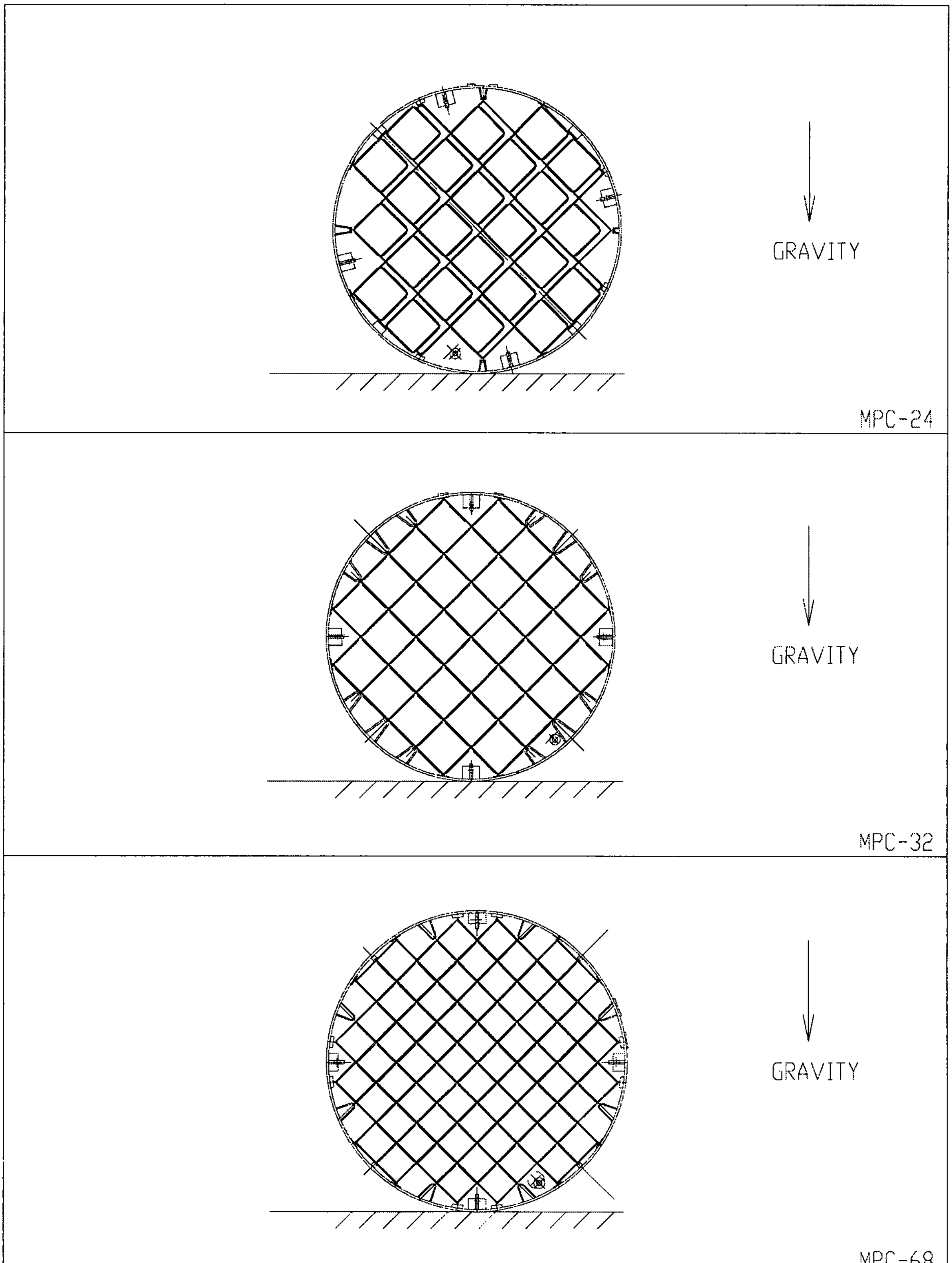

FIGURE 3.1.3; 45° DROP ORIENTATIONS FOR THE MPCs

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3.2 WEIGHTS AND CENTERS OF GRAVITY

Tables 3.2.1 and 3.2.2 provide the calculated weights of the individual HI-STORM 100 components as well as the total system weights. The actual weights will vary within a narrow range of the calculated values due to the tolerances in metal manufacturing and fabrication permitted by the ASME Codes. Contained water mass during fuel loading is not included in this table.

The locations of the calculated centers of gravity (CGs) are presented in Table 3.2.3. All centers of gravity are located on the cask centerline since the non-axisymmetric effects of the cask system plus contents are negligible.

Table 3.2.4 provides the lift weight when the HI-TRAC transfer cask with the heaviest fully loaded MPC is being lifted from the fuel pool. The effect of buoyancy is neglected, and the weight of rigging is set at a conservative value.

In all weight tables, bounding values are also listed where necessary for use in structural calculations where their use will provide a conservative result.

TABLE 3.2.1
HI-STORM OVERPACK WEIGHT DATA

Item	Bounding Weight (lb)
MPC-24	
• Without SNF	42,000
• Fully loaded with SNF and Fuel Spacers	90,000†††
MPC-32	
• Without SNF	36,000
• Fully loaded with SNF and Fuel Spacers	90,000†††
MPC-68/68F/68FF	
• Without SNF	39,000
• Fully loaded with SNF and Fuel Spacers	90,000†††
MPC-24E/EF	
• Without SNF	45,000
• Fully loaded with SNF and Fuel Spacers	90,000†††
HI-STORM 100 Overpack†	
• Overpack top lid	23,000
• Overpack w/ lid (empty)	270,000
• Overpack w/ fully loaded MPC-24	360,000
• Overpack w/ fully loaded MPC-32	360,000
• Overpack w/ fully loaded MPC-68/68F/68FF	360,000
• Overpack w/ fully loaded MPC-24E/EF	360,000
HI-STORM 100S(232) Overpack†	
• Overpack top lid	25,500††
• Overpack w/ lid (empty)	270,000
• Overpack w/ fully loaded MPC-24	360,000
• Overpack w/ fully loaded MPC-32	360,000
• Overpack w/ fully loaded MPC-68/68F/68FF	360,000
• Overpack w/ fully loaded MPC-24E/EF	360,000

TABLE 3.2.1 (CONTINUED)
HI-STORM OVERPACK WEIGHT DATA

Item	Bounding Weight (lb)
HI-STORM 100S(243) Overpack†	
• Overpack top lid	25,500††
• Overpack w/ lid (empty)	270,000
• Overpack w/ fully loaded MPC-24	360,000
• Overpack w/ fully loaded MPC-32	360,000
• Overpack w/ fully loaded MPC-68/68F/68FF	360,000
• Overpack w/ fully loaded MPC-24E/EF	360,000
HI-STORM 100A Overpack†	Same as above
HI-STORM 100S Version B(218) Overpack (values in parentheses use high density concrete in overpack body)	
• Overpack top lid	29,000
• Overpack w/ lid (empty)	270,000 (305,000)
• Overpack w/ fully loaded MPC-24	360,000 (395,000)
• Overpack w/ fully loaded MPC-32	360,000 (395,000)
• Overpack w/ fully loaded MPC-68/68F/68FF	360,000 (395,000)
• Overpack w/ fully loaded MPC-24E/EF	360,000 (395,000)
HI-STORM 100S Version B(229) Overpack (values in parentheses use high density concrete in overpack body)	
• Overpack top lid	29,000
• Overpack w/ lid (empty)	270,000 (320,000)
• Overpack w/ fully loaded MPC-24	360,000 (410,000)
• Overpack w/ fully loaded MPC-32	360,000 (410,000)
• Overpack w/ fully loaded MPC-68/68F/68FF	360,000 (410,000)
• Overpack w/ fully loaded MPC-24E/EF	360,000 (410,000)

† The bounding weights for the HI-STORM 100S(232) and 100S(243) overpacks listed in the above table are based on a maximum concrete (dry) density of 160.8 pcf. For improved shielding effectiveness, higher density concrete (up to 200 pcf dry) can be poured in the radial cavity of each of the HI-STORM 100S overpacks. At 200 pcf, the bounding weights of an empty overpack and a fully loaded overpack increase to 320,000 lb and 410,000 lb, respectively. Higher density concrete cannot be used in the HI-STORM 100 or 100A overpacks.

†† Based on a maximum concrete (dry) density of 155 pcf. For improved shielding effectiveness, higher density concrete (up to 200 pcf dry) can be poured in the HI-STORM 100S lids. At 200 pcf, the bounding weight of the lid increases to 28,000 lb.

††† Based on the following maximum fuel assembly weights (as applicable):
1,680 lb per assembly (including non-fuel hardware) for PWR fuel that requires fuel spacers
1,720 lb per assembly (including non-fuel hardware) for PWR fuel that does not require fuel spacers
730 lb per assembly (including channels and DFCs) for BWR fuel

TABLE 3.2.2
HI-TRAC 125 TRANSFER CASK WEIGHT DATA

Item	Bounding Weight (lb)
Top Lid	2,750
Pool Lid	12,500
Transfer Lid	24,500
HI-TRAC 125 w/ Top Lid and Pool Lid (water jacket filled)	143,500
HI-TRAC 125 w/ Top Lid and Transfer Lid (water jacket filled)	155,000
HI-TRAC 125 w/ Top Lid, Pool Lid, and fully loaded MPC-24 (water jacket filled)	226,000
HI-TRAC 125 w/ Top Lid, Pool Lid, and fully loaded MPC-32 (water jacket filled)	233,500
HI-TRAC 125 w/ Top Lid, Pool Lid, and fully loaded MPC-68/68F/68FF(water jacket filled)	231,000
HI-TRAC 125 w/ Top Lid, Pool Lid, and fully loaded MPC-24E/EF (water jacket filled)	229,000
HI-TRAC 125 w/ Top Lid, Transfer Lid, and fully loaded MPC-24 (water jacket filled)	237,500
HI-TRAC 125 w/ Top Lid, Transfer Lid, and fully loaded MPC-32 (water jacket filled)	245,000
HI-TRAC 125 w/ Top Lid, Transfer Lid, and fully loaded MPC-68/68F/68FF (water jacket filled)	242,500
HI-TRAC 125 w/ Top Lid, Transfer Lid, and fully loaded MPC-24E/EF (water jacket filled)	240,500

TABLE 3.2.2 (CONTINUED)
HI-TRAC 100 TRANSFER CASK WEIGHT DATA

Item	Bounding Weight (lb)
Top Lid	1,500
Pool Lid	8,000
Transfer Lid	17,000
HI-TRAC 100 w/ Top Lid and Pool Lid (water jacket filled)	102,000
HI-TRAC 100 w/ Top Lid and Transfer Lid (water jacket filled)	111,000
HI-TRAC 100 w/ Top Lid, Pool Lid, and fully loaded MPC-24 (water jacket filled)	183,500
HI-TRAC 100 w/ Top Lid, Pool Lid, and fully loaded MPC-32 (water jacket filled)	191,000
HI-TRAC 100 w/ Top Lid, Pool Lid, and fully loaded MPC-68/68F/68FF (water jacket filled)	188,500
HI-TRAC 100 w/ Top Lid, Pool Lid, and fully loaded MPC-24E/EF (water jacket filled)	186,500
HI-TRAC 100 w/ Top Lid, Transfer Lid, and fully loaded MPC-24 (water jacket filled)	192,000
HI-TRAC 100 w/ Top Lid, Transfer Lid, and fully loaded MPC-32 (water jacket filled)	199,000
HI-TRAC 100 w/ Top Lid, Transfer Lid, and fully loaded MPC-68/68F/68FF (water jacket filled)	196,500
HI-TRAC 100 w/ Top Lid, Transfer Lid, and fully loaded MPC-24E/EF (water jacket filled)	194,500

TABLE 3.2.2 (CONTINUED)
HI-TRAC 125D TRANSFER CASK WEIGHT DATA

Item	Bounding Weight (lb)
Top Lid	2,750
Pool Lid	12,500
HI-TRAC 125D w/ Top Lid and Pool Lid (water jacket filled)	146,000
HI-TRAC 125D w/ Top Lid, Pool Lid, and fully loaded MPC-24 (water jacket filled)	228,500
HI-TRAC 125D w/ Top Lid, Pool Lid, and fully loaded MPC-32 (water jacket filled)	236,000
HI-TRAC 125D w/ Top Lid, Pool Lid, and fully loaded MPC-68/68F/68FF (water jacket filled)	233,500
HI-TRAC 125D w/ Top Lid, Pool Lid, and fully loaded MPC-24E/EF (water jacket filled)	231,500

TABLE 3.2.2 (CONTINUED)
HI-TRAC 100D TRANSFER CASK WEIGHT DATA

Item	Bounding Weight (lb)
Top Lid	1,500
Pool Lid	8,000
HI-TRAC 100D w/ Top Lid and Pool Lid (water jacket filled)	102,000
HI-TRAC 100D w/ Top Lid, Pool Lid, and fully loaded MPC-24 (water jacket filled)	183,500
HI-TRAC 100D w/ Top Lid, Pool Lid, and fully loaded MPC-32 (water jacket filled)	191,000
HI-TRAC 100D w/ Top Lid, Pool Lid, and fully loaded MPC-68/68F/68FF (water jacket filled)	188,500
HI-TRAC 100D w/ Top Lid, Pool Lid, and fully loaded MPC-24E/EF (water jacket filled)	186,500

TABLE 3.2.3
CENTERS OF GRAVITY OF HI-STORM SYSTEM CONFIGURATIONS

Component	Height of CG Above Datum† (in)
MPC-24 (empty)	109.0
MPC-32 (empty)	113.2
MPC-68/68F/68FF (empty)	111.5
MPC-24E/EF (empty)	108.9
HI-STORM 100 Overpack (empty)	116.8
HI-STORM 100S(232) Overpack (empty)	111.7
HI-STORM 100S(243) Overpack (empty)	117.4
HI-STORM 100S Version B(218) Overpack (empty)(height using standard weight concrete bounds height calculated using high density concrete)	108.77(108.45)
HI-STORM 100S Version B(229) Overpack (empty)(height using standard weight concrete bounds height calculated using high density concrete)	114.27(113.94)
HI-STORM 100 Overpack w/ fully loaded MPC-24	118.8
HI-STORM 100 Overpack w/ fully loaded MPC-32	118.7
HI-STORM 100 Overpack w/ fully loaded MPC-68/68F/68FF	119.0
HI-STORM 100 Overpack w/ fully loaded MPC-24E/EF	119.2
HI-STORM 100S(232) Overpack w/ fully loaded MPC-24	113.8
HI-STORM 100S(232) Overpack w/ fully loaded MPC-32	113.7
HI-STORM 100S(232) Overpack w/ fully loaded MPC-68/68F/68FF	114.0
HI-STORM 100S(232) Overpack w/ fully loaded MPC-24E/EF	114.2
HI-STORM 100S(243) Overpack w/ fully loaded MPC-24	118.1
HI-STORM 100S(243) Overpack w/ fully loaded MPC-32	117.9
HI-STORM 100S(243) Overpack w/ fully loaded MPC-68/68F/68FF	118.2
HI-STORM 100S(243) Overpack w/ fully loaded MPC-24E/EF	118.4
HI-STORM 100S Version B(218) Overpack w/ fully loaded MPC-24	110.83
HI-STORM 100S Version B(218) Overpack w/ fully loaded MPC-32	111.88
HI-STORM 100S Version B(218) Overpack w/ fully loaded MPC-68/68F/68FF	111.45
HI-STORM 100S Version B(218) Overpack w/ fully loaded MPC-24E/EF	110.80

† See notes at end of table.

TABLE 3.2.3 (CONTINUED)
CENTERS OF GRAVITY OF HI-STORM SYSTEM CONFIGURATIONS

Component	Height of CG Above Datum† (in)
HI-STORM 100S Version B(229) Overpack w/ fully loaded MPC-24	114.95
HI-STORM 100S Version B(229) Overpack w/ fully loaded MPC-32	116.00
HI-STORM 100S Version B(229) Overpack w/ fully loaded MPC-68/68F/68FF	115.58
HI-STORM 100S Version B(229) Overpack w/ fully loaded MPC-24E/EF	114.93
HI-TRAC 125 Transfer Cask w/ Top Lid, Transfer Lid, and fully loaded MPC-24 (water jacket filled)	99.5
HI-TRAC 125 Transfer Cask w/ Top Lid, Transfer Lid, and fully loaded MPC-32 (water jacket filled)	99.5
HI-TRAC 125 Transfer Cask w/ Top Lid, Transfer Lid, and fully loaded MPC-68/68F/68FF (water jacket filled)	99.8
HI-TRAC 125 Transfer Cask w/ Top Lid, Transfer Lid, and fully loaded MPC-24E/EF (water jacket filled)	100.1
HI-TRAC 100 Transfer Cask w/ Top Lid and Pool Lid (water jacket filled)	91.0
HI-TRAC 100 Transfer Cask w/ Top Lid and Transfer Lid (water jacket filled)	91.1
HI-TRAC 100 Transfer Cask w/ Top Lid, Pool Lid, and fully loaded MPC-24 (water jacket filled)	97.3
HI-TRAC 100 Transfer Cask w/ Top Lid, Pool Lid, and fully loaded MPC-32 (water jacket filled)	97.2
HI-TRAC 100 Transfer Cask w/ Top Lid, Pool Lid, and fully loaded MPC-68/68F/68FF (water jacket filled)	97.6
HI-TRAC 100 Transfer Cask w/ Top Lid, Pool Lid, and fully loaded MPC-24E/EF (water jacket filled)	98.0
HI-TRAC 100 Transfer Cask w/ Top Lid, Transfer Lid, and fully loaded MPC-24 (water jacket filled)	100.3
HI-TRAC 100 Transfer Cask w/ Top Lid, Transfer Lid, and fully loaded MPC-32 (water jacket filled)	100.3
HI-TRAC 100 Transfer Cask w/ Top Lid, Transfer Lid, and fully loaded MPC-68/68F/68FF (water jacket filled)	100.7
HI-TRAC 100 Transfer Cask w/ Top Lid, Transfer Lid, and fully loaded MPC-24E/EF (water jacket filled)	101.0

† See notes at end of table.

TABLE 3.2.3 (CONTINUED)
CENTERS OF GRAVITY OF HI-STORM SYSTEM CONFIGURATIONS

Component	Height of CG Above Datum (in)
HI-TRAC 125D Transfer Cask w/ Top Lid and Pool Lid (water jacket filled)	92.4
HI-TRAC 125D Transfer Cask w/ Top Lid, Pool Lid, and fully loaded MPC-24 (water jacket filled)	97.6
HI-TRAC 125D Transfer Cask w/ Top Lid, Pool Lid, and fully loaded MPC-32 (water jacket filled)	97.5
HI-TRAC 125D Transfer Cask w/ Top Lid, Pool Lid, and fully loaded MPC-68/68F/68FF (water jacket filled)	97.8
HI-TRAC 125D Transfer Cask w/ Top Lid, Pool Lid, and fully loaded MPC-24E/EF (water jacket filled)	98.2
HI-TRAC 100D Transfer Cask w/ Top Lid and Pool Lid (water jacket filled)	87.0
HI-TRAC 100D Transfer Cask w/ Top Lid, Pool Lid, and fully loaded MPC-24 (water jacket filled)	99.2
HI-TRAC 100D Transfer Cask w/ Top Lid, Pool Lid, and fully loaded MPC-32 (water jacket filled)	101.2
HI-TRAC 100D Transfer Cask w/ Top Lid, Pool Lid, and fully loaded MPC-68/68F/68FF (water jacket filled)	100.4
HI-TRAC 100D Transfer Cask w/ Top Lid, Pool Lid, and fully loaded MPC-24E/EF (water jacket filled)	99.1

Notes:

1. The datum used for calculations involving the HI-STORM is the bottom of the overpack baseplate. The datum used for calculations involving the HI-TRAC is the bottom of the pool lid or transfer lid, as appropriate.

2. The datum used for calculations involving only the MPC is the bottom of the MPC baseplate.

3. The CG heights of the HI-STORM overpacks are calculated based on standard density concrete (i.e., 150 pcf dry). At higher densities, the CG heights are slightly lower, which makes the HI-STORM overpacks less prone to tipping.

TABLE 3.2.4
LIFT WEIGHT ABOVE POOL WITH HI-TRAC 125

Item	Estimated Weight (lb)	Bounding Weight (lb)
HI-TRAC 125 w/ Top Lid and Pool Lid (water jacket filled)	142,976	
MPC-32 fully loaded with SNF and fuel spacers	89,765†	
HI-TRAC 125 Top Lid	-2,730††	
Water in MPC and HI-TRAC 125 Annulus	16,570	
Water in Water Jacket	-9,757†††	
Lift yoke	4,200	
Inflatable annulus seal	50	
TOTAL	241,074	250,000

† Includes MPC closure ring.

†† HI-TRAC top lid weight is included in transfer cask weight. However, the top lid is not installed during in-pool operations.

††† Total weight of HI-TRAC 125 includes water in water jacket. However, during removal from the fuel pool no water is in the water jacket since the water within the MPC cavity provides sufficient shielding.

TABLE 3.2.4 (CONTINUED)
LIFT WEIGHT ABOVE POOL WITH HI-TRAC 100

Item	Estimated Weight (lb)	Maximum Weight (lb)
HI-TRAC 100 w/ Top Lid and Pool Lid (water jacket filled)	100,194	
MPC-32 fully loaded with SNF and fuel spacers	89,765†	
MPC closure ring	-140	
HI-TRAC 100 Top Lid	-1,203††	
Water in MPC and HI-TRAC 100 Annulus	16,570	
Water in Water Jacket	-7,562†††	
Lift yoke	3,200	
Inflatable annulus seal	50	
TOTAL	200,874††††	200,000

Note: HI-TRAC transfer cask weight is without removable portion of pocket trunnion.

† Includes MPC closure ring.

†† HI-TRAC top lid weight is included in transfer cask weight. However, the top lid is not installed during in-pool operations.

††† Total weight of HI-TRAC 100 includes water in water jacket. However, during removal from the fuel pool no water is in the water jacket since the water within the MPC cavity provides sufficient shielding.

†††† Under worst case conditions, removal of a portion of water from the MPC may be required to reduce the in-pool lift weight.

TABLE 3.2.4 (CONTINUED)
LIFT WEIGHT ABOVE POOL WITH HI-TRAC 125D

Item	Estimated Weight (lb)	Bounding Weight (lb)
HI-TRAC 125D w/ Top Lid and Pool Lid (water jacket filled)	145,635	
MPC-32 fully loaded with SNF and fuel spacers	89,765†	
HI-TRAC 125D Top Lid	-2,575††	
Water in MPC and HI-TRAC 125D Annulus	16,570	
Water in Water Jacket	-8,955†††	
Lift yoke	4,200	
Inflatable annulus seal	50	
TOTAL	244,690	250,000

† Includes MPC closure ring.

†† HI-TRAC top lid weight is included in transfer cask weight. However, the top lid is not installed during in-pool operations.

††† Total weight of HI-TRAC 125D includes water in water jacket. However, during removal from the fuel pool no water is in the water jacket since the water within the MPC cavity provides sufficient shielding.

TABLE 3.2.4 (CONTINUED)
LIFT WEIGHT ABOVE POOL WITH HI-TRAC 100D

Item	Estimated Weight (lb)	Maximum Weight (lb)
HI-TRAC 100D w/ Top Lid and Pool Lid (water jacket filled)	99,106	
MPC-32 fully loaded with SNF and fuel spacers	89,765†	
MPC closure ring	-140	
HI-TRAC 100D Top Lid	-1,213††	
Water in MPC and HI-TRAC 100D Annulus	16,570	
Water in Water Jacket	-7,665†††	
Lift yoke	4,200	
Inflatable annulus seal	50	
TOTAL	200,673††††	200,000

† Includes MPC closure ring.

†† HI-TRAC top lid weight is included in transfer cask weight. However, the top lid is not installed during in-pool operations.

††† Total weight of HI-TRAC 100D includes water in water jacket. However, during removal from the fuel pool no water is in the water jacket since the water within the MPC cavity provides sufficient shielding.

†††† Under worst case conditions, removal of a portion of water from the MPC may be required to reduce the in-pool lift weight.

3.3 MECHANICAL PROPERTIES OF MATERIALS

Table 2.2.6 provides a comprehensive listing of materials of construction, applicable code, and ITS designation for all functional parts in the HI-STORM 100 System. This section provides the mechanical properties used in the structural evaluation. 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 envelopes the maximum and minimum temperatures under all service conditions discussed in the preceding section where structural analysis is performed.

The materials selected for use in the MPC, HI-STORM 100 Overpack, and HI-TRAC transfer cask are presented in the Bills-of-Material 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 example, the HI-TRAC inner shell is a structural material, while the lead between the inner and outer shell is a nonstructural material. For nonstructural materials, the only 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 lead in HI-TRAC and plain concrete in HI-STORM 100 are included.

3.3.1 Structural Materials

3.3.1.1 Alloy X

A hypothetical material termed Alloy X is defined for all MPC structural components. The material properties of Alloy X are the least favorable values from the set of candidate alloys. The purpose of a least favorable material definition is to ensure that all structural analyses are conservative, regardless of the actual MPC material. For example, when evaluating the stresses in the MPC, it is conservative to work with the minimum values for yield strength and ultimate strength. This guarantees that the material used for fabrication of the MPC will be of equal or greater strength than the hypothetical material used in the analysis. In the structural evaluation, the only property for which it is not always conservative to use the set of minimum values is the coefficient of thermal expansion. Two sets of values for the coefficient of thermal expansion are specified, a minimum set and a maximum set. For each analysis, the set of coefficients, minimum or maximum that causes the more severe load on the cask system is used.

Table 3.3.1 lists the numerical values for the material properties of Alloy X versus temperature. These values, taken from the ASME Code, Section II, Part D [3.3.1], are used in all structural analyses. A minimum requirement on yield strength is set for MPC Lids in Table 3.3.1, to ensure that the lid internal threads have enough capacity under the lifted load as mandated by NUREG-0612. The maximum temperatures in some MPC components may exceed the allowable limits of temperature during short time duration loading operations, off-normal transfer operations, or storage accident events. However, no maximum temperature for Alloy X used at or within the confinement boundary exceeds 1000°F. As shown in ASME Code Case N-47-33 (Class 1 Components in

Elevated Temperature Service, 1995 Code Cases, Nuclear Components), the strength properties of austenitic stainless steels do not change due to exposure to 1000°F temperature for up to 10,000 hours. Therefore, there is no significant effect on mechanical properties of the confinement or basket material during the short time duration loading. A further description of Alloy X, including the materials from which it is derived, is provided in Appendix 1.A.

Two properties of Alloy X that are not included in Table 3.3.1 are weight density and Poisson's ratio. These properties are assumed constant for all structural analyses, regardless of temperature. The values used are shown in the table below.

PROPERTY	VALUE
Weight Density (lb/in^3)	0.290
Poisson's Ratio	0.30

3.3.1.2 Carbon Steel, Low-Alloy and Nickel Alloy Steel

The carbon steels used in the structural qualification of the HI-STORM 100 System are SA516 Grade 70, SA515 Grade 70, and SA36. The nickel alloy and low alloy steels are SA203-E and SA350-LF3, respectively. These steels are not constituents of Alloy X. The material properties of SA516 Grade 70 and SA515 Grade 70 are shown in Tables 3.3.2. The material properties of SA203-E and SA350-LF3 are given in Table 3.3.3. The material properties of SA36 are shown in Table 3.3.6.

Two properties of these steels that are not included in Tables 3.3.2, 3.3.3 and 3.3.6 are weight density and Poisson's ratio. These properties are assumed constant for all structural analyses. The values used are shown in the table below.

PROPERTY	VALUE
Weight Density (lb/in^3)	0.283
Poisson's Ratio	0.30

3.3.1.3 Bolting Materials

Material properties of the bolting materials used in the HI-STORM 100 System and HI-TRAC lifting trunnions are given in Table 3.3.4. The properties of representative anchor studs used to fasten HI-STORM 100A are listed in Table 1.2.7.

3.3.1.4 Weld Material

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

3.3.2.1 Solid Neutron Shield

The solid neutron shielding material in the HI-TRAC top lid and transfer lid doors is not considered as a structural member of the HI-STORM 100 System. Its load carrying capacity is neglected in all structural analyses except where such omission would be non-conservative. The only material property of the solid neutron shield that is important to the structural evaluation is weight density ($1.63 g/cm^3$).

3.3.2.2 Solid Neutron Absorber

The fuel basket solid neutron absorber is not a structural member of the HI-STORM 100 System. Its load carrying capacity is neglected in all structural analyses. The only material property of the solid neutron absorber that is important to the structural evaluation is weight density. As the MPC fuel baskets can be constructed with neutron absorber panels of variable areal density, the weight that produces the most severe cask load is assumed in each analysis (density $2.644 g/cm^3$).

3.3.2.3 Concrete

The primary function of the plain concrete in the HI-STORM storage overpack is shielding. Concrete in the HI-STORM 100 Overpack is not considered as a structural member, except to withstand compressive, bearing, and penetrant loads. While concrete is not considered a structural member, its mechanical behavior must be quantified to determine the stresses in the structural members (steel shells surrounding it) under accident conditions. Table 3.3.5 provides the concrete mechanical properties. Allowable, bearing strength in concrete for normal loading conditions is calculated in accordance with ACI 318.1 -89 (92) [3.3.2]. The procedure specified in ASTM C-39 is utilized to verify that the assumed compressive strength will be realized in the actual in-situ pours. In addition, although the concrete is not reinforced (since the absence of reinforcement does not degrade the compressive strength), the requirements of ACI-349-85 [3.3.3] are imposed to insure the suitability of the concrete mix. Appendix 1.D provides additional information on the requirements on plain concrete for use in HI-STORM 100 storage overpack.

To enhance the shielding performance of the HI-STORM storage overpack, high density concrete can be used during fabrication. The permissible range of concrete densities is specified in Table 1.D.1. The structural calculations consider the most conservative density value (i.e., maximum or minimum weight), as appropriate.

3.3.2.4 Lead

Lead is not considered as a structural member of the HI-STORM 100 System. Its load carrying capacity is neglected in all structural analysis, except in the analysis of a tornado missile strike where it acts as a missile barrier. Applicable mechanical properties of lead are provided in Table 3.3.5.

3.3.2.5 Aluminum Heat Conduction Elements

In early vintage MPCs, aluminum heat conduction elements may be located between the fuel basket and MPC vessel. They are optional thin flexible elements whose sole function is to transmit heat as described in Chapter 4. They are not credited with any structural load capacity and are shaped to provide negligible resistance to basket thermal expansion. The total weight of the aluminum inserts is less than 1,000 lb. per MPC.

TABLE 3.3.1
ALLOY X MATERIAL PROPERTIES

Temp. (Deg. F)	Alloy X				
	S_y ‡	S_u †	α_{min}	α_{max}	E
-40	30.0 (33.0)	75.0 (70.0)	8.54	8.55	28.82
100	30.0 (33.0)	75.0 (70.0)	8.54	8.55	28.14
150	27.5 (30.25)	73.0 (68.1)	8.64	8.67	27.87
200	25.0 (27.5)	71.0 (66.2)	8.76	8.79	27.6
250	23.75 (26.12)	68.5 (63.85)	8.88	8.9	27.3
300	22.5 (24.75)	66.0 (61.5)	8.97	9.0	27.0
350	21.6 (23.76)	65.2 (60.75)	9.10	9.11	26.75
400	20.7 (22.77)	64.4 (60.0)	9.19	9.21	26.5
450	20.05 (22.06)	64.0 (59.65)	9.28	9.32	26.15
500	19.4 (21.34)	63.5 (59.3)	9.37	9.42	25.8
550	18.8 (20.68)	63.3 (59.1)	9.45	9.50	25.55
600	18.2 (20.02)	63.1 (58.9)	9.53	9.6	25.3
650	17.8 (19.58)	62.8 (58.6)	9.61	9.69	25.05
700	17.3 (19.03)	62.5 (58.4)	9.69	9.76	24.8
750	16.9 (18.59)	62.2 (58.1)	9.76	9.81	24.45
800	16.6 (18.26)	61.7 (57.6)	9.82	9.90	24.1

Definitions:

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

Notes:

1. Source for S_y values is Table Y-1 of [3.3.1].
2. Source for S_u values is Table U of [3.3.1].
3. Source for α_{min} and α_{max} values is Table TE-1 of [3.3.1].
4. Source for E values is material group G in Table TM-1 of [3.3.1].

‡ Values in the parentheses correspond to yield stress of MPC Lids which are 10% greater than the minimum yield stress values tabulated in Table 1.A.3. These higher values are only credited for the stress analysis of the MPC Lid lifting holes.

† The ultimate stress of Alloy X is dependent on the product form of the material (i.e., forging vs. plate). Values in parentheses are based on SA-336 forged materials (type F304, F304LN, F316, and F316LN), which are used solely for the one-piece construction MPC lids. All other values correspond to SA-240 plate material.

TABLE 3.3.2
SA516 AND SA515, GRADE 70 MATERIAL PROPERTIES

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

Definitions:

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

Notes:
1. Source for S_y values is Table Y-1 of [3.3.1].
2. Source for S_u values is Table U of [3.3.1].
3. Source for α values is material group C in Table TE-1 of [3.3.1].
4. Source for E values is "Carbon steels with C less than or equal to 0.30%" in Table TM-1 of [3.3.1].
5. Values for SA515 are given in parentheses where different from SA516.

TABLE 3.3.3
SA350-LF3 AND SA203-E MATERIAL PROPERTIES

Temp. (Deg. F)	SA350-LF3 and LF2			SA350-LF3/SA203-E		SA203-E		
	S_m	S_y	S_u	E	α	S_m	S_y	S_u
-20	23.3	37.5 (36.0)	70.0	28.2	---	23.3	40.0	70.0
100	23.3	37.5 (36.0)	70.0	27.6	6.27	23.3	40.0	70.0
200	22.8 (21.9)	34.2 (32.9)	68.5 (70.0)	27.1	6.54	23.3	36.5	70.0
300	22.2 (21.3)	33.2 (31.9)	66.7 (70.0)	26.7	6.78	23.3	35.4	70.0
400	21.5 (20.6)	32.2 (30.9)	64.6 (70.0)	26.1	6.98	22.9	34.3	68.8
500	20.2 (19.4)	30.3 (29.2)	60.7 (70.0)	25.7	7.16	21.6	32.4	64.9
600	18.5 (17.8)	- (26.6)	- (70.0)	-	-	-	-	-
700	16.8 (17.3)	- (26.0)	- (70.0)	-	-	-	-	-

Definitions:

S_m = Design Stress Intensity (ksi)
S_y = Yield Stress (ksi)
S_u = Ultimate Stress (ksi)
α = Coefficient of Thermal Expansion (in./in. per degree F x 10^{-6})
E = Young's Modulus (psi x 10^6)

Notes:

1. Source for S_m values is ASME Code.
2. Source for S_y values is ASME Code.
3. Source for S_u values is ratioing S_m values.
4. Source for α values is material group E in Table TE-1 of [3.3.1].
5. Source for E values is material group B in Table TM-1 of [3.3.1].
6. Values for LF2 are given in parentheses where different from LF3.

TABLE 3.3.4
BOLTING MATERIAL PROPERTIES

SB637-N07718					
Temp. (Deg. F)	S_y	S_u	E	α	S_m
-100	150.0	185.0	29.9	---	50.0
-20	150.0	185.0	---	---	50.0
70	150.0	185.0	29.0	7.05	50.0
100	150.0	185.0	---	7.08	50.0
200	144.0	177.6	28.3	7.22	48.0
300	140.7	173.5	27.8	7.33	46.9
400	138.3	170.6	27.6	7.45	46.1
500	136.8	168.7	27.1	7.57	45.6
600	135.3	166.9	26.8	7.67	45.1
SA193 Grade B7 (2.5 to 4 inches diameter)					
Temp. (Deg. F)	S_y	S_u	E	α	-
100	95.0	115.00	-	5.73	-
200	88.5	107.13	-	6.09	-
300	85.1	103.02	-	6.43	-
400	82.3	99.63	-	5.9	-

Definitions:

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

Notes:

1. Source for S_m values is Table 4 of [3.3.1].
2. Source for S_y values is ratioing design stress intensity values.
3. Source for S_u values is ratioing design stress intensity values.
4. Source for α values is Tables TE-1 and TE-4 of [3.3.1], as applicable.
5. Source for E values is Table TM-1 of [3.3.1].
6. Source for S_y values for SA193 bolts is Table Y-1 of [3.3.1]; source for S_u is by ratioing S_y.

TABLE 3.3.4 (CONTINUED)
BOLTING MATERIAL PROPERTIES

Temp. (Deg. F)	S_y	S_u	E	α	S_m
SA193 Grade B7 (less than 2.5 inch diameter)					
100	105.0	125.00	-	5.73	-
200	98.0	116.67	-	6.09	-
300	94.1	112.02	-	6.43	
400	91.5	108.93	-	6.74	-
SA705-630/SA564-630 (Age Hardened at 1075 degrees F)					
200	115.6	145.0	28.5	5.9	---
300	110.7	145.0	27.9	5.9	---
400	106.9	145.0	27.3	5.91	---
SA705-630/SA564-630 (Age Hardened at 1100 degrees F)					
200	106.3	140.0	28.5	5.9	---
300	101.9	140.0	27.9	5.9	---
400	98.3	136.3	27.3	5.91	---
SA705-630/SA564-630 (Age Hardened at 1150 degrees F)					
200	97.1	135.0	28.5	5.9	---
300	93.0	135.0	27.9	5.9	---

Definitions:

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

Notes:
1. Source for S_y values is Table Y-1 of [3.3.1].
2. Source for S_u values is Table U of [3.3.1].
3. Source for α values is Tables TE-1 and TE-4 of [3.3.1], as applicable.
4. Source for E values is Table TM-1 of [3.3.1].

TABLE 3.3.5
CONCRETE AND LEAD MECHANICAL PROPERTIES

PROPERTY	VALUE					
CONCRETE:						
Compressive Strength (psi)	See Table 1.D.1					
Nominal Density (lb/ft^3)	See Table 1.D.1					
Allowable Bearing Stress (psi)	1,823†					
Allowable Axial Compression (psi)	1,266†					
Allowable Flexure, extreme fiber tension (psi)	187†,††					
Allowable Flexure, extreme fiber compression (psi)	2,145†					
Mean Coefficient of Thermal Expansion (in/in/deg. F)	5.5E-06					
Modulus of Elasticity (psi)	57,000 (compressive strength (psi))$^{1/2}$					
LEAD:	-40°F	-20°F	70°F	200°F	300°F	600°F
Yield Strength (psi)	700	680	640	490	380	20
Modulus of Elasticity (ksi)	2.4E+3	2.4E+3	2.3E+3	2.0E+3	1.9E+3	1.5E+3
Coefficient of Thermal Expansion (in/in/deg. F)	15.6E-6	15.7E-6	16.1E-6	16.6E-6	17.2E-6	20.2E-6
Poisson's Ratio	0.40					
Density (lb/cubic ft.)	708					

Notes:
1. Concrete allowable stress values based on ACI 318.1-89 (92).
2. Lead properties are from [3.3.5].

† Values listed correspond to concrete compressive stress = 3,300 psi
†† No credit for tensile strength of concrete is taken in the calculations

TABLE 3.3.6
SA36 AND CARBON STEEL MATERIAL PROPERTIES

Temp. (Deg. F)	SA36 AND CARBON STEEL			
	S_y	S_u	α	E
-40	36.0	58.0	---	29.95
100	36.0	58.0	5.53	29.34
150	34.4	55.4	5.71	29.1
200	32.8	52.8	5.89	28.8
250	32.35	52.1	6.09	28.6
300	31.9	51.4	6.26	28.3
350	31.35	50.5	6.43	28.0
400	30.8	49.6	6.61	27.7
450	29.95	48.3	6.77	27.5
500	29.1	46.9	6.91	27.3
550	27.85	44.9	7.06	27.0
600	26.6	42.9	7.17	26.7
650	26.1	42.1	7.30	26.1
700	25.9	41.7	7.41	25.5

Definitions:

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

Notes:
1. Source for S_y values is Table Y-1 of [3.3.1].
2. Source for S_u values is ratioing S_y values.
3. Source for α values is material group C in Table TE-1 of [3.3.1].
4. Source for E values is "Carbon steels with C less than or equal to 0.30%" in Table TM-1 of [3.3.1].

3.4 GENERAL STANDARDS FOR CASKS

3.4.1 Chemical and Galvanic Reactions

In this section, it is shown that there is no credible mechanism for significant chemical or galvanic reactions in the HI-STORM 100 System during long-term storage operations (including HI-STORM 100S and HI-STORM 100A).

The MPC, which is filled with helium, provides a nonaqueous and inert environment. Insofar as corrosion is a long-term time-dependent phenomenon, the inert gas environment in the MPC precludes the incidence of corrosion during storage on the ISFSI. Furthermore, the only dissimilar material groups in the MPC are: (1) the neutron absorber material and stainless steel and (2) aluminum (found in some early vintage MPCs) and stainless steel. Neutron absorber materials and stainless steel have been used in close proximity in wet storage for over 30 years. Many spent fuel pools at nuclear plants contain fuel racks, which are fabricated from neutron absorber materials and stainless steel materials, with geometries similar to the MPC. Not one case of chemical or galvanic degradation has been found in fuel racks built by Holtec. This experience provides a sound basis to conclude that corrosion will not occur in these materials. Additionally, the aluminum conduction inserts and stainless steel basket are very close on the galvanic series chart. Aluminum, like other metals of its genre (e.g., titanium and magnesium) rapidly passivates in an aqueous environment, leading to a thin ceramic (Al_2O_3) barrier, which renders the material essentially inert and corrosion-free over long periods of application. The physical properties of the material, e.g., thermal expansion coefficient, diffusivity, and thermal conductivity, are essentially unaltered by the exposure of the aluminum metal stock to an aqueous environment.

The aluminum in the optional heat conduction elements (found in some early vintage MPCs) will quickly passivate in air and in water to form a protective oxide layer that prevents any significant hydrogen production during MPC cask loading and unloading operations. The aluminum in the neutron absorber material may also react with the water to generate hydrogen gas. The exact rate of generation and total amount of hydrogen generated is a function of a number of variables (see Section 1.2.1.3.1) and cannot be predicted with any certainty. Therefore, to preclude the potential for hydrogen ignition during lid welding or cutting, the operating procedures in Chapter 8 require monitoring for combustible gas and purging the space beneath the MPC lid with an inert gas during these activities. Once the MPC cavity is drained, dried, and backfilled with helium, the source of the hydrogen gas (the aluminum-water reaction) is eliminated.

The HI-STORM 100 storage overpack and the HI-TRAC transfer cask each combine low alloy and nickel alloy steels, carbon steels, neutron and gamma shielding materials, and bolting materials. All of these materials have a long history of non-galvanic behavior within close proximity of each other. The internal and external steel surfaces of each of the storage overpacks are sandblasted and coated to preclude surface oxidation. The HI-TRAC coating does not chemically react with borated water. Therefore, chemical or galvanic reactions involving the storage overpack materials are highly unlikely and are not expected.

In accordance with NRC Bulletin 96-04 [3.4.7], a review of the potential for chemical, galvanic, or other reactions among the materials of the HI-STORM 100 System, its contents and the operating environments, which may produce adverse reactions, has been performed. Table 3.4.2 provides a listing of the materials of fabrication for the HI-STORM 100 System and evaluates the performance of the material in the expected operating environments during short-term loading/unloading operations and long-term storage operations. As a result of this review, no operations were identified which could produce adverse reactions beyond those conditions already analyzed in this FSAR.

3.4.2 Positive Closure

There are no quick-connect/disconnect ports in the confinement boundary of the HI-STORM 100 System. The only access to the MPC is through the storage overpack lid, which weighs over 23,000 pounds (see Table 3.2.1). The lid is fastened to the storage overpack with large bolts. Inadvertent opening of the storage overpack is not feasible; opening a storage overpack requires mobilization of special tools and heavy-load lifting equipment.

3.4.3 Lifting Devices

As required by Reg. Guide 3.61, in this subsection, analyses for all lifting operations applicable to the deployment of a member of the HI-STORM 100 family are presented to demonstrate compliance with applicable codes and standards.

The HI-STORM 100 System has the following components and devices participating in lifting operations: lifting trunnions located at the top of the HI-TRAC transfer cask, lid lifting connections for the HI-STORM 100 lid and for other lids in the HI-TRAC transfer cask, connections for lifting and carrying a loaded HI-STORM 100 vertically, and lifting connections for the loaded MPC.

Analyses of HI-STORM 100 storage overpack and HI-TRAC transfer cask lifting devices are reported in this submittal. Analyses of MPC lifting operations are presented in the HI-STAR 100 FSAR (Docket Number 72-1008, Subsection 3.4.3) and are also applicable here.

The evaluation of the adequacy of the lifting devices entails careful consideration of the applied loading and associated stress limits. The load combination D+H, where H is the "handling load", is the generic case for all lifting adequacy assessments. The term D denotes the dead load. Quite obviously, D must be taken as the bounding value of the dead load of the component being lifted. In all lifting analyses considered in this document, the handling load H is assumed to be 0.15D. In other words, the inertia amplifier during the lifting operation is assumed to be equal to 0.15g. This value is consistent with the guidelines of the Crane Manufacturer's Association of America (CMAA), Specification No. 70, 1988, Section 3.3, which stipulates a dynamic factor equal to 0.15 for slowly executed lifts. Thus, the "apparent dead load" of the component for stress analysis purposes is $D^* = 1.15D$. Unless otherwise stated, all lifting analyses in this report use the "apparent dead load", D^*, as the lifted load.

Analysis methodology to evaluate the adequacy of the lifting device may be analytical or numerical. For the analysis of the trunnion, an accepted conservative technique for computing the bending stress is to assume that the lifting force is applied at the tip of the trunnion "cantilever" and that the stress state is fully developed at the base of the cantilever. This conservative technique, recommended in NUREG-1536, is applied to all trunnion analyses presented in this SAR and has also been applied to the trunnions analyzed in the HI-STAR 100 FSAR.

In general, the stress analysis to establish safety pursuant to NUREG-0612, Regulatory Guide 3.61, and the ASME Code, requires evaluation of three discrete zones which may be referred to as (i) the trunnion, (ii) the trunnion/component interface, hereinafter referred to as Region A, and (iii) the rest of the component, specifically the stressed metal zone adjacent to Region A, herein referred to as Region B. During this discussion, the term "trunnion" applies to any device used for lifting (i.e., trunnions, lift bolts, etc.)

Stress limits germane to each of the above three areas are discussed below:

i. Trunnion: NUREG-0612 requires that under the "apparent dead load", D^*, the maximum primary stress in the trunnion be less than 10% of the trunnion material ultimate strength and less than 1/6th of the trunnion material yield strength. Because of the materials of construction selected for trunnions in all HI-STORM 100 System components, the ultimate strength-based limit is more restrictive in every case. Therefore, all trunnion safety factors reported in this document pertain to the ultimate strength-based limit.

ii. Region A: Trunnion/Component Interface: Stresses in Region A must meet ASME Code Level A limits under applied load D*. Additionally, Regulatory Guide 3.61 requires that the primary stress under 3D*, associated with the cross-section, be less than the yield strength of the applicable material. In cases involving section bending, the developed section moment may be compared against the plastic moment at yield. The circumferential extent of the characteristic cross-section at the trunnion/component interface is calculated based on definitions from ASME Section III, Subsection NB and is defined in terms of the shell thickness and radius of curvature at the connection to the trunnion block. By virtue of the construction geometry, only the mean shell stress is categorized as "primary" for this evaluation.

iii. Region B: Typically, the stresses in the component in the vicinity of the trunnion/component interface are higher than elsewhere. However, exceptional situations exist. For example, when lifting a loaded MPC, the MPC baseplate, which supports the entire weight of the fuel and the fuel basket, is a candidate location for high stress even though it is far removed from the lifting location (which is located in the top lid).

   Even though the baseplate in the MPC would normally belong to the Region B category, for conservatism it was considered as Region A in the HI-STAR 100 SAR.

The pool lid and the transfer lid of the HI-TRAC transfer cask also fall into this dual category. In general, however, all locations of high stress in the component under D^* must also be checked for compliance with ASME Code Level A stress limits.

Unless explicitly stated otherwise, all analyses of lifting operations presented in this report follow the load definition and allowable stress provisions of the foregoing. Consistent with the practice adopted throughout this chapter, results are presented in dimensionless form, as safety factors, defined as

$$\text{Safety Factor, } \beta = \frac{\text{Allowable Stress in the Region Considered}}{\text{Computed Maximum Stress in the Region}}$$

The safety factor, defined in the manner of the above, is the added margin over what is mandated by the applicable code (NUREG-0612 or Regulatory Guide 3.61).

In the following subsections, we briefly describe each of the lifting analyses performed to demonstrate compliance with regulations. Summary results are presented for each of the analyses.

It is recognized that stresses in Region A are subject to two distinct criteria, namely Level A stress limits under D* and yield strength at 3D*. We will identify the applicable criteria in the summary tables, under the column heading "Item", using the "3D*" identifier.

All of the lifting analyses reported on in this Subsection are designated as Load Case 01 in Table 3.1.5.

3.4.3.1 125 Ton HI-TRAC Lifting Analysis - Trunnions

The lifting device in the HI-TRAC 125 cask is presented in Holtec Drawing 1880 (Section 1.5 herein). The two lifting trunnions for HI-TRAC are spaced at 180 degrees. The trunnions are designed for a two-point lift in accordance with the aforementioned NUREG-0612 criteria. Figure 3.4.21 shows the overall lifting configuration. The lifting analysis demonstrates that the stresses in the trunnions, computed using the conservative methodology described previously, comply with NUREG-0612 provisions.

Specifically, the following results are obtained:

HI-TRAC 125 Lifting Trunnions†		
	Value (ksi)	Safety Factor
Bending stress	16.09	1.13
Shear stress	7.26	1.50
† The lifted load is 245,800 lb.(a value that bounds the actual lifted weight from the pool after the lift yoke weight is eliminated per Table 3.2.4).		

Note that the safety factor presented in the previous table represents the additional margin beyond the mandated limit of 6 on yield strength and 10 on tensile strength.

Similar calculations have been performed for the HI-TRAC 125D cask, which differs from the HI-TRAC 125 with respect to the material options for the lifting trunnions. The lifting trunnions for the HI-TRAC 125 are fabricated from SB637-N07718; the lifting trunnions for the HI-TRAC 125D can be fabricated from either SB637-N07718 or SA564-630. The bounding results for the HI-TRAC 125D are:

HI-TRAC 125D Lifting Trunnions†		
	Value (ksi)	Safety Factor
Bending stress	13.57	1.03
Shear stress	7.26	1.16
† The lifted load is 245,800 lb.(a value that bounds the actual lifted weight from the pool after the lift yoke weight is eliminated per Table 3.2.4).		

3.4.3.2 125 Ton HI-TRAC Lifting - Trunnion Lifting Block Welds, Bearing, and Thread Shear Stress (Region A)

As part of the Region A evaluation, the weld group connecting the lifting trunnion block to the inner and outer shells, and to the HI-TRAC top flange, is analyzed. Conservative analyses are also performed to determine safety factors for bearing stress and for thread shear stress at the interface between the trunnion and the trunnion block. The following results are obtained for the HI-TRAC 125 and 125D transfer casks:

125 Ton HI-TRAC Lifting Trunnion Block (Region A Evaluation)			
Item	**Value (ksi)**	**Allowable (ksi)**	**Safety Factor**
Trunnion Block Bearing Stress	5.95	11.4	1.91
Trunnion Block Thread Shear Stress	5.05	6.84	1.35
Weld Shear Stress (3D*)	4.35†	11.4	2.62

† No quality factor has been applied to the weld group. (Subsection NF or NUREG-0612 do not apply penalty factors to the structural welds).

3.4.3.3 125 Ton HI-TRAC Lifting - Structure near Trunnion (Region B/Region A)

A three-dimensional elastic model of the HI-TRAC 125 metal components is analyzed using the ANSYS finite element code. The structural model includes, in addition to the trunnion and the trunnion block, a portion of the inner and outer HI-TRAC shells and the HI-TRAC top flange. Stress results over the characteristic interface section are summarized and compared with allowable strength limits per ASME Section III, Subsection NF, and per Regulatory Guide 3.61. The results show that the primary stresses in the HI-TRAC 125 structure comply with the level A stress limits for Subsection NF structures.

The results from the analysis are summarized below:

HI-TRAC 125 Trunnion Region (Regions A and B)			
Item	**Value (ksi)**	**Allowable (ksi)**	**Safety Factor**
Membrane Stress	6.50	17.5	2.69
Membrane plus Bending Stress	8.71	26.25	3.01
Membrane Stress (3D*)	19.5	34.6	1.77

The results above are also valid for the HI-TRAC 125D since the dimensions and the configuration of the inner shell, outer shell, top flange, and the trunnion block are the same in both the HI-TRAC 125 and 125D transfer casks, and the dimension used in the finite element model for the trunnion length conservatively bounds both transfer casks.

3.4.3.4 100 Ton HI-TRAC Lifting Analysis

The lifting trunnions and the trunnion blocks for the 100 Ton HI-TRAC are identical to the trunnions analyzed for the 125 Ton HI-TRAC. However, the outer shell geometry (outer diameter) is different. A calculation performed in the spirit of strength-of-materials provides justification that, despite the difference in local structure at the attachment points, the stresses in the body of the HI-TRAC 100 Ton unit meet the allowables set forth in Subsection 3.1.2.2.

Figure 3.4.10 illustrates the differences in geometry, loads, and trunnion moment arms between the body of the 125-Ton HI-TRAC and the body of the 100-Ton HI-TRAC. It is reasonable to assume that the level of stress in the 100 Ton HI-TRAC body, in the immediate vicinity of the interface (Section X-X in Figure 3.4.10), is proportional to the applied force and the bending moment applied. In the figure, the subscripts 1 and 0 refer to 100 Ton and 125 Ton casks, respectively. Figure 3.4.10 shows the location of the area centroid (with respect to the outer surface) and the loads and moment arms associated with each construction. Conservatively, neglecting all other interfaces between the top of the trunnion block and the top flange and between the sides of the trunnion block and the shells, equilibrium is maintained by developing a force and a moment in the section comprised of the two shell segments interfacing with the base of the trunnion block.

The most limiting stress state is in the outer shell at the trunnion block base interface. The stress level in the outer shell at Section X-X is proportional to P/A + Mc/I. Evaluating the stress for a unit width of section permits an estimate of the stress state in the HI-TRAC 100 outer shell if the corresponding stress state in the HI-TRAC 125 is known (the only changes are the applied load, the moment arm and the geometry). Using the geometry shown in Figure 3.4.10 gives the result as:

Stress (HI-TRAC 100 outer shell) = 1.242 x Stress (HI-TRAC 125 outer shell)

The tabular results in the previous subsection can be adjusted accordingly and are reported below:

100 Ton HI-TRAC Near Trunnion (Region A and Region B)	
Item	**Safety Factor**
Membrane Stress	2.17
Membrane plus Bending Stress	2.42
Membrane Stress (3D*)	1.43

3.4.3.5 HI-STORM 100 Lifting Analyses

There are two vertical lifting scenarios for the HI-STORM 100 storage overpack carrying a fully loaded MPC. Figure 3.4.17 shows a schematic of these lifting scenarios. Both lifting scenarios are examined using finite element models that focus on the local regions near the lift points. The analysis is based on the geometry of the HI-STORM 100; the alterations to the lid and to the length of the overpack barrel to configure the HI-STORM 100S have no effect on the conclusions reached in the area of the baseplate. Therefore, there is no separate analysis for the baseplate, inboard of the inner shell, for the HI-STORM 100S as the results are identical to or bounded by the results presented here. Since the upper portion of the HI-STORM 100S, the HI-STORM 100S lid, and the radial ribs and anchor block have a different configuration than the HI-STORM 100, separate calculations have been performed for these areas of the HI-STORM 100S. Similarly, where differences in construction between the HI-STORM 100 and the HI-STORM 100S Version B exist, separate calculations have been performed and the results summarized here.

Scenario #1 considers a "bottom lift" where the fully loaded HI-STORM 100 storage overpack is lifted vertically by four synchronized hydraulic jacks each positioned at one of the four inlet air vents. This lift allows for installation and removal of "air pads" which may be used for horizontal positioning of HI-STORM 100 at the ISFSI pad.

Scenario #2, labeled the "top lift scenario" considers the lifting of a fully loaded HI-STORM 100 vertically through the four lifting lugs located at the top end.

No structural credit is assumed for the HI-STORM concrete in either of the two lifting scenarios except as a vehicle to transfer compressive loads.

For the bottom lift, a three-dimensional one-quarter symmetry finite element model of the bottom region of the HI-STORM 100 storage overpack is constructed. The model includes the inner shell, the outer shell, the baseplate, the inlet vent side and top plates, and the radial plates connecting the inner and outer shells.

In the finite element analysis, the concrete is modeled as an equivalent pressure load applied over the baseplate as well as the four horizontal inlet vent plates. In reality, the concrete is supported only at the four inlet vents, directly above the hydraulic jacks. In other words, the concrete has sufficient strength to carry its own weight between these four support locations. The average shear stress in the concrete on a vertical cross section at the edge of an inlet vent is calculated as:

$$\tau_{concrete} = \frac{\rho V}{2A}$$

where:

- ρ equals the weight density of concrete;
- V equals the volume of unsupported concrete between two adjacent inlet vents;

A cross-sectional area of concrete at location of maximum shear stress;

For $\rho = 160.8$ lb/ft^3, $V = 231$ ft^3, and $A = 5{,}665$ in^2 (= 27.5 in × 206 in), the average shear stress is only 3.28 psi, which is negligible compared to the allowable shear stress of 126.5 psi for 4,000 psi compressive strength concrete. If the density of concrete is increased to 200 lb/ft^3, the shear stress increases by roughly 0.8 psi. Clearly, the concrete can support this load. Moreover, the positive effect that the concrete strength has on the results outweighs any adverse impact due to high density concrete. Therefore, the safety factors reported in this subsection (where the concrete is treated like water) for the bottom lift remain conservative for concrete densities up to 200 lb/ft^3.

For the analysis of the "top lift" scenario, a three-dimensional 1/8-symmetry finite element model of the top segment of HI-STORM 100 storage overpack is constructed. The metal HI-STORM 100 material is modeled (shells, radial plates, lifting block, ribs, vent plates, etc.) using shell or solid elements. Lumped weights are used to ensure that portions of the structure not modeled are, in fact, properly represented as part of a lifted load. The model is supported vertically at the lifting lug. The results are reported in tabular form at the end of this subsection.

The finite element results for the HI-STORM 100, as well as the results of similar analyses for the HI-STORM 100S, are based on inner and outer shell thicknesses of 1-1/4" and 3/4", respectively. Per Bill of Material 1575 and Drawing 3669, the thickness of both shells may be changed to 1" as an option for the HI-STORM 100 and 100S overpacks. With respect to the lifting analyses, the 1" thick inner and outer shells would have a negligible effect on the maximum calculated stress in the inlet vent horizontal plate, the HI-STORM baseplate, and the radial ribs. Therefore, the safety factors reported below for the HI-STORM 100 and 100S are valid for either thickness option.

To provide an alternate calculation to demonstrate that the bolt anchor blocks are adequate, we compute the average normal stress in the net metal area of the block under three times the lifted load. Further conservatism is introduced by including an additional 15% for dynamic amplification, i.e., the total load is equal to 3D*.

The average normal load in one bolt anchor block is

Load = 3 x 1.15 x 360,000 lb./4 = 310,500 lb. (Weight comes from Table 3.2.1)

The net area of the bolt anchor block is

Area = (3.14159)/4 x (5" x 5" - 3.25" x 3.25") = 11.34 sq. inch (Dimensions from BM-1575)

Therefore, the safety factor (yield strength at 350 degrees F/calculated stress from Table 3.3.3) is

SF = 31,400 psi/ (Load/Area) = 1.14

The shear stress in the threads of the lifting block is also examined. This analysis considers a cylindrical area of material under an axial load resisting the load by shearing action. The diameter of the area is the basic pitch diameter of the threads, and the length of the cylinder is the thread engagement length.

The analysis also examines the capacity of major welds in the load path and the compression capacity of the pedestal shield and pedestal shield shell.

The table below summarizes key results obtained from the analyses described above for the HI-STORM 100.

HI-STORM 100 Top and Bottom Lifting Analyses†‡			
Item	**Value (ksi)**	**Allowable (ksi)**	**Safety Factor**
Primary Membrane plus Bending - Bottom Lift - Inlet Vent Plates - Region B	8.0	26.3	3.28
Primary Membrane - Top Lift - Radial Rib Under Lifting Block - Region B	6.67	17.5	2.63
Primary Membrane plus Bending – Top Lift - Baseplate – Region B	7.0	26.3	3.75
Primary Membrane Region A (3D*)	19.97	33.15	1.66
Primary Membrane plus Bending Region A (3D*)	24.02	33.15	1.38
Lifting Block Threads - Top Lift – Region A (3D*)	10.67	18.84	1.76
Lifting Stud - Top Lift –Region A (3D*)	43.733	108.8	2.49
Welds – Anchor Block-to-Radial Rib Region B	5.74	19.695	3.43
Welds – Anchor Block-to-Radial Rib Region A (3D*)	17.21	19.62	1.14
Welds – Radial Rib-to-Inner and Outer Shells Region B	5.83	21.00	3.60
Welds – Radial Rib-to-Inner and Outer Shells Region A (3D*)	17.49	19.89	1.13
Weld – Baseplate-to Inner Shell Region A (3D*)	1.59	19.89	12.48
Weld – Baseplate-to-Inlet Vent Region A (3D*)	14.89	19.89	1.33
Pedestal Shield Concrete (3D*)	0.096	1.266	13.19
Pedestal Shell (3D*)	3.269	33.15	10.14

† Regions A and B are defined at beginning of Subsection 3.4.3

‡ The lifted load is 360000 lb. and an inertia amplification of 15% is included.

It is concluded that all structural integrity requirements are met during a lift of the HI-STORM 100 storage overpack under either the top lift or the bottom lift scenario. All factors of safety are greater than 1.0 using criteria from the ASME Code Section III, Subsection NF for Class 3 plate and shell supports and from USNRC Regulatory Guide 3.61.

Similar calculations have been performed for the HI-STORM 100S where differences in configuration warrant. The results are summarized in the table below:

HI-STORM 100S Top and Bottom Lifting Analyses†‡			
Item	**Value (ksi)**	**Allowable (ksi)**	**Safety Factor**
Primary Membrane plus Bending - Bottom Lift - Inlet Vent Plates - Region A (3D*)	9.824	33.15	3.374
Lifting Block Threads - Top Lift – Region A (3D*)	7.950	18.840	2.37
Lifting Stud - Top Lift –Region A (3D*)	49.806	83.7	1.68
Welds – Anchor Block-to-Radial Rib Region B	5.556	21.0	3.78
Welds – Anchor Block-to-Radial Rib Region A (3D*)	16.670	18.84	1.13
Welds – Radial Rib-to-Inner and Outer Shells Region B	5.631*	21.00	3.73*
Welds – Radial Rib-to-Inner and Outer Shells Region A (3D*)	16.895*	19.89	1.18*
Weld – Baseplate-to Inner Shell Region A (3D*)	1,592	19.89	12.49
Weld – Baseplate-to-Inlet Vent Region A (3D*)	8.982	19.89	2.214
Radial Rib Membrane Stress – Bottom Lift Region A (3D*)	10.58	33.15	3.132
Pedestal Shield Concrete (3D*)	0.095	1.535	16.17
Pedestal Shell (3D*)	3.235	33.15	10.24

† Regions A and B are defined at beginning of Subsection 3.4.3

‡ The lifted load is 410,000 lb and an inertia amplification of 15% is included. The increased weight (over the longer HI-STORM 100) comes from conservatively assuming an increase in concrete weight density in the HI-STORM 100S overpack and lid to provide additional safety margin.

* Result is specific to HI-STORM 100S overpacks fabricated with full height radial plates. For HI-STORM 100S overpacks fabricated with shorter top and bottom radial plates (i.e., two-piece configuration), the results tabulated below for the HI-STORM 100S Version B overpack, for the radial rib to inner and outer shell welds, are bounding.

Similar calculations have been performed for the HI-STORM 100S, Version B where differences in configuration warrant. The results are summarized in the table below for the heaviest HI-STORM 100S Version B (using high density concrete and with SA 564-630 stud material):

HI-STORM 100S Version B Top and Bottom Lifting Analyses			
Item	**Value (ksi)**	**Allowable (ksi)**	**Safety Factor**
Primary Membrane - Bottom Lift - Inlet Vent Plates - Region A (3D*)	27.06	33.15	1.22
Primary Membrane + Bending - Bottom Lift - Inlet Vent Plates - Region A (3D*)	20.455	33.15	1.62
Lifting Block Threads - Top Lift –Region A (3D*)	9.315	19.620	2.11
Lifting Stud - Top Lift –Region A (3D*)	49.369	108.8	2.20
Welds – Anchor Block-to-Radial Rib Region B	5.507	19.695	3.58
Welds – Anchor Block-to-Radial Rib Region A (3D*)	16.523	19.620	1.19
Welds – Radial Rib-to-Inner and Outer Shells Region B	6.120	21.00	3.43
Welds – Radial Rib-to-Inner and Outer Shells Region A (3D*)	18.36	19.89	1.08
Weld – Baseplate-to Inner Shell Region A (3D*)	2.724	19.89	7.302
Radial Rib to Inner and Outer Shell – Bottom Lift Region A (3D*)	18.360	19.89	1.08

For the longest HI-STORM 100S, Version B, with high-density concrete, the lifted load is 406,400 lb.

It is concluded that all structural integrity requirements are met during a lift of the HI-STORM 100, HI-STORM 100S, and HI-STORM 100S, Version B storage overpacks under either the top lift or the bottom lift scenario. All factors of safety are greater than 1.0 using criteria from the ASME Code Section III, Subsection NF for Class 3 plate and shell supports and from USNRC Regulatory Guide 3.61.

3.4.3.6 MPC Lifting Analysis

The MPC can be inserted or removed from an overpack by lifting cleats that are designed for installation into threaded holes in the top lid. The strength requirements of the attachment bolts and base metal are examined based on the requirements of NUREG 0612. Sufficiency of thread engagement length and bolt pre-load are also considered. The MPC top closure is examined considering the top lid as "Region B", where satisfaction of ASME Code Level A requirements is demonstrated. The analysis also considers highly stressed regions of the top closure as "region A" where applied load is 3D*. The MPC baseplate is analyzed under normal handling and subject to the allowable strengths appropriate to a component considered in "Region B". Finally, the baseplate region is further analyzed where loading is "3D*" consistent with the MPC baseplate being considered as "Region A". The definitions of "Region A", "Region B", and "3D*" as they apply to lifting analyses have been introduced at the beginning of this subsection.

The following table summarizes the minimum safety factors from these analyses. As stated earlier, safety factors tabulated below represent margins that are over and beyond those implied by the loading magnification mandated in NUREG 0612 or Regulatory Guide 3.61, as appropriate.

Summary of MPC Lifting Analyses			
Item	**Thread Engagement Safety Factor (NUREG-0612)**	**Region A Safety Factor (Note 1)**	**Region B Safety Factor(Note 1)**
MPC	1.013 (Note 2)	1.54	1.08

Notes:

1. Safety factor is for MPC baseplate.
2. The Safety Factor is calculated at 475°F based on a minimum yield strength of 33 ksi at room temperature for MPC Lids.

When dual lids are used on the MPC, the outer lid transfers the entire lifted load to the peripheral weld. The maximum bending stress in the outer lid from the lifted load can be conservatively computed by strength of materials theory using the solution for a simply supported circular plate under a central concentrated load equal to 115% of the bounding MPC load. The calculation and result are presented below using tabular results from Timoshenko, Strength of Materials, Vol. II, 3rd Edition.

P = 90,000 lb. x 1.15
Outer Diameter a = 67.375"
Effective Central Diameter where load is applied b= 13.675" (conservative assumption)
a/b = 5
Lid thickness = 4.75" (Dual lids)
From the reference, k=1.745 and the maximum bending stress under the amplified lifted load is

$\sigma = kP/h^2 = 8005$ psi

Table 3.4.7 provides results for the stress in the lid under normal condition internal pressure. For the case with dual lids, the stress must be doubled. From the table, the pressure stress is

S = 2 x 1,633 psi

Therefore, the combined bending stress at the center of the dual lid is 11,271. Using the allowable strength from Table 3.4.7, the safety factor is

SF = 25,450 psi/11,271 psi = 2.258

3.4.3.7 Miscellaneous Lid Lifting Analyses

The HI-STORM 100 lid lifting analysis is performed to ensure that the threaded connections provided in the lid are adequately sized. The lifting analysis of the top lid is based on a vertical orientation of loading from an attached lifting device. The top lid of the HI-STORM 100 storage overpack is lifted using four lugs that are threaded into holes in the top plate of the lid (Holtec Drawing 1495, Section 1.5). It is noted that failure of the lid attachment would not result in any event of safety consequence because a free-falling HI-STORM 100 lid cannot strike a stored MPC (due to its size and orientation). Operational limits on the carry height of the HI-STORM 100 lid above the top of the storage overpack containing a loaded MPC preclude any significant lid rotation out of the horizontal plane in the event of a handling accident. Therefore, contact between the top of the MPC and the edge of a dropped lid due to uncontrolled lowering of the lid during the lid placement operation is judged to be a non-credible scenario. Except for location of the lift points, the lifting device for the HI-STORM 100S and for the HI-STORM 100S, Version B lid is the same as for the regular HI-STORM 100 lid. Since the lid weight for the HI-STORM 100S, Version B bounds the HI-STORM 100 and the HI-STORM 100S, the calculated safety factors for the lifting of the HI-STORM 100S lid are reduced and are also reported in the summary table below.

In addition to the HI-STORM 100 top lid lifting analysis, the strength qualification of the lid lifting holes, and associated lid lifting devices, for the HI-TRAC pool lid and top lid has been performed. The qualification is based on the Regulatory Guide 3.61 requirement that a load factor of 3 results in stresses less than the yield stress. The results for the HI-TRAC 125 bound the results for the HI-TRAC 125D, the HI-TRAC 100, and the HI-TRAC 100D, since the lid weights used in the calculation are greater than or equal to all other HI-TRAC lid weights. Example commercially available lifting structures are considered and it is shown that thread engagement lengths are acceptable. Loads to lifting devices are permitted to be at a maximum angle of 45 degrees from vertical. A summary of results, pertaining to the various lid lifting operations, is given in the table below:

Summary of HI-STORM 100 Lid Lifting Analyses

Item	Dead Load (lb)	Minimum Safety Factor
HI-STORM 100 (100S) Top Lid Lifting	23,000 (29,000†)	4.925 (3.906)
HI-TRAC Pool Lid Lifting	12,500	3.594 (Note 1)
HI-TRAC Top Lid Lifting	2,750	11.3
† Bounding weight of HI-STORM 100S, Version B top lid with 200 pcf concrete.		

Note 1: Safety Factor is calculated based on a conservative thread engagement of 1".

The analysis demonstrates that thread engagement is sufficient for the threaded holes used solely for lid lifting and that commercially available lifting devices engaging the threaded holes, are available.

We note that all reported safety factors are based on an allowable strength equal to 33.3% of the yield strength of the lid material when evaluating shear capacity of the internal threads and based on the working loads of the commercially available lifting devices associated with the respective threaded holes.

3.4.3.8 HI-TRAC Pool Lid Analysis - Lifting MPC From the Spent Fuel Pool (Load Case 01 in Table 3.1.5)

During lifting of the MPC from the spent fuel pool, the HI-TRAC pool lid supports the weight of a loaded MPC plus water (see Figure 3.4.21). Calculations are performed to show structural integrity under this condition for both the HI-TRAC 100 and the HI-TRAC 125 transfer casks. In accordance with the general guidelines set down at the beginning of Subsection 3.4.3, the pool lid is considered as both Region A and Region B for evaluating safety factors. The analysis shows that the stress in the pool lid top plate is less than the Level A allowable stress under pressure equivalent to the heaviest MPC, contained water, and lid self weight (Region B evaluation). Stresses in the lids and bolts are also shown to be below yield under three times the applied lifted load (Region A evaluation using Regulatory Guide 3.61 criteria). The threaded holes in the HI-TRAC pool lid are also examined for acceptable engagement length under the condition of lifting the MPC from the pool. It is demonstrated that the pool lid peripheral bolts have adequate engagement length into the pool lid to permit the transfer of the required load. The safety factor is defined based on the strength limits imposed by Regulatory Guide 3.61.

The following table summarizes the results of the analyses for the HI-TRAC pool lid for each of the four transfer cask types. Results given in the following table compare calculated stress (or load) and allowable stress (or load). In all cases, the safety factor is defined as the allowable value divided by the calculated value.

HI-TRAC Pool Lid Lifting a Loaded MPC Evaluation†			
Item	Value (ksi)	Allowable (ksi)	Safety Factor
Lid Bending Stress - HI-TRAC 125/125D - Region B Analysis - Pool Lid Top Plate	10.1	26.3	2.604
Lid Bending Stress - HI-TRAC 125/125D - Region B Analysis - Pool Lid Bottom Plate	5.05	26.3	5.208
Lid Bending Stress - HI-TRAC 100/100D - Region B Analysis- Pool Lid Top Plate	10.06	26.3	2.614
Lid Bending Stress - HI-TRAC 100/100D - Region B Analysis- Pool Lid Bottom Plate	6.425	26.3	4.093
Lid Bolt Stress - HI-TRAC 125 – (3D*)	18.92	95.0	5.02
Lid Bolt Stress - HI-TRAC 100 – (3D*)	18.21	95.0	5.216
Lid Bolt Force - HI-TRAC 125D – (3D*)	25.77‡	84.05‡	3.262
Lid Bolt Force - HI-TRAC 100D – (3D*)	24.80‡	84.05‡	3.389
Lid Bending Stress - HI-TRAC 125/125D - Region A Analysis - Pool Lid Top Plate (3D*)	30.3	33.15	1.094
Lid Bending Stress - HI-TRAC 125/125D - Region A Analysis - Pool Lid Bottom Plate (3D*)	15.15	33.15	2.188
Lid Bending Stress –HI-TRAC 100/100D – Region A Analysis- Pool Lid Top Plate (3D*)	30.19	33.15	1.098
Lid Bending Stress –HI-TRAC 100/100D – Region A Analysis- Pool Lid Bottom Plate (3D*)	19.28	33.15	1.72
Lid Thread Engagement Length (HI-TRAC 125)	137.4‡	267.9‡	1.949

† Region A and B defined at beginning of Subsection 3.4.3.
‡ Calculated and allowable value for this item in (kips).

3.4.3.9 HI-TRAC Transfer Lid Analysis - Lifting MPC Away from Spent Fuel Pool (Load Case 01 in Table 3.1.5)

During transfer to or from a storage overpack using a HI-TRAC 125 or a HI-TRAC 100, the HI-TRAC transfer lid supports the weight of a loaded MPC. Figure 3.4.21 illustrates the lift operation. In accordance with the general lifting analysis guidelines, the transfer lid should be considered as both a Region A (Regulatory Guide 3.61 criteria) and a Region B location (ASME Section III, Subsection NF for Class 3 plate and shell structures) for evaluation of safety factors. The HI-TRAC 125 transfer lid and the HI-TRAC 100 transfer lid are analyzed separately because of differences in geometry. The HI-TRAC 125D and HI-TRAC 100D employ specially designed mating devices in combination with the pool lid to transfer a loaded MPC to or from a storage overpack. Thus, a transfer lid analysis is not performed for the HI-TRAC 125D or the HI-TRAC 100D. Results for the HI-TRAC 125D and HI-TRAC 100D pool lids are presented in the previous subsection.

It is shown that the transfer lid doors can support a loaded MPC together with the door weight without exceeding ASME NF stress limits and the more conservative limits of Regulatory Guide 3.61. It is also shown that the connecting structure transfers the load to the cask body without overstress. The following tables summarize the results for both HI-TRAC casks:

HI-TRAC 125 Transfer Lid – Lifting Evaluation†			
Item	Value (ksi)	Allowable (ksi)	Safety Factor
HI-TRAC 125 - Door Plate – (3D*)	9.381	32.7	3.486
HI-TRAC 125 - Door Plate – Region B	3.127	26.25	8.394
HI-TRAC 125 – Wheel Track (3D*)	26.91	36.0	1.338
HI-TRAC 125 - Door Housing Bottom Plate-Region B	7.701	26.25	3.409
HI-TRAC 125 - Door Housing Bottom Plate-(3D*)	23.103	32.7	1.415
HI-TRAC 125 - Door Housing Stiffeners- (3D*)	4.131	32.7	7.913
HI-TRAC 125 - Housing Bolts-Region B	29.96	57.5	1.919
HI-TRAC 125 – Housing Bolts (3D*)	89.88	95.0	1.057
HI-TRAC 125 – Lid Top Plate (3D*)	30.907	32.7	1.058

† Region A and B defined at beginning of Subsection 3.4.3

HI-TRAC 100 Transfer Lid – Lifting Evaluation†			
Item	Value (ksi)	Allowable (ksi)	Safety Factor
HI-TRAC 100 - Door Plate – (3D*)	22.188	32.7	1.474
HI-TRAC 100 - Door Plate – Region B	7.396	26.25	3.549
HI-TRAC 100 – Wheel Track (3D*)	13.011	36.0	2.767
HI-TRAC 100 – Door Housing Bottom Plate- Region B	7.447	26.25	3.525
HI-TRAC 100 – Door Housing Bottom Plate- (3D*)	22.336	32.7	1.464
HI-TRAC 100 – Door Housing Stiffeners- (3D*)	4.917	32.7	6.65
HI-TRAC 100 – Welds Connecting Door Housing Stiffeners (3D*)	11.802	32.7	2.771
HI-TRAC 100 - Housing Bolts-Region B	22.478	57.5	2.558
HI-TRAC 100 – Housing Bolts (3D*)	67.423	95.0	1.409
HI-TRAC 100 – Lid Top Plate (3D*)	19.395	32.7	1.686

† Region A and B defined at beginning of Subsection 3.4.3

3.4.3.10 HI-TRAC Bottom Flange Evaluation during Lift (Load Case 01 in Table 3.1.5)

During a lifting operation, the HI-TRAC transfer cask body supports the load of a loaded MPC, and the transfer lid (away from the spent fuel pool) or the pool lid plus contained water (lifting from the spent fuel pool). In either case, the load is transferred to the bottom flange of HI-TRAC through the bolts and a state of stress in the flange and the supporting inner and outer shells is developed. Figure 3.4.21 illustrates the lifting operation. This area of the HI-TRAC 125 is analyzed to demonstrate that the required limits on stress are maintained for both ASME and Regulatory Guide 3.61. The bottom flange is considered as an annular plate subject to a total bolt load acting at the bolt circle and supported by reaction loads developed in the inner and outer shells of HI-TRAC. The solution for maximum flange bending stress is found in the classical literature and stresses and corresponding safety factors developed for the bottom flange and for the outer and inner shell weld shear stress. Since the welds are partial penetration, weld stress evaluation bounds an evaluation of direct stress. The table below summarizes the results of the evaluation.

Safety Factors in HI-TRAC Bottom Flange During a Lift Operation			
Item	**Value(ksi)**	**Allowable(ksi)**	**Safety Factor**
Bottom Flange – Region B	7.798	26.25	3.37
Bottom Flange (3D*)	23.39	33.15	1.42
Outer Shell (3D*)	4.773	33.15	6.94

The bottom flanges of the HI-TRAC 125D and HI-TRAC 100D are different from the HI-TRAC 125 in several respects. Namely, the thickness of the bottom flange is less, and the groove weld connecting the bottom flange to the inner shell is smaller. In addition, the bottom flange of the HI-TRAC 125D and HI-TRAC 100D is reinforced by eight gusset plates, whereas the HI-TRAC 125 bottom flange is not reinforced. Therefore, to account for these differences, the evaluation described above has been repeated for the HI-TRAC 125D and the HI-TRAC 100D. The results are summarized in the tables below. Note that the following results are conservative since the HI-TRAC 125D and HI-TRAC 100D bottom flange evaluations neglect the reinforcing strength of the gusset plates.

Safety Factors in HI-TRAC 125D Bottom Flange During a Lift Operation			
Item	**Value(ksi)**	**Allowable(ksi)**	**Safety Factor**
Bottom Flange – Region B	9.594	26.25	2.74
Bottom Flange (3D*)	28.78	33.15	1.15
Outer Shell (3D*)	4.710	33.15	7.04

Safety Factors in HI-TRAC 100D Bottom Flange During a Lift Operation			
Item	**Value(ksi)**	**Allowable(ksi)**	**Safety Factor**
Bottom Flange – Region B	8.646	26.25	3.04
Bottom Flange (3D*)	25.94	33.15	1.28
Outer Shell (3D*)	5.499	33.15	6.03

3.4.3.11 Conclusion

Synopses of lifting device, device/component interface, and component stresses, under all contemplated lifting operations for the HI-STORM 100 System have been presented in the foregoing. The HI-STORM storage overpack and the HI-TRAC transfer cask have been evaluated for limiting stress states. The results show that all factors of safety are greater than 1.

3.4.4 Heat

The thermal evaluation of the HI-STORM 100 System is reported in Chapter 4.

3.4.4.1 Summary of Pressures and Temperatures

Design pressures and design temperatures for all conditions of storage are listed in Tables 2.2.1 and 2.2.3, respectively.

3.4.4.2 Differential Thermal Expansion

Consistent with the requirements of Reg. Guide 3.61, Load Cases F1 (Table 3.1.3) and E4 (Table 3.1.4) are defined to study the effect of differential thermal expansion among the constituent components in the HI-STORM 100 System. The temperatures necessary to perform the differential thermal expansion analyses for the MPC in the HI-STORM 100 and HI-TRAC casks are provided in Chapter 4. The material presented in Subsection 4.4.5 demonstrates that a physical interference between discrete components of the HI-STORM 100 System (e.g. storage overpack and enclosure vessel) will not develop due to differential thermal expansion during any operating condition.

3.4.4.2.1 Normal Hot Environment

Closed form calculations are performed in Subsection 4.4.6 to demonstrate that initial gaps between the HI-STORM 100 storage overpack or the HI-TRAC transfer cask and the MPC canister, and between the MPC canister and the fuel basket, will not close due to thermal expansion of the system components under loading conditions, defined as F1 and E4 in Tables 3.1.3 and 3.1.4, respectively. To assess this in the most conservative manner, the thermal solutions computed in Chapter 4, including the thermosiphon effect, are surveyed for the following information.

- The radial temperature distribution in each of the fuel baskets at the location of peak center metal temperature.

- The highest and lowest mean temperatures of the canister shell for the hot environment condition.

Using the above temperature information, simplified thermoelastic solutions of equivalent axisymmetric problems are used to obtain conservative estimates of gap closures. The following procedure, which conservatively neglects axial variations in temperature distribution, is utilized.

1. Use the surface temperature information for the fuel basket to define a parabolic distribution in the fuel basket that bounds (from above) the actual temperature distribution. Using this result, generate a conservatively high estimate of the radial and axial growth of the different fuel baskets using classical closed form solutions for thermoelastic deformation in cylindrical bodies.

2. Use the temperatures obtained for the canister to predict an estimate of the radial and axial growth of the canister to check the canister-to-basket gaps.

3. Use the temperatures obtained for the canister to predict an estimate of the radial and axial growth of the canister to check the canister-to-storage overpack and canister-to-HI-TRAC gaps.

4. For given initial clearances, compute the operating clearances.

The results are summarized in Table 4.4.10 for normal storage conditions. The clearances between the MPC basket and canister structure, as well as between the MPC shell and storage overpack or HI-TRAC inside surface, are sufficient to preclude a temperature induced interference from differential thermal expansions under normal operating conditions.

3.4.4.2.2 Fire Accident

It is shown in Chapter 4 that the fire accident has a small effect on the MPC temperatures because of the short duration of the fire accidents and the large thermal inertia of the storage overpack. Therefore, a structural evaluation of the MPC under the postulated fire event is not required. The conclusions reached in Subsection 3.4.4.2.1 are also appropriate for the fire accident with the MPC housed in the storage overpack. Analysis of fire accident temperatures of the MPC housed within the HI-TRAC for thermal expansion is unnecessary, as the HI-TRAC, directly exposed to the fire, expands to increase the gap between the HI-TRAC and MPC.

As expected, the external surfaces of the HI-STORM 100 storage overpack that are directly exposed to the fire event experience maximum rise in temperature. The outer shell and top plate in the top lid are the external surfaces that are in direct contact with heated air from fire. The table below, extracted from data provided in Chapter 4, provides the maximum temperatures attained at the key locations in HI-STORM 100 storage overpack under the postulated fire event.

Component	Maximum Fire Condition Temperature (Deg. F)
Storage Overpack Inner Shell	300
Storage Overpack Radial Concrete Mid-Depth	184
Storage Overpack Outer Shell	570
Storage Overpack Lid	<570

The following conclusions are readily reached from the above table.

- The maximum metal temperature of the carbon steel shell most directly exposed to the combustion air is well below 600°F (Table 2.2.3 applicable short-term temperature limit). 600°F is well below the permissible temperature limit in the ASME Code for the outer shell material.

- The bulk temperature of concrete is well below the normal condition temperature limit of 300°F specified in Table 2.2.3 and Appendix 1.D. ACI-349-85 permits 350°F as the short-term temperature limit; the shielding concrete in the HI-STORM 100 Overpack, as noted in Appendix 1.D, will comply with the specified compositional and manufacturing provisions of ACI-349-85. As the detailed information in Section 4.6 shows, the radial extent in the concrete where the local temperature exceeds 350°F begins at the outer shell/concrete interface and ends in less than one-inch. Therefore, the potential loss in the shielding material's effectiveness is less than 4% of the concrete shielding mass in the overpack annulus.

- The metal temperature of the inner shell does not exceed 300°F at any location, which is below the accident condition temperature limit of 400°F specified in Table 2.2.3 for the inner shell.

- The presence of a stitch weld between the overpack inner shell and the overpack top plate ensures that there will be no pressure buildup in the concrete annulus due to the concrete losing water that then turns to steam.

The above summary confirms that the postulated fire event will not jeopardize the structural integrity of the HI-STORM 100 Overpack or significantly diminish its shielding effectiveness.

The above conclusions, as relevant, also apply to the HI-TRAC fire considered in Chapter 4. Water jacket over-pressurization is precluded by the safety valve set point. The non-structural effects of loss of water have been evaluated in Chapter 5 and shown to meet regulatory limits. Therefore, it is concluded that the postulated fire event will not cause significant loss in storage overpack or HI-

TRAC shielding function.

3.4.4.3 Stress Calculations

This subsection presents calculations of the stresses in the different components of the HI-STORM 100 System from the effects of mechanical load case assembled in Section 3.1. Loading cases for the MPC fuel basket, the MPC enclosure vessel, the HI-STORM 100 storage overpack and the HI-TRAC transfer cask are listed in Tables 3.1.3 through 3.1.5, respectively. The load case identifiers defined in Tables 3.1.3 through 3.1.5 denote the cases considered.

The purpose of the analyses is to provide the necessary assurance that there will be no unacceptable risk of criticality, unacceptable release of radioactive material, unacceptable radiation levels, or impairment of ready retrievability of fuel from the MPC and the MPC from the HI-STORM 100 storage overpack or from the HI-TRAC transfer cask.

For all stress evaluations, the allowable stresses and stress intensities for the various HI-STORM 100 System components are based on bounding high metal temperatures to provide additional conservatism (Table 3.1.17 for the MPC basket, for example).

In addition to the loading cases germane to stress evaluations mentioned above, three cases pertaining to the stability of HI-STORM 100 are also considered (Table 3.1.1).

The results of various stress calculations on components are reported. The calculations are either performed directly as part of the text, or carried out in a separate calculation report that provides details of strength of materials evaluations or finite element numerical analysis. The specific calculations reported in this subsection are:

1. MPC stress calculations
2. HI-STORM 100 storage overpack stress calculations
3. HI-TRAC stress calculations

The MPC calculations reported in this document are complemented by analyses in the HI-STAR 100 Dockets. As noted earlier in this chapter, calculations for MPC components that are reported in HI-STAR 100 FSAR and SAR (Docket Numbers 72-1008 or 71-9261) are not repeated here unless geometry or load changes warrant reanalysis. For example, analysis of the MPC lid under normal conditions is not included in this submittal since neither the MPC lid loading nor geometry is affected by the MPC being placed in HI-TRAC or HI-STORM 100. MPC stress analyses reported herein focus on the basket and canister stress distributions due to the design basis (45g) lateral deceleration imposed by a non-mechanistic tip-over of the HI-STORM 100 storage overpack or a horizontal drop of HI-TRAC. In the submittals for the HI-STAR 100 FSAR and SAR (Docket Numbers 72-1008 and 71-9261, for storage and transport, respectively), the design basis deceleration was 60g. In this submittal the design basis deceleration is 45g. However, since the geometry of the MPC external boundary condition, viz. canister-to-storage overpack gap, has changed, a reanalysis of the MPC stresses under the lateral deceleration loads is required. This analysis is performed and the results are summarized in this subsection.

The HI-STORM 100 storage overpack and the HI-TRAC transfer cask have been evaluated for certain limiting load conditions that are germane to the storage and operational modes specified for the system in Tables 3.1.1 and 3.1.5. The determination of component safety factors at the locations considered in the HI-STORM 100 storage overpack and in the HI-TRAC transfer cask is based on the allowable stresses permitted by the ASME Code Section III, Subsection NF for Class 3 plate and shell support structures.

3.4.4.3.1 MPC Stress Calculations

The structural function of the MPC in the storage mode is stated in Section 3.1. The calculations presented here demonstrate the ability of the MPC to perform its structural function. The purpose of the analyses is to provide the necessary assurance that there will be no unacceptable risk of criticality, unacceptable release of radioactive material, or impairment of ready retrievability.

3.4.4.3.1.1 Analysis of Load Cases E.3.b, E.3.c (Table 3.1.4) and F.3.b, F.3.c (Table 3.1.3)

Analyses are performed for each of the MPC designs. The following subsections describe the model, individual loads, load combinations, and analysis procedures applicable to the MPC. Unfortunately, unlike vertical loading cases, where the analyses performed in the HI-STAR 100 dockets remain fully applicable for application in HI-STORM 100, the response of the MPC to a horizontal loading event is storage overpack-geometry dependent. Under a horizontal drop event, for example, the MPC and the fuel basket structure will tend to flatten. The restraint to this flattening offered by the storage overpack will clearly depend on the difference in the diameters of the storage overpack internal cavity and that of the outer surface of the MPC. In the HI-STORM 100 storage overpack, the diameter difference is larger than that in HI-STAR 100; therefore, the external restraint to MPC ovalization under a horizontal drop event is less effective. For this reason, the MPC stress analysis for lateral loading scenarios must be performed anew for the HI-STORM 100 storage overpack; the results from the HI-STAR 100 analyses will not be conservative. The HI-TRAC transfer casks and HI-STAR 100 overpack inner diameters are identical. Therefore, the analysis of the MPC in the HI-STAR 100 overpack under 60g's for the side impact (Docket 72-1008) bounds the analysis of the MPC in the HI-TRAC under 45g's.

Description of Finite Element Models of the MPCs Under Lateral Loading

A finite element model of each MPC is used to assess the effects of the accident loads. The models are constructed using ANSYS [3.4.1], and they are identical to the models used in Holtec's HI-STAR 100 submittals in Docket Numbers 72-1008 and 71-9261. The following model description is common to all MPCs.

The MPC structural model is two-dimensional. It represents a one-inch long cross section of the MPC fuel basket and MPC canister.

The MPC model includes the fuel basket, the basket support structures, and the MPC shell. A basket support is defined as any structural member that is welded to the inside surface of the MPC shell. A portion of the storage overpack inner surface is modeled to provide the correct restraint conditions for the MPC. Figures 3.4.1 through 3.4.9 show typical MPC models. The fuel basket support structure shown in the figures is a multi-plate structure consisting of solid shims or support members having two separate compressive load supporting members. For conservatism in the finite element model some dual path compression members (i.e., "V" angles) are simulated as single columns. Therefore, the calculated stress intensities in the fuel basket angle supports from the finite element solution are conservatively overestimated in some locations.

The ANSYS model is not intended to resolve the detailed stress distributions in weld areas. Individual welds are not included in the finite element model. A separate analysis for basket welds and for the basket support "V" angles is performed outside of ANSYS.

No credit is taken for any load support offered by the neutron absorber panels, sheathing, and the aluminum heat conduction elements. Therefore, these so-called non-structural members are not represented in the model. The bounding MPC weight used, however, does include the mass contributions of these non-structural components.

The model is built using five ANSYS element types: BEAM3, PLANE82, CONTAC12, CONTAC26, and COMBIN14. The fuel basket and MPC shell are modeled entirely with two-dimensional beam elements (BEAM3). Plate-type basket supports are also modeled with BEAM3 elements. Eight-node plane elements (PLANE82) are used for the solid-type basket supports. The gaps between the fuel basket and the basket supports are represented by two-dimensional point-to-point contact elements (CONTAC12). Contact between the MPC shell and the storage overpack is modeled using two-dimensional point-to-ground contact elements (CONTAC26) with an appropriate clearance gap.

Two orientations of the deceleration vector are considered. The 0-degree drop model includes the storage overpack-MPC interface in the basket orientation illustrated in Figure 3.1.2. The 45-degree drop model represents the storage overpack-MPC interface with the basket oriented in the manner of Figure 3.1.3. The 0-degree and the 45-degree drop models are shown in Figures 3.4.1 through 3.4.6. Table 3.4.1 lists the element types and number of elements for current MPCs.

A contact surface is provided in the model used for drop analyses to represent the interface between the storage overpack channels and the MPC. As the MPC makes contact with the storage overpack, the MPC shell deforms to mate with the channels that are welded at equal intervals around the storage overpack inner surface. The nodes that define the elements representing the fuel basket and the MPC shell are located along the centerline of the plate material. As a result, the line of nodes that forms the perimeter of the MPC shell is inset from the real boundary by a distance that is equal to half of the shell thickness. In order to maintain the specified MPC shell/storage overpack gap dimension, the radius of the storage overpack channels is decreased by an equal amount in the model.

The three discrete components of the HI-STORM 100 System, namely the fuel basket, the MPC shell, and the storage overpack or HI-TRAC transfer cask, are engineered with small diametral clearances which are large enough to permit unconstrained thermal expansion of the three components under the rated (maximum) heat duty condition. A small diametral gap under ambient conditions is also necessary to assemble the system without physical interference between the contiguous surfaces of the three components. The required gap to ensure unrestricted thermal expansion between the basket and the MPC shell is small and will further decrease under maximum heat load conditions, but will introduce a physical nonlinearity in the structural events involving lateral loading (such as side drop of the system) under ambient conditions. It is evident from the system design drawings that the fuel basket that is non-radially symmetric is in proximate contact with the MPC shell at a discrete number of locations along the circumferences. At these locations, the MPC shell, backed by the channels attached to the storage overpack, provides a support line to the fuel basket during lateral drop events. Because the fuel basket, the MPC shell, and the storage overpack or HI-TRAC are all three-dimensional structural weldments, their inter-body clearances may be somewhat uneven at different azimuthal locations. As the lateral loading is increased, clearances close at the support locations, resulting in the activation of the support from the storage overpack or HI-TRAC.

The bending stresses in the basket and the MPC shell at low lateral loading levels which are too small to close the support location clearances are secondary stresses since further increase in the loading will activate the storage overpack's or HI-TRAC's transfer cask support action, mitigating further increase in the stress. Therefore, to compute primary stresses in the basket and the MPC shell under lateral drop events, the gaps should be assumed to be closed. However, in the analyses, we have conservatively assumed that an initial gap of 0.1875" exists, in the direction of the applied deceleration, at all support locations between the fuel basket and the MPC shell and that the clearance gap between the shell and the storage overpack at the support locations is 3/16". In the evaluation of safety factors for the MPC-24, MPC-32, and MPC-68, the total stress state produced by the applied loading on these configurations is conservatively compared with primary stress levels, even though the self-limiting stresses should be considered secondary in the strict definition of the Code. To illustrate the conservatism, we have eliminated the secondary stress (that develops to close the clearances) in the comparison with primary stress allowable values and report safety factors for the MPC-24E that are based only on primary stresses necessary to maintain equilibrium with the inertia forces.

ANSYS requires that for a static solution all bodies be constrained to prevent rigid body motion. Therefore, in the 0 degree and 45 degree drop models, two-dimensional linear spring elements (COMBIN14) join the various model components, i.e., fuel basket and enclosure vessel, at the point of initial contact. This provides the necessary constraints for the model components in the direction of the impact. By locating the springs at the points of initial contact, where the gaps remain closed, the behavior of the springs is identical to the behavior of a contact element. Linear springs and contact elements that connect the same two components have equal stiffness values.

Description of Individual Loads and Boundary Conditions Applied to the MPCs

The method of applying each individual load to the MPC model is described in this subsection. The individual loads are listed in Table 2.2.14. A free-body diagram of the MPC corresponding to each individual load is given in Figures 3.4.7-3.4.9. In the following discussion, reference to vertical and horizontal orientations is made. Vertical refers to the direction along the cask axis, and horizontal refers to a radial direction.

Quasi-static structural analysis methods are used. The effects of any dynamic load factors (DLFs) are included in the final evaluation of safety factors. All analyses are carried out using the design basis decelerations in Table 3.1.2.

The MPC models used for side drop evaluations are shown in Figures 3.4.1 through 3.4.6. In each model, the fuel basket and the enclosure vessel are constrained to move only in the direction that is parallel to the acceleration vector. The storage overpack inner shell, which is defined by three nodes needed to represent the contact surface, is fixed in all degrees of freedom. The fuel basket, enclosure vessel, and storage overpack inner shell are all connected at one location by linear springs, as described in Subsection 3.4.4.3.1.1 (see Figure 3.4.1, for example). Detailed side drop evaluations here focus on an MPC within a HI-STORM 100 storage overpack. Since the analyses performed in Docket Number 72-1008 for the side drop condition in the HI-STAR 100 storage overpack demonstrates a safe condition under a 60g deceleration, no new analysis is required for the MPC and contained fuel basket and fuel during a side drop in the HI-TRAC, which is limited to a 45g deceleration (HI-TRAC and HI-STAR 100 overpacks have the same inside dimensions).

Accelerations

During a side impact event, the stored fuel is directly supported by the cell walls in the fuel basket. Depending on the orientation of the drop, 0 or 45 degrees (see Figures 3.4.8 and 3.4.9), the fuel is supported by either one or two walls. In the finite element model this load is effected by applying a uniformly distributed pressure over the full span of the supporting walls. The magnitude of the pressure is determined by the weight of the fuel assembly, the axial length of the fuel basket support structure, the width of the cell wall, and the impact acceleration. It is assumed that the load is evenly distributed along an axial length of basket equal to the fuel basket support structure. For example, the pressure applied to an impacted cell wall during a 0-degree side drop event is calculated as follows:

$$p = \frac{a_n W}{L c}$$

where:

p = pressure

a_n = ratio of the impact acceleration to the gravitational acceleration

W = weight of a stored fuel assembly

L = axial length of the fuel basket support structure

c = width of a cell wall

For the case of a 45-degree side drop the pressure on any cell wall equals p (defined above) divided by the square root of 2.

It is evident from the above that the effect of deceleration on the fuel basket and canister metal structure is accounted for by amplifying the gravity field in the appropriate direction.

Internal Pressure

Design internal pressure is applied to the MPC model. The inside surface of the enclosure vessel shell is loaded with pressure. The magnitude of the internal pressure applied to the model is taken from Table 2.2.1.

For this load condition, the center node of the fuel basket is fixed in all degrees of freedom to numerically satisfy equilibrium.

Temperature

Temperature distributions are developed in Chapter 4 and applied as nodal temperatures to the finite element model of the MPC enclosure vessel (confinement boundary). Maximum design heat load has been used to develop the temperature distribution used to demonstrate compliance with ASME Code stress intensity levels.

Analysis Procedure

The analysis procedure for this set of load cases is as follows:

1. The stress intensity and deformation field due to the combined loads is determined by the finite element solution. Results are postprocessed and tabulated in the calculation package associated with this FSAR.

2. The results for each load combination are compared to allowables. The comparison with allowable values is made in Subsection 3.4.4.4.

3.4.4.3.1.2 Analysis of Load Cases E1.a and E1.c (Table 3.1.4)

Since the MPC shell is a pressure vessel, the classical Lame's calculations should be performed to demonstrate the shell's performance as a pressure vessel. We note that dead load has an insignificant effect on this stress state. We first perform calculations for the shell under internal pressure. Subsequently, we examine the entire confinement boundary as a pressure vessel subject to both internal pressure and temperature gradients. Finally, we perform confirmatory hand calculations to gain confidence in the finite element predictions.

The stress from internal pressure is found for normal and accident pressures conditions using classical formulas:

Define the following quantities:

P = pressure, r = MPC radius, and t = shell thickness.

Using classical thin shell theory, the circumferential stress, $\sigma_1 = Pr/t$, the axial stress $\sigma_2 = Pr/2t$, and the radial stress $\sigma_3 = -P$ are computed for both normal and accident internal pressures. The results are given in the following table (conservatively using the outer radius for r):

Classical Shell Theory Results for Normal and Accident Internal Pressures				
Item	**σ_1 (psi)**	**σ_2 (psi)**	**σ_3 (psi)**	**$\sigma_1 - \sigma_3$ (psi)**
P= 100 psi	6838	3419	-100	6938
P= 200 psi	13675	6838	-200	13875

- Finite Element Analysis (Load Case E1.a and E1.c of Table 3.1.4)

The MPC shell, the top lid, and the baseplate together form the confinement boundary (enclosure vessel) for storage of spent nuclear fuel. In this section, we evaluate the operating condition consisting of dead weight, internal pressure, and thermal effects for the hot condition of storage. The top and bottom plates of the MPC enclosure vessel (EV) are modeled using plane axisymmetric elements, while the shell is modeled using the axisymmetric thin shell element. The thickness of the top lid varies in the different MPC types and can be either a single thick lid, or two dual lids welded around their common periphery; the minimum thickness top lid is modeled in the finite element analysis. As applicable, the results for the MPC top lid are modified to account for the fact that in the dual lid configuration, the two lids act independently under mechanical loading. The temperature distributions for all MPC constructions are nearly identical in magnitude and gradient and reflect the thermosiphon effect inside the MPC. Temperature differences across the thickness of both the baseplate and the top lid exist during HI-STORM 100's operations. There is also a thermal gradient from the center of the top lid and baseplate out to the shell wall. The metal temperature profile is essentially parabolic from the centerline of the MPC out to the MPC shell. There is also a parabolic temperature profile along the length of the MPC canister. Figure 3.4.11 shows a sketch of the confinement boundary structure with identifiers A-I locating points where temperature input data is used to represent a continuous temperature distribution for analysis purposes. The overall dimensions of the confinement boundary are also shown in the figure.

The temperatures for confinement thermal stress analysis are determined from the thermal numerical analyses supporting the results in Chapter 4. The MPC-68 is identified to have the maximum through thickness thermal gradients. For conservatism, a bounding temperature profile is defined for all MPC types and used as input for thermal stress analysis. The particular thermal inputs used are for an MPC inside of a HI-STORM 100 or 100S; the corresponding inputs for an MPC inside of a HI-STORM 100S Version B are not bounding. Because of the intimate contact between the two lid plates when the MPC lid is a two-piece unit, there is no significant thermal discontinuity through the thickness; thermal stresses arising in the MPC top lid will be bounding when there is only a single lid. Therefore, for thermal stresses, results from the analysis that considers the lid as a one-piece unit are used and are amplified to reflect the increase in stress in the dual lid configuration.

Figure 3.4.12 shows details of the finite element model of the top lid (considered as a single piece), canister shell, and baseplate. The top lid is modeled with 40 axisymmetric quadrilateral elements; the weld connecting the lid to the shell is modeled by a single element solely to capture the effect of the top lid attachment to the canister offset from the middle surface of the top lid. The MPC canister is modeled by 50 axisymmetric shell elements, with 20 elements concentrated in a short length of shell appropriate to capture the so-called "bending boundary layer" at both the top and bottom ends of the canister. The remaining 10 shell elements model the MPC canister structure away from the shell ends in the region where stress gradients are expected to be of less importance. The baseplate is modeled by 20 axisymmetric quadrilateral elements. Deformation compatibility at the connections is enforced at the top by the single weld element, and deformation and rotation compatibility at the bottom by additional shell elements between nodes 106-107 and 107-108.

The geometry of the model is listed below (terms are defined in Figure 3.4.12):

H_t = 9.5" (the minimum total thickness lid is assumed)

R_L = 0.5 x 67.25" (Bill of Materials for Top Lid)

L_{MPC} = 190.5" (Design Drawings in Section 1.5)

t_s = 0.5"

t_{BP} = 0.5 x 68.375"

β= $2\sqrt{R_s t_s} \approx 12"$ (the "bending boundary layer")

Stress analysis results are obtained for two cases as follows:

a. internal pressure = 100 psi

b. internal pressure = 100 psi plus applied temperatures

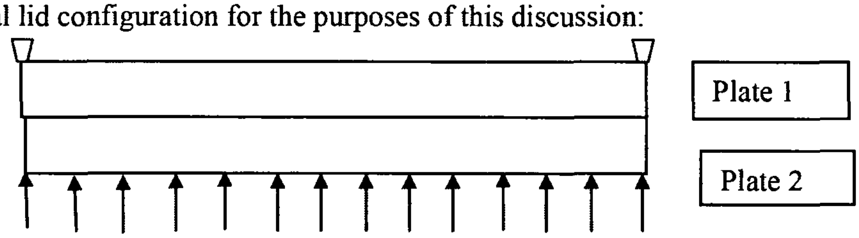
For this configuration, dead weight of the top lid acts to reduce the stresses due to pressure. For example, the equivalent pressure simulating the effect of the weight of the top lid is an external pressure of 3 psi, which reduces the pressure difference across the top lid to 97 psi. The dead weight of the top lid is neglected to provide additional conservatism in the results. The dead weight of the baseplate, however, adds approximately 0.73 psi to the effective internal pressure acting on the base. The effect of dead weight is still insignificant compared to the 100 psi design pressure, and is therefore neglected. The thermal loading in the confinement vessel is obtained by developing a parabolic temperature profile to the entire length of the MPC canister and to the top lid and baseplate. The temperature data provided at locations A-I in Figure 3.4.11 and 3.4.12 are sufficient to establish the profiles. Through-thickness temperatures are assumed linearly interpolated between top and bottom surfaces of the top lid and baseplate. Finally, in the analysis, all material properties and expansion coefficients are considered to be temperature-dependent in the model.

Results for stress intensity are reported for the case of internal pressure alone and for the combined loading of pressure plus temperature (Load Case E1.c in Table 3.1.4). Tables 3.4.7 and 3.4.8 report results at the inside and outside surfaces of the top lid and baseplate at the centerline and at the extreme radius. Canister results are reported in the "bending boundary layer" and at a location near mid-length of the MPC canister. In the tables, the calculated value is the value from the finite element analysis, the categories are P_m = primary membrane; $P_L + P_b$ = local membrane plus primary bending; and $P_L + P_b + Q$ = primary plus secondary stress intensity. The allowable strength value is obtained from the appropriate table in Section 3.1 for Level A conditions, and the safety factor SF is defined as the allowable strength divided by the calculated value. Allowable strengths for Alloy X are taken at 550 degrees F, 400 degrees F, and 500 degrees F, respectively, for the MPC lid, baseplate, and canister shell. The results given in Tables 3.4.7 and 3.4.8 demonstrate the ruggedness of the MPC as a confinement boundary. Since mechanically induced stresses in the top lid are increased when a dual lid configuration is considered, the stress results obtained from an analysis of a single top lid must be corrected to reflect the maximum stress state when a dual lid configuration is considered. The modifications required are based on the following logic:

Consider the case of a simply supported circular plate of thickness h under uniform lateral pressure "q". Classical strength of materials provides the solution for the maximum stress, which occurs at the center of the plate, in the form:

$\sigma_s = 1.225q(a/h)^2$ where a is the radius of the plate and h is the plate thickness.

Now consider the MPC simply supported top lid as fabricated from two plates "1" and "2", of thickness h_1 and h_2, respectively, where the lower surface of plate 2 is subjected to the internal pressure "q", the upper surface of plate 1 is the outer surface of the helium retention boundary, and the lower surface of plate 1 and the upper surface of plate 2 are in contact. The following sketch shows the dual lid configuration for the purposes of this discussion:



From classical plate theory, if it is assumed that the interface pressure between the two plates is uniform and that both plates deform to the same central deflection, then if

$h_1+h_2=h$, and if $h_2/h_1=r$

the following relations exist between the maximum stress in the two individual plates, σ_1, σ_2 and the maximum stress σ_s in the single plate of thickness "h" (assuming that all three plates are the same material):

$$\frac{\sigma_1}{\sigma_s}=\frac{(1+r)^2}{(1+r^3)} \qquad \frac{\sigma_2}{\sigma_s}=\frac{(1+r)^2}{(1+r^3)}r$$

Since the two lid thicknesses are the same in the dual lid configuration, r = 1.0 so that the stresses in plates 1 and 2 are both two times larger than the maximum stress computed for the single plate lid having the same total thickness. In Tables 3.4.7 and 3.4.8, bounding results for the single lid configuration are reported; a doubling of the calculated stress values (and a halving of the top lid safety factors) results when the dual lid configuration is considered.

Per the design drawings in Section 1.5, the top plate in the dual lid configuration is stainless steel (Alloy X), and the bottom plate is fabricated from stainless steel or carbon steel with a stainless steel covering. Although the top and bottom plates may be different materials, the stress amplification factor of 2, which is used to convert the results from the one-piece MPC lid to the dual lid configuration as explained above, is conservative since carbon steel has a higher Young's modulus than stainless steel. Therefore, the carbon steel bottom plate would be stiffer, and the stress in the top plate would be less versus the dual lid configuration with stainless steel top and bottom plates.

- Evaluation of MPC Baseplate Alternate Support Configuration

The stress state in the MPC baseplate and adjacent canister is evaluated to assess the effect of the discrete support of the MPC under the action of vertical loading plus pressure and temperature. The alternate MPC supports consist of bearing pads (shims) at six locations around the periphery plus a central support to transfer vertical loads to the HI-STORM. The baseplate of the MPC has been previously analyzed under loading from the fuel basket and the fuel assemblies assuming the baseplate plate continuously supported around the periphery by the MPC canister shell (e.g., this condition arises during lifting and lowering of the MPC into the storage overpack). To evaluate the effect of a discrete support configuration, a finite element model of ½ of the baseplate is constructed using shell elements and includes a sufficient portion of the MPC canister to simulate the canister-to-baseplate joint and the bending boundary layer in the canister shell. Vertical loads from fuel assemblies and fuel basket are applied to the baseplate as a uniform pressure and a ring loading, respectively (these loads have been applied in the same manner in the evaluation of the baseplate under the MPC lowering condition for HI-STORM 100 system). The total vertical load is resisted at the peripheral and central discrete support locations. Under normal conditions of storage, the baseplate/canister is subject to normal service pressure and temperature plus the one-g dead weight loading. The state of stress in the MPC under design pressure and normal operating temperature has been previously considered using an axi-symmetric finite element model, and the results are discussed above (see "Finite Element Analysis") and summarized in Tables 3.4.7 and 3.4.8 (Level A condition). In Table 3.4.8, although the actual metal temperatures were used to develop the solution for the thermal stresses, the allowable stresses were conservatively chosen at the design temperature rather than at the actual operating temperature as befits a Level A analysis.

The stress intensities arising in the MPC baseplate and in the lower portion of the canister from the added vertical load are added to the previously determined stress intensities arising from internal pressure and temperature (reported in Table 3.4.8 and adjusted downward for actual service pressure) to obtain the total stress intensity for the Level A normal operating condition. The computed stress intensities are then amplified to simulate the vertical seismic event and again summed with the results from Table 3.4.8 to obtain the total stress intensity for the Level D condition.

The primary and secondary stress intensities in the MPC baseplate and canister shell are computed for the Level A normal operating condition. The maximum primary stress intensity in the MPC baseplate is also determined for the Level D vertical seismic event. All computed safety factors are above 1.0.

3.4.4.3.1.3 Elastic Stability and Yielding of the MPC Basket under Compression Loads (Load Case F3 in Table 3.1.3)

This load case corresponds to the scenario wherein the loaded MPC is postulated to drop causing a compression state in the fuel basket panels.

a. Elastic Stability

Following the provisions of Appendix F of the ASME Code [3.4.3] for stability analysis of Subsection NG structures, (F-1331.5(a)(1)), a comprehensive buckling analysis is performed using ANSYS. For this analysis, ANSYS's large deformation capabilities are used. This feature allows ANSYS to account for large nodal rotations in the fuel basket, which are characteristic of column buckling. The interaction between compressive and lateral loading, caused by the deformation, is exactly included. Subsequent to the large deformation analysis, the basket panel that is most susceptible to buckling failure is identified by a review of the results. The lateral displacement of a node located at the mid-span of the panel is measured for the range of impact decelerations. The buckling or collapse load is defined as the impact deceleration for which a slight increase in its magnitude results in a disproportionate increase in the lateral displacement.

The stability requirement for the MPC fuel basket under lateral loading is satisfied if two-thirds of the collapse deceleration load is greater than the design basis horizontal acceleration (Table 3.1.2). This analysis was performed for the HI-STAR 100 submittal (Docket Number 72-1008) under a 60g deceleration loading. Within the HI-STAR 100 FSAR (Docket Number 72-1008), Figures 3.4.27 through 3.4.32 are plots of lateral displacement versus impact deceleration for the MPC-24, MPC-32, and MPC-68. It should be noted that the displacements (in the HI-STAR 100 FSAR) in Figures 3.4.27 through 3.4.31 are expressed in 1×10^{-1} inch and Figure 3.4.32 is expressed in 1×10^{-2} inch. The plots in the HI-STAR 100 FSAR clearly show that the large deflection collapse load of the MPC fuel basket is greater than 1.5 times the design basis deceleration for all baskets in all orientations. The results for the MPC-24E are similar. Thus, the requirements of Appendix F are met for lateral deceleration loading under Subsection NG stress limits for faulted conditions.

An alternative solution for the stability of the fuel basket panel is obtained using the methodology espoused in NUREG/CR-6322 [3.4.13]. In particular, we consider the fuel basket panels as wide plates in accordance with Section 5 of NUREG/CR-6322. We use eq.(19) in that section with the "K" factor set to the value appropriate to a clamped panel. Material properties are selected corresponding to a metal temperature of 600 degrees F which bounds computed metal temperatures at the periphery of the basket. In general, the basket periphery sees the largest loading in an impact scenario. The critical buckling stress is:

$$\sigma_{cr} = \left(\pi / K \right)^2 \frac{E}{12\left(1-\nu^2\right)} \left(\frac{h}{a} \right)^2$$

where h is the panel thickness, a is the unsupported panel length, E is the Young's Modulus of Alloy X at 600 degrees F, ν is Poisson's Ratio, and K=0.65 (per Figure 6 of NUREG/CR-6322).

The MPC-24 has a small h/a ratio; the results of the finite element stress analyses under design basis deceleration load show that this basket is subject to the highest compressive load in the panel. Therefore, the critical buckling load is computed using the geometry of the MPC-24. The following table shows the results from the finite element stress analysis and from the stability calculation.

Panel Buckling Results From NUREG/CR-6322			
Item	**Finite Element Stress (ksi)**	**Critical Buckling Stress (ksi)**	**Factor of Safety**
Stress	12.585	44.44	3.531

For a stainless steel member under an accident condition load, the recommended safety factor is 2.12. We see that the calculated safety factor exceeds this value; therefore, we have independently confirmed the stability predictions of the large deflection analysis based on classical plate stability analysis by employing a simplified method.

Stability of the basket panels, under longitudinal deceleration loading, is demonstrated in the following manner. Under 60g deceleration in Docket Number 71-9261, the axial compressive stress was computed for all fuel basket types, and the bounding result was determined as:

4,074 psi (for MPC 24E)

For the 45g design basis decelerations for HI-STORM 100, the basket axial stresses are reduced by 25%.

The above values represent the amplified weight, including the nonstructural sheathing and the neutron absorber material, divided by the bearing area resisting axial movement of the basket. To demonstrate that elastic instability is not a concern, the buckling stress for an MPC-24 flat panel is computed.

For elastic stability, Reference [3.4.8] provides the formula for critical axial stress as

$$\sigma_{cr} = \frac{4\,\pi^2 E}{12\,(1-\nu^2)} \left(\frac{T}{W}\right)^2$$

where T is the panel thickness and W is the width of the panel, E is the Young's Modulus at the metal temperature and ν is the metal Poisson's Ratio. The following table summarizes the calculation for the critical buckling stress using the formula given above:

Elastic Stability Result for a Flat Panel	
Reference Temperature	725 degrees F
T (MPC-24)	5/16 inch
W	10.777 inch
E	24,600,000 psi
Critical Axial Stress	74,781 psi

It is noted the critical axial stress is an order of magnitude greater than the computed basket axial stress reported in the foregoing and demonstrates that elastic stability under longitudinal deceleration load is not a concern for any of the fuel basket configurations.

b. Yielding

The safety factor against yielding of the basket under longitudinal compressive stress from a design basis inertial loading is given, using the bounding result for the MPC-24E, by

SF = 17,100/4,074 = 4.197

Therefore, plastic deformation of the fuel basket under design basis deceleration is not credible.

3.4.4.3.1.4 <u>MPC Baseplate Analysis (Load Case E2)</u>

Minimum safety factors have been reported for Load Case E2 in Subsection 3.4.3.6 where an evaluation has been performed for stresses under three times the apparent load D*. A bounding analysis is performed in the HI-STAR 100 FSAR (Docket Number 72-1008, Appendix 3.I) to evaluate the stresses in the MPC baseplate during a vertical end drop (Load Case E3.a). During a fire (Load Case E5), the MPC baseplate is subjected to the accident internal pressure, dead load, and the fire temperature (which serves only to lower the allowable strengths). The results for Load Cases E3.a and E5 are summarized below:

MPC Baseplate Minimum Safety Factors – Load Cases E3.a and E5			
Item	Value (ksi)	Allowable (ksi)	Safety Factor
Center of Baseplate – Primary Bending (Load Case E3.a) (Note 1)	35.93	67.32	1.87
Center of Baseplate – Primary Bending (Load Case E5)	46.38	54.23	1.17

Notes:

1. Detailed analysis presented in Appendix 3.I of HI-STAR 100 FSAR (Docket 72-1008).

3.4.4.3.1.5 Analysis of the MPC Top Closure (Load Case E2)

The FSAR for the HI-STAR 100 System (Docket Number 72-1008, Appendix 3.E) contains stress analysis of the MPC top closure during lifting. Loadings in that analysis are also valid for the HI-STORM 100 System. From Table 2.2.1, the off-normal design internal pressure is 110 psi, or ten percent greater than the normal design pressure. Whereas Level A service limits are used to establish allowables for the normal design pressure, Level B service limits are used for off-normal loads. Since Subsection NB of the ASME Code permits an identical 10% increase in allowable stress intensity values for primary stress intensities generated by Level B Service Loadings, it stands to reason that the safety factors reported for normal pressure are also valid for the case of off-normal design internal pressure.

3.4.4.3.1.6 Structural Analysis of the Fuel Support Spacers (Load Case E3.a)

Upper and lower fuel support spacers are utilized to position the active fuel region of the spent nuclear fuel within the poisoned region of the fuel basket. It is necessary to ensure that the spacers will continue to maintain their structural integrity after an accident event. Ensuring structural integrity implies that the spacer will not buckle under the maximum compressive load, and that the maximum compressive stress will not exceed the compressive strength of the spacer material (Alloy X). Detailed calculations in Docket Number 72-1008, Appendix 3.J, demonstrate that large structural margins in the fuel spacers are available for the entire range of spacer lengths which may be used in HI-STORM 100 applications (for the various acceptable fuel types). The calculations for the HI-STORM 100 45g load are bounded by those for the HI-STAR 100 60g load.

3.4.4.3.1.7 External Pressure (Load Case E1.b, Table 3.1.4)

The design external pressure for the MPC is zero psig. The outer surface of the MPC shell is conservatively subject to a net external pressure of 2 psig. The methodology for analysis of the MPC under this external pressure is provided in the HI-STAR 100 FSAR Docket Number 72-1008. Using the identical methodology with input loads and decelerations appropriate to the HI-STORM, safety factors > 1.0 are obtained for all relevant load cases.

3.4.4.3.1.8 Miscellaneous MPC Structural Evaluations

Calculations are performed to determine the minimum fuel basket weld size, the capacity of the sheathing welds, the stresses in the MPC cover plates, and the stresses in the fuel basket supports. The following paragraphs briefly describe each of these evaluations.

The fillet welds in the fuel basket honeycomb are made by an autogenous operation that has been shown to produce highly consistent and porosity free weld lines. However, Subsection NG of the ASME Code permits only 40% quality credit on double fillet welds which can be only visually examined (Table NG-3352-1). Subsection NG, however, fails to provide a specific stress limit on such fillet welds. In the absence of a Code mandated limit, Holtec International's standard design procedure requires that the weld section possess as much load resistance capability as the parent metal section. Since the loading on the honeycomb panels is essentially that of section bending, it is possible to develop a closed form expression for the required weld throat thickness "t" corresponding to panel thickness "h".

The sheathing is welded to the fuel basket cell walls to protect and position the neutron absorber material. Force equilibrium relationships are used to demonstrate that the sheathing weld is adequate to support a 45g deceleration load applied vertically and horizontally to the sheathing and the confined neutron absorber material. The analysis assumes that the weld is continuous and then modifies the results to reflect the amplification due to intermittent welding.

The MPC cover plates are welded to the MPC lid during loading operations. The cover plates are part of the confinement boundary for the MPC. No credit is taken for the pressure retaining abilities of the quick disconnect couplings for the MPC vent and drain. Therefore, the MPC cover plates must meet ASME Code, Section III, Subsection NB limits for normal, off-normal, and accident conditions. Conservatively, the accident condition pressure loading is applied, and it is demonstrated that the Level A limits for Subsection NB are met where possible.

The fuel basket internal to the MPC canister is supported by a combination of angle fuel basket supports and flat plate or solid bar fuel basket supports. These fuel basket supports are subject to significant load only when a lateral acceleration is applied to the fuel basket and the contained fuel. The quasi-static finite element analyses of the MPC's, under lateral inertia loading, focused on the structural details of the fuel basket and the MPC shell. Basket supports were modeled in less detail, which served only to properly model the load transfer path between fuel basket and canister. Safety factors reported for the fuel basket supports from the finite element analyses, are overly conservative, and do not reflect available capacity of the fuel basket angle support. A strength of materials analysis of the fuel basket angle supports is performed to complement the finite element results. Weld stresses in the load path are computed, direct stress in the support members is evaluated, and stability of the support legs is examined for all fuel basket support configurations.

The results of these evaluations are summarized in the tables below.

Minimum Weld Sizes for Fuel Baskets			
Basket Type	**Panel Thickness (h), in**	**t/h Ratio**	**Minimum Weld Size (t), in**
MPC-24	5/16	0.566	0.177
MPC-68	1/4	0.522	0.130
MPC-32	9/32	0.578	0.163
MPC-24E	5/16	0.516	0.161

Miscellaneous Stress Results for MPC			
Item	**Stress (ksi)**	**Allowable Stress (ksi)**	**Safety Factor**
Shear Stress in Sheathing Weld	7.724	27.93	3.62
Bending Stress in MPC Cover Plate (Level A)	14.08	25.425	1.81
Bending Stress in MPC Cover Plate (Level D)	28.16	61.02	2.17
Shear Stress in MPC Cover Plate Weld	7.55	18.99	2.52
Shear Stress in Fuel Basket Support Weld	19.78	26.67	1.35
Combined Stress in Fuel Basket Support Plates	32.393	59.1	1.82
Load in Basket Support Legs (Stability)	2.185 kips/in	8.886 kips/in	4.07

3.4.4.3.1.9 Structural Integrity of Damaged Fuel Containers

The damaged fuel containers or canisters (DFCs) to be deployed in the HI-STAR 100 System transport package have been evaluated to demonstrate that the containers are structurally adequate to support the mechanical loads postulated during normal operations, while in long-term storage, and during a hypothetical end drop. The evaluations address the following damaged/failed fuel containers for transportation in the HI-STAR 100 System:

- Holtec-designed MPC-24E (PWR) DFC
- Holtec-designed MPC-68 (BWR) DFC
- Transnuclear-designed DFC for Dresden Unit 1 fuel
- Transnuclear-designed Thoria Rod Canister for Dresden Unit 1

The structural load path in each of the analyzed containers is evaluated using basic strength of materials formulations. The various structural components are modeled as axial or bending members and their stresses are computed. Depending on the particular DFC, the load path includes components such as the container sleeve and collar, various weld configurations, load tabs, closure components and lifting bolts. Axial plus bending stresses are computed, together with applicable bearing stresses and weld stresses. Comparisons are then made with the appropriate allowable strengths at temperature. Input data for all DFCs comes from the applicable drawings. The design temperature for lifting evaluations is set at 150°F (since the DFC is in the spent fuel pool). The design temperature for accident conditions is set at 725°F.

*For those DFCs designed to be handled when loaded, t*he DFC lift point(s) must be designed in accordance with Item 3 in Section 5.1.6 of NUREG-0612 [3.1.1]. The remaining components of the damaged fuel container are governed by the stress limits of the ASME Code Section III, Subsection NG [3.4.10] and Section III, Appendix F [3.4.3], as applicable.

The following table presents the minimum safety factors, from all of the stress computations, for each of the above listed DFCs.

DFC Type	Loading Condition – DFC Component	Calculated Stress (ksi)	Allowable Stress (ksi)	Safety Factor = (Allowable Stress) / (Calculated Stress)	Remarks
Holtec-designed MPC-24E (PWR) DFC					
	60g End Drop – Baseplate-to-Container Sleeve Welds	3.95	26.59	6.73	ASME Level D stress limit
Holtec-designed MPC-68 (BWR) DFC					
	60g End Drop – Baseplate-to-Container Sleeve Welds	1.59	26.59	16.7	ASME Level D stress limit
Transnuclear-designed DFC for Dresden Unit 1	Normal Lift – Lid Frame Assembly	0.527	4.583	8.70	Bearing stress
	60g End Drop – Bottom Assembly	12.32	37.92	3.08	ASME Level D stress limit
Transnuclear-designed Thoria Rod Canister for Dresden Unit 1	Normal Lift – Lid Frame Assembly	0.373	4.583	12.3	Bearing stress
	60g End Drop – Bottom Assembly	8.73	37.92	4.34	ASME Level D stress limit

The table above demonstrates that the DFCs are structurally adequate to support the mechanical loads postulated during normal operations and during a hypothetical end drop. Moreover, since the HI-STAR design basis handling accident bounds the corresponding load for HI-STORM (60g vs. 45g), the DFCs can be carried safely in both the HI-STAR and HI-STORM Systems.

3.4.4.3.1.10 Analysis of MPC Baseplate and Closure Lid (Load Case E5)

During a fire (Load Case E5), the MPC baseplate is subjected to the accident pressure plus dead load, and the fire temperature (which serves only to lower the allowable strengths). The results of this analysis are summarized below:

MPC Baseplate Minimum Safety Factors – Load Cases E5			
Item	Value (ksi)	Allowable (ksi)	Safety Factor
Center of Baseplate – Primary Bending (Load Case E5)	46.32	54.23	1.17

The closure lid and the closure lid peripheral weld are also examined for maximum stresses developed during the storage fire. The closure lid is modeled as a single simply supported plate and is subject to dead load plus accident internal pressure. Results are presented for both the single and dual lid configuration (in parentheses). The results for minimum safety factor are reported in the table below:

MPC Top Closure Lid – Minimum Safety Factors – Load Case E5			
Item	Stress (ksi) or Load (lb.)	Allowable Stress (ksi) or Load Capacity (lb.)	Safety Factor
Lid Bending Stress – Load Case E5	3.158/(6.316)	54.225	17.17/(8.58)
Lid-to-Shell Peripheral Weld Load – Load Case E5	713,047	1,477,000†	2.07

† Based on 0.625" single groove weld and conservatively includes a quality factor of 0.45.

We note from the above that all safety factors are greater than 1.0.

3.4.4.3.2 HI-STORM 100 Storage Overpack Stress Calculations

The structural functions of the storage overpack are stated in Section 3.1. The analyses presented here demonstrate the ability of components of the HI-STORM 100 storage overpack to perform their structural functions in the storage mode. Load Cases considered are given in Table 3.1.5. The nomenclature used to identify the load cases (Load Case Identifier) considered is also given in Table 3.1.5.

The purpose of the analyses is to provide the necessary assurance that there will be no unacceptable release of radioactive material, unacceptable radiation levels, or impairment of ready retrievability of the MPC from the storage overpack. Results obtained using the HI-STORM 100 configuration are identical to or bound results for the HI-STORM 100S configuration.

3.4.4.3.2.1 HI-STORM 100 Compression Under the Static Load of a Fully Loaded HI-TRAC Positioned on the Top of HI-STORM 100 (Load Case 01 in Table 3.1.5)

During the loading of HI-STORM 100, a HI-TRAC transfer cask with a fully loaded MPC may be placed on the top of a HI-STORM 100 storage overpack. During this operation, the HI-TRAC may be held by a single-failure-proof lifting device so a handling accident is not credible. The HI-STORM 100 storage overpack must, however, possess the compression capacity to support the additional dead load. The following analysis provides the necessary structural integrity demonstration; safety factors are large and results for the HI-STORM 100 overpack are representative of the margins for the 100S and 100S Version B overpacks.

Define the following quantities for analysis purposes:

W_{HT} = Bounding weight of HI-TRAC 125D (loaded w/ MPC-32) = 236,000 lb (Table 3.2.2)

W_{MD} = Weight of mating device = 15,000 lb

$W_{TOTAL} = W_{HT} + W_{MD}$ = 251,000 lb

The total weight of the HI-TRAC 125D plus the mating device is greater than the weight of a loaded HI-TRAC 125 with the transfer lid. Therefore, the following calculations use the weight for the HI-TRAC 125D as input.

The dimensions of the compression components of HI-STORM 100 are as follows:

outer diameter of outer shell =	D_o = 132.5"
thickness of outer shell =	t_o = 0.75" (1" for HI-STORM 100S Version B)
outer diameter of inner shell =	D_i = 76"
thickness of inner shell =	t_i = 1.25" (1" for HI-STORM 100S Version B)
thickness of radial ribs =	t_r = 0.75" (ribs are not full-length for HI-STORM 100S Version B; HI-STORM 100S can be fabricated with full or partial length ribs)

In what follows, detailed results are provided using the classic HI-STORM 100 dimensions. While Bill of Material 1575 provides the option to fabricate the inner and outer shells from 1" thick material, the above dimensions (i.e., t_o and t_i) are used because they minimize the total cross sectional metal area.

The metal area of the outer shell is

$$A_o = \frac{\pi}{4}(D_o^2 - (D_o - 2\,t_o)^2) = \frac{\pi}{4}(132.5^2 - 131^2)$$
$$= 310.43\ in^2$$

The metal area of the radial ribs is

$$A_r = 4\,t_r\,(D_o - 2\,t_o - D_i)/2 = \frac{3}{2}(131 - 76) = 82.5\ in^2$$

The metal area of the inner shell is

$$A_i = \frac{\pi}{4}(76^2 - 73.5^2) = 293.54 \quad in^2$$

In the HI-STORM 100, there are four radial ribs that extend full length and can carry load. For the HI-STORM 100S and the HI-STORM 100S Version B, the radial ribs are not counted as part of the compression load carrying area since they are not required to be full-length. The concrete radial shield can also support compression load. The area of concrete available to support compressive loading is

$$A_{concrete} = \frac{\pi}{4}((D_o - 2\,t_o)^2 - (D_i)^2) - A_r$$
$$= \frac{\pi}{4}(131^2 - 76^2)\ - 82.5\ in^2$$
$$= (8{,}994 - 82.5)\ in^2 = 8{,}859.5\ in^2$$

The areas computed above are calculated at a section below the air outlet vents. To correct the above areas for the presence of the air outlet vents (HI-STORM 100 only since HI-STORM 100S and HI-STORM 100S, Version B have the air outlet vents located in the lid), we note that Bill-of-Materials 1575 in Chapter 1 gives the size of the horizontal plate of the air outlet vents as:

Peripheral width = w = 16.5"
Radial depth = d = 27.5" (over concrete in radial shield)

Using these values, the following final areas are obtained:

$A_o = A_o(\text{no vent}) - 4t_o w = 260.93$ sq. inch

$A_i = A_i(\text{no vent}) - 4t_i w = 211.04$ sq. inch

$A_{concrete} = A_{concrete}(\text{no vent}) - 4dw = 7044.2$ sq. inch

The loading case is a Level A load condition. The load is apportioned to the steel and to the concrete in accordance with the values of EA for the two materials (E(steel) = 28,000,000 psi and E(concrete)=3,605,000 psi).

$$\begin{aligned} EA(\text{steel}) &= 28 \, x \, 10^6 \, \text{psi} \, x \, (260.93 + 211.04 + 82.5) \, \text{in}^2 \\ &= 15{,}525.2 \, \text{lb} \, x \, 10^6 \, \text{lbs}. \end{aligned}$$

$$\begin{aligned} EA(\text{concrete}) &= 3.605 \text{ x } 10^6 \text{ x } (7044.2) \text{ in}^2 \\ &= 25{,}394.3 \text{ x } 10^6 \text{ lb}. \end{aligned}$$

Therefore, the total HI-TRAC load will be apportioned as follows:

$F_{STEEL} = (15{,}525.2/40{,}919.5) \text{ x } 251{,}000 = 95{,}231.5$ lb.

$F_{CONCRETE} = (25{,}394.3/40{,}919.5) \text{ x } 251{,}000 = 155{,}768.5$ lb.

Therefore, if the load is apportioned as above, with all load-carrying components in the path acting, the compressive stress in the steel is

If we conservatively neglect the compression load bearing capacity of concrete, then

$$\sigma_{STEEL} = \frac{251{,}000}{554.5} = 452.7 \text{ psi}$$

If we include the concrete, then the maximum compressive stress in the concrete is:

$$\sigma_{CONCRETE} = \frac{F_{CONCRETE}}{A_{CONCRETE}} = 22.1 \text{ psi}$$

It is clear that HI-STORM 100 storage overpack can support the dead load of a fully loaded HI-TRAC 125D and the mating device placed on top for MPC transfer into or out of the HI-STORM 100 storage overpack cavity. The calculated stresses at a cross-section through the air outlet ducts are small and give rise to large factors of safety. The metal cross-section at the base of the HI-STORM storage overpack will have a slightly larger metal area (because the width of the air-inlet ducts is smaller) but will be subject to additional dead load from the weight of the supported metal components of the HI-STORM storage overpack plus the loaded HI-TRAC weight. At the base of the storage overpack, the additional stress in the outer shell and the radial plates is due solely to the weight of the component. Based on the maximum concrete density, the additional stress in these components is computed as:

$\Delta\sigma$ = (200lb./cu.ft.) x 18.71 ft./144 sq.in./sq.ft. = 26.0 psi

This stress will be further increased by a small amount because of the material cut away by the air-inlet ducts; however, the additional stress still remains small. The inner shell, however, is subject to additional loading from the top lid of the storage overpack and from the radial shield. From the Structural Calculation Package (HI-981928)(see Subsection 3.6.4 for the reference), and from Table 3.2.1, the following weights are obtained (for conservatism, use the 100S, Version B lid weight with 200 pcf concrete even though the shell geometry is for the classic HI-STORM 100):

HI-STORM 100S, Version B Top Lid weight < 29,000 lb.
HI-STORM 100 Inner Shell weight < 19,000 lb.
HI-STORM 100 Shield Shell weight < 11,000 lb.

Note that the shield shell was removed from the HI-STORM 100 design as of June 2001. However, it is conservative to include the shield shell weight in the following calculations.

Using the calculated inner shell area at the top of the storage overpack for conservatism, gives the metal area of the inner shell as:

$A_i = A_i(\text{no vent}) - 4t_iw$ = 211.04 sq. inch

Therefore, the additional stress from the HI-STORM 100S, Version B storage overpack components, at the base of the overpack, is:

$\Delta\sigma$ = 280 psi

and a maximum compressive stress in the inner shell predicted as:

Maximum stress = 453 psi + 280 psi = 733 psi

The safety factor at the base of the storage overpack inner shell (minimum section) is

SF = 17,500psi/733 psi = 23.9

The preceding analysis is bounding for the 100 Ton HI-TRAC transfer cask because of the lower HI-TRAC weight.

The preceding analysis is representative of all overpacks since the bounding lid weight from the Version B has been used. Based on the computed safety factor, it is concluded that all versions of the HI-STORM 100 and HI-STORM 100S can safely support the heaviest HI-TRAC while performing a vertical fuel transfer operation.

3.4.4.3.2.2 HI-STORM 100 Lid Integrity Evaluation (Load Case 02.c, Table 3.1.5)

A non-mechanistic tip over of the HI-STORM 100 results in high decelerations at the top of the storage overpack. The storage overpack lid diameter is less than the storage overpack outer diameter. This ensures that the storage overpack lid does not directly strike the ground but requires analysis to demonstrate that the lid remains intact and does not separate from the body of the storage overpack. Figure 3.4.19 shows the scenario.

The HI-STORM 100 overpack has two lid designs, which rely on different mechanisms to resist separation from the overpack body. The original design relies solely on the lid studs to resist the shear and axial loads on the lid. In the new design, the bolt holes are enlarged and a shear ring is welded to the underside of the lid top plate. These changes insure that the lid studs only encounter axial (tensile) loads. The in-plane load is resisted by the shear ring as it bears against the top plate. The HI-STORM 100S and the HI-STORM 100S, Version B has only one lid design, which utilizes a shear ring. Calculations have been performed for both HI-STORM 100 lid configurations, as well as the HI-STORM 100S and the HI-STORM 100S, Version B lid geometry, to demonstrate that the lid can withstand a non-mechanistic tip-over.

The deceleration level for the non-mechanistic tip-over bounds all other decelerations, directed in the plane of the lid, experienced under other accident conditions such as flood or earthquake as can be demonstrated by evaluating the loads resulting from these natural phenomena events.

It is shown that the weight of the HI-STORM 100 lid, amplified by the design basis deceleration, can be supported entirely by the shear capacity available in the four studs†. If only a single stud is loaded initially during a tipover (because of tolerances), the stud hole will enlarge rather than the stud fail in shear. Therefore, it is assured that all four bolts will resist the tipover load regardless of the initial position of the HI-STORM 100 lid.

The following tables summarize the limiting results obtained from the detailed analyses, and from the similar detailed analysis for the HI-STORM 100 lid with shear ring, for the HI-STORM 100S(243), and for the HI-STORM 100S, Version B(229). The results for the longer HI-STORM 100S and HI-STORM 100S, Version B bound the corresponding results for the shorter versions of these units.

† The tip-over event is non-mechanistic by definition since the HI-STORM 100 System is designed to preclude tip-over under all normal, off-normal, and accident conditions of storage, including extreme natural phenomena events. Thus, the tip-over event cannot be categorized as an operating or test condition as contemplated by ASME Section III, Article NCA-2141. The bolted connection between the overpack top lid and the overpack body provided by the top lid studs and nuts serves no structural function during normal or off-normal storage conditions, or for credible accident events. Therefore, the ASME Code does not apply to the construction of the HI-STORM top plate-to-overpack connection (the lid studs, nuts, and the through holes in the top plate). However, for conservatism, the stress limits from ASME III, Subsection NF are used for the analysis of the lid bolts.

HI-STORM 100 Top Lid Integrity (No Shear Ring)			
Item	Value (ksi)	Allowable (ksi)	Safety Factor
Lid Shell-Lid Top Plate Weld Shear Stress	6.733	29.4	4.367
Lid Shell-Lid Top Plate Combined Stress	9.11	29.4	3.226
Attachment Bolt Shear Stress	44.82	60.9	1.359
Attachment Bolt Combined Shear and Tension Interaction at Interface with Anchor Block	-------	------	1.21

HI-STORM 100 Top Lid Integrity (With Shear Ring)			
Item	Value (ksi)	Allowable (ksi)	Safety Factor
Lid Top Plate-to-Lid Shell Weld Combined Stress	7.336	29.4	4.007
Shield Block Shells-to-Lid Top Plate Weld Combined Stress	1.768	29.4	16.63
Attachment Bolt Tensile Stress	28.02	107.13	3.823
Shear Ring-to-Lid Top Plate Weld Stress	32.11	40.39	1.258
Shear Ring Bearing Stress	25.43	63.0	2.477
Top Plate-to-Outer Shell Weld Stress	35.61	40.39	1.134

HI-STORM 100S(243) Top Lid Integrity†			
Item	Value (ksi)	Allowable (ksi)	Safety Factor
Inner and Outer Shell Weld to Base	17.61	29.4	1.669
Shield Block Shell-to-Lid Weld Shear Stress	7.692	29.4	3.822
Attachment Bolt Tensile Stress	37.38	107.13	2.866
Shear Ring-to-Overpack Shell Weld Stress	33.24	42.0	1.264
Shear Ring Bearing Stress	19.36	63.0	3.254
Lid Shield Ring-to-Shear Ring Weld Stress	20.95	42.0	2.004

† Results are based on a bounding weight of 28,000 lb for the HI-STORM 100S top lid.

HI-STORM 100S, Version B(229) Top Lid Integrity†			
Item	**Value (ksi)**	**Allowable (ksi)**	**Safety Factor**
Lid Outer Ring to Lid Shield Ring Weld	26.15	30.3	1.159
Shield Block Shell-to-Lid Weld Shear Stress	26.94	30.3	1.125
Attachment Bolt Tensile Stress	41.563	107.13	2.578
Shear Ring-to-Overpack Shell Weld Stress	30.57	42.0	1.374
Shear Ring Bearing Stress	20.59	63.0	3.06
Lid Shield Ring-to-Shear Ring Weld Stress	32.36	42.0	1.298

† Results are based on a bounding weight of 29,000 lb for the HI-STORM 100S, Version B top lid.

3.4.4.3.2.3 Vertical Drop of HI-STORM 100 Storage Overpack (Load Case 02.a of Table 3.1.5)

A loaded HI-STORM 100, with the top lid in place, drops vertically and impacts the ISFSI. Figure 3.4.20 illustrates the drop scenario. The regions of the structure that require detailed examination are the storage overpack top lid, the inlet vent horizontal plate, the pedestal shield, the inlet vent vertical plate, and all welds in the load path. These components are examined for the Level D event of a HI-STORM 100 drop developing the design basis deceleration.

The table provided below summarizes the results of the analyses for the weight and configuration of the HI-STORM 100. The results for the HI-STORM 100S are bounded by the results given below. Any calculation pertaining to the pedestal is bounding since the pedestal dimensions and corresponding weights are less in the HI-STORM 100S. The HI-STORM 100S, Version B, however, has sufficient differences in configuration to merit a separate evaluation using similar analyses; therefore, a separate summary table of results is provided for the HI-STORM 100S, Version B.

HI-STORM 100 Load Case 02.a Evaluation			
Item	**Value (ksi)**	**Allowable (ksi)**	**Safety Factor**
Lid Bottom Plate Bending Stress Intensity	6.00	58.7	9.777†
Lid Bottom Plate Collapse Load	10450x1.06 (in.*lb./in.)	12730 (in.*lb./in.)	1.15†
Weld- lid bottom plate-to-lid shell	10.91	29.4	2.695
Lid Shell – Membrane Stress Intensity	1.90	39.1	20.58
Lid Top (2" thick) Plate Bending Stress Intensity	11.27	58.7	5.208*
Inner Shell –Membrane Stress Intensity	11.46	39.1	3.41
Outer Shell –Membrane Stress Intensity	3.401	39.1	11.495
Inlet Vent Horizontal Plate Bending Stress Intensity	46.20	58.7	1.271
Inlet Vent Vertical Plate Membrane Stress Intensity	12.86	39.1	3.04
Pedestal Shield – Compression	1.252	1.266	1.011
Weld – outer shell-to-baseplate	2.569	29.4	11.443
Weld – inner shell-to-baseplate	6.644	29.4	4.425
Weld-Pedestal shell-to-baseplate	2.281	29.4	12.887

† Note that the dynamic load factor for the lid top plate is negligible and for the lid bottom plate is 1.06. This dynamic load factor has been incorporated in the above table.

* For the HI-STORM 100S, this safety factor is conservatively evaluated to be 1.357 because of increased load on the upper of the two lid plates.

Applicable analyses are performed for the HI-STORM 100S, Version B for the amplified loads resulting from the vertical drop of a fully loaded cask with the top lid in place.

HI-STORM 100S, Version B Load Case 02.a Evaluation			
Item	**Value (ksi)**	**Allowable (ksi)**	**Safety Factor**
Lid Vent Shield Bending Stress Intensity	13.09	36.0	2.75
Lid Inner Ring Compression	16.80	24.0	1.43
Inner Shell Compression	8.180	35.94	4.39
Outer Shell Compression	2.604	35.94	13.8
Weld – outer shell-to-baseplate	5.404	29.4	5.44
Weld – inner shell-to-baseplate	7.183	29.4	4.093

An assessment of the potential for instability of the compressed inner and outer shells under the compressive loading during the drop event has also been performed. The methodology is from ASME Code Case N-284 (Metal Containment Shell Buckling Design Methods, Division I, Class MC (8/80)). This Code Case has been previously accepted by the NRC as an acceptable method for evaluation of stability in vessels. The results obtained are conservative in that the loading in the shells is assumed to be uniformly distributed over the entire length of the shells. In reality, the component due to the amplified weight of the shell varies from zero at the top of the shell to the maximum value at the base of the shell. It is concluded that large factors of safety exist so that elastic or plastic instability of the inner and outer shells does not provide a limiting condition. The results for the HI-STORM 100 bound similar results for the HI-STORM 100S since the total weight of the "S" configuration is decreased (see Subsection 3.2). The same methodology has been used for an assessment of the HI-STORM 100S Version B with the same conclusion; namely, that elastic or plastic instability of the inner and outer shells is not a concern under the postulated design basis load cases.

The results do not show any gross regions of stress above the material yield point that would imply the potential for gross deformation of the storage overpack subsequent to the handling accident. MPC stability has been evaluated in the HI-STAR 100 FSAR for a drop event with 60g deceleration and shown to satisfy the Code Case N-284 criteria. Therefore, ready retrievability of the MPC is maintained as well as the continued performance of the HI-STORM 100 storage overpack as the primary shielding device.

3.4.4.3.3 <u>HI-TRAC Transfer Cask Stress Calculations</u>

The structural functions of the transfer cask are stated in Section 3.1. The analyses presented here demonstrate the ability of components of the HI-TRAC transfer cask to perform their structural functions in the transfer mode. Load Cases considered are given in Table 3.1.5.

The purpose of the analyses is to provide the necessary assurance that there will be no unacceptable release of radioactive material, unacceptable radiation levels, or impairment of ready retrievability.

3.4.4.3.3.1 Analysis of Pocket Trunnions (Load Case 01 of Table 3.1.5)

The HI-TRAC 125 and HI-TRAC 100 transfer casks have pocket trunnions attached to the outer shell and to the water jacket. During the rotation of HI-TRAC from horizontal to vertical or vice versa (see Figure 3.4.18), these trunnions serve to define the axis of rotation. The HI-TRAC is also supported by the lifting trunnions during this operation. Two load conditions are considered: Level A when all four trunnions support load during the rotation; and, Level B when the hoist cable is assumed slack so that the entire load is supported by the rotation trunnions. A dynamic amplification of 15% is assumed in both cases appropriate to a low-speed operation. Figure 3.4.23 shows a free body of the trunnion and shows how the applied force and moment are assumed to be resisted by the weld group that connects the trunnion to the outer shell. Drawings 1880 (sheet 10) and 2145 (sheet 10) show the configuration. An optional construction for the HI-TRAC 100 permits the pocket trunnion base to be split to reduce the "envelope" of the HI-TRAC. For that construction, bolts and dowel pins are used to insure that the force and moment applied to the pocket trunnions are transferred properly to the body of the transfer cask. The analysis also evaluates the bolts and dowel pins and demonstrates that safety factors greater than 1.0 exist for bolt loads, dowel bearing and tear-out, and dowel shear. Allowable strengths and loads are computed using applicable sections of ASME Section III, Subsection NF.

Unlike the HI-TRAC 125 and the HI-TRAC 100, the HI-TRAC 125D and HI-TRAC 100D are designed and fabricated without pocket trunnions. An L-shaped rotation frame is used to upend and downend the HI-TRAC 125D and HI-TRAC 100D, instead of pocket trunnions. Thus, a pocket trunnion analysis is not applicable to the HI-TRAC 125D or the HI-TRAC 100D.

The table below summarizes the results for the HI-TRAC 125 and the HI-TRAC 100:

Pocket Trunnion Weld Evaluation Summary			
Item	Value (ksi)	Allowable (ksi)†	Safety Factor
HI-TRAC 125 Pocket Trunnion-Outer Shell Weld Group Stress	7.979	23.275	2.917
HI-TRAC 125 Pocket Trunnion–Water Jacket Weld Group Stress	5.927	23.275	3.9
HI-TRAC 100 Pocket Trunnion-Outer Shell Weld Group Stress	6.603	23.275	3.525
HI-TRAC 100 Pocket Trunnion–Water Jacket Weld Group Stress	5.244	23.275	4.438
HI-TRAC 100 Pocket Trunnion–Bolt Tension at Optional Split	45.23	50.07	1.107
HI-TRAC 100 Pocket Trunnion–Bearing Stress on Base Surfaces at Dowel	6.497	32.7	5.033
HI-TRAC 100 Pocket Trunnion–Tear-out Stress on Base Surfaces at Dowel	2.978	26.09	8.763
HI-TRAC 100 Pocket Trunnion–Shear Stress on Dowel Cross Section at Optional Split	29.04	37.93	1.306

† Allowable stress is reported for the Level B loading, which results in the minimum safety factor.

To provide additional information on the local stress state adjacent to the rotation trunnion, a new finite element analysis is undertaken to provide details on the state of stress in the metal structure surrounding the rotation trunnions for the HI-TRAC 125. The finite element analysis has been based on a model that includes major structural contributors from the water jacket enclosure shell panels, radial channels, end plates, outer and inner shell, and bottom flange. In the finite element analysis, the vertical trunnion load has been oriented in the direction of the HI-TRAC 125 longitudinal axis. The structural model has been confined to the region of the HI-TRAC adjacent to the rotation trunnion block; the extent of the model in the longitudinal direction has been determined by calculating the length of the "bending boundary layer" associated with a classical shell analysis. This was considered to be a sufficient length to capture maximum shell stresses arising from the Level B (off-normal) rotation trunnion loading. The local nature of the stress around the trunnion block is clearly demonstrated by the finite element results.

Consistent with the requirements of ASME Section III, Subsection NF, for Class 3 components, safety factors for primary membrane stress have been computed. Primary stresses are located away from the immediate vicinity of the trunnion; although the NF Code sets no limits on primary plus secondary stresses that arise from the gross structural discontinuity immediately adjacent to the trunnion, these stresses are listed for information. The results are summarized in the table below for the Level B load distribution for the HI-TRAC 125.

ITEM -HI-TRAC 125	CALCULATED VALUE	ALLOWABLE VALUE
Longitudinal Stress - (ksi) (Primary Stress -Inner Shell)	-0.956	23.275
Tangential Stress (ksi) (Primary Stress - Inner Shell)	-1.501	23.275
Longitudinal Stress (ksi) (Primary Stress – Outer Shell)	-0.830	23.275
Tangential Stress (ksi) (Primary Stress - Outer Shell)	-0.436	23.275
Longitudinal Stress - (ksi) (Primary Stress – Radial Channels)	2.305	23.275
Tangential Stress (ksi) (Primary Stress - Radial Channels)	-0.631	23.275
Longitudinal Stress - (ksi) (Primary plus Secondary Stress -Inner Shell)	1.734	No Limit (34.9)*
Tangential Stress (ksi) (Primary plus Secondary Stress - Inner Shell)	-1.501	NL
Longitudinal Stress (ksi) (Primary plus Secondary Stress - Outer Shell)	2.484	NL
Tangential Stress (ksi) (Primary plus Secondary Stress - Outer Shell)	-2.973	NL
Longitudinal Stress - (ksi) (Primary plus Secondary Stress - Radial Channels)	-13.87	NL
Tangential Stress (ksi) (Primary plus Secondary Stress - Radial Channels)	-2.303	NL

* The NF Code sets no limits (NL) for primary plus secondary stress (see Table 3.1.17). Nevertheless, to demonstrate the robust design with its large margins of safety, we list here, for information only, the allowable value for Primary Membrane plus Primary Bending Stress appropriate to temperatures up to 650 degrees F.

The only stress of any significance is the longitudinal stress in the radial channels. This stress occurs immediately adjacent to the trunnion block/radial channel interface and by its localized nature is identifiable as a stress arising at the gross structural discontinuity (secondary stress).

The finite element analysis has also been performed for the HI-TRAC 100 transfer cask. The following table summarizes the results:

ITEM –HI-TRAC 100	CALCULATED VALUE	ALLOWABLE VALUE
Longitudinal Stress - (ksi) (Primary Stress –Inner Shell)	-0.756	23.275
Tangential Stress (ksi) (Primary Stress - Inner Shell)	-2.157	23.275
Longitudinal Stress (ksi) (Primary Stress – Outer Shell)	-0.726	23.275
Tangential Stress (ksi) (Primary Stress - Outer Shell)	-0.428	23.275
Longitudinal Stress - (ksi) (Primary Stress – Radial Channels)	2.411	23.275
Tangential Stress (ksi) (Primary Stress - Radial Channels)	-0.5305	23.275
Longitudinal Stress - (ksi) (Primary plus Secondary Stress - Inner Shell)	2.379	NL
Tangential Stress (ksi) (Primary plus Secondary Stress - Inner Shell)	-2.157	NL
Longitudinal Stress (ksi) (Primary plus Secondary Stress - Outer Shell)	3.150	NL
Tangential Stress (ksi) (Primary plus Secondary Stress - Outer Shell)	-3.641	NL
Longitudinal Stress - (ksi) (Primary plus Secondary Stress - Radial Channels)	-15.51	NL
Tangential Stress (ksi) (Primary plus Secondary Stress - Radial Channels)	-2.294	NL

The finite element analyses of the metal structure adjacent to the trunnion block did not include the state of stress arising from the water jacket internal pressure. These stresses are conservatively computed based on a two-dimensional strip model that neglects the lower annular plate. The water jacket bending stresses are summarized below:

Tangential Bending Stress in Water Jacket Outer Panel from Water Pressure (including hydrostatic and inertia effects)	Calculated Value (ksi)
HI-TRAC 125	14.18
HI-TRAC 100	13.63

To establish a minimum safety factor for the outer panels of the water jacket for the Level A condition, we must add primary membrane circumferential stress from the trunnion load analysis to primary circumferential bending stress from the water jacket bending stress. Then, the safety factors may be computed by comparison to the allowable limit for primary membrane plus primary bending stress. The following results are obtained:

Results for Load Case 01 in Water Jacket (Load Case 01) – Level A Load			
Circumferential Stress in Water Jacket Outer Enclosure	**CALCULATED VALUE (ksi)**	**ALLOWABLE VALUE (ksi)**	**SAFETY FACTOR (allowable value/calculated value)**
HI-TRAC 125	14.57	26.25	1.80
HI-TRAC 100	13.94	26.25	1.88

To arrive at minimum safety factors for primary membrane plus bending stress in the outer panel of the water jacket for the Level B condition, we amplify the finite element results the trunnion load analysis, add the appropriate stress from the two-dimensional water jacket calculation, and compare the results to the increased Level B allowable. The following results are obtained:

Results for Load Case 01 in Water Jacket (Load Case 01) – Level B Load			
Circumferential Stress in Water Jacket Outer Enclosure	**CALCULATED VALUE (ksi)**	**ALLOWABLE VALUE (ksi)**	**SAFETY FACTOR (allowable value/calculated value)**
HI-TRAC 125	14.81	35.0	2.36
HI-TRAC 100	14.16	35.0	2.47

All safety factors are greater than 1.0; the Level A load condition governs.

3.4.4.3.3.2 Lead Slump in HI-TRAC 125 - Horizontal Drop Event (Case 02.b in Table 3.1.5)

During a side drop of the HI-TRAC 125 transfer cask, the lead shielding must be shown not to slump and cause significant amounts of shielding to be lost in the top area of the lead annulus. Slumping of the lead is not considered credible in the HI-TRAC transfer cask because of:

a. the shape of the interacting surfaces
b. the ovalization of the shell walls under impact
c. the high coefficient of friction between lead and steel
d. The inertia force from the MPC inside the HI-TRAC will compress the inner shell at the impact location and locally "pinch" the annulus that contains the lead; this opposes the tendency for the lead to slump and open up the annulus at the impact location.

Direct contact of the outer shell of the HI-TRAC with the ISFSI pad is not credible since there is a water jacket that surrounds the outer shell. The water jacket metal shell will experience most of the direct impact. Nevertheless, to conservatively analyze the lead slump scenario, it is assumed that there is no water jacket, the impact occurs far from either end of the HI-TRAC so as to ignore any strengthening of the structure due to end effects, the impact occurs directly on the outer shell of the HI-TRAC, and the contact force between HI-TRAC and the MPC is ignored. All of these assumptions are conservative in that their imposition magnifies any tendency for the lead to slump.

To confirm that lead slump is not credible, a finite element analysis of the lead slump problem, incorporating the conservatisms listed above, during a postulated HI-TRAC 125 horizontal drop (see Figure 3.4.22) is carried out. The HI-TRAC 125 cask body modeled consists only of an inner steel shell, an outer steel shell, and a thick lead annulus shield contained between the inner and outer shell. A unit length of HI-TRAC is modeled and the contact at the lead/steel interface is modeled as a compression-only interface. Interface frictional forces are conservatively neglected. As the HI-TRAC 125 has a greater lead thickness, analysis of the HI-TRAC 125 is considered to bound the HI-TRAC 100 and the HI-TRAC 100D. Furthermore, since there are no differences between the HI-TRAC 125 and the HI-TRAC 125D with respect to the finite element model, the results are valid for both 125-Ton transfer casks.

The analysis is performed in two parts:

First, to maximize the potential for lead/steel separation, the shells are ignored and the gap elements grounded. This has the same effect as assuming the shells to be rigid and maximizes the potential and magnitude of any separation at the lead/steel interface (and subsequent slump). This also maximizes the contact forces at the portion of the interface that continues to have compression forces developed. The lead annulus is subjected to a 45g deceleration and the deformation, stress field, and interface force solution developed. This solution establishes a conservative result for the movement of the lead relative to the metal shells.

In the second part of the analysis, the lead is removed and replaced by the conservative (high) interface forces from the first part of the analysis. These interface forces, together with the 45g deceleration-induced inertia forces from the shell self weight are used to obtain a solution for the stress and deformation field in the inner and outer metal shells.

The results of the analysis are as follows:

a. The maximum predicted lead slump at a location 180 degrees from the impact point is 0.1". This gap decreases gradually to 0.0" after approximately 25 degrees from the vertical axis. The decrease in the diameter of the inner shell of the transfer cask (in the direction of the deceleration) is approximately 0.00054". This demonstrates that ovalization of the HI-TRAC shells does not occur. Therefore, the lead shielding deformation is confined to a local region with negligible deformation of the confining shells.

b. The stress intensity distribution in the shells demonstrates that high stresses are concentrated, as anticipated, only near the assumed point of impact with the ISFSI pad. The value of the maximum stress intensity (51,000 psi) remains below the allowable stress intensity for primary membrane plus primary bending for a Level D event (58,700 psi). Thus, the steel shells continue to perform their function and contain the lead. The stress distribution, obtained using the conservatively large interface forces, demonstrates that permanent deformation could occur only in a localized region near the impact point. Since the "real" problem precludes direct impact with the outer shell, the predicted local yielding is simply a result of the conservatisms imposed in the model.

It is concluded that a finite element analysis of the lead slump under a 45g deceleration in a side drop clearly indicates that there is no appreciable change in configuration of the lead shielding and no overstress of the metal shell structure. Therefore, retrievability of the MPC is not compromised and the HI-TRAC transfer cask continues to provide shielding.

3.4.4.3.3.3 HI-TRAC Lid Stress Analysis During HI-TRAC Drop Accident (Load Case 02.b in Table 3.1.5)

The stress in the HI-TRAC 125 transfer lid is analyzed when the lid is subject to the deceleration loads of a side drop Figure 3.4.22 is a sketch of the scenario. The analysis shows that the cask body, under a deceleration of 45g's, will not separate from the transfer lid during the postulated side drop. This event is considered a Level D event in the ASME parlance.

The bolts that act as doorstops to prevent opening of the doors are also checked for their load capacity. It is required that sufficient shear capacity exists to prevent both doors from opening and exposing the MPC.

The only difference between the HI-TRAC 100 and the HI-TRAC 125 transfer lid doors is that the HI-TRAC 100 has less lead and has no middle steel plate. A similar analysis of the HI-TRAC 100 shows that all safety factors are greater than 1.0. The table given below summarizes the results for both units:

Transfer Lid Attachment Integrity Under Side Drop			
Item – Shear Capacity	**Value (kip) or (ksi)**	**Capacity (kip) or (ksi)**	**Safety Factor= Capacity/Value**
HI-TRAC 125 Attachment (kip)	1,272.0	1,475.0	1.159
HI-TRAC 125 Door Lock Bolts (ksi)	20.24	48.3	2.387
HI-TRAC 100 Attachment (kip)	1,129.0	1,503.0	1.331
HI-TRAC 100 Door Lock Bolts (ksi)	13.81	48.3	3.497

All safety factors are greater than 1.0 and are based on actual interface loads. For the HI-TRAC 125 and the HI-TRAC 100, the interface load (primary impact at transfer lid) computed from the handling accident analysis is bounded by the values given below:

BOUNDING INTERFACE LOADS COMPUTED FROM HANDLING ACCIDENT ANALYSES	
Item	**Bounding Value (kip)**
HI-TRAC 125	1,300
HI-TRAC 100	1,150

The HI-TRAC 125D and HI-TRAC 100D transfer casks do not utilize a transfer lid. Instead, the MPC is transferred to or from a storage overpack using the HI-TRAC pool lid and a special mating device. Therefore, an analysis is performed to demonstrate that the pool lid will not separate from the cask body during the postulated side drop. The results of the analyses are summarized in the following tables for the HI-TRAC 125D and the HI-TRAC 100D.

HI-TRAC 125D Pool Lid Attachment Integrity Under Side Drop			
Item	**Calculated Value**	**Allowable Limit**	**Safety Factor**
Lateral Shear Force (kips)	562.5	1085	1.929
Maximum Bolt Tensile Stress (ksi)	2.548	116.7	45.8
Combined Tension and Shear Interaction	0.269	1.00	3.72

HI-TRAC 100D Pool Lid Attachment Integrity Under Side Drop			
Item	**Calculated Value**	**Allowable Limit**	**Safety Factor**
Lateral Shear Force (kips)	360.0	1085	3.015
Maximum Bolt Tensile Stress (ksi)	1.477	116.7	79.0
Combined Tension and Shear Interaction	0.11	1.00	9.08

3.4.4.3.3.4 Stress Analysis of the HI-TRAC Water Jacket (Load Case 03 in Table 3.1.5)

The water jacket is assumed subject to internal pressure from pressurized water and gravity water head. Calculations are performed for the HI-TRAC 125, the HI-TRAC 125D, the HI-TRAC 100, a nd the HI-TRAC 100D to determine the water jacket stress under internal pressure plus hydrostatic load. Results are obtained for the water jacket configuration and the connecting welds for all HI-TRAC transfer casks. The table below summarizes the results of the analyses.

Water Jacket Stress Evaluation			
Item	**Value (ksi)**	**Allowable (ksi)**	**Safety Factor**
HI-TRAC 125 Water Jacket Enclosure Shell Panel Bending Stress	14.18	26.25	1.851
HI-TRAC 100 Water Jacket Enclosure Shell Panel Bending Stress	13.63	26.25	1.926
HI-TRAC 125 Water Jacket Bottom Flange Bending Stress	18.3	26.25	1.434
HI-TRAC 100 Water Jacket Bottom Flange Bending Stress	16.92	26.25	1.551
HI-TRAC 125 Weld Stress – Bottom Flange to Outer Shell Double Fillet Weld	14.79	21.0	1.42
HI-TRAC 125 - Radial Rib Direct Stress	2.198	17.5	7.961
HI-TRAC 100 - Radial Rib Direct Stress	1.975	17.5	8.861
HI-TRAC 125D Water Jacket Bottom Flange Bending Stress	18.88	26.25	1.39
HI-TRAC 125D Water Jacket Enclosure Shell Panel Bending Stress	10.80	26.25	2.43
HI-TRAC 125D Weld Stress – Enclosure Panel to Radial Rib Plug Welds	1.093	17.5	16.01
HI-TRAC 125D Weld Stress – Bottom Flange to Outer Shell Single Fillet Weld	3.133	21.0	6.70
HI-TRAC 100D Water Jacket Bottom Flange Bending Stress	16.69	26.25	1.57
HI-TRAC 100D Water Jacket Enclosure Shell Panel Bending Stress	12.75	26.25	2.06

HI-TRAC 100D Weld Stress – Enclosure Panel to Radial Rib Plug Welds	0.680	17.5	25.7
HI-TRAC 100D Weld Stress – Bottom Flange to Outer Shell Single Fillet Weld	2.836	21.0	7.40

3.4.4.3.3.5 HI-TRAC Top Lid Separation (Load Case 02.b in Table 3.1.5)

The potential of top lid separation under a 45g deceleration side drop event requires evaluation. It is concluded by analysis that the connection provides acceptable protection against top lid separation. It is also shown that the bolts and the lid contain the MPC within the HI-TRAC cavity during and after a drop event. The results from the HI-TRAC 125 bound the corresponding results from the HI-TRAC 100 because the top lid bolts are identical in the two units and the HI-TRAC 125 top lid weighs more. The analysis also bounds the HI-TRAC 125D and the HI-TRAC 100D because the postulated side drop of the HI-TRAC 125, during which the transfer lid impacts the target surface, produces a larger interface load between the MPC and the top lid of the HI-TRAC than the nearly horizontal drop of the HI-TRAC 125D and the HI-TRAC 100D. The table below provides the results of the bounding analysis.

HI-TRAC Top Lid Separation Analysis

Item	Value	Capacity	Safety Factor= Capacity/Value
Attachment Shear Force (lb.)	123,750	957,619	7.738
Tensile Force in Stud (lb.)	132,000	1,117,222	8.464
Bending Stress in Lid (ksi)	35.56	58.7	1.65
Shear Load per unit Circumferential Length in Lid (lb./in)	533.5	29,400	55.10

3.4.4.4 Comparison with Allowable Stresses

Consistent with the formatting guidelines of Reg. Guide 3.61, calculated stresses and stress intensities from the finite element and other analyses are compared with the allowable stresses and stress intensities defined in Subsection 3.1.2.2 per the applicable sections of [3.4.2] and [3.4.4] for defined normal and off-normal events and [3.4.3] for accident events (Appendix F).

3.4.4.4.1 MPC

In Amendment #5 to the HI-STORM CoC, the weight limits for fuel assemblies to be stored in the MPCs were increased from 1,680 lbs to 1,720 lbs per assembly for PWR fuel and from 700 lbs to 730 lbs per assembly for BWR fuel. In order to account for this small increase in fuel weight, the results of the MPC stress analysis under lateral loading, which is described in Subsection 3.4.4.3.1.1, are uniformly scaled based on the percentage weight increase. Specifically, the results for the MPC-68 are scaled by a factor of 1.043 (=730/700) and results for the other MPCs are scaled by a factor of 1.024 (=1720/1680). This approach is acceptable because (i) the finite element analysis results are based on linear elastic material properties and (ii) the percentage increases in total weight, considering the stored fuel, fuel basket, and MPC shell, are less than the factors above. Finally, since the stresses associated with closing the support clearance gaps between the fuel basket and the MPC shell and between the MPC shell and the overpack are secondary stress components, as explained in Subsection 3.4.4.3.1.1, the use of a linear scale factor is an appropriate means of computing the primary stresses in the fuel basket and MPC shell.

Table 3.4.6 provides summary data extracted from the numerical analysis results for the fuel basket, enclosure vessel, and fuel basket supports after scaling to adjust for the increased fuel assembly weights. The results presented in Table 3.4.6 are based on the design basis deceleration and do not include any dynamic amplification due to internal elasticity of the structure (i.e., local inertia effects). Calculations suggest that a uniform conservative dynamic amplifier for the fuel basket would be 1.08 independent of the duration of impact. If we recognize that the tip-over event for HI-STORM 100 is a long duration event, then a dynamic amplifier of 1.04 is appropriate. The summary data provided in Table 3.4.3 and 3.4.4 gives the lowest safety factor computed for the fuel basket and for the MPC, respectively. Safety factors reported for the MPC shell in Table 3.4.4 are based on allowable strengths at 500 deg. F. Modification of the fuel basket safety factor for dynamic amplification leaves considerable margin. Factors of safety greater than 1 indicate that calculated results are less than the allowable strengths.

A perusal of the results in Tables 3.4.3 and 3.4.4 under different load combinations for the fuel basket and the enclosure vessel reveals that all factors of safety are above 1.0 even if we use the most conservative value for dynamic amplification factor. The relatively modest factor of safety in the fuel basket under side drop events (Load Case F3.b and F3.c) in Table 3.4.3 warrants further explanation since a very conservative finite element model of the structure has been utilized in the analysis.

The wall thickness of the storage cells, which is by far the most significant variable in a fuel basket's structural strength, is significantly greater in the MPCs than in comparable fuel baskets licensed in the past. For example, the cell wall thickness in the TN-32 basket (Docket No. 72-1021, M-56), is 0.1 inch and that in the NAC-STC basket (Docket No. 71-7235) is 0.048 inch. In contrast, the cell wall thickness in the MPC-68 is 0.25 inch. In spite of their relatively high flexural rigidities, computed margins in the fuel baskets are rather modest. This is because of some assumptions in the analysis that lead to an overstatement of the state of stress in the fuel basket. For example:

i. The section properties of longitudinal fillet welds that attach contiguous cell walls to each other are completely neglected in the finite element model (Figure 3.4.7). The fillet welds strengthen the cell wall section modulus at the very locations where maximum stresses develop.

ii. The radial gaps at the fuel basket-MPC shell and at the MPC shell-storage overpack interface are explicitly modeled. As the applied loading is incrementally increased, the MPC shell and fuel basket deform until a "rigid" backing surface of the storage overpack is contacted, making further unlimited deformation under lateral loading impossible. Therefore, some portion of the fuel basket and enclosure vessel (EV) stress has the characteristics of secondary stresses (which by definition, are self-limited by deformation in the structure to achieve compatibility). For conservativeness in the incremental analysis, we make no distinction between deformation controlled (secondary) stress and load controlled (primary) stress in the stress categorization of the MPC-24, 32, and 68 fuel baskets. We treat all stresses, regardless of their origin, as primary stresses. Such a conservative interpretation of the Code has a direct (adverse) effect on the computed safety factors. As noted earlier, the results for the MPC-24E are properly based only on primary stresses to illustrate the conservatism in the reporting of results for the MPC-24, 32, and 68 baskets.

iii. A uniform pressure simulates the SNF inertia loading on the cell panels, which is a most conservative approach for incorporating the SNF/cell wall structure interaction.

The above assumptions act to depress the computed values of factors of safety in the fuel basket finite element analysis and render conservative results.

The reported factors of safety do not include the effect of dynamic load amplifiers. The duration of impact and the predominant natural frequency of the basket panels under drop events result in the dynamic load factors that do not exceed 1.08. Therefore, since all reported factors of safety for all fuel basket types are greater than the DLF, the MPC is structurally adequate for its intended functions.

Tables 3.4.7 and 3.4.8 report stress intensities and safety factors for the confinement boundary subject to internal pressure alone and internal pressure plus the normal operating condition temperature with the most severe thermal gradient. The final values for safety factors in the various locations of the confinement boundary provide assurance that the MPC enclosure vessel is a robust pressure vessel.

3.4.4.4.2 Storage Overpack and HI-TRAC

The result from analyses of the storage overpack and the HI-TRAC transfer cask is shown in Table 3.4.5. The location of each result is indicated in the table. Safety factors for lifting operations where three times the lifted load is applied are reported in Section 3.4.3.

The table shows that all allowable stresses are much greater than their associated calculated stresses and that safety factors are above the limit of 1.0.

3.4.4.5 Elastic Stability Considerations

3.4.4.5.1 MPC Elastic Stability

Stability calculations for the MPC have been carried out in the HI-STAR 100 FSAR, Docket Number 72-1008. Using identical methodology with input loads and decelerations appropriate to the HI-STORM, safety factors > 1.0 are obtained for all relevant load cases. Note that for HI-STORM, the design external pressure differential is reduced to 0.0 psi, and the peak deceleration under accident events is reduced from 60g's (HI-STAR) to 45g's.

3.4.4.5.2 HI-STORM 100 Storage Overpack Elastic Stability

HI-STORM 100 (and 100S and the 100S Version B) storage overpack shell buckling is not a credible scenario since the two steel shells plus the entire radial shielding act to resist vertical compressive loading. Subsection 3.4.4.3.2.3 develops values for compressive stress in the steel shells of the storage overpack. Because of the low value for compressive stress coupled with the fact that the concrete shielding backs the steel shells, we can conclude that instability is unlikely. Note that the entire weight of the storage overpack can also be supported by the concrete shielding acting in compression. Therefore, in the unlikely event that a stability limit in the steel was approached, the load would simply shift to the massive concrete shielding. Notwithstanding the above comments, stability analyses of the storage overpack have been performed for bounding cases of longitudinal compressive stress with nominal circumferential compressive stress and for bounding circumferential compressive stress with nominal axial compressive stress. This latter case is for a bounding all-around external pressure on the HI-STORM 100 outer shell. The latter case is listed as Load Case 05 in Table 3.1.5 and is performed to demonstrate that explosions or other environmental events that could lead to an all-around external pressure on the outer shell do not cause a buckling instability. ASME Code Case N-284, a methodology accepted by the NRC, has been used for this analysis. The storage overpack shells for the HI-STORM 100 are examined individually assuming that the four radial plates provide circumferential support against a buckling deformation mode. The analysis of the storage overpack outer shell for a bounding external pressure of

$$p_{ext} = 30 \text{ psi}$$

together with a nominal compressive axial load that bounds the dead weight load at the base of the outer shell, gives a safety factor against an instability of:

$$\text{Safety Factor} = (1/0.466) \times 1.34 = 2.88$$

The factor 1.34 is included in the above result since the analysis methodology of Code Case N-284 builds in this factor for a stability analysis for an accident condition. The suite of stability analyses have also been performed for the HI-STORM 100S Version B. No credit is taken for any support provided by the concrete shielding and the effect of support by radial ribs is conservatively neglected (since the ribs in the HI-STORM 100S Version B do not extend the full height of the overpack). It is shown that the safety factor computed for the classic HI-STORM 100 is a lower bound for all of the

HI-STORM 100S versions.

The external pressure for the overpack stability considered here significantly bounds the short-time 10-psi differential pressure (between outer shell and internal annulus) specified in Table 2.2.1.

The same postulated external pressure condition can also act on the HI-TRAC during movement from the plant to the ISFSI pad. In this case, the lead shielding acts as a backing for the outer shell of the HI-TRAC transfer cask just as the concrete does for the storage overpack. The water jacket metal structure provides considerable additional structural support to the extent that it is reasonable to state that instability under external pressure is not credible. If it is assumed that the all-around water jacket support is equivalent to the four locations of radial support provided in the storage overpack, then it is clear that the instability result for the storage overpack bounds the results for the HI-TRAC transfer cask. This occurs because the R/t ratio (mean radius-to-wall thickness) of the HI-TRAC outer shell is less than the corresponding ratio for the HI-STORM storage overpack. Therefore, no HI-TRAC analysis is performed.

3.4.5 Cold

A discussion of the resistance to failure due to brittle fracture is provided in Subsection 3.1.2.3.

The value of the ambient temperature has two principal effects on the HI-STORM 100 System, namely:

i. The steady-state temperature of all material points in the cask system will go up or down by the amount of change in the ambient temperature.

ii. As the ambient temperature drops, the absolute temperature of the contained helium will drop accordingly, producing a proportional reduction in the internal pressure in accordance with the Ideal Gas Law.

In other words, the temperature gradients in the system under steady-state conditions will remain the same regardless of the value of the ambient temperature. The internal pressure, on the other hand, will decline with the lowering of the ambient temperature. Since the stresses under normal storage condition arise principally from pressure and thermal gradients, it follows that the stress field in the MPC under –40 degree F ambient would be smaller than the "heat" condition of storage, treated in the preceding subsection. Additionally, the allowable stress limits tend to increase as the component temperatures decrease.

Therefore, the stress margins computed in Section 3.4.4 can be conservatively assumed to apply to the "cold" condition as well.

Finally, it can be readily shown that the HI-STORM 100 System is engineered to withstand "cold" temperatures (-40 degrees F), as set forth in the Technical Specification, without impairment of its storage function.

Unlike the MPC, the HI-STORM 100 storage overpack is an open structure; it contains no pressure. Its stress field is unaffected by the ambient temperature, unless low temperatures produce brittle fracture due to the small stresses which develop from self-weight of the structure and from the minute difference in the thermal expansion coefficients in the constituent parts of the equipment (steel and concrete). To prevent brittle fracture, all steel material in HI-STORM 100 is qualified by impact testing as set forth in the ASME Code (Table 3.1.18).

The structural material used in the MPC (Alloy X) is recognized to be completely immune from brittle fracture in the ASME Codes.

As no liquids are included in the HI-STORM 100 storage overpack design, loads due to expansion of freezing liquids are not considered. The HI-TRAC transfer cask utilizes demineralized water in the water jacket. However, the specified lowest service temperature for the HI-TRAC is 0 degrees F and a 25% ethylene glycol solution is required for the temperatures from 0 degrees F to 32 degrees F. Therefore, loads due to expansion of freezing liquids are not considered.

There is one condition, however, that does require examination to insure ready retrievability of the fuel. Under a postulated loading of an MPC from a HI-TRAC transfer cask into a cold HI-STORM 100 storage overpack, it must be demonstrated that sufficient clearances are available to preclude interference when the "hot" MPC is inserted into a "cold" storage overpack. To this end, a bounding analysis for free thermal expansions has been performed in Subsection 4.4.6, wherein the MPC shell is postulated at its maximum design basis temperature and the thermal expansion of the overpack is ignored. The results from the evaluation of free thermal expansion are summarized in Table4.4.10. The final radial clearance (greater than 0.25" radial) is sufficient to preclude jamming of the MPC upon insertion into a cold HI-STORM 100 storage overpack.

3.4.6 HI-STORM 100 Kinematic Stability under Flood Condition (Load Case A in Table 3.1.1)

The flood condition subjects the HI-STORM 100 System to external pressure, together with a horizontal load due to water velocity. Because the HI-STORM 100 storage overpack is equipped with ventilation openings, the hydrostatic pressure from flood submergence acts only on the MPC. As stated in subsection 3.1.2.1.1.3, the design external pressure for the MPC bounds the hydrostatic pressure from flood submergence. Subsection 3.4.4.5.2 has reported a positive safety factor against instability from external pressure in excess of that expected from a complete submergence in a flood. The analysis performed below is also valid for the HI-STORM 100S and the HI-STORM 100S, Version B.

The water velocity associated with flood produces a horizontal drag force, which may act to cause sliding or tip-over. In accordance with the provisions of ANSI/ANS 57.9, the acceptable upper bound flood velocity, V, must provide a minimum factor of safety of 1.1 against overturning and sliding. For HI-STORM 100, we set the upper bound flood velocity design basis at 15 feet/sec. Subsequent calculations conservatively assume that the flow velocity is uniform over the height of the storage overpack.

The overturning horizontal force, F, due to hydraulic drag, is given by the classical formula:

$$F = Cd\ A\ V^*$$

where:

V^* is the velocity head = $\frac{\rho V^2}{2g}$; (ρ is water weight density, and g is acceleration due to gravity).

A: projected area of the HI-STORM 100 cylinder perpendicular to the fluid velocity vector.

Cd: drag coefficient

The value of Cd for flow past a cylinder at Reynolds number above 5E+05 is given as 0.5 in the literature (viz. Hoerner, Fluid Dynamics, 1965).

The drag force tending to cause HI-STORM 100's sliding is opposed by the friction force, which is given by

$$F_f = \mu K\ W$$

where:

μ = limiting value of the friction coefficient at the HI-STORM 100/ISFSI pad interface (conservatively taken as 0.25, although literature citations give higher values).

K = buoyancy coefficient (documented in HI-981928, Structural Calculation Package for HI-STORM 100 (see citation in Subsection 3.6.4).

W: Minimum weight of HI-STORM 100 with an empty MPC.

Sliding Factor of Safety

The factor of safety against sliding, b_1, is given by

$$\beta_1 = \frac{F_f}{F} = \frac{\mu KW}{Cd\ A\ V^*}$$

It is apparent from the above equation, β, will be minimized if the empty weight of HI-STORM 100 is used in the above equation.

As stated previously, $\mu = 0.25$, $Cd = 0.5$.

V^* corresponding to 15 ft./sec. water velocity is 218.01 lb per sq. ft.

A = length x diameter of HI-STORM 100 = 132.5" x 231.25"/144 sq. in./sq.ft. = 212.78 sq. ft.

K = buoyancy factor = 0.64 (per calculations in HI-981928)

W = empty weight of overpack w/ lid = 270,000 lbs. (Table 3.2.1)

Substituting in the above formula for β, we have

$\beta_1 = 1.86 > 1.1$ (required)

Since the weight of the HI-STORM 100S or HI-STORM 100S, Version B, plus the weight of an empty MPC-32 (i.e., the lightest MPC) is greater than 270,000 lb, the above calculation is also valid for these two units for the entire range of concrete densities.

Overturning Factor of Safety

For determining the margin of safety against overturning b_2, the cask is assumed to pivot about a fixed point located at the outer edge of the contact circle at the interface between HI-STORM 100 and the ISFSI. The overturning moment due to a force F_T applied at height H^* is balanced by a restoring moment from the reaction to the cask buoyant force KW acting at radius D/2.

$$F_T H^* = KW \frac{D}{2}$$

$$F_T = \frac{K W D}{2 H^*}$$

W is the empty weight of the storage overpack.

We have,

W = 270,000 lb. (Table 3.2.1)

H^* = 119.2" (maximum height of mass center per Table 3.2.3)

D = 132.5" (Holtec Drawing 1495)

K = 0.64 (calculated in HI-981928)

F_T = 96,040 lb.

F_T is the horizontal drag force at incipient tip-over.

F = Cd A V* = 23,194 lbs. (drag force at 15 feet/sec)

The safety factor against overturning, β_2, is given as:

$$\beta_2 = \frac{F_T}{F} = 4.14 > 1.1 \text{ (required)}$$

This result bounds the result for the HI-STORM 100S, for the HI-STORM 100S Version B, as well as for the densified concrete shielding option, since the calculation uses a conservative lower bound weight and a bounding height for the center of gravity.

In the next subsection, results are presented to show that the load F (equivalent to an inertial deceleration of F/360,000 lb = 0.0644 g's applied to the loaded storage overpack) does not lead to large global circumferential stress or ovalization of the storage overpack that could prevent ready retrievability of the MPC. It is shown in Subsection 3.4.7 that a horizontal load equivalent to 0.47g's does not lead to circumferential stress levels and ovalization of the HI-STORM storage overpack to prevent ready retrievability of the MPC. The load used for that calculation clearly bounds the side load induced by flood.

3.4.7 Seismic Event and Explosion - HI-STORM 100

3.4.7.1 Seismic Event (Load Case C in Table 3.1.1)

Overturning Analysis

The HI-STORM 100 System plus its contents may be assumed to be subject to a seismic event consisting of three orthogonal statistically independent acceleration time-histories. For the purpose of performing a conservative analysis to determine the maximum ZPA that will not cause incipient tipping, the HI-STORM 100 System is considered as a rigid body subject to a net horizontal quasi-static inertia force and a vertical quasi-static inertia force. This is consistent with the approach used in previously licensed dockets. The vertical seismic load is conservatively assumed to act in the most unfavorable direction (upwards) at the same instant. The vertical seismic load is assumed to be equal to or less than the net horizontal load with ε being the ratio of vertical component to one of the horizontal components. For use in calculations, define D_{BASE} as the contact patch diameter, and H_{CG} as the height of the centroid of an empty HI-STORM 100 System (no fuel). Conservatively, assume

D_{BASE} = 132.5" (Drawing 1495, Sheet 1 specifies 133.875" including overhang for welding)

Tables 3.2.1 and 3.2.3 give HI-STORM 100 weight data and center-of-gravity heights.

The weights and center-of-gravity heights are reproduced here for calculation of the composite center-of-gravity height of the storage overpack together with an empty MPC.

Weight (pounds)	C.G. Height (Inches); H
Overpack - $W_o = 270{,}000$	116.8
MPC-24 - $W_{24} = 42{,}000$	$109.0 + 24 = 133.0$ †
MPC-68 - $W_{68} = 39{,}000$	$111.5 + 24 = 135.5$
MPC-32 – $W_{32} = 36{,}000$	$113.2 + 24 = 137.2$
MPC-24E – $W_{24E} = 45{,}000$	$108.9 + 24 = 132.9$

The height of the composite centroid, H_{CG}, is determined from the equation

$$H_{cg} = \frac{W_o \times 116.8 + W_{MPC} \times H}{W_o + W_{MPC}}$$

Performing the calculations for all of the MPCs gives the following results:

	H_{cg} (inches)
MPC-24 with storage overpack	118.98
MPC-68 with storage overpack	119.16
MPC-32 with storage overpack	119.20
MPC-24E with storage overpack	119.10

A conservative overturning stability limit is achieved by using the largest value of H_{CG} (call it H) from the above. Because the HI-STORM 100 System is a radially symmetric structure, the two horizontal seismic accelerations can be combined vectorially and applied as an overturning force at the C.G. of the cask. The net overturning static moment is

$$WG_H H$$

where W is the total system weight and G_H is the resultant zero period acceleration seismic loading (vectorial sum of two orthogonal seismic loads) so that WG_H is the inertia load due to the resultant horizontal acceleration. The overturning moment is balanced by a vertical reaction force, acting at the outermost contact patch radial location $r = D_{BASE}/2$. The resistive moment is minimized when the vertical zero period acceleration G_V tends to reduce the apparent weight of the cask. At that instant,

† From Table 3.2.3, it is noted that MPC C.G. heights are measured from the base of the MPC. Therefore, the thickness of the overpack baseplate and the concrete MPC pedestal must be added to determine the height above ground.

the moment that resists "incipient tipping" is:

$$W\ (1 - G_V)\ r$$

Performing a static moment balance and eliminating W results in the following inequality to ensure a "no-overturning condition:

$$G_H + \frac{r}{H} G_V \leq \frac{r}{H}$$

Using the values of r and H for the HI-STORM 100 (r = 66.25", H = 119.20"), representative combinations of G_H and G_V that satisfy the limiting equality relation are computed and tabulated below:

Acceptable Net Horizontal G-Level (HI-STORM100), G_H	**Acceptable Vertical G-Level, G_V**
0.467	0.16
0.445	0.20
0.417	0.25
0.357	0.357

We repeat the above computations using the weight and c.g. location of the HI-STORM 100S(232). Because of the lowered center of gravity positions, the maximum net horizontal "G" levels are slightly increased.

Performing the calculations for all of the MPCs gives the following results:

	H_{cg} (inches)
MPC-24 with storage overpack	113.89
MPC-68 with storage overpack	114.07
MPC-32 with storage overpack	114.11
MPC-24E with storage overpack	114.01

Using the values of r and H for the HI-STORM 100S(232) (r = 66.25", H = 114.11"), representative combinations of G_H and G_V that satisfy the limiting equality relation are computed and tabulated below:

Acceptable Net Horizontal G-Level (HI-STORM 100S(232)), G_H	Acceptable Vertical G-Level, G_V
0.488	0.16
0.464	0.20
0.435	0.25
0.367	0.367

The limiting values of G_H and G_V for the HI-STORM 100S(243), which is taller than the HI-STORM 100S(232), are the same as the HI-STORM 100.

If the HI-STORM 100 or the HI-STORM 100S is fabricated using high density concrete (i.e., above 160.8 pcf dry), the C.G. height of the overpack decreases and thereby enables the cask system to withstand higher g-loads. This conclusion becomes immediately clear when the maximum acceptable vertical g-level is expressed in the following form:

$$G_V = 1 - \frac{H}{r} G_H$$

For fixed values of G_H and r, the value of G_V increases as H decreases. Therefore, the representative combinations of G_H and G_V given above for the HI-STORM 100 and the HI-STORM 100S are conservative for the densified concrete shielding option.

Since the HI-STORM 100S, Version B has further reduced the centroid of the loaded units, it is expected that acceptable G-Levels are further increased. The following calculations provide the limiting G-level combinations for the HI-STORM 100S Version B with standard weight concrete. As noted previously, the result for standard weight concrete will bound the corresponding result for the high density concrete (densified) shielding option.

We repeat the above computations using the weight and c.g. location of the HI-STORM 100S(218). Because of the lowered center of gravity positions, the maximum net horizontal "G" levels are slightly increased.

Performing the calculations for all of the MPCs gives the following results:

	H_{cg} (inches)
MPC-24 with storage overpack	109.88
MPC-68 with storage overpack	110.12
MPC-32 with storage overpack	110.23
MPC-24E with storage overpack	109.93

Using the values of r and H for the HI-STORM 100S, Version B(218) (r = 66.25", H = 110.23"), representative combinations of G_H and G_V that satisfy the limiting equality relation are computed and tabulated below:

Acceptable Net Horizontal G-Level (HI-STORM 100S, Version B(218)), G_H	Acceptable Vertical G-Level, G_V
0.505	0.16
0.481	0.20
0.451	0.25
0.376	0.375

The limiting values of G_H and G_V for the HI-STORM 100S, Version B(229), which is taller than the HI-STORM 100S, Version B(218), are bounded by the values listed for the HI-STORM 100.

Primary Stresses in the HI-STORM 100 Structure Under Net Lateral Load Over 180 degrees of the Periphery

Under a lateral loading, the storage overpack will experience axial primary membrane stress in the inner and outer shells as it resists bending as a "beam-like" structure. Under the same kind of lateral loading over one-half of the periphery of the cylinder, the shells will tend to ovalize under the loading and develop circumferential stress. Calculations for stresses in both the axial and circumferential direction are required to demonstrate satisfaction of the Level D structural integrity requirements and to provide confidence that the MPC will be readily removable after a seismic event, if necessary. An assessment of the stress state in the structure under the seismic induced load will be shown to bound the results for any other condition that induces a peripheral load around part of the HI-STORM 100 storage overpack perimeter. The specific analyses are performed using the geometry and loading for the HI-STORM 100; the results obtained for stress levels and the safety assessment are also applicable to an assessment of the HI-STORM 100S.

A simplified calculation to assess the flexural bending stress in the HI-STORM 100 structure under the limiting seismic event (at which tipping is incipient) is presented in the following:

A representative net horizontal acceleration of 0.47g is used to determine the primary stresses in the HI-STORM 100 storage overpack. The corresponding lateral seismic load, F, is given by

$$F = 0.47\ W$$

This load will be maximized if the upper bound HI-STORM 100 weight (W = 410,000 lbs. (Table 3.2.1)) is used. Accordingly,

$F = (0.47)(410{,}000) = 192{,}700$ lbs.

No dynamic amplification is assumed as the overpack, considered as a beam, has a natural frequency well into the rigid range.

The moment, M, at the base of the HI-STORM 100 due to this lateral force is given by

$$M = \frac{F\,H}{2}$$

where H = height of HI-STORM 100 (taken conservatively as 235 inches). Note that the loading has now been approximated as a uniform load acting over the full height of the cask.

The flexural stress, σ, is given by the ratio of the moment M to the section modulus of the steel shell structure, z, which is computed to be 12,640 in^3 for the HI-STORM 100 overpack with inner and outer shell thicknesses of 1-1/4" and 3/4", respectively. The use of this value is conservative since the steel section modulus associated with the optional 1" thick inner and outer shell design is slightly higher.

Therefore,

$$\sigma = \frac{(192{,}700)\,(235)}{(12{,}640)\,(2)} = 1{,}791 \text{ psi}$$

We note that the strength of concrete has been neglected in the above calculation.
The maximum axial stress in the storage overpack shell will occur on the "compressive" side where the flexural bending stress algebraically sums with the direct compression stress σ_d from vertical compression.

From the representative acceleration tables, the vertical seismic accelerations corresponding to the net 0.47g horizontal acceleration is below 0.25g.

Therefore, using the maximum storage overpack weight (bounded by 410,000 lbs. from data in Table 3.2.1)

$$\sigma_d = \frac{(410{,}000)\,(1.25)}{554.47} = 924 \text{ psi}$$

where 554.47 sq. inch is the metal area (cross section) of the steel structure in the HI-STORM 100 storage overpack as computed in Subsection 3.4.4.3.2.1. The total axial stress, therefore, is

$$\sigma_T = 1{,}791 + 924 = 2{,}715 \text{ psi}$$

Per Table 3.1.12, the allowable membrane stress intensity for a Level D event is 39,750 psi at 350 degrees F.

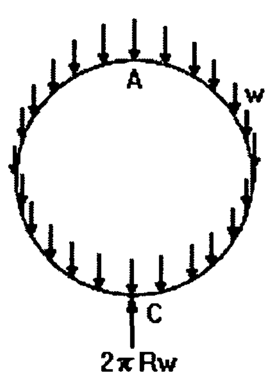
The Factor of Safety, β, is, therefore

$$\beta = \frac{39{,}750}{2{,}715} = 14.6$$

Examination of the stability calculations for the overpack outer shell under a 45-g vertical end drop demonstrates that no instability will result from this compressive load induced by a seismic or other environmental load leading to bending of the storage overpack as a beam.

The previous calculation has focused on the axial stress in the members developed assuming that the storage overpack does not overturn but resists the lateral load by remaining in contact with the ground and bending like a beam. Since the lateral loading is only over a portion of the periphery, there is also the potential for this load to develop circumferential stress in the inner and outer shells to resist ovalization of the shells. To demonstrate continued retrievability of the MPC after a seismic event, it must be shown that either the stresses remain in the elastic range or that any permanent deformation that develops due to plasticity does not intrude into the MPC envelope after the event is ended. In the following subsection, classical formulas for the deformation of rings under specified surface loadings are used to provide a conservative solution for the circumferential stresses in the HI-STORM 100. Specifically, the solution for a point-supported ring subject to a gravitational induced load, as depicted in the sketch below, is implemented. This solution provides a conservative estimate of the circumferential stress and the deformation of the ring that will develop under the actual applied seismic load.

Ring supported at base and loaded by its own weight, w, given per unit circumferential length.



The solution considers the geometry and load appropriate to a unit length of the inner and outer shells of the HI-STORM 100 storage overpack with a total weight equal to the overpack bounding weight (no MPC) subject to a 45g deceleration inertial loading. The numerical results for the 45g tipover event can be directly applied here by multiplying by the factor "X", where "X" reflects the differences in the deceleration and the weights used for the tipover event and for the seismic load case here in this subsection.

X = (0.47g/45g) x (410,000lb./270,000lb.) = 0.0159

Using this factor on the tipover solution gives the following bounding results for maximum stresses (without regard for sign and location of the stress) and deformations:

Maximum circumferential stress due to bending moment = (29,310 psi x X) = 466 psi

Maximum circumferential stress due to mean tangential force = (18,900 lb./2 sq.inch) x X = 150.3 psi

Change in diameter in the direction of the load = -0.11" x X = -0.0017"

Change in diameter perpendicular to the direction of the load = +0.06" x X = 0.0010"

From the above results, it is clear that no permanent ovalization of the storage overpack occurs during the seismic event and that circumferential stresses will remain elastic and are bounded by the stresses computed based on considering the storage overpack as a simple beam. Therefore, the safety factors based on maximum values of axial stress are appropriate. The magnitudes of the diameter changes that are suggested by the ring solution clearly demonstrate that ready retrievability of the MPC is maintained after the seismic event.

Because of the low values for the calculated axial stress, the conclusions of the previous section are also valid for the HI-STORM 100S, and for the HI-STORM 100S, Version B.

Potential for Concrete Cracking

It can be readily shown that the concrete shielding material contained within the HI-STORM 100 structure will not crack due to the flexuring action of HI-STORM 100 during a bounding seismic event that leads to a maximum axial stress in the storage overpack. For this purpose, the maximum axial strain in the steel shell is computed by dividing the tensile stress developed by the seismic G forces (for the HI-STORM 100, for example) by the Young's Modulus of steel.

$$\zeta = \frac{1{,}791 - 858}{28\,\mathrm{E}{+}06} = 33.3\,\mathrm{E}{-}06$$

where the Young's Modulus of steel is taken from Table 3.3.2 at 350 degrees F.

The acceptable concrete strain in tension is estimated from information in ACI-318.1 for plain concrete. The ratio of allowable tensile stress to concrete Young' Modulus is computed as

Allowable Concrete Strain = $(5 \times (0.75) \times (f)^{1/2})/(57{,}000(f)^{1/2}) = 65.8E\text{-}06$

In the above expression, f is the concrete compressive strength.

Therefore, we conclude that considerable margins against tensile cracking of concrete under the bounding seismic event exist.

Sliding Analysis

An assessment of sliding of the HI-STORM 100 System on the ISFSI pad during a postulated seismic event is performed using a one-dimensional "slider block on friction supported surface" dynamic model. The results for the shorter HI-STORM 100S are comparable. The HI-STORM 100 is simulated as a rigid block of mass 'm' placed on a surface, which is subject to a sinusoidal acceleration of amplitude 'a'. The coefficient of friction of the block is assumed to be reduced by a factor α to recognize the contribution of vertical acceleration in the most adverse manner (vertical acceleration acts to reduce the downward force on the friction interface). The equation of motion for such a "slider block" is given by:

$$m\ddot{x} = R + m\,a \sin \omega t$$

where:

$\ddot{x}$: relative acceleration of the slider block (double dot denotes second derivative of displacement 'x' in time)

a: amplitude of the sinusoidal acceleration input

ω: frequency of the seismic input motion (radians/sec)

t: time coordinate

R is the resistive Coulomb friction force that can reach a maximum value of μ(mg) (μ = coefficient of friction) and which always acts in the direction of opposite to $\dot{x}(t)$.

Solution of the above equation can be obtained by standard numerical integration for specified values of m, a, α and μ. The calculation is performed for representative horizontal and vertical accelerations of 0.47g and 0.16g, respectively. The input values are summarized below.

a = 0.47g

$\alpha =$ 0.84 = 1 - vertical acceleration (= 0.16g)

m = 360,000 lbs/g

$\mu =$ 0.25

For establishing the appropriate value of ω, reference is made to the USAEC publication TID-7024, "Nuclear Reactor and Earthquakes", page 35, 1963, which states that the significant energy of all seismic events in the U.S. essentially lies in the range of 0.4 to 10 Hz. Taking the mid-point value

$$\omega = (6.28)\ (0.5)\ (0.4+10) = 32.7 \text{ rad/sec.}$$

The numerical solution of the above equation yields the maximum excursion of the slider block x_{max} as 0.12 inches, which is negligible compared to the spacing between casks.

Calculations performed at lower values of ω show an increase in x_{max} with reducing ω. At 1 Hz, for example, $x_{max} = 3.2$ inches. It is apparent from the above that there is a large margin of safety against inter-module collision within the HI-STORM 100 arrays at an ISFSI, where the minimum installed spacing is over 2 feet (Table 1.4.1).

The above dynamic analysis indicates that the HI-STORM 100 System undergoes minimal lateral vibration under a seismic input with net horizontal ZPA g-values as high as 0.47 even under a bounding (from below) low interface surface friction coefficient of 0.25. Data reported in the literature (ACI-349R (97), Commentary on Appendix B) indicates that values of the coefficient of friction, μ, as high as 0.7 are obtained at steel/concrete interfaces.

To ensure against unreasonably low coefficients of friction, the ISFSI pad design may require a "broom finish" at the user's discretion. The bottom surface of the HI-STORM 100 is manufactured from plate stock (i.e. non-machine finish). A coefficient of friction value of 0.53 is considered to be a conservative numerical value for the purpose of ascertaining the potential for incipient sliding of the HI-STORM 100 System. If a higher value is used, the coefficient of friction is required to be verified by test (see Table 2.2.9).

The relationship between the vertical ZPA, G_V, (conservatively assumed to act opposite to the normal gravitational acceleration), and the resultant horizontal ZPA G_H to insure against incipient sliding is given from static equilibrium considerations as:

$$G_H + \mu G_V \leq \mu$$

Using a conservative value of μ equal to 0.53, the above relationship provides governing ZPA limits for a HI-STORM 100 (or 100S) System arrayed in a freestanding configuration. The table below gives representative combinations that meet the above limit.

G_H (in g's)	G_V (in g's)
0.445	0.16
0.424	0.20
0.397	0.25
0.350	0.34

Since the sliding inequality is independent of the weight and centroid of the cask system, the results above remain valid for HI-STORM overpacks with high density concrete and with different heights.

If the values for the DBE event at an ISFSI site satisfy the above inequality relationship for incipient sliding with coefficient of friction equal to 0.53, then the non-sliding criterion set forth in NUREG-1536 is assumed to be satisfied a'priori. However, if the ZPA values violate the inequality by a small amount, then it is permissible to satisfy the non-sliding criterion by implementing measures to roughen the HI-STORM 100/ISFSI pad interface to elevate the value of μ to be used in the inequality relation. To demonstrate that the value of μ for the ISFSI pad meets the required value implied by the above inequality, a series of Coulomb friction tests (under the QA program described in Chapter 13) shall be performed as follows:

Pour a concrete block with horizontal dimensions no less than 2' x 2' and a block thickness no less than 0.5'. Finish the top surface of the block in the same manner as the ISFSI pad surface will be prepared.

Prepare a 6" x 6" x 2" SA516 Grade 70 plate specimen (approximate weight = 20.25 lb.) to simulate the bottom plate of the HI-STORM 100 overpack. Using a calibrated friction gage attached to the steel plate, perform a minimum of twenty (20) pull tests to measure the static coefficient of friction at the interface between the concrete block and the steel plate. The pull tests shall be performed on at least ten (10) different locations on the block using varying orientations for the pull direction.

The coefficient of friction to be used in the above sliding inequality relationship will be set as the average of the results from the twenty tests.

The satisfaction of the "no-sliding" criterion set down in the foregoing shall be carried out along with the "no-overturning" qualification (using the static moment balance method in the manner described at the beginning of this subsection) and documented as part of the ISFSI facility's 10CFR72.212 evaluation.

Alternative Evaluation of Overturning and Sliding

In this subsection, an evaluation of the propensity for the free standing cask to be in a state of either incipient overturning or incipient sliding has been performed using a simple static analysis that is independent of time phasing of the input acceleration time histories and considers only the Zero Period Acceleration (ZPA) obtained from the response spectra. For both incipient overturning and incipient sliding, the following inequality must be satisfied to ensure satisfaction of the static criteria.

$G_H + \mu G_V \leq \mu$

For the incipient overturning evaluation, μ=(radius of cask base/height to loaded cask center-of-gravity). For the incipient sliding evaluation, μ= Coulomb coefficient of friction =0.53 at the cask/ISFSI pad interface (unless testing justifies use of a higher value). The inequality has been derived assuming that the cask is resting on a flat and level surface that is subject to a seismic event characterized by a response spectra set with the net horizontal and vertical Zero Period Acceleration (ZPA) denoted by G_H and G_V, respectively.

This "screening" evaluation provides a conservative criterion to insure that top-of-pad acceleration time histories from the aggregate effect of soil structure interaction and free field acceleration would not predict initiation of overturning or sliding. If on-the-pad acceleration time histories are available, the applicable inequality (for overturning and sliding) may be satisfied at each time instant during the Design Basis Earthquake with G_H and G_V representing coincident values of the magnitude of the net horizontal and vertical acceleration vectors.

3.4.7.2 Explosion (Load Case 05 in Table 3.1.5)

In the preceding subsection, it has been demonstrated that incipient tipping of the storage overpack will not occur under a side load equal to 0.47 times the weight of the cask. For a fully loaded cask with high density concrete, this side load is equal to

F = 192,700 lb.

If it is assumed that this side load is uniformly distributed over the height of the cask and that the cask centroid is approximately at the half-height of the overpack, then an equivalent pressure, P, acting over 180 degrees of storage overpack periphery, can be defined as follows:

P x (DH) = F

Where D = overpack outside diameter, and H = minimum height of a storage overpack (HI-STORM 100S Version B(218)).

For D = 132.5" and H = 218", the equivalent pressure is

P = 192,700 lb/(132.5" x 218") = 6.67 psi

Therefore, establishing 5 psi as the design basis steady state pressure differential (Table 2.2.1) across the overpack diameter is reasonable.

Since the actual explosion produces a transient wave, the use of a static incipient tip calculation is very conservative. To evaluate the margin against tip-over from a short-time pressure pulse, a Working Model analysis of the two-dimensional dynamic motion of the HI-STORM subject to a given initial angular velocity is carried out. Figures 3.4.25 and 3.4.26 provide details of the model and the solution for a HI-STORM 100 System (simulated as a rigid body) having a weight and inertia property appropriate to a minimum weight cask of height H=235". The results show that an initial angular velocity of 0.626 radians/second does not lead to a tipover of the storage overpack. The results bound those obtained for the HI-STORM 100S(232) and for the HI-STORM 100S Version B (229) since the overall cask height is reduced. The results for the HI-STORM 100S(243) are roughly equal to the results for the HI-STORM 100 since the differences in height and weight are negligible. The results for the HI-STORM 100S Version B will be bounded by the results presented because of lower centroid location.

Continuing, the initial angular velocity can be related to a square wave pressure pulse of magnitude P and time duration T by the following formula:

$$I\omega = (P \times D \times H) \times (0.5 \times H) \times T$$

The above formula relates the change in angular motion resulting from an impulsive moment about the base of the overpack. D is the diameter of the outer shell, H is the height of the storage overpack, and I is the mass moment of inertia of the storage overpack about the mass center (assumed to be at half-height). For D=132.5", H=235", P=10 psi, T=1 second, and I=64,277,000 lb.inch sec^2, the resulting initial angular velocity is:

$$\omega = 0.569 \text{ radians/second}$$

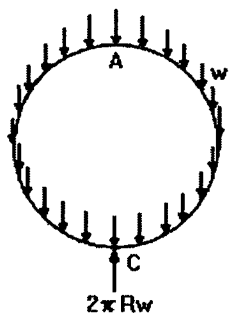
Therefore, an appropriate short time pressure limit is 10 psi with pulse duration less than or equal to 1 second. Table 2.2.1 sets this as the short-time external pressure differential.

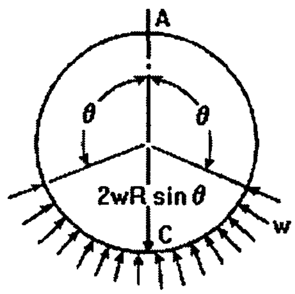
The overpack is also qualified to sustain without tip-over a lateral impulse load of 60 psi (differential pressure for 85 milliseconds maximum) [3.4.5].

The analysis in Subsection 3.4.7.1 evaluates ovalization of the shell by considering the seismically applied load as a line loading along the height of the overpack that is balanced by inertial body forces in the metal ring. The same solutions can be used to examine the circumferential stress state that would be induced to resist an external pressure that developed around one-half of the periphery. Such a pressure distribution may be induced by a pressure wave crossing the cask from a nearby explosion. It is shown here that a uniform pressure load over one-half of the overpack outer shell gives rise to an elastic stress state and deformation state that is bounded by a large margin by the results just presented for the seismic event in Subsection 3.4.7.1.

The case of an external pressure load from an explosion pressure wave (Load Case 05 in Table 3.1.5) is examined by combining the solutions for two different load cases. The combined case that results is a balance of pressure load over one-half the perimeter and inertial body forces. The sketch below describes this:

Case 1 + Case 3





Both cases are considered under identical total loads (with the angle in case 3 set to 90 degrees). Therefore, adding the results from the two cases results in the desired combined case; namely, the balance of a peripheral external pressure with internal all around loading simulating an inertia load (since the reactions are identical in magnitude and opposite in direction, there is a complete cancellation of the concentrated loads).

Examination of the results shows that the algebraic sum of the two solutions gives results that are smaller in magnitude than the case 1 solution for a line loading balanced by inertially induced body forces. The applied loading used to develop the solution for case 1 is 56,180 lb. per inch of storage overpack axial length. This load is equivalent to an external pressure P = 424 psi applied over one-half of the outer perimeter of the shell as is shown below:

P x D = 56,180 lb./inch D = 132.5" Therefore, P = 424 psi

Since this is higher by a large margin than any postulated external pressure load, circumferential stresses induced by the differential pressure specified in Table 2.2.1 are insignificant. Specifically, by adding the results from the two solutions (ring load case 1 for a point support reaction to a body force + ring load case 3 for a point support reaction to a lateral pressure over one-half of the perimeter), it is determined that the circumferential bending stress from case 1 is reduced by the factor "R" to obtain the corresponding stress from the combined case. R is computed as the ratio of moment magnitudes from the combined case to the results of case 1 alone.

R = (maximum bending moment from case 1 + case 3)/(maximum bending moment from case 1)
= 0.75/6.197 = 0.12

Examination of the graphs from the moment distribution from the two solutions shows that the individual terms always subtract and nearly cancel each other at every location.

Therefore, it is concluded that the maximum circumferential stress that develops under a pressure of 424 psi applied over one-half of the perimeter, and conservatively assumed balanced by inertia loading, is

Stress = 29,310 psi x 0.12 = 3517 psi

The stress due to a differential pressure of 10 psi (Table 2.2.1) is only 2.36% of the above value and needs no further evaluation for stress limits or deformation to demonstrate retrievability of the MPC. Because of the large margin obtained for a specific set of values appropriate to the HI-STORM 100, the same conclusion is reached for the HI-STORM 100S and the HI-STORM 100S, Version B; that is, differential pressures of the postulated magnitude will not affect retrievability of the stored MPC.

3.4.7.3 Anchored HI-STORM Systems Under High-Seismic DBE (Load Case C in Table 3.1.1)

The anchored HI-STORM System (Figures 1.1.4 and 1.1.5) is assumed to be subjected to quasi-static inertial seismic loads corresponding to the ZPA design basis limits given in Table 2.2.8. The results from this quasi-static analysis are used to evaluate structural margins for the preloaded anchor studs and the sector lugs. In the quasi-static evaluation, the effect of the "rattling" of the MPC inside of the overpack is accounted for by the imposition of a dynamic load factor of 2.0 on the incremental stresses that arise during the seismic event. In addition to the quasi-static analysis, confirmatory 3-D dynamic analyses are performed using base acceleration excitation histories developed from two sets of response spectra. Figure 3.4.30 shows the two sets of response spectra that are assumed to be imposed at the top of the ISFSI pad. One set of response spectra is the Regulatory Guide 1.60 spectra for 5% damping with zero period acceleration conservatively amplified to 1.5 in each direction. This spectra set has been used as the input spectra at many nuclear plants in the U.S. (although generally, the ZPA was much below 1.0). Three statistically independent acceleration time histories (two horizontal labeled as "H1", "H2") and one vertical (labeled as "VT") have been developed. A twenty-second duration event was considered. Figures 3.4.31 to 3.4.33 show the time histories. The second set of response spectra used for time history analysis has similar levels of zero period acceleration but has higher peak spectral acceleration values in the low frequency range (2-3 Hz). This spectra set is the design basis set for a Pacific coast U.S. plant. Figures 3.4.34 to 3.4.36 (labeled as "FN", "FP" for the two horizontal acceleration histories and "FV" for the vertical acceleration time history), show the corresponding time histories simulating a long duration seismic event (170 seconds).

The objectives of the quasi-static and dynamic seismic analyses are the following:

i. Quantify the structural safety factor in the anchor studs and in the sector lugs that constitute the fastening system for the loaded HI-STORM 100A overpack. The structural safety factor is defined as the ratio of the permitted stress (stress intensity) per Subsection "NF" of the ASME Code to the maximum stress (stress intensity) developed in the loaded component.

ii. Compute the safety factor against fatigue failure of the anchor studs from a single seismic event.

iii. Quantify the interface loads applicable to the ISFSI pad to enable the ISFSI owner to design the ISFSI pad under the provisions of ACI-349 (85). The bounding interface loads computed for the maximum intensity seismic event (ZPA) and for extreme environmental loads may be used in pad design instead of the site-specific loads calculated for the loadings applicable to the particular ISFSI.

The above design objectives are satisfied by performing analyses of a loaded HI-STORM 100A System using a conservative set of input data and a conservative dynamic model. Calculations using the quasi-static model assume that the net horizontal inertia loads and the vertical inertia load correspond to the weight of the loaded cask times the appropriate ZPA. The results from the analyses are set down as the interface loads, and may be used in the ISFSI pad design work effort by the ISFSI owner. The information on the seismic analysis is presented in five paragraphs as follows:

Input data for analysis
Quasi-static model and results
Dynamic model and modeling assumptions.
Results of dynamic analysis
Summary of interface loads

a. Input Data for Analysis:

Key input data for the seismic analysis of a loaded HI-STORM 100A System is summarized in Table 3.4.10. As can be seen from Table 3.4.10, the input data used in the analysis is selected to bound the actual data, wherever possible, so as to maximize the seismic response. For example, a bounding weight of the loaded MPC and HI-STORM 100A overpack is used because an increase in the weight of the system directly translates into an increased inertial loading on the structure.

For quasi-static analysis, bounding ZPA values of 1.5 in all three directions are used with the vertical event directed upward to maximize the stud tension. The resulting ZPAs are then further amplified by the dynamic load factor (DLF=2.0) to reflect "rattling" of the MPC within the overpack. Input data for anchor stud lengths are representative. We consider long and short studs in order to evaluate the effect of stud spring rate.

For the confirmatory dynamic analyses, the time history base excitations are shown in Figures 3.4.31 through 3.4.36 and the propensity for "rattling" is included in the model.

b. Quasi-Static Model and Results:

We consider the HI-STORM100A baseplate as a rigid plate resting on the ISFSI pad with the twenty-eight studs initially preloaded so as to impart a compressive load at the baseplate pad interface that is balanced by a tensile load in the studs prior to the seismic event occurring. The discrete studs are replaced by a thin ring located at the stud circle radius for analysis purposes. The thickness of the thin ring is set so that the ring area is equal to the total stress area of the twenty-eight studs. Figure 3.4.37 shows a view of a segment of the baseplate with the outline of the ring. The ISFSI pad is represented by a linear spring and a rotational spring with spring constants determined from the exact solution for a rigid circular punch pressed into a elastic half-space. We assume that subsequent to pre-tensioning the studs, the seismic event occurs, represented by a net horizontal load DH and a net vertical load DV. In the analysis, the input loads DH and DV are:

$$G_H = (1.5^2 \text{ x } 2)^{1/2} \text{ x DLF} = 4.242 \; ; \quad G_V = 1.5 \text{ x DLF} = 3.0$$

$$DH = G_H \text{ x } 360{,}000 \text{ lb.} \; ; \quad DV = -G_V \text{ x } 360{,}000 \text{ lb}$$

DH is the magnitude of the vector sum of the two horizontal ZPA accelerations multiplied by the bounding HI-STORM 100A weight. Similarly, DV is an upward directed load due to the vertical ZPA acceleration. The upward direction is chosen in order to maximize the stud tension as the assemblage of studs and foundation resists overturning from the moment induced by DH applied at the centroid of the cask. Figure 3.4.38 shows the free-body diagram associated with the seismic event. Essentially, we consider an analysis of a pre-compressed interface and determine the interface joint behavior under the imposition of an external loading (note that this kind of analysis is well established in the pressure vessel and piping area where it is usually associated with establishing the effectiveness of a gasketed joint). An analysis is performed to determine the maximum stud tension that results if the requirement of no separation between baseplate and pad is imposed under the imposed loading. The following result is obtained from static equilibrium, for a preload stress of 60 ksi, when the "no separation condition" is imposed:

$$\frac{2a/3h_{cg}\left(F_{preload}/W + 1\right)\left(1 + \alpha_1\right)}{G_H - 2a/3h_{cg}\left(G_V\left(1 + \alpha_1\right)/\left(1 + \alpha\right)\right)} = 1.016$$

In the above equation,

$F_{preload}$ = (Total stress area of twenty-eight, 2" diameter studs) x 60 ksi = 4,200,000 lb.

W = Bounding weight of loaded HI-STORM 100A = 360,000 lb.

a = 73.25 inches,

h_{cg} = 118.5 inches

The coefficients α and α_1 relate the stiffness of the totality of studs to the stiffness of the foundation under direct loading and under rotation. The result given above is for the representative case of stud free length "L", equal to

L= 42 inches, which gives α and α_1 equal to 0.089 and 0.060, respectively.

A simplified confirmatory analysis of the above problem can be performed by considering the limiting case of a rigid baseplate and a rigid ISFSI pad. In the limit of a rigid ISFSI pad (foundation), the coefficients α and α_1 go to zero. A related solution for the case of a rigid baseplate and a rigid foundation can be obtained when the criteria is not incipient separation, but rather, a more "liberal" incipient rotation about a point on the edge of the baseplate. That solution is given in "Mechanical Design of Heat Exchangers and Pressure Vessel Components", by Singh and Soler (Arcturus Publishers, 1984). The result is (for 60 ksi pre-stress in each stud):

$$\frac{a/h_{cg}\left(F_{preload}/W+1\right)}{G_H - a/h_{cg}\left(G_V\right)} = 1.284$$

Although not a requirement of any design code imposed herein, the right hand side of the previous relationships can be viewed as the safety factor against incipient separation (or rotation about an edge) at the radius "a". Note that since we have assumed a bounding event, there is an additional margin of 1.5 in results since the Reg. Guide 1.60 event has not been applied with a ZPA in excess of 1.0.

For the real seismic event associated with a western U.S. plant having a slightly lower horizontal ZPA and a reduced vertical ZPA (see Figure 3.4.30). Using the same DLF =2.0 to account for "rattling" of the confined MPC:

$$G_H = 4.1 \quad ; \quad G_V = 2.6,$$

the aforementioned safety factors are:

SF (incipient separation) = 1.076
SF (incipient edging) = 1.372

The increment of baseplate displacement and rotation, up to incipient separation, is computed from the equilibrium and compatibility equations associated with the free body in Figure 3.4.38 and the change in stud tension computed. The following formula gives the stud tensile stress in terms of the initial preload and the incremental change from the application of the horizontal and vertical seismic load.

$$\sigma_{stud} = \sigma_{preload} + \alpha \frac{W}{NA_{stress}}\left(\frac{-G_V}{1+\alpha} + \left(\frac{3h_{cg}}{2a}\right)\left(\frac{c}{a}\right)\left(\frac{G_H}{1+\alpha_1}\right)\right)$$

In the above formula,

N = number of studs = 28 (maximum number based on HI-STORM dimensions). For lower seismic inputs, this might be reduced (in groups of 4 to retain symmetry).

A_{stress} = tensile stress area of a 2" diameter stud

2c = stud circle diameter

The results demonstrate that there is a relatively small change in stud stress from the initial pre-tension condition with the ISFSI pad foundation resisting the major portion of the overturning moment. For the geometry considered (maximum stud free length and nominal pre-stress), the maximum tensile stress in the stud increases by 9.1%. The following table summarizes the results from the quasi-static analysis using minimum ultimate strength for the stud to compute the safety factors. Note that under the seismic load, the direct stress in the stud is limited to 70% of the stud ultimate strength (per Appendix F of the ASME Code Section III). The allowable pad compressive stress is determined from the ACI Code assuming confined concrete and the minimum concrete compressive strength from Table 2.0.4. Because of the large compressive load at the interface from the pre-tensioning operation, the large frictional resistance inhibits sliding of the cask. Consequently, there will be no significant shear stress in the studs. Safety factors for sliding are obtained by comparing the ratio of horizontal load to vertical load with the coefficient of friction between steel and concrete (0.53). Values in parenthesis represent results obtained using ZPA values associated with the real seismic event for the western U.S. plant instead of the bounding Reg. Guide 1.60 event.

SUMMARY OF RESULTS FOR STUDS AND INTERFACE FROM QUASI-STATIC SEISMIC EVALUATION WITH DLF = 2.0, Stud Prestress = 60 ksi			
Item	**Calculated Value**	**Allowable Value**	**Safety Factor = (Allowable Value/Calculated Value)**
Stud Stress(ksi) (42" stud free length)	65.48 (65.18)	87.5	1.336 (1.343)
Maximum Pad Pressure (ksi)(42" stud free length)	3.126 (3.039)	4.76	1.52 (1.57)
Stud Stress (ksi)(16" stud free length)	73.04 (72.34)	87.5	1.20 (1.21)
Maximum Pad Pressure(ksi) (16" stud free length)	2.977 (2.898)	4.76	1.60 (1.64)
Overpack Sliding	0.439 (0.407)	0.53	1.21 (1.31)

The effect of using a minimum stud free length in the embedment design is to increase the values of the coefficients α and α_1 because the stud stiffness increases. The increase in stud stiffness, relative to the foundation stiffness results in an increase in incremental load on the studs. This is a natural and expected characteristic of preloaded configurations. It is noted that the stud safety factors are based on minimum ultimate strength and can be increased, without altering the calculated results, by changing the stud material.

The quasi-static analysis methodology has also been employed to evaluate the effects of variation in the initial pre-stress on the studs. The following tables reproduce the results above for the cases of lower bound stud pre-stress (55 ksi) and upper bound stud pre-stress (65 ksi) on the studs. Only the results using the values associated with the Reg. Guide 1.60 bounding event are reported.

SUMMARY OF RESULTS FOR STUDS AND INTERFACE FROM QUASI- STATIC SEISMIC EVALUATION WITH DLF = 2.0, Stud Prestress = 55 ksi			
Item	**Calculated Value**	**Allowable Value**	**Safety Factor = (Allowable Value/Calculated Value)**
Stud Stress(ksi) (42" stud free length)	60.48	87.5	1.45
Maximum Pad Pressure (ksi)(42" stud free length)	3.012	4.76	1.58
Stud Stress (ksi)(16" stud free length)	68.07	87.5	1.29
Maximum Pad Pressure(ksi) (16" stud free length)	2.862	4.76	1.663
Overpack Sliding	0.488	0.53	1.09

SUMMARY OF RESULTS FOR STUDS AND INTERFACE FROM QUASI- STATIC SEISMIC EVALUATION WITH DLF = 2.0, Stud Prestress = 65 ksi			
Item	**Calculated Value**	**Allowable Value**	**Safety Factor = (Allowable Value/Calculated Value)**
Stud Stress(ksi) (42" stud free length)	70.48	87.5	1.24
Maximum Pad Pressure (ksi)(42" stud free length)	3.24	4.76	1.47
Stud Stress (ksi)(16" stud free length)	78.07	87.5	1.12
Maximum Pad Pressure(ksi) (16" stud free length)	3.091	4.76	1.54
Overpack Sliding	0.399	0.53	1.33

The results above confirm the expectations that an increase in preload increases the safety factor against sliding. The calculated coefficient of friction in the above tables is computed as the ratio of applied horizontal load divided by available vertical load. For all combinations examined, ample margin against incipient separation at the interface exists.

Based on the results from the quasi-static analysis, an assessment of the safety factors in the sector lugs is obtained by performing a finite element analysis of a repeated element of one of the sector lugs. Figure 3.4.39 shows the modeled section and the finite element mesh. The stud load is conservatively applied as a uniform downward pressure applied over a 5"x5" section of the extended baseplate simulating the washer between two gussets. This is conservative as the rigidity of the washer is neglected. The opposing pressure loading from the interface pressure is applied as a pressure over the entire extended baseplate flat plate surface. Only one half the thickness of each gusset plate is included in the model. The outer shell is modeled as 3/4" thick, which corresponds to the minimum thickness option per Bill of Material 1575.

Two cases are considered: (1) the pre-loaded state (a Normal Condition of Storage-Level A stress limits apply); and, (2), the seismic load condition at the location of the maximum tensile load in a stud (an Accident Condition of Storage – Level D stress intensity limits apply). Figures 3.4.40 and 3.4.41 present the stress results for the following representative input conditions:

Level A analysis - Preload stress/bolt = 60 ksi

Level D analysis - Maximum Bolt stress (includes seismic increment) = 65.5 ksi

In the Level A analysis, the resisting local foundation pressure exactly balances the preload. For the Level D analysis, the opposing local foundation pressure = 190 psi (average over the area between gussets). This represents the reduced pressure under the highest loaded stud under the induced rotation of the storage system.

The most limiting weld stress is obtained by evaluating the available load capacity of the fillet weld attaching the extended baseplate annulus region to the gussets (approximately 25 inches of weld per segment) using a limit strength equal to 42% of the ultimate strength of the base material.

The following table summarizes the limiting safety factors for the sector lugs. Allowable values for primary bending stress and stress intensity are from Tables 3.1.10 and 3.1.12 for SA-516 Grade 70 at 300 degrees F.

SUMMARY OF RESULTS FOR SECTOR LUGS FROM QUASI-STATIC SEISMIC EVALUATION			
Item	**Calculated Value**	**Allowable Value**	**Safety Factor = (Allowable Value/Calculated Value)**
Maximum Primary Membrane + Bending Stress Away From Loaded Region and Discontinuity (ksi) – Case 1 - Preload	15.62	26.3	1.68
Maximum Primary Membrane + Bending Stress Intensity Away From Loaded Region and Discontinuity (ksi) – Case 2 - Preload + Seismic	36.67	60.6	1.65
Maximum Weld Shear Load (kips)	150.8	194.9	1.29

c. Dynamic Model and Modeling Assumptions:

The dynamic model of the HI-STORM 100A System consists of the following major components.

i. The HI-STORM 100 overpack is modeled as a six degree-of-freedom (rigid body) component.

ii. The loaded MPC is also modeled as a six degree-of-freedom (rigid body) component that is free to rattle inside the overpack shell. Gaps between the two bodies reflect the nominal dimensions from the drawings.

iii. The contact between the MPC and the overpack is characterized by a coefficient of restitution and a coefficient of friction. For the dynamic analysis, the coefficient of restitution is set to 0.0, reflecting the large areas of nearly flat surface that come into contact and have minimal relative rebound. The coefficient of friction is set to 0.5 between all potentially contacting surfaces of the MPC/overpack interface.

iv. The anchor studs, preloaded to axial stress σ_i (Table 3.4.10), induce a contact stress between the overpack base and the ISFSI pad. The loaded cask-pad interface can support a certain amount of overturning moment before an uplift (loss of circularity of the contact patch) occurs. The anchor studs are modeled as individual linear springs connecting the periphery of the extended baseplate to the ISFSI pad section. The resistance of the foundation is modeled by a vertical linear spring and three rotational springs connected between the cask baseplate center point and the surface of the flat plate modeling the driven ISFSI pad. The ISFSI pad is driven with the three components of acceleration time history applied simultaneously.

The HI-STORM 100A dynamic model described above is implemented on the public domain computer code WORKING MODEL (also known as VisualNastran) (See Subsection 3.6.2 for a description of the algorithm).

Figures 3.4.42 and 3.4.43 show the rigid body components of the dynamic model before and after assembly. The linear springs are not shown. Mass and inertia properties of the rigid bodies are consistent with the bounding property values in Table 3.4.10.

d. Results of Dynamic Analysis:

Figures 3.4.44 –3.4.47 show results of the dynamic analysis using the Reg. Guide 1.60 seismic time histories as input accelerations to the ISFSI pad. Figure 3.4.44 shows variation in the vertical foundation compressive force. Figure 3.4.45 shows the corresponding load variation over time for the stud having the largest instantaneous tensile load. An initial preload of approximately 150,000 lb is applied to each stud (corresponding to 60,160 psi stud tensile stress). This induces an initial compression load at the interface approximately equal to 571,000 lb. (including the dead weight of the loaded HI-STORM). Figures 3.4.44 and 3.4.45 clearly demonstrate that the foundation resists the majority of the oscillatory and impactive loading as would be expected of a preloaded configuration. Figure 3.4.46 shows the impulse (between the MPC and HI-STORM 100A) as a function of time. It is clear that the "spikes" in both the foundation reaction and the stud load over the total time of the event are related to the impacts of the rattling MPC. The results provide a graphic demonstration that the rattling of the MPC inside the overpack must be accounted for in any quasi-static representation of the event. The quasi-static results presented herein for the anchored system, using a DLF = 2.0, are in excellent agreement with the dynamic simulation results.

We note that the dynamic simulation, which uses an impulse-momentum relationship to simulate the rattling contact, leads to results having a number of sharp peaks. Given that the stress intensity limits in the Code assume static analyses, filtering of the dynamic results is certainly appropriate prior to comparing with any static allowable strength. We conservatively do not perform any filtering of the results prior to comparison with the quasi-static analysis; we note only that any filtering of the dynamic results to eliminate high-frequency effects resulting from the impulse-momentum contact model would increase the safety factors. Finally, Figure 3.4.47 shows the ratio of the net interface horizontal force (needed to maintain equilibrium) to the instantaneous compression force at the ISFSI pad interface with the base of the HI-STORM 100A. This ratio, calculated at each instant of time from the dynamic analysis results using the Reg. Guide 1.60 event, represents an instantaneous coefficient of friction that is required to ensure no interface relative movement. Figure 3.4.47 demonstrates that the required coefficient of friction is below the available value 0.53. Thus, the dynamic analysis confirms that the foundation interface compression, induced by the preloading action, is sufficient to maintain a positive margin against sliding without recourse to any resistance from the studs.

The results of the dynamic analysis using acceleration time histories from the Reg. Guide 1.60 response spectra (grounded at 1.5 g's) confirm the ability of the quasi-static solution, coupled with a dynamic load factor, to correctly establish structural safety factors for the anchored cask. The dynamic analysis confirms that stud stress excursions from the preload value are minimal despite the large overturning moments that need to be balanced.

A second dynamic simulation has been performed using the seismic time histories appropriate to a pacific coast U.S. nuclear plant (Figures 3.4.34-3.4.36). The ZPA of these time histories are slightly less than the Reg. Guide 1.60 time histories but the period of relatively strong motion extends over a longer time duration. The results from this second simulation exhibit similar behavior as those results presented above and provide a second confirmation of the validity of the safety factors predicted by the quasi-static analysis. Reference [3.4.14] (see Subsection 3.8) provides archival information and backup calculations for the results summarized here.

Stress cycle counting using Figure 3.4.45 suggests 5 significant stress cycles per second provides a bounding number for fatigue analysis. A fatigue reduction factor of 4 is appropriate for the studs (per ASME Code rules). Therefore, a conservative analysis of fatigue for the stud is based on an alternating stress range of:

S(alt) = .5 x (22,300 psi) x 4 = 44,600 psi for 5 cycles per second. The value for the stress range is obtained as the difference between the largest tensile stress excursions from the mean value as indicated in the figure.

To estimate fatigue life, we use a fatigue curve from the ASME Code for high strength steel bolting materials (Figure I.9.4 in Appendix I, ASME Code Section III Appendices) For an amplified alternating stress intensity range of 44,600 psi, Figure I.9.4 predicts cyclic life of 3,000 cycles. Therefore, the safety factor for failure of a stud by fatigue during one Reg. Guide 1.60 seismic event is conservatively evaluated as:

SF(stud fatigue) = 3,000/100 = 30.

For the long duration event, even if we make the conservative assumption of a nine-fold increase in full range stress cycles, the safety factor against fatigue failure of an anchor stud from a single seismic event is 3.33. Recognizing that the fatigue curve itself is developed from test data with a safety factor of 20 on life and 4 on stress, the results herein demonstrate that fatigue failure of the anchor stud, from a single seismic event, is not credible.

e. Summary of Interface Loads for ISFSI Pad Design:

Bounding interface loads are set down for use by the ISFSI pad designer and are based on the validated quasi-static analysis and a dynamic load factor of 2.0:

BOUNDING INTERFACE LOADS FOR ISFSI PAD STRUCTURAL/SEISMIC DESIGN	
D (Cask Weight)	360 kips
D (Anchor Preload @ 65 ksi)	4,550 kips
E (Vertical Load)	1,080 kips
E (Net Horizontal Surface ShearLoad)	1,527.35 kips
E (Overturning Moment)	15,083 kip-ft.

3.4.8 Tornado Wind and Missile Impact (Load Case B in Table 3.1.1 and Load Case 04 in Table 3.1.5)

During a tornado event, the HI-STORM 100 System is assumed to be subjected to a constant wind force. It is also subject to impacts by postulated missiles. The maximum wind speed is specified in Table 2.2.4 and the three missiles, designated as large, intermediate, and small, are described in Table 2.2.5.

In contrast to a freestanding HI-STORM 100 System, the anchored overpack is capable of withstanding much greater lateral pressures and impulsive loads from large missiles. The quasi-static analysis result, presented in the previous subsection, can be used to determine a maximum permitted base overturning moment that will provide at least the same stud safety factors. This is accomplished by setting $G_V = 0.0$, DLF =1 and finding an appropriate G_H that gives equal or better stud safety factors. The resulting value of G^*_H establishes the limit overturning moment for combined tornado missile plus wind., M_L. (G^*_H x Weight x h_{cg}) is conservatively set as the maximum permissible moment at the base of the cask due to combined action of lateral wind and tornado missile loading. Thus, if the lateral force from a tornado missile impact is F at height h and that from steady tornado wind action is a resultant force W acting at cask mid-height (0.5H), and the two loads are acting synergistically to overturn the cask, then their magnitudes must satisfy the inequality

$0.5WH + Fh \leq M_L$

where the limit moment is established to ensure that the safety factors for seismic load remain bounding.

M_L = 18,667 kip-ft.

Tornado missile impact factors should be factored into "F" prior to determining the validity of the above inequality for any specific site.

In the case of a freestanding system, the post impact response of the HI-STORM 100 System is required to assess stability. Both the HI-STORM 100 storage overpack, and the HI-TRAC transfer cask are assessed for missile penetration.

The results for the post-impact response of the HI-STORM 100 storage overpack demonstrate that the combination of tornado missile plus either steady tornado wind or instantaneous tornado pressure drop causes a rotation of the HI-STORM 100 to a maximum angle of inclination less than 3 degrees from vertical. This is much less than the angle required to overturn the cask. The results for the HI-STORM 100 are bounding since the HI-STORM 100S and the HI-STORM 100S Version B have a lower center of gravity when loaded. Since Appendix C uses a lower bound cask weight of 302,000 lb, the results are also bounding for HI-STORM overpacks that utilize high density concrete.

The maximum force (not including the initial pulse due to missile impact) acting on the projected area of the storage overpack is computed to be:

F = 91,920 lbs.

The instantaneous impulsive force due to the missile strike is not computed here; its effect is felt as an initial angular velocity imparted to the storage overpack at time equal to zero. The net resultant force due to the simultaneous pressure drop is not an all-around distributed loading that has a net resultant, but rather is more likely to be distributed only over 180 degrees (or less) of the storage overpack periphery. The circumferential stress and deformation field will be of the same order of magnitude as that induced by a seismic loading. Since the magnitude of the force due to F is less than the magnitude of the net seismically induced force considered in Subsection 3.4.7, the storage overpack global stress analysis performed in Subsection 3.4.7 remains governing. In the next subsection, results are provided for the circumferential stress and ovalization of the portion of the storage overpack due to the bounding estimate for the impact force of the intermediate missile.

3.4.8.1 HI-STORM 100 Storage Overpack

This subsection considers the post impact behavior of the HI-STORM 100 System after impact from tornado missiles. During an impact, the system consisting of missile plus storage overpack and MPC satisfies conservation of linear and angular momentum. The large missile impact is assumed to be inelastic. This assumption conservatively transfers all of the momentum from the missile to the system. The intermediate missile and the small missile are assumed to be unyielding and hence the entire initial kinetic energy is assumed to be absorbed by motion of the cask and local yielding and denting of the storage overpack surface. It is shown that cask stability is maintained under the postulated wind and large missile loads. The conclusion is also valid for the HI-STORM 100S and for the HI-STORM 100S Version B with or without the densified concrete shielding option since their lower centers of gravity inherently provide additional stability margin.

The penetration potential of the missile strikes (Load Case 04 in Table 3.1.5) is examined first. The detailed calculations show that there will be no penetration through the concrete surrounding the inner shell of the storage overpack or penetration of the top closure plate. Therefore, there will be no impairment to the confinement boundary due to missile strikes during a tornado. Since the inner shell is not compromised by the missile strike, there will be no permanent deformation of the inner shell. Therefore, ready retrievability is assured after the missile strike. The following paragraphs summarize the analysis work for the HI-STORM 100.

a. The small missile will dent any surface it impacts, but no significant puncture force is generated. The 1" missile can enter the air ducts, but geometry prevents a direct impact with the MPC.

b. The following table summarizes the denting and penetration analysis performed for the intermediate missile. Denting is used to connote a local deformation mode encompassing material beyond the impacting missile envelope, while penetration is used to connote a plug type failure mechanism involving only the target material immediately under the impacting missile. The results are applicable to the HI-STORM 100 and to the HI-STORM 100S. The HI-STORM 100S version B has a thicker outer shell than the classic HI-STORM 100, and a lid configuration that consists of a 1" lid cover plate backed by concrete and a 3" thick lid vent shield plate that acts as a barrier to a top lid missile strike. Therefore, the tabular results presented below are bounding for the HI-STORM 100S Version B.

Location	Denting (in.)	Thru-Thickness Penetration
Storage overpack outer Shell	6.87†	Yes (>0.75 in.)
Radial Concrete	9.27	No (<27.25 in.)
Storage overpack Top Lid	0.4	No (<4 in.)

† Based on minimum outer shell thickness of 3/4". Penetration is less for HI-STORM 100 and 100S overpacks with 1" thick outer shell.

The primary stresses that arise due to an intermediate missile strike on the side of the storage overpack and in the center of the storage overpack top lid are determined next. The analysis of the storage lid for the HI-STORM 100 bounds that for the HI-STORM 100S; because of the additional energy absorbing material (concrete) in the direct path of a potential missile strike on the top lid of the HI-STORM 100S lid, the energy absorbing requirements of the circular plate structure are much reduced. The analysis demonstrates that Level D stress limits are not exceeded in either the overpack outer shell or the top lid. The safety factor in the storage overpack, considered as a cantilever beam under tip load, is computed, as is the safety factor in the top lids, considered as two centrally loaded plates. The applied load, in each case, is the missile impact load. Similar calculations are performed for the HI-STORM 100S Version B using the same model and methodology. A summary of the results for axial stress in the storage overpack is given in the table below with numbers in parentheses representing the results of calculations for the geometry of the HI-STORM 100S Version B:

HI-STORM 100 MISSILE IMPACT - Global Axial Stress Results			
Item	**Value (ksi)**	**Allowable (ksi)**	**Safety Factor**
Outer Shell – Side Strike	14.35†(15.17)	39.75	2.77†(2.62)
Top Lid - End Strike	44.14(47.57)	57.0 (50.65)	1.29(1.065)

† Based on HI-STORM 100 overpack with inner and outer shell thicknesses of 1-1/4" and 3/4", respectively. Result is bounding for HI-STORM 100 overpacks made with 1" thick inner and outer shells because the section modulus of the steel structure is greater.

To demonstrate ready retrievability of the MPC, we must show that the storage overpack suffers no permanent deformation of the inner shell that would prevent removal of the MPC after the missile strike. To demonstrate ready retrievability (for both HI-STORM 100 and for HI-STORM 100S) a conservative evaluation of the circumferential stress and deformation state due to the missile strike on the outer shell is performed. A conservative estimate for the 8" diameter missile impact force, "Pi", on the side of the storage overpack is calculated as:

Pi = 843,000 lb.

This force is conservative in that the target overpack is assumed rigid; any elasticity serves to reduce the peak magnitude of the force and increase the duration of the impact. The use of the upper bound value is the primary reason for the high axial stresses resulting from this force. To demonstrate continued ability to retrieve the MPC subsequent to the strike, circumferential stress and deformation that occurs locally in the ring section near the location of the missile strike are investigated.

Subsection 3.4.7 presents stress and displacement results for a composite ring of unit width consisting of the inner and outer shells of the storage overpack. The solution assumes that the net loading is 56,184 lb. applied on the 1" wide ring (equivalent to a 45g deceleration applied uniformly along the height on a storage overpack weight of 270,000 lb.). This solution can be applied directly to evaluate the circumferential stress and deformation caused by a tornado missile strike on the outer shell. Using the results for the 45g tipover event, an attenuation factor to adjust the results is developed that reflects the difference in load magnitude and the width of the ring that is effective in resisting the missile strike force. The strike force Pi is resisted by a combination of inertia force and shear resistance from the portion of the storage overpack above and below the location of the strike. The ring theory solution to determine the circumferential stress and deformation conservatively assumes that inertia alone, acting on an effective length of ring, balances the applied point load Pi. The effective width of ring that balances the impact load is conservatively set as the diameter of the impacting missile (8") plus the effect of the "bending boundary layer" length. This boundary layer length is conservatively set as a multiple of twice the square root of the product of mean radius times the average thickness of two shells making up the cylindrical body of the storage overpack. The mean radius of the composite cylinder and the average thickness of the inner and outer shells are

R_{mean} = 48"

T =.5 x (.75"+1.25") = 1"

The bending boundary layer "β" in a shell is generally accepted to be given as $(2(R_{mean}T)^{1/2})$ = 13.85" for this configuration. That is, the effect of a concentrated load is resisted mainly in a length along the shell equal to the bending boundary layer. For a strike away from the ends of the shell, a boundary layer length above and below the strike location would be effective (i.e., double the boundary layer length). However, to conservatively account for resistance above and below the location of the strike, this calculated result is only increased by 1.5 in the following analysis (rather than 2). Therefore, the effective width of ring is assumed as:

13.85" x 1.5 + 8" = 28.78"

The solution for the 45g tipover event (performed for a unit ring width and a load of 56,184 lb.) is directly applicable if we multiply all stress and displacement results by the factor "Y" where

Y = (1"/28.78") x (843,000 lb./56,184 lb.) = 0.521

Using this factor gives the following bounding results for maximum circumferential stresses (without regard for sign and location of the stress) and deformations due to the postulated tornado missile strike on the side of the storage overpack outer shell:

Maximum circumferential stress due to bending moment = (29,310 psi x Y) = 15,271 psi

Maximum circumferential stress due to mean tangential force = (18,900 lb./2 sq.inch) x Y = 4,923 psi

Change in diameter in the direction of the load = -0.11" x Y = -0.057"

Change in diameter perpendicular to the direction of the load = +0.06" x Y = 0.031"

Based on the above calculation, the safety factor on maximum stress for this condition is

SF = 39,750psi/15,271 psi = 2.60

The allowable stress for the above calculation is the Level D membrane stress intensity limit from Table 3.1.12. This is a conservative result since the stress intensity is localized and need not be compared to primary membrane stress intensity. Even with the overestimate of impact strike force used in the calculations here, the stresses remain elastic and the calculated diameter changes are small and do not prevent ready retrievability of the MPC. Note that because the stresses remain in the elastic range, there will be no post-strike permanent deformation of the inner shell.

The above calculations remain valid for the HI-STORM 100S, Version B using normal weight concrete and are bounding for the case where densified concrete is used.

3.4.8.2 HI-TRAC Transfer Cask

3.4.8.2.1 Intermediate Missile Strike

HI-TRAC is always held by the handling system while in a vertical orientation completely outside of the fuel building (see Chapter 2 and Chapter 8). Therefore, considerations of instability due to a tornado missile strike are not applicable. However, the structural implications of a missile strike require consideration.

The penetration potential of the 8" missile strike on HI-TRAC (Load Case 04 in Table 3.1.5) is examined at two locations:

1. the lead backed outer shell of HI-TRAC.
2. the flat transfer lid consisting of multiple steel plates with a layer of lead backing.

In each case, it is shown that there is no penetration consequence that would lead to a radiological release. The following paragraphs summarize the analysis results.

a. The small missile will dent any surface it impacts, but no significant puncture force is generated.

b. The following table summarizes the denting and penetration analysis performed for the intermediate missile. Denting connotes a local deformation mode encompassing material beyond the impacting missile envelope, while penetration connotes a plug type failure mechanism involving only the target material immediately under the impacting missile. Where there is through-thickness penetration, the lead and the inner plate absorb any residual energy remaining after penetration of the outer plate in the 100 Ton HI-TRAC transfer lid. The table summarizes the bounding results for both transfer casks.

Location	Denting (in.)	Thru-Thickness Penetration
Outer Shell - lead backed	0.498	No (<1.0 in.)
Outer Transfer Lid Door	0.516	No (<0.75 in.) (HI-TRAC 125) Yes (>0.5 in.) (HI-TRAC 100)

Based on the above results, the intermediate missile will penetrate the ½" thick bottom plate of the HI-TRAC 100D pool lid. However, the lead and the pool lid top plate will absorb any residual energy remaining after penetration of the bottom plate. The 8" missile will not penetrate the pool lid for the HI-TRAC 125D because it has a thicker bottom plate than the HI-TRAC 125 transfer lid door. In addition, the results for the 8" missile strike on the HI-TRAC outer shell are valid for the HI-TRAC 125D and the HI-TRAC 100D since all four transfer casks have the same outer shell thickness.

While the transfer cask is being transported in a horizontal orientation, the MPC lid is exposed. We conservatively assume no protective plate in place during this transport operation and evaluate the capacity of the lid peripheral groove weld to resist the impact load. The calculated result is as follows:

HI-TRAC MISSILE IMPACT - Capacity Results			
Item	**Value (lb)**	**Capacity (lb)**	**Safety Factor = Capacity/Value**
Top Lid Weld	2,262,000	2,789,000	1.23

The final calculation in this subsection is an evaluation of the circumferential stress and deformation consequences of the horizontal missile strike on the periphery of the HI-TRAC shell. It is assumed that the HI-TRAC is simply supported at its ends (while in transit) and is subject to a direct impact from the 8" diameter missile. To compute stresses, an estimate of the peak impact force is required. The effect of the water jacket to aid in the dissipation of the impact force is conservatively neglected. The only portion of the HI-TRAC cylindrical body that is assumed to resist the impact load is the two metal shells. The lead is assumed only to act as a separator to maintain the spacing between the shells. The previous results from the lead slump analysis demonstrate that this conservative assumption on the behavior of the lead is valid. The peak value of the impact force is a function of the stiffness of the target. The target stiffness in this postulated event has the following contributions to the stiffness of the structure.

a. a global stiffness based on a beam deformation mode, and
b. a local stiffness based on a shell deformation mode

The global spring constant (i.e., the inverse of the global deflection of the cask body as a beam under a unit concentrated load) is a function of location of the strike along the length of the cask. The spring constant value varies from a minimum for a strike at the half-height to a maximum value for a strike near the supports (the trunnions). Since the peak impact force is larger for larger stiffness, it is conservative to maximize the spring constant value. Therefore, in the calculation, we neglect this spring constant for the computation of peak impact force and focus only on the spring constant arising from the local deformation as a shell, in the immediate vicinity of the strike. To this end, the spring constant is estimated by considering the three-dimensional effects of the shell solution to be replaced by the two-dimensional action of a wide ring. The width of the ring is equal to the "bending boundary layer" length on either side of the strike location plus the diameter of the striking missile. Following the analysis methodology already utilized subsection 3.4.8.1, the following information is obtained:

The mean radius of the composite cylinder and the average thickness of the inner and outer shells, are (use the 100 Ton HI-TRAC data since it provides an upper bound on stress and deformation):

$R_{mean} = 36.893$

T =.5 x (.75"+1.00") = 0.875"

The bending boundary layer "β" in a shell is generally accepted to be given as $(2(R_{mean}T)^{1/2})$. To account for resistance above and below the location of the strike, this calculated result is conservatively increased by multiplying by 1.5. Therefore, the effective width of ring is:

11.22" x 1.5 + 8" = 24.84"

The missile impact is modeled as a point load, acting on the ring, of magnitude equal to Pi = 20,570 lb. The use of a point load in the analysis is conservative in that it overemphasizes the local stress. The actual strike area is an 8" diameter circle (or larger, if the effect of the water jacket were included).

The force is assumed resisted by inertia forces in the ring section. From the results, a spring constant can be defined as the applied load divided by the change in diameter of the ring section in the direction of the applied load. Based on this approach, the following local spring constant is obtained:

$K = Pi/D1_H = Pi/0.019" = 1{,}083{,}000$ lb./inch

To determine the peak impact force, a dynamic analysis of a two-body system has been performed using the "Working Model" dynamic simulation code. A two mass-spring damper system is considered with the defined spring constant representing the ring deformation effect. Figure 3.4.24 shows the results from the dynamic analysis of the impact using the computer code "Working Model". The small square mass represents the missile, while the larger mass represents the portion of the HI-TRAC "ring" assumed to participate in the local impact. The missile weight is 275.5 lb. and the participating HI-TRAC weight is set to the weight of the equivalent ring used to determine the spring constant.

The peak impact force that results in each of the two springs used to simulate the local elasticity of the HI-TRAC (ring) is:

F(spring) = 124,400 lb.

Since there are two springs in the model, the total impact force is:

P(impact) = 248,800 lb.

To estimate circumferential behavior of the ring under the impact, the previous solution (using a load of 20,570 lb.) is used and amplified by the factor "Z", where:

Z = 248,800 lb./20,570 lb. = 12.095

Consequently, the maximum circumferential stress due to the ring moment, away from the impact location, is:

3,037psi x (69,260 in-lb/180,900 in-lb) x Z = 14,230 psi

At the same location, the mean stress adds an additional component (the ring area is computed based on the effective width of the ring).

(5,143 lb./43.47 sq.in) x Z = 1431 psi

Therefore, the safety factor on circumferential stress causing ovalization of an effective ring section that is assumed to resist the impact is:

SF(ring stress) = 39,750 psi/(1431psi + 14,230psi) = 2.54

The allowable stress for this safety factor calculation is obtained from Table 3.1.12 for primary membrane stress intensity for a Level D event at 350 degrees F material temperature. Noting that the actual circumferential stress in the ring remains in the elastic range, it is concluded that the MPC remains readily retrievable after the impact since there is no permanent ovalization of the cavity after the event. As noted previously, the presence of the water jacket adds an additional structural barrier that has been conservatively neglected in this analysis.

3.4.8.2.2 Large Missile Strike

The effects of a large tornado missile strike on the side (water jacket outer enclosure) of a loaded HI-TRAC has been simulated using a transient finite element model of the transfer cask and loaded MPC. The transient finite element code LSDYNA3D has been used (approved by the NRC for use in impact analysis (see Appendix 3.A, reference [3.A.4] for the benchmarking of this computer code)). An evaluation of MPC retrievability and global stress state (away from the impact area) are of primary interest. The finite element model includes the loaded MPC, the HI-TRAC inner and outer shells, the HI-TRAC water jacket, the lead shielding, and the appropriate HI-TRAC lids. The water in the water jacket has been neglected for conservatism in the results. The large tornado missile has been simulated by an impact force-time pulse applied on an area representing the frontal area of an 1800-kg. vehicle. The force-time data used has been previously approved by the USNRC (Bechtel Topical Report BC-TOP-9A, "Design of Structures for Missile Impact", Revision 2, 9/1974). The frontal impact area used in the finite element analysis is that area recommended in NUREG-0800, SRP 3.5.1.4, Revision 2, 1981).

A summary of the results is presented below for the HI-TRAC 100 and HI-TRAC 125 transfer casks. Since the dimensions of the inner shell, the outer shell, the lead shielding, and the water jacket enclosure panels are the same in both the HI-TRAC 125 and the HI-TRAC 125D, the results from the HI-TRAC 125 are considered accurate for the HI-TRAC 125D. Likewise, the results from the HI-TRAC 100 are valid for the HI-TRAC 100D. The allowable value listed for the stress intensity for this Level D event comes from Table 3.1.17.

The results from the dynamic analysis have been summarized below.

SUMMARY OF RESULTS FROM LARGE TORNADO MISSILE IMPACT ANALYSIS		
ITEM – HI-TRAC 100	**CALCULATED VALUE**	**ALLOWABLE VALUE**
Maximum Stress Intensity in Water Jacket (ksi)	33.383	58.7
Maximum Stress Intensity in Inner Shell (ksi)	15.6	58.7
Maximum Plastic Strain in Water Jacket	0.0	-
Maximum Plastic Strain in Inner Shell	0.0	-

ITEM – HI-TRAC 125	CALCULATED VALUE	ALLOWABLE VALUE
Maximum Stress Intensity in Water Jacket (ksi)	33.697	58.7
Maximum Stress Intensity in Inner Shell (ksi)	18.669	58.7
Maximum Plastic Strain in Water Jacket	0.0	-
Maximum Plastic Strain in Inner Shell	0.0	-

The above results demonstrate that:

1. The retrievability of the MPC in the wake of a large tornado missile strike is not adversely affected since the inner shell does not experience any plastic deformation.

2. The maximum primary stress intensity, away from the impact interface on the HI-TRAC water jacket, is below the applicable ASME Code Level D allowable limit for NF, Class 3 structures.

3.4.9 HI-TRAC Drop Events (Load Case 02.b in Table 3.1.5)

During transit, the HI-TRAC 125 or HI-TRAC 100 transfer cask may be carried horizontally with the transfer lid in place. Analyses have been performed to demonstrate that under a postulated carry height; the design basis 45g deceleration is not exceeded. The analyses have been performed using two different simulation models. A simplified model of the drop event is performed using the computer simulation code "Working Model 2D". The analysis using "Working Model 2D" assumed the HI-TRAC and the contained MPC acted as a single rigid body. A second model of the drop event uses DYNA3D, considers the multi-body analysis of HI-TRAC and the contained MPC as individual bodies, and is finite element based. In what follows, we outline the problem and the results obtained using each solution methodology.

3.4.9.1 Working Model 2D Analysis of Drop Event

The analysis model conservatively neglects all energy absorption by any component of HI-TRAC; all kinetic energy is transferred to the ground through the spring-dampers that simulate the foundation (ground). If the HI-TRAC suffers a handling accident causing a side drop to the ground, impact will only occur at the top and bottom ends of the vessel. The so-called "hard points" are the top end lifting trunnions, the bottom end rotation trunnions, and the projecting ends of the transfer lid. Noting that the projecting hard points are of different dimensions and will impact the target at different times because of the HI-TRAC geometry, any simulation model must allow for this possibility.

A dynamic analysis of a horizontal drop, with the lowest point on the HI-TRAC assumed 50" above the surface of the target (larger than the design basis limit of 42"), is considered for the HI-TRAC 125 and for the HI-TRAC 100. Figure 3.4.22 shows the transfer cask orientation. The HI-TRAC is considered as a rigid body (calculations demonstrate that the lowest beam mode frequency is well above 33 Hz so that no dynamic amplification need be included). The effects of the ISFSI pad and the underlying soil are included using a simple spring-damper model based on a static classical Theory of Elasticity solution. The "worst" orientation of a horizontally carried HI-TRAC with the transfer cask impacting an elastic surface is considered. The HI-TRAC is assumed to initially impact the target with the impact force occurring over the rectangular surface of the transfer lid (11.875" x 81"). "Worst" is defined here as meaning an impact at a location having the maximum value of an elastic spring constant simulating the resistance of the target interface. The geometry and material properties reflect the USNRC accepted reference pad and soil (Table 2.2.9 - the pad thickness used is 36" and the Young's Modulus of the elastic soil is the upper limit value E=28,000 psi). The use of an elastic representation of the target surface is conservative as it minimizes the energy absorption capacity of the target and maximizes the deceleration loads developed during the impact. The spring constant is also calculated based on an assumption that impact at the lower end of HI-TRAC first occurs at the pocket trunnion. The results demonstrate that this spring constant is lower and therefore would lead to a lower impact force. Therefore, the dynamic analysis of the handling accident is performed assuming initial impact with the flat rectangular short end of the transfer lid. Subsequent to the initial impact, the HI-TRAC rotates in accordance with the dynamic equations of equilibrium and a secondary impact at the top of the transfer cask occurs. The impact is at the edge of the water jacket.

The following table summarizes the results from the dynamic analyses (using the Working Model 2D computer code):

HI-TRAC Handling Analysis – Working Model Analysis of Horizontal Drop			
Item	**Value**	**Allowable**	**Safety Factor**
HI-TRAC 125 – Primary Impact Deceleration (g's)	32.66	45	1.38
HI-TRAC 125 – Secondary Impact Deceleration (g's)	26.73	45	1.68
HI-TRAC 100 – Primary Impact Deceleration (g's)	33.18	45	1.36
HI-TRAC 100 – Secondary Impact Deceleration (g's)	27.04	45	1.66
Axial Membrane Stress Due to HI-TRAC 125 Bending as a Beam - Level D Drop (psi)	19.06	39.75	2.085
Axial Membrane Stress Due to HI-TRAC 100 Bending as a Beam - Level D Drop (psi)	15.77	39.75	2.52

In the table above, the decelerations are measured at points corresponding to the base and top of the fuel assemblies contained inside the MPC. The dynamic drop analysis reported above, using the Working Model 2D rigid body-spring model proved that decelerations are below the design basis value and that global stresses were within allowable limits.

3.4.9.2 DYNA3D Analysis of Drop Event

An independent evaluation of the drop event to delineate the effect of target non-linearity and the flexibility of the transfer cask has been performed using DYNA3D. Both the HI-TRAC 125 and HI-TRAC 100 transfer casks are modeled as part of the cask-pad-soil interaction finite element model set forth in NUREG/CR-6608 and validated by an NRC reviewed and approved Holtec topical report (see reference [3.A.4] in Appendix 3.A). The model uses the identical MPC and target pad/soil models employed in the accident analyses of the HI-STORM 100 overpack. The HI-TRAC inner and outer shells, the contained lead, the transfer lid, the water jacket metal structure, and the top lids are included in the model. The water jacket is assumed empty for conservatism.

Two side drop orientations are considered (see Figures 3.4.27 and 3.4.28). The first drop assumes that the plane of the lifting and rotation trunnions is horizontal with primary impact on the short side of the transfer lid. This maximizes the angle of slapdown, and represents a credible drop configuration where the HI-TRAC cask is dropped while being carried horizontally. The second drop orientation assumes primary impact on the rotation trunnion and maximizes the potential for the lifting trunnion to participate in the secondary impact. This is a non-credible event that assumes complete separation from the transfer vehicle and a ninety-degree rotation prior to impact. Nevertheless, it is the only configuration where the trunnions could be involved in both primary and secondary impacts.

For each simulation performed, the lowest point on the HI-TRAC cask (either the transfer lid edge or the rotation trunnion) is set at 42" above the target interface. Decelerations are measured at the top lid, the cask centroidal position, and the transfer lid. Normal forces were measured at the primary impact interface, at the secondary impact interface, and at the top lid/MPC interface. Decelerations are filtered at 350 Hz.

The following key results summarize the analyses:

ITEM	HI-TRAC 125		HI-TRAC 100		ALLOWABLE
Initial Orientation of Trunnions	**Horizontal**	**Vertical**	**Horizontal**	**Vertical**	
Max. Top Lid Vertical Deceleration – Secondary Impact (g's)	25.5	32	36.5	45[†]	45
Centroid Vertical Deceleration – at Time of Secondary Impact (g's)	9.0	13.0	10.0	17.5	45
Max. Transfer Lid Vertical Deceleration – Primary Impact (g's)	30.8	23.5	35.0	31.75	45
Maximum Normal Force at Primary Impact Site (kips)	1,950.	1,700	1,700	1,700	-
Maximum Normal Force at Secondary Impact Site (kips)	1,300.	1,850.	1,500.	1,450.	-
Maximum MPC/Top Lid Interface Force (kips)	132.	-	39.	-	-
Maximum Diametral Change of Inner Shell (inch)	0.228	0.113	Not Computed	0.067	0.3725
Maximum Von Mises Stress (ksi)	37.577	38.367	40.690	40.444	58.7*

[†] The deceleration at the top of the basket is estimated at 41 g's

* Allowable Level D Stress Intensity for Primary Plus Secondary Stress Intensity

The results summarized above demonstrate that both the HI-TRAC 125 and HI-TRAC 100 transfer casks are sufficiently robust to perform their function during and after the postulated handling accidents. We also note that the results, using the Working Model single rigid body dynamic model (see Subsection 3.4.9.1), are in reasonable agreement with the results predicted by the DYNA3D multi-body finite element dynamic model although performed for a different drop height with deceleration measurements at different locations on the HI-TRAC.

The results reported above for maximum interface force at the top lid/MPC interface are used as input to a separate analysis, which demonstrates that the top lid contains the MPC during and after a handling accident. The results reported above for the maximum normal force at the primary impact site (the transfer lid) have been used to calculate the maximum interface force at the bottom flange/transfer lid interface. This result is needed to insure that the interface forces used to evaluate transfer lid separation are indeed bounding. To obtain the interface force between the HI-TRAC transfer lid and the HI-TRAC bottom flange, it is sufficient to take a free-body of the transfer lid and write the dynamic force equilibrium equation for the lid. Figure 3.4.29 shows the free body with appropriate notation. The equation of equilibrium is:

$$M_{TL} a_{TL} = F_I - G_I$$

where

M_{TL} = the mass of the transfer lid
a_{TL} = the time varying acceleration of the centroid of the transfer lid
F_I = the time varying contact force at the interface with the target
G_I = the time varying interface force at the bottom flange/transfer lid interface

Solving for the interface force give the result

$$G_I = F_I - M_{TL} a_{TL}$$

Using the appropriate transfer lid mass and acceleration, together with the target interface force at the limiting time instant, provides values for the interface force. The table below provides the results of this calculation for the HI-TRAC 125 and HI-TRAC 100 transfer casks.

Item	Calculated from Equilibrium (kips)
HI-TRAC 125 – Trunnions Horizontal	1,183.
HI-TRAC 125 – Trunnions Vertical	1,272.
HI-TRAC 100 – Trunnions Horizontal	1,129.
HI-TRAC 100 – Trunnions Vertical	1,070.

3.4.9.3 Horizontal Drop of HI-TRAC 125D

The previous subsection addressed the 42" horizontal drop of the HI-TRAC 125 and HI-TRAC 100, including an evaluation of the bolted connection between the transfer lid, which sustains the primary impact, and the cylindrical body of the loaded HI-TRAC. The HI-TRAC 125D does not have a bolted connection between the bottom flange and the cylindrical body of the cask. However, the transverse protrusions (bottom flange, lifting trunnions, and optional attachment lugs/support tabs at the top of the cask) spawn different impact scenarios. The uncontrolled lowering of the cask is assumed to occur from a height of 42" measured to the lowest location on the HI-TRAC 125D in the horizontal orientation.

The maximum decelerations for the HI-TRAC 125D are comparable to the drop results for the HI-TRAC 125 when the plane of the lifting and rotation trunnions is vertical. Although the HI-TRAC 125D has no rotation trunnions, its bottom flange extends radially beyond the water jacket shell by approximately the same amount as the HI-TRAC 125 rotation trunnions and thereby establishes a similar "hard point" for primary impact in terms of distance from the cask centerline. More important, because the bottom flange is positioned closer to the base of the HI-TRAC 125D than the rotation trunnions are in the HI-TRAC 125, the slap-down angle for the HI-TRAC 125D is less. The shallower angle decreases the participation of the lifting trunnion during the secondary impact, and increases the participation of the water jacket shell. Since the water jacket shell is a more flexible structure than the lifting trunnion, the deceleration of the HI-TRAC 125D cask during secondary impact is slightly less than the calculated deceleration of the HI-TRAC 125. In the HI-TRAC 125D, there is no bolted connection at the bottom flange/cask body interface that is active in load transfer from the flange to the cask body. It is therefore concluded that this drop scenario for the HI-TRAC 125D is bounded by the similar evaluation for the HI-TRAC 125. The same rationale applies to the HI-TRAC 100D versus the HI-TRAC 100. In fact, the protruding segments of the HI-TRAC 100D bottom flange are not in the same impact plane as the lifting trunnions; therefore, a secondary impact involving a lifting trunnion is not possible. Therefore, the drop scenarios analyzed for the HI-TRAC 100 bound any 42" horizontal drop of a HI-TRAC 100D.

A second HI-TRAC 125D drop scenario, where the two attachment lugs/support tabs are oriented in a vertical plane, is the most limiting scenario. This drop event is unique to HI-TRAC 125D serial numbers 3 and 4, since these are the only two transfer casks fabricated with attachment lugs/support tabs. The tab dimensions are such that primary impact occurs at the top end of the cask when the support tabs impact the target surface, followed by a slap-down and a secondary impact at the bottom flange. Note that this drop scenario does not exist for the HI-TRAC 100D since it is has no attachment lugs/support tabs.

The evaluation of the limiting HI-TRAC 125D drop scenario is performed using the computer code Working Model 3D (WM) (now known as Visual Nastran Desktop). First, the WM code is used to simulate the "Scenario A" drop of the HI-TRAC 125 in order to establish appropriate parameters to "benchmark" WM against the DYNA3D solution. The table below summarizes the results of the Working Model/DYNA3D benchmark comparison. Figure 3.4.48 shows the benchmark configuration after the drop event.

Comparison of HI-TRAC 125 Drop Results (Scenario A)		
	DYNA3D	Working Model
Vertical Deceleration of Top Lid (secondary impact) g's	32	33.49
Vertical Deceleration at Bottom Lid (primary impact on rotation trunnion) g's	23.5	23.59

The benchmarked Working Model simulation was then modified to simulate the second drop scenario of the HI-TRAC 125D with support tabs in a vertical plane; primary impact now occurred at the top end with secondary impact at the bottom flange. Figure 3.4.49 shows the configuration of the HI-TRAC 125D after this scenario. The impact parameters were unchanged from the benchmark model except for location. The acceleration results from the 42" horizontal drop of the HI-TRAC 125D in this second drop scenario are summarized below.

Results From HI-TRAC 125D 42" Drop	
Vertical Deceleration of Top Lid (primary impact on support tab) g's	36.75
Vertical Deceleration of Pool Lid (secondary impact on bottom flange) g's	29.27

The resulting g loads at the top of the active fuel region for the HI-TRAC 125D, with primary impact on the support tabs, are increased over the loads computed for the HI-TRAC 125 but remain well below the design basis limit.

Finally, stress calculations similar to those presented in Subsection 3.4.9.1 for the HI-TRAC 125 have also been performed for the HI-TRAC 125D using the above maximum decelerations. The table below summarizes the results:

Item	Value	Allowable	Safety Factor
Axial Membrane Stress Due to HI-TRAC 125D Bending as a Beam - Level D Drop (psi)	26.13	39.75	1.521
Shear Stress in Outer Shell Circumferential Weld Due to HI-TRAC 125D Bending as a Beam - Level D Drop (psi)	27.43	29.40	1.072

3.4.10 HI-STORM 100 Non-Mechanistic Tip-over and Vertical Drop Event (Load Cases 02.a and 02.c in Table 3.1.5)

Pursuant to the provision in NUREG-1536, a non-mechanistic tip-over of a loaded HI-STORM 100 System on to the ISFSI pad is considered in this report. Analyses are also performed to determine the maximum deceleration sustained by a vertical free fall of a loaded HI-STORM 100 System from an 11" height onto the ISFSI pad. The objective of the analyses is to demonstrate that the plastic deformation in the fuel basket is sufficiently limited to permit the stored SNF to be retrieved by normal means, does not have a adverse effect on criticality safety, and that there is no significant loss of radiation shielding in the system.

Ready retrievability of the fuel is presumed to be ensured: if global stress levels in the MPC structure meet Level D stress limits during the postulated drop events; if any plastic deformations are localized; and if no significant permanent ovalization of the overpack into the MPC envelope space, remains after the event.

Subsequent to the accident events, the storage overpack must be shown to contain the shielding so that unacceptable radiation levels do not result from the accident.

Appendix 3.A provides a description of the dynamic finite element analyses undertaken to establish the decelerations resulting from the postulated event. A non-mechanistic tip-over is considered together with an end drop of a loaded HI-STORM 100 System. A dynamic finite element analysis of each event is performed using a commercial finite element code well suited for such dynamic analyses with interface impact and non-linear material behavior. This code and methodology have been fully benchmarked against Lawrence Livermore Laboratories test data and correlation [3.4.12].

The table below provides the values of computed peak decelerations at the top of the fuel basket for the vertical drop and the non-mechanistic tipover scenarios. It is seen that the peak deceleration is below 45 g's.

Filtered Results for Drop and Tip-Over Scenarios for HI-STORM

Drop Event	Max. Deceleration at the Top of the Basket (g's)	
	Set A(36" Thick Pad)	Set B(28" Thick Pad)
End Drop for 11 Inches	43.98	41.53
Non-Mechanistic Tip-over	42.85	39.91

The tipover analysis performed in Appendix 3.A is based on the HI-STORM 100 geometry and a bounding weight. The fact that the HI-STORM 100S(232) is shorter and has a lower center of gravity suggests that the impact kinetic energy is reduced so that the target would absorb the energy with a lower maximum deceleration. However, since the actual weight of a HI-STORM 100S(232) is less than that of a HI-STORM 100 by a significant amount, the predicted maximum rigid body deceleration would tend to increase slightly. Since there are two competing mechanisms at work, it is not a foregone conclusion that the maximum rigid body deceleration level is, in fact, reduced if a HI-STORM 100S(232) suffers a non-mechanistic tipover onto the identical target as the HI-STORM 100. The situation is clearer for the HI-STORM 100S(243), which is virtually equal in weight to the HI-STORM 100, yet its center of gravity when loaded is almost one inch lower. In what follows, we present a summary of the analysis undertaken to demonstrate conclusively that the result for maximum deceleration level in the HI-STORM 100 tipover event does bound the corresponding value for the HI-STORM 100S(232), and, therefore, we need only perform a detailed dynamic finite element analysis for the HI-STORM 100.

Appendix 3.A presents a result for the angular velocity of the cylindrical body representing a HI-STORM 100 just prior to impact with the defined target. The result is expressed in Subsection 3.A.6 in terms of the cask geometry, and the ratio of the mass divided by the mass moment of inertia about the corner point that serves as the rotation origin. Since the mass moment of inertia is also linearly related to the mass, the angular velocity at the instant just prior to target contact is independent of the cask mass. Subsequent to target impact, we investigate post-impact response by considering the cask as a cylinder rotating into a target that provides a resistance force that varies linearly with distance from the rotation point. We measure "time" as starting at the instant of impact, and develop a one-degree-of freedom equation for the post-impact response (for the rotation angle into the target) as:

$$\ddot{\theta} + \omega^2\theta = 0$$

where

$$\omega^2 = \frac{kL^3}{3I_A}$$

The initial conditions at time=0 are: the initial angle is zero and the initial angular velocity is equal to the rigid body angular velocity acquired by the tipover from the center-of-gravity over corner position. In the above relation, L is the length of the overpack, I is the mass moment of inertia defined in Appendix 3.A, and k is a "spring constant"associated with the target resistance. If we solve for the maximum angular acceleration subsequent to time = 0, we obtain the result in terms of the initial angular velocity as:

$$\ddot{\theta}_{max} = \omega\dot{\theta}_0$$

If we form the maximum linear acceleration at the top of the four-inch thick lid of the overpack, we can finally relate the decelerations of the HI-STORM 100 and the HI-STORM 100S(232) solely in terms of their geometry properties and their mass ratio. The value of "k", the target spring rate is the same for both overpacks so it does not appear in the relationship between the two decelerations. After substituting the appropriate geometry and calculated masses, we determine that the ratio of maximum rigid body decelerations at the top surface of the four-inch thick top lid plates is:

$A_{HI\text{-}STORM\ 100S(232)}/A_{HI\text{-}STORM\ 100} = 0.946$

Therefore, as postulated, there is no need to perform a separate DYNA3D analysis for the HI-STORM 100S hypothetical tipover.

Moreover, according to Appendix 3.A, analysis of a single mass impacting a spring with a given initial velocity shows that the maximum deceleration "a_M" of the mass is related to the dropped weight "w" and the drop height "h" as follows:

$$a_M \sim \frac{\sqrt{h}}{\sqrt{w}}$$

In other words, as the dropped weight increases, the maximum deceleration of the mass decreases. Therefore, the rigid body decelerations calculated in Appendix 3.A serve as a conservative upper bound for the densified concrete shielding option.

The same considerations apply to the HI-STORM 100S Version B. The overall lengths are reduced from the classic HI-STORM 100, but the actual weights may be reduced. Therefore, calculations similar to those given above for the HI-STORM 100S are needed to conclusively demonstrate that the non-mechanistic tipover analysis of the classic HI-STORM 100 remains bounding. The results of the calculations, which demonstrate that the design basis limits are met, are presented below together with maximum G levels computed for the 11" vertical drop:

ITEM	A HI-STORM 100S VERSION B(218)/A HI-STORM 100	A HI-STORM 100S VERSION B(229)/A HI-STORM 100	Max. Calculated G Level 11" Drop
HI-STORM 100S Version B(218)	0.91	-	44.378
HI-STORM 100S Version B(229)	-	0.98	43.837

A simple elastic strength of materials calculation is performed to demonstrate that the cylindrical storage overpack will not permanently deform to the extent that the MPC cannot be removed by normal means after a tip-over event. The results demonstrate that the maximum diametrical closure of the cylindrical cavity is less than the initial clearance between the overpack MPC support channels and the MPC canister. Primary circumferential membrane stresses in the MPC shell remain in the elastic range during a tip-over (see Table 3.4.6 summary safety factors); therefore, no permanent global ovalization of the MPC shell occurs as a result of the drop.

To demonstrate that the shielding material will continue to perform its function after a tip-over accident, the stress and strain levels in the metal components of the storage overpack are examined at the end of the tip-over event. The results obtained in Appendix 3.A for impact decelerations conservatively assumed a rigid storage overpack model to concentrate nearly all energy loss in the target. However, to assess the state of stress and strain in the storage overpack after an accident causing a tip-over, the tip-over analysis was also performed using a non-rigid storage overpack model using overpack material properties listed in Appendix 3.A. Figure 3.4.13 shows the calculated von Mises stress in the top lid and outer shell at 0.08 seconds after the initiation of impact. Figure 3.4.14 shows the residual plastic strains in the same components. Figures 3.4.15 and 3.4.16 provide similar results for the inner shell, the radial plates, and the support channels†. The results show that while some plastic straining occurs, accompanied by stress levels above the yield stress of the material, there is no tearing in the metal structure which confines the radiation shielding (concrete). Therefore, there is no gross failure of the metal shells enclosing the concrete. The shielding concrete will remain inside the confines of the storage overpack and maintain its performance after the tipover event. Although the preceding results are based on an overpack model having inner and outer shell thicknesses of 1-1/4" and 3/4", respectively, the conclusion holds for the optional HI-STORM design with 1" thick inner and outer shells since having a thicker steel shell at the primary point of impact provides more strength and greater protection against a cavity breach. The results from these analyses are also applicable to the HI-STORM 100S and the HI-STORM 100S, Version B since the structural material at the top of the cask that would be locally deformed after a tipover event is essentially the same.

† During fabrication the channels are attached to the inner shell by one of two methods, either the channels are welded directly to the inner shell or they are welded to a pair of L-shaped angles (i.e., channel mounts) that are pre-fastened to the inner shell. The results presented in Figures 3.4.16a and 3.4.16b bound the results from both methods of attachment.

3.4.11 Storage Overpack and HI-TRAC Transfer Cask Service Life

The term of the 10CFR72, Subpart L C of C, granted by the NRC is 20 years; therefore, the License Life (please see glossary) of all components is 20 years. Nonetheless, the HI-STORM 100 and 100S Storage overpacks and the HI-TRAC transfer cask are engineered for 40 years of design life, while satisfying the conservative design requirements defined in Chapter 2, including the regulatory requirements of 10CFR72. In addition, the storage overpack and HI-TRAC are designed, fabricated, and inspected under the comprehensive Quality Assurance Program discussed in Chapter 13 and in accordance with the applicable requirements of the ACI and ASME Codes. This assures high design margins, high quality fabrication, and verification of compliance through rigorous inspection and testing, as describe in Chapter 9 and the design drawings in Section 1.5. Technical Specifications defined in Chapter 12 assure that the integrity of the cask and the contained MPC are maintained throughout the components' design life. The design life of a component, as defined in the Glossary, is the minimum duration for which the equipment or system is engineered to perform its intended function if operated and maintained in accordance with the FSAR. The design life is essentially the lower bound value of the service life, which is the expected functioning life of the component or system. Therefore, component longevity should be: licensed life < design life < service life. (The licensed life, enunciated by the USNRC, is the most pessimistic estimate of a component's life span.) For purposes of further discussion, we principally focus on the service life of the HI-STORM 100 System components that, as stated earlier, is the reasonable expectation of equipment's functioning life span.

The service life of the storage overpack and HI-TRAC transfer cask is further discussed in the following sections.

3.4.11.1 Storage Overpack

The principal design considerations that bear on the adequacy of the storage overpack for the service life are addressed as follows:

Exposure to Environmental Effects

In the following text, all references to HI-STORM 100 also apply to HI-STORM 100S and to the HI-STORM 100S Version B. All exposed surfaces of HI-STORM 100 are made from ferritic steels that are readily painted. Concrete, which serves strictly as a shielding material, is completely encased in steel. Therefore, the potential of environmental vagaries such as spalling of concrete, are ruled out for HI-STORM 100. Under normal storage conditions, the bulk temperature of the HI-STORM 100 storage overpack 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 100 storage overpack. 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 100 because HI-STORM 100 does not rely on rebars (indeed, it contains no rebars). As discussed in Appendix 1.D, the aggregates, cement and water used in the storage cask concrete are carefully controlled to provide high durability and resistance to temperature effects. The configuration of the storage overpack assures resistance to freeze-thaw degradation. In addition, the storage overpack is specifically designed for a full range of enveloping design basis natural phenomena that could occur over the 40-year design life of the storage overpack as defined in Subsection 2.2.3 and evaluated in Chapter 11.

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 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 overpack throughout the 40-year design life are defined in Chapter 9. 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 100 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 overpack.

The above findings are consistent with those of the NRC's Waste Confidence Decision Review [3.4.11], which concluded that dry storage systems designed, fabricated, inspected, and operate in accordance with such requirements are adequate for a 100-year service life while satisfying the requirements of 10CFR72.

3.4.11.2 Transfer Cask

The principal design considerations that bear on the adequacy of the HI-TRAC Transfer Cask for the service life are addressed as follows:

Exposure to Environmental Effects

All transfer cask materials that come in contact with the spent fuel pool are coated to facilitate decontamination. The HI-TRAC is designed for repeated normal condition handling operations with high factor of safety, particularly for the lifting trunnions, to assure structural integrity. The resulting cyclic loading produces stresses that are well below the endurance limit of the trunnion material, and therefore, will not lead to a fatigue failure in the transfer cask. All other off-normal or postulated accident conditions are infrequent or one-time occurrences that do not contribute significantly to fatigue. In addition, the transfer cask utilizes materials that are not susceptible to brittle fracture during the lowest temperature permitted for loading, as discussed in Chapter 12.

Material Degradation

All transfer cask materials that are susceptible to corrosion are coated. The controlled environment in which the HI-TRAC is used mitigates damage due to direct exposure to corrosive chemicals that may be present in other industrial applications. The infrequent use and relatively low neutron flux to which the HI-TRAC materials are subjected do not result in radiation embrittlement or degradation of the HI-TRAC's shielding materials that could impair the HI-TRAC's intended safety function. The HI-TRAC transfer cask materials are selected for durability and wear resistance for their deployment.

Maintenance and Inspection Provisions

The requirements for periodic inspection and maintenance of the HI-TRAC transfer cask throughout the 40-year design life are defined in Chapter 9. These requirements include provisions for routine inspection of the HI-TRAC transfer cask for damage prior to each use, including an annual inspection of the lifting trunnions. Precautions are taken during lid handling operations to protect the sealing surfaces of the pool lid. The leak tightness of the liquid neutron shield is verified periodically. The water jacket pressure relief valves and other fittings used can be easily removed.

3.4.12 MPC Service Life

The term of the 10CFR72, Subpart L C of C, granted by the NRC (i.e., licensed life) is 20 years. Nonetheless, the HI-STORM 100 MPC is designed for 40 years of design life, while satisfying the conservative design requirements defined in Chapter 2, including the regulatory requirements of 10CFR72. Additional assurance of the integrity of the MPC and the contained SNF assemblies throughout the 40-year life of the MPC is provided through the following:

- Design, fabrication, and inspection in accordance with the applicable requirements of the ASME Code as described in Chapter 2 assures high design margins.
- Fabrication and inspection performed in accordance with the comprehensive Quality Assurance program discussed in Chapter 13 assures competent compliance with the fabrication requirements.
- Use of materials with known characteristics, verified through rigorous inspection and testing, as described in Chapter 9, assures component compliance with design requirements.
- Use of welding procedures in full compliance with Section III of the ASME Code ensures high-quality weld joints.

Technical Specifications, as defined in Chapter 12, have been developed and imposed on the MPC that assure that the integrity of the MPC and the contained SNF assemblies are maintained throughout the 40-year design life of the MPC.

The principal design considerations bearing on the adequacy of the MPC for the service life are summarized below.

Corrosion

All MPC materials are fabricated from corrosion-resistant austenitic stainless steel and passivated aluminum. The corrosion-resistant characteristics of such materials for dry SNF storage canister applications, as well as the protection offered by these materials against other material degradation effects, are well established in the nuclear industry. The moisture in the MPC is removed to eliminate all oxidizing liquids and gases and the MPC cavity is backfilled with dry inert helium at the time of closure to maintain an atmosphere in the MPC that provides corrosion protection for the SNF cladding throughout the dry storage period. The preservation of this non-corrosive atmosphere is assured by the inherent sealworthiness of the MPC confinement boundary integrity (there are no gasketed joints in the MPC).

Structural Fatigue

The passive non-cyclic nature of dry storage conditions does not subject the MPC to conditions that might lead to structural fatigue failure. Ambient temperature and insolation cycling during normal dry storage conditions and the resulting fluctuations in MPC thermal gradients and internal pressure is the only mechanism for fatigue. These low-stress, high-cycle conditions cannot lead to a fatigue failure of the MPC that is made from stainless alloy stock (endurnce limit well in excess of 20,000 psi). All other off-normal or postulated accident conditions are infrequent or one-time occurrences, which cannot produce fatigue failures. Finally, the MPC uses materials that are not susceptible to brittle fracture.

Maintenance of Helium Atmosphere

The inert helium atmosphere in the MPC provides a non-oxidizing environment for the SNF cladding to assure its integrity during long-term storage. The preservation of the helium atmosphere in the MPC is assured by the robust design of the MPC confinement boundary described in Section 7.1. Maintaining an inert environment in the MPC mitigates conditions that might otherwise lead to SNF cladding failures. The required mass quantity of helium backfilled into the canister at the time of closure and the associated fabrication and closure requirements for the canister are specifically set down to assure that an inert helium atmosphere is maintained in the canister throughout the 40-year design life.

Allowable Fuel Cladding Temperatures

The helium atmosphere in the MPC promotes heat removal and thus reduces SNF cladding temperatures during dry storage. In addition, the SNF decay heat will substantially attenuate over a 40-year dry storage period. Maintaining the fuel cladding temperatures below allowable levels during long-term dry storage mitigates the damage mechanism that might otherwise lead to SNF cladding failures. The allowable long-term SNF cladding temperatures used for thermal acceptance of the MPC design are conservatively determined, as discussed in Section 4.3.

Neutron Absorber Boron Depletion

The effectiveness of the fixed borated neutron absorbing material used in the MPC fuel basket design requires that sufficient concentrations of boron be present to assure criticality safety during worst case design basis conditions over the 40-year design life of the MPC. Information on the characteristics of the borated neutron absorbing material used in the MPC fuel basket is provided in Subsection 1.2.1.3.1. The relatively low neutron flux, which will continue to decay over time, to which this borated material is subjected, does not result in significant depletion of the material's available boron to perform its intended safety function. In addition, the boron content of the material used in the criticality safety analysis is conservatively based on the minimum specified boron areal density (rather than the nominal), which is further reduced by 25% for analysis purposes, as described in Section 6.1. Analysis discussed in Section 6.3.2 demonstrates that the boron depletion in the neutron absorber material is negligible over a 50-year duration. Thus, sufficient levels of boron are present in the fuel basket neutron absorbing material to maintain criticality safety functions over the 40-year design life of the MPC.

The above findings are consistent with those of the NRC's Waste Confidence Decision Review, which concluded that dry storage systems designed, fabricated, inspected, and operated in the manner of the requirements set down in this document are adequate for a 100-year service life, while satisfying the requirements of 10CFR72.

3.4.13 Design and Service Life

The discussion in the preceding sections seeks to provide the logical underpinnings for setting the design life of the storage overpacks, the HI-TRAC transfer cask, and the MPCs as forty years. Design life, as stated earlier, is a lower bound value for the expected performance life of a component (service life). If operated and maintained in accordance with this Final Safety Analysis Report, Holtec International expects the service life of its HI-STORM 100 and HI-STORM 100S Version's components to substantially exceed their design life values.

Table 3.4.1

FINITE ELEMENTS IN THE MPC STRUCTURAL MODELS

MPC Type	Model Type		
Element Type	**Basic**	**0 Degree Drop**	**45 Degree Drop**
MPC-24	1068	1114	1113
BEAM3	1028	1028	1028
PLANE82	0	0	0
CONTAC12	40	38	38
CONTAC26	0	45	45
COMBIN14	0	3	2
MPC-32	1374	1604	1603
BEAM3	1346	1346	1346
CONTAC12	28	27	24
CONTAC26	0	229	228
COMBIN14	0	2	5
MPC-68	1842	2066	2063
BEAM3	1782	1782	1782
PLANE82	16	16	16
CONTAC12	44	43	40
CONTAC26	0	223	222
COMBIN14	0	2	3
MPC-24E	1070	1124	1122
BEAM3	1030	1030	1030
PLANE82	0	0	0
CONTAC12	40	38	38
CONTAC26	0	53	52
COMBIN14	0	3	2

TABLE 3.4.2
HI-STORM 100 SYSTEM MATERIAL COMPATIBILITY WITH OPERATING ENVIRONMENTS

Material/Component	Fuel Pool (Borated and Unborated Water)†	ISFSI Pad (Open to Environment)
Alloy X: - MPC Fuel Basket - MPC Baseplate - MPC Shell - MPC Lid - MPC Fuel Spacers	Stainless steels have been extensively used in spent fuel storage pools with both borated and unborated water with no adverse reactions or interactions with spent fuel.	The MPC internal environment will be an inert (helium) atmosphere and the external surface will be exposed to ambient air. No adverse interactions identified.
Aluminum: - Heat Conduction Elements	Aluminum and stainless steel form a galvanic couple. However, aluminum will be used in a passivated state. Upon passivation, aluminum forms a thin ceramic (Al_2O_3) barrier. Therefore, during the short time they are exposed to pool water, significant corrosion of aluminum or production of hydrogen is not expected (see operational requirements under "Neutron Absorber Material" below).	In a non-aqueous atmosphere, galvanic corrosion is not expected.
Neutron Absorber Material:	Extensive in-pool experience on spent fuel racks with no adverse reactions. See Chapter 8 for additional requirements for combustible gas monitoring and required actions for control of combustible gas accumulation under the MPC lid.	No adverse potential reactions identified.

† HI-TRAC/MPC short-term operating environment during loading and unloading.

TABLE 3.4.2 (CONTINUED)
HI-STORM 100 SYSTEM MATERIAL COMPATIBILITY WITH OPERATING ENVIRONMENTS

Material/Component	Fuel Pool (Borated and Unborated Water)†	ISFSI Pad (Open to Environment)
Steels: - SA350-LF2 - SA350-LF3 - SA203-E - SA515 Grade 70 - SA516 Grade 70 - SA193 Grade B7 - SA106 (HI-TRAC)	All exposed steel surfaces (except seal areas, and pocket trunnions) will be coated with paint specifically selected for performance in the operating environments. Even without coating, no adverse reactions (other than nominal corrosion) have been identified. Lid bolts are plated and the threaded portion of the bolt anchor blocks is coated to seal the threaded area.	Internal surfaces of the HI-TRAC will be painted and maintained. Exposed external surfaces (except those listed in fuel pool column) will be painted and will be maintained with a fully painted surface. No adverse reactions identified.
Steels: - SA516 Grade 70 - SA203-E - SA350-LF3 - A36 Storage Overpack	HI-STORM 100 storage overpack is not exposed to fuel pool environment.	Internal and external surfaces will be painted (except for bolt locations that will have protective coating). External surfaces will be maintained with a fully painted surface. No adverse reaction identified.
Stainless Steels: - SA240 304 - SA193 Grade B8 - 18-8 S/S Miscellaneous Components	Stainless steels have been extensively used in spent fuel storage pools with both borated and unborated water with no adverse reactions.	Stainless steel has a long proven history of corrosion resistance when exposed to the atmosphere. These materials are used for bolts and threaded inserts. No adverse reactions with steel have been identified. No impact on performance.

† HI-TRAC/MPC short-term operating environment during loading and unloading.

TABLE 3.4.2 (CONTINUED)
HI-STORM 100 SYSTEM MATERIAL COMPATIBILITY
WITH OPERATING ENVIRONMENTS

Material/Component	Fuel Pool (Borated and Unborated Water)†	ISFSI Pad (Open to Environment)
Nickel Alloy: - SB637-NO7718 - SA564-630 H1100 (for HI-TRAC 125D only) Lifting Trunnion	No adverse reactions with borated or unborated water.	Exposed to weathering effects. No adverse reactions with storage overpack closure plate. No impact on performance.
Brass/Bronze: - Pressure Relief Valve HI-TRAC	Small surface of pressure relief valve will be exposed. No significant adverse impact identified.	Exposed to external weathering. No loss of function expected.
Holtite-A: - Solid Neutron Shield	The neutron shield is fully enclosed. No adverse reaction identified. No adverse reactions with thermal expansion foam or steel.	The neutron shield is fully enclosed in the outer enclosure. No adverse reaction identified. No adverse reactions with thermal expansion foam or steel.

† HI-TRAC/MPC short-term operating environment during loading and unloading.

TABLE 3.4.2 (CONTINUED)
HI-STORM 100 SYSTEM MATERIAL COMPATIBILITY WITH OPERATING ENVIRONMENTS

Material/Component	Fuel Pool (Borated and Unborated Water)†	ISFSI Pad (Open to Environment)
Paint: - as per Appendix 1.C	Paint used for the HI-TRAC exterior surface has acceptable performance for short-term exposure in mild borated pool water. Paint selected for HI-TRAC internal surfaces has excellent high temperature resistance properties. Will only be exposed to demineralized water during in-pool operations as annulus is filled prior to placement in the spent fuel pool and the inflatable seal prevents fuel pool water in-leakage. No adverse interaction identified which could affect MPC/fuel assembly performance.	Good performance on surfaces. Discoloration is not a concern.
Elastomer Seals:	No adverse reactions identified.	Only used during fuel pool operations.
Lead:	Enclosed by carbon steel. Lead is not exposed to fuel pool water. Lead has no interaction with carbon steel.	Enclosed by carbon steel. Lead is not exposed to ambient environment. Lead has no interaction with carbon steel.
Concrete:	Storage overpack is not exposed to fuel pool water.	Concrete is enclosed by carbon steel and not exposed to ambient environment. Concrete has no interaction with carbon steel.

† HI-TRAC/MPC short-term operating environment during loading and unloading.

TABLE 3.4.3
FUEL BASKET RESULTS - MINIMUM SAFETY FACTORS

Load Case I.D.	Loading†	Safety Factor	Location in FSAR
F1	T, T'	No interference	Subsection 3.4.4.2
F2	D + H	2.87	Table 3.4.9 of Docket 72-1008
F3			
F3.a	D + H' (end drop)	3.6	3.4.4.3.1.3
F3.b	D + H' (side drop 0 deg.)	1.29	Table 3.4.6
F3.c	D + H' (side drop 45 deg.)	1.25	Table 3.4.6

† The symbols used for the loadings are defined in Table 2.2.13.

TABLE 3.4.4
MPC RESULTS - MINIMUM SAFETY FACTOR

Load Case I.D.	Load Combination[†,††]	Safety Factor	Location in FSAR Where the Analysis is Performed
E1			
E1.a	Design internal pressure, P_i	4.30[†††] 1.326 1.20 N/A	E1.a Lid — Table 3.4.7 Baseplate — 3.I.8.1 of Docket 72-1008 Shell — Table 3.4.7 Supports
E1.b	Design external pressure, P_o	4.30[†††] 1.326 23.3 N/A	E1.b Lid — P_i bounds Baseplate — P_i bounds Shell — 3.4.4.3.1.7 (buckling methodology in 3.H of Docket 72-1008 Supports
E1.c	Design internal pressure, P_i, plus Temperature T	1.09	E1.c Shell — Table 3.4.8
E2	D + H + (P_i, P_o)	1.8[†††] 1.08 2.64*0.967(stress), 45.5 5.85	Lid — 3.E.8.1.2 of Docket 72-1008 Baseplate — 3.4.3.6 Shell — Table 3.4.9 of Docket 72-1008 Buckling methodology in 3.H of Docket 72-1008 Supports — Table 3.4.9 of Docket 72-1008

Note: 0.967 multiplier reflects increase in MPC shell design temperature to 500 deg. F.

† The symbols used for the loadings are defined in Table 2.2.13

†† Note that in analyses, bounding pressures are applied, i.e., in buckling calculations P_o is used, and in stress evaluations either P_o or P_i is appropriate

††† Minimum safety factor is based on the dual lid configuration.

TABLE 3.4.4 (CONTINUED)
MPC RESULTS - MINIMUM SAFETY FACTOR

Load Case I.D.	Load Combination[†,††]	Safety Factor	Location in FSAR		
E3					
E3.a	$(P_i,P_o) + D + H'$, end drop	1.4[†††]	E3.a	Lid	3.E.8.2.1.2 of Docket 72-1008
		1.87		Baseplate	3.I.8.3 of Docket 72-1008
		1.72		Shell	Buckling methodology in 3.H of Docket 72-1008
		N/A		Supports	
E3.b	$(P_i,P_o) + D + H'$, side drop 0 deg.	1.4[†††]	E3.b	Lid	end drop bounds
		1.87		Baseplate	end drop bounds
		1.02		Shell	Table 3.4.6
		1.13		Supports	Table 3.4.6
E3.c	$(P_i,P_o) + D + H'$, side drop 45 deg.	1.4[†††]	E3.c	Lid	end drop bounds
		1.87		Baseplate	end drop bounds
		1.38		Shell	Table 3.4.6
		1.50		Supports	Table 3.4.6

† The symbols used for the loadings are defined in Table 2.2.13

†† Note that in analyses, bounding pressures are applied, i.e., in buckling calculations P_o is used, and in stress evaluations either P_o or P_i is appropriate

††† Minimum safety factor is based on the dual lid configuration.

TABLE 3.4.4 (CONTINUED)
MPC RESULTS - MINIMUM SAFETY FACTOR

Load Case I.D.	Load Combination†, ††	Safety Factor	Location in FSAR	
E4	T	Subsection 3.4.4.2 shows there are no primary stresses from thermal expansion.	Subsection 3.4.4.2	
E5	$D + T^* + (P_i^*, P_o^*)$	8.6†††	Lid	3.4.4.3.1.10
		1.17	Baseplate	3.4.4.3.1.10
		1.15 (buckling)	Shell	Buckling methodology in 3.H of Docket 72-1008
		2.60 (stress)		3.4.4.3.1.2 (stress)
		N/A	Supports	N/A

† The symbols used for the loadings are defined in Table 2.2.13.

†† Note that in analyses, bounding pressures are applied, i.e., in buckling calculations P_o is used, and in stress evaluations either P_o or P_i is appropriate.

††† Minimum safety factor is based on the dual lid configuration.

TABLE 3.4.5
HI-STORM 100 STORAGE OVERPACK AND HI-TRAC RESULTS - MINIMUM SAFETY FACTORS

Load Case I.D.	Loading†	Safety Factor	Location in FSAR	
01	$D + H + T + (P_o, P_i)$		Overpack	
		1.33	Shell (inlet vent)/Base	3.4.3.5
		N/A	Top Lid	N/A
			HI-TRAC	
		2.69(125); 2.17(100)	Shell	3.4.3.3; 3.4.3.4
		2.604 (ASME Code limit)	Pool Lid	3.4.3.8
		2.61 (ASME Code limit)	Top Lid	N/A
		2.91; 1.11(optional bolts)	Pocket Trunnion	3.4.4.3.3.1
02				
02.a	$D + H' + (P_o, P_i)$		Overpack	
	(end drop/tip-over)	1.271	Shell	3.4.4.3.2.3
		1.125	Top Lid	3.4.4.3.2.2
			HI-TRAC	
02.b	$D + H' + (P_o, P_i)$	1.52	Shell	3.4.9.3
	(side drop)	1.159	Transfer Lid	3.4.4.3.3.3
		1.651	Top Lid	3.4.4.3.3.5
03	D (water jacket)	1.39	3.4.4.3.3.4	
04	M (small and medium penetrant missiles)	2.60 (Side Strike); 1.065(End strike)	Overpack	3.4.8.1
		1.23 (End Strike)	HI-TRAC	3.4.8.2.1

† The symbols used for the loadings are defined in Table 2.2.13.

TABLE 3.4.6
MINIMUM SAFETY FACTORS FOR MPC COMPONENTS DURING TIP-OVER 45g DECELERATIONS

Component - Stress Result	MPC-24		MPC-68	
	0 Degrees	45 Degrees	0 Degrees	45 Degrees
Fuel Basket - Primary Membrane (P_m)	3.38 (1134)	4.72 (396)	2.89 (1603)	4.18 (1603)
Fuel Basket - Local Membrane Plus Primary Bending (P_L+P_b)	1.29 (1065)	1.30 (577)	2.09 (1590)	1.38 (774)
Enclosure Vessel - Primary Membrane (P_m)	6.39*.967 (1354)	6.46*.967 (1370)	6.29*.967 (2393)	6.58*.967 (2377)
Enclosure Vessel - Local Membrane Plus Primary Bending (P_L+P_b)	2.46*.967 (1278)	2.92*.967 (1247)	1.05*.967 (1925)	1.50*.967 (1925)
Basket Supports – Primary Membrane (P_m)	N/A	N/A	6.86 (1710)	8.98 (1699)
Basket Supports - Local Membrane Plus Primary Bending (P_L+P_b)	N/A	N/A	1.13 (1715)	1.50 (1704)

Notes:

1. Corresponding ANSYS element number shown in parentheses.
2. Multiplier of 0.967 reflects increase in Enclosure Vessel Design Temperature from 450 deg. F to 500 deg. F (Table 2.2.3).
3. Safety factors for the MPC-24 and MPC-68 have been reduced (divided by factors of 1.024 and 1.043, respectively) to adjust for the fuel assembly weight increase (see Subsection 3.4.4.4.1)

TABLE 3.4.6 (CONTINUED)
MINIMUM SAFETY FACTORS FOR MPC COMPONENTS DURING TIP-OVER
45g DECELERATIONS

	MPC-32	
Component - Stress Result	**0 Degrees**	**45 Degrees**
Fuel Basket - Primary Membrane (P_m)	3.43 (715)	4.84 (366)
Fuel Basket - Local Membrane Plus Primary Bending (P_L+P_b)	1.47 (390)	1.25 (19)
Enclosure Vessel - Primary Membrane (P_m)	4.01*.967 (1091)	5.46*.967 (1222)
Enclosure Vessel - Local Membrane Plus Primary Bending (P_L+P_b)	1.08*.967 (1031)	1.43*.967 (1288)
Basket Supports - Primary Membrane (P_m)	3.36 (905)	4.74 (905)
Basket Supports - Local Membrane Plus Primary Bending (P_L+P_b)	1.27 (901)	1.67 (908)

Notes:

1. Corresponding ANSYS element number shown in parentheses.
2. Multiplier of 0.967 reflects increase in Enclosure Vessel Design Temperature from 450 deg. F to 500 deg. F (Table 2.2.3).
3. Safety factors for the MPC-32 has been reduced (divided by factor of 1.024) to adjust for the fuel assembly weight increase (see Subsection 3.4.4.4.1)

TABLE 3.4.6 (CONTINUED)
MINIMUM SAFETY FACTORS FOR MPC-24E COMPONENTS DURING TIP-OVER
45g DECELERATIONS

Components – Stress Result	0 Degrees	45 Degrees
Fuel Basket – Primary Membrane (P_m)	-10,554 (3.50)	-7,608 (4.86)
Fuel Basket – Primary Membrane plus Primary Bending ($P_L + P_b$)	38,029 (1.46)	32,745 (1.70)
Enclosure Vessel – Primary Membrane (P_m)	6,611 (6.57*.967)	6,612 (6.57*.967)
Enclosure Vessel – Primary Membrane plus Primary Bending ($P_L + P_b$)	23,680 (2.75*.967)	16,868 (3.87*.967)

Notes:

1. All stresses are reported in psi units and are based on closed gaps (primary stresses only).
2. The numbers shown in parentheses are the corresponding safety factors.
3. Multiplier of 0.967 reflects the increase in Enclosure Vessel Design Temperature from 450 deg. F to 500 deg. F (Table 2.2.3).
4. Stress results/safety factors for the MPC-24E have been multiplied/divided by a factor of 1.024 to adjust for the fuel assembly weight (See subsection 3.4.4.4.1).

TABLE 3.4.7
STRESS INTENSITY RESULTS FOR CONFINEMENT BOUNDARY - INTERNAL PRESSURE ONLY

Locations (Per Fig. 3.4.11)	Calculated Value of Stress Intensity (psi)	Category	Table 3.1.13 Allowable Value (psi)†	Safety Factor (Allowable/Calculated)
Top Lid††				
A	1,633	$P_L + P_b$	25,450	15.6
Neutral Axis	21.9	P_m	16,950	774
B	1,604	$P_L + P_b$	25,450	15.9
C	695	$P_L + P_b$	25,450	36.6
Neutral Axis	732	P_m	16,950	23.2
D	2,962	$P_L + P_b$	25,450	8.59
Baseplate				
E	19,773	$P_L + P_b$	28,100	1.42
Neutral Axis	415	P_m	18,700	45.1
F	20,601	$P_L + P_b$	28,100	1.36
G	9,610	$P_L + P_b$	28,100	2.92
Neutral Axis	2,268	P_m	18,700	8.25
H	8,279	$P_L + P_b$	28,100	3.39

† Allowable stress intensities are evaluated at 550 degrees F (lid), 400 degrees F (baseplate), and 500 degrees F (canister).

†† Stresses for the top lid are reported for the single lid configuration; a doubling of the calculated stress values (and a halving of the top lid safety factors) results when the dual lid configuration is considered.

TABLE 3.4.7 (CONTINUED)
STRESS INTENSITY RESULTS FOR CONFINEMENT BOUNDARY - INTERNAL PRESSURE ONLY

Locations (Per Fig. 3.4.11)	Calculated Value of Stress Intensity (psi)	Category	Table 3.1.13 Allowable Value (psi)†	Safety Factor (Allowable/Calculated)
Canister				
I	6,788	P_m	17,500	2.58
Upper Bending Boundary Layer Region	7,202 7,014	$P_L + P_b + Q$ P_L	52,500 26,300	7.29 3.75
Lower Bending Boundary Layer Region	43,645 11,349	$P_L + P_b + Q$ P_L	52,500 26,300	1.20 2.32

† Allowable stress intensities are evaluated at 550 degrees F (lid), 400 degrees F (baseplate), and 500 degrees F (canister).

TABLE 3.4.8
PRIMARY AND SECONDARY STRESS INTENSITY RESULTS FOR CONFINEMENT BOUNDARY - PRESSURE PLUS THERMAL LOADING

Locations (Per Fig. 3.4.11)	Calculated Value of Stress Intensity (psi)	Category	Allowable Stress Intensity (psi)†	Safety Factor (Allowable/Calculated)
Top Lid††				
A	7,866	$P_L + P_b + Q$	50,850	6.46
Neutral Axis	6,553	$P_m + P_L$	25,450	3.88
B	3,409	$P_L + P_b + Q$	50,850	14.9
C	13,646	$P_L + P_b + Q$	50,850	3.73
Neutral Axis	12,182	$P_m + P_L$	25,450	2.09
D	11,145	$P_L + P_b + Q$	50,850	4.56
Baseplate				
E	19,417	$P_L + P_b + Q$	56,100	2.89
Neutral Axis	223.1	$P_m + P_L$	28,100	126
F	19,860	$P_L + P_b + Q$	56,100	2.82
G	4,836	$P_m + P_L + Q$	56,100	11.6
Neutral Axis	1,201	$P_m + P_L$	28,100	23.4
H	4,473	$P_L + P_b + Q$	56,100	12.5

† Allowable stress intensities are evaluated at 550 degrees F (lid), 400 degrees F (baseplate), and 500 degrees F (canister).

†† Stresses for the top lid are reported for the single lid configuration; a doubling of the calculated stress values (and a halving of the top lid safety factors) results when the dual lid configuration is considered.

TABLE 3.4.8 (CONTINUED)
PRIMARY AND SECONDARY STRESS INTENSITY RESULTS FOR CONFINEMENT BOUNDARY - PRESSURE PLUS THERMAL LOADING

Locations (Per Fig. 3.4.11)	Calculated Value of Stress Intensity (psi)	Category	Allowable Stress Intensity (psi)†	Safety Factor (Allowable/Calculated)
Canister				
I	6,799	P_L	26,300	3.87
Upper Bending Boundary Layer Region	12,813 12,185	$P_L + P_b + Q$ P_L	52,500 26,300	4.10 2.16
Lower Bending Boundary Layer Region	48,378 12,028	$P_L + P_b + Q$ P_L	52,500 26,300	1.09 2.19

† Allowable stress intensities are evaluated at 550 degrees F (lid), 400 degrees F (baseplate), and 500 degrees F (canister).

TABLE 3.4.9
SAFETY FACTORS FROM SUPPLEMENTARY CALCULATIONS

Item	Loading	Safety Factor	FSAR Location Where Details are Provided
HI-STORM Top Lid Weld Shear	Tipover	3.22	3.4.4.3.2.2
HI-STORM Lid Bottom Plate	End Drop	9.777	3.4.4.3.2.3
HI-STORM Lid Bottom Plate Welds	End Drop	2.695	3.4.4.3.2.3
Pedestal Shield Compression	End Drop	1.011	3.4.4.3.2.3
HI-STORM Inlet Vent Plate Bending Stress	End Drop	1.271	3.4.4.3.2.3
HI-STORM Lid Top Plate Bending	End Drop –100 100S	5.208 1.357	3.4.4.3.2.3
HI-TRAC Pocket Trunnion Weld	HI-TRAC Rotation	2.92	3.4.4.3.3.1
HI-TRAC 100 Optional Bolts - Tension	HI-TRAC Rotation	1.11	3.4.4.3.3.1
HI-STORM 100 Shell	Seismic Event	14.6	3.4.7
HI-TRAC Transfer Lid Door Lock Bolts	Side Drop	2.387	3.4.4.3.3.3
HI-TRAC Transfer Lid Separation	Side Drop	1.159	3.4.4.3.3.3
HI-STORM 100 Top Lid	Missile Impact	1.20	3.4.8.1
HI-STORM 100 Shell	Missile Impact	2.77	3.4.8.1
HI-TRAC Water Jacket –Enclosure Shell Bending	Pressure	1.85	3.4.4.3.3.4
HI-TRAC Water Jacket – Enclosure Shell Bending	Pressure plus Handling	1.80	3.4.4.3.3.1
HI-TRAC Water Jacket – Bottom Flange Bending	Pressure	1.39	3.4.4.3.3.4
HI-TRAC Water Jacket – Weld	Pressure	1.42	3.4.4.3.3.4
Fuel Basket Support Plate Bending	Side Drop	1.82	3.4.4.3.1.8
Fuel Basket Support Leg Stability	Side Drop	4.07	3.4.4.3.1.8
Fuel Basket Support Welds	Side Drop	1.35	3.4.4.3.1.8
MPC Cover Plates in MPC Lid	Normal Condition Internal Pressure	1.81	3.4.4.3.1.8
MPC Cover Plate Weld	Accident Condition Internal Pressure	2.52	3.4.4.3.1.8
HI-STORM Storage Overpack	External Pressure	2.88	3.4.4.5.2
HI-STORM Storage Overpack Circumferential Stress	Missile Strike	2.60	3.4.8.1
HI-TRAC Transfer Cask Circumferential Stress	Missile Strike	2.61	3.4.8.2
HI-TRAC Transfer Cask Axial Membrane Stress	Side Drop	1.52	3.4.9.3

TABLE 3.4.10
INPUT DATA FOR SEISMIC ANALYSIS OF ANCHORED HI-STORM 100 SYSTEM

Item	Data Used	Actual Value and Reference
Cask height, inch	231.25	231.25" (Dwg. 1495)
Contact diameter at ISFSI pad, inch	146.5	146.5 (Dwg. 3187)
Overpack empty, wt. Kips	270	267.87 (Table 3.2.1)
Bounding wt. of loaded MPC, kips	90	88.135 (Table 3.2.1)
Overpack-to-MPC radial gap (inch)	2.0	2.0' (Dwg. 1495, Sheets 2 and 5)
Overpack C.G. height above ISFSI pad, inch	117.0	116.8 (Table 3.2.3)
Overpack with Loaded MPC - C.G. height above ISFSI pad	118.5	118.5 (Table 3.2.3)
Applicable Response Spectra	Fig. 3.4-31 to 3.4-36	Figure 3.4-30
ZPA: Horizontal 1 Horizontal 2 Vertical	RG 1.60 Western Plant 1.5 1.45 1.5 1.45 1.5 1.3	Site-Specific
No. of Anchor Studs	28	Up to 28
Anchor Stud Diameter Inch Yield stress, ksi Ultimate stress, ksi Free length, inch* Pre-load tensile stress, ksi*	 2.0 80 (minimum) 125 (minimum) 16-42 55-65	 2.0 (BOM 3189) Table 1.2.7 Table 1.2.7 Site-specific 55-65

*For the confirmatory dynamic analyses, bolt spring rates were computed using the maximum length, and the preload stress was slightly above 60.1 ksi. For the static analysis, all combinations were evaluated.