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 requirement, the justification for the exception or clarification, and the Holtec approach to meet the intent of the NUREG-1536 requirement.

2.0 PRINCIPAL DESIGN CRITERIA

The design criteria for the MPC, HI-STORM 100 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.

† 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).

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, to the maximum extent practicable, 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, to the maximum extent practicable, as discussed in Section 2.2.4. The principal exception is the MPC lid, vent and drain *port* cover plates, and closure ring welds to the MPC lid and shell, as discussed in Section 2.2.4. 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.

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 final weld surface, in accordance with the ~~D~~*d*esign ~~D~~*d*rawings 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, a hydrostatic pressure test and a helium leak test, in accordance with the Design Drawings and Technical Specification requirements contained in *Appendix A to the CoC* ~~Chapter 12.~~

The structural analysis of the MPC, in conjunction with the redundant closures and nondestructive examination, hydrostatic pressure testing, and helium leak testing performed during MPC fabrication and MPC closure, 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. ~~Compliance with the ASME Code is fully consistent with that used by other canister-based dry storage systems previously approved by the NRC.~~

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 100 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 allowable zircaloy fuel cladding temperature limits to prevent cladding failure during long-term dry storage conditions for *moderate burnup fuel in* the MPC are based on LLNL Report *UCID-21181* [2.2.14]. To provide additional conservatism, the permissible fuel cladding temperature limits, which are lower than those calculated with the LLNL methodology, have been calculated based on PNL Report *6189* [2.0.3]. Stainless steel cladding is demonstrated to withstand higher temperatures than that of zircaloy cladding in EPRI Report *TR-106440* [2.2.13]. However, the zircaloy fuel cladding temperature limits are conservatively applied to the stainless steel fuel cladding. *Allowable fuel cladding temperatures for high burnup fuel assemblies are determined using a creep-strain model, developed by Holtec, and described in further detail in Appendix 4.A.* The allowable fuel cladding temperatures which correspond to varying cooling times for the SNF to be stored in the MPCs are provided in Table 2.2.3.

The short-term allowable fuel cladding temperature that is applicable to off-normal and accident conditions, as well as the fuel loading, canister closure, and canister transfer operations in the HI-TRAC transfer cask, is 570°C (1058 °F) based on PNL-4835 [2.2.15]. The MPC is backfilled with 99.995% pure helium ~~at a mass specified~~ in *accordance with* ~~*Chapter 12*~~ *the Technical Specifications* during canister sealing operations to promote heat transfer and prevent cladding degradation.

The 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 in accordance with the *Approved Contents section of Appendix B to the CoC.* ~~*Technical Specifications contained in Chapter 12.*~~

Each MPC model 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, subject to other restrictions in the CoC, such as preferential fuel loading and location requirements for damaged fuel containers (DFCs) and fuel with integral non-fuel hardware (e.g., control rod assemblies). The second is regionalized fuel loading, wherein the basket is segregated into two regions as defined in Appendix B to the CoC. Region 1 is the inner region where fuel assemblies with higher heat emission rates may be stored and Region 2 is the outer region where fuel assemblies with lower heat emission rates are stored. Regionalized loading allows for storage of fuel assemblies with higher heat emission rates (in Region 1) than would otherwise be authorized for loading under a uniform loading strategy. Regionalized loading strategies must also comply with other requirements of the CoC, such as those for

DFCs and non-fuel hardware. Specific fuel assembly cooling time, burnup, and decay heat limits for regionalized loading are provided in the Approved Contents section of Appendix B to the CoC. The two fuel loading regions are defined by fuel storage location number in Table 2.1.13 (refer to Figures 1.2.2 through 1.2.4A).

Shielding

The allowable doses for an ISFSI using the HI-STORM 100 System are delineated in 10CFR72.104 and 72.106. Compliance with ~~*this criteria*~~ *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 7.*

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

The MPCs are designed for design basis fuel ~~at the maximum burnup and minimum cooling times,~~ as described in Sections 2.1.7 and 5.2. The radiological source term for the MPCs are limited based on the burnup and cooling times specified in *Appendix B to the CoC* ~~*the Technical Specifications contained in Chapter 12.*~~ Calculated dose rates for each MPC are provided in Section 5.1. These dose rates are used to perform an occupational exposure evaluation in accordance with 10CFR20, 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 ~~intact~~ fuel with optimum ~~unborated~~ 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, ~~*and*~~ fixed borated neutron absorbing materials (Boral) incorporated into the fuel basket assembly, *and, for certain MPC models, soluble boron in the MPC water*. The minimum specified boron concentration verified during Boral manufacture is further reduced by 25% for criticality analysis. No credit is taken for burnup. The maximum allowable initial enrichment for fuel assemblies to be stored in each MPC are limited in accordance with the *Approved Contents section of Appendix B to the CoC.* ~~*Technical Specifications contained in Chapter 12.*~~ *Soluble boron concentration requirements are delineated in the Technical Specifications in Appendix A to the CoC.*

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. A non-mechanistic breach of the canister and subsequent release of available fission products in accordance with specified release fractions is considered, as discussed in Section 7.3. The confinement function of the MPC is verified through hydrostatic testing, helium leak testing and weld examinations performed in accordance with the acceptance test program in Chapter 9 ~~*and the Technical Specifications contained in Chapter 12*~~.

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 ~~10CFR72 Technical Specifications for the~~ HI-STORM 100 System *CoC.* ~~contained in *Chapter 12.*~~

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 ~~contained~~ *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 100 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 100 Overpack Design Criteria

General

The HI-STORM 100 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 100 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 100 overpack concrete is shielding of the gamma and neutron radiation emitted by the spent nuclear fuel.

Unlike other concrete storage casks, the HI-STORM 100 overpack concrete is enclosed in steel inner and outer shells connected to each other by four radial ribs, and top and bottom plates. Where typical concrete storage casks are reinforced by rebar, the HI-STORM 100 overpack is supported by the inner and outer shells connected by four ribs. As the HI-STORM 100 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-318-95 [2.0.1].

In recognition of the conservative assessment of the HI-STORM 100 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 100 overpack concrete as specified 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. ~~Compliance with the ASME Code is fully consistent with those used by other canister-based dry storage systems previously approved by the NRC.~~

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 *Cask Transport Evaluation program described in* Technical Specification *Section 5.0* ~~requirements~~ contained in *Appendix A to the CoC.* ~~Chapter 12.~~ 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 temperature limit for the overpack concrete is less than the limit in NUREG-1536, which limits the local concrete temperature to 300°F, if Type II cement is used and aggregates are selected which are acceptable for concrete in this temperature range. Appendix 1.D specifies the cement and aggregate requirements to allow the utilization of the 300°F temperature limit of NUREG-1536; however, a conservative long-term temperature limit of 200 °F is applied to the concrete. For short term conditions the concrete temperature limit of 350°F is specified in accordance with Appendix A of 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 at the site 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 site 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 Chapters 5 and 10. 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* ~~at~~ the cask ~~midplane~~ for all MPCs ~~to 35 mrem/hr or less,~~ 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. In addition, overpack dose rates are limited in accordance with the Technical Specifications provided in *Appendix A to the CoC.* ~~*Chapter 12.*~~

<u>Confinement</u>

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.

<u>Operations</u>

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 ~~10CFR72 Technical Specifications for the~~ HI-STORM 100 System *CoC.* ~~contained in *Chapter 12*~~.

<u>Acceptance Tests and Maintenance</u>

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.

<u>Decommissioning</u>

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 *to the maximum extent practicable*, 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 ~~*contained in Chapter 12.*~~ 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 lid incorporates 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 allowable heat load provided in the Technical Specifications ~~*contained in Chapter 12.*~~ 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 corresponding Technical Specifications applicable to the HI-TRAC during hot and cold conditions is contained in Chapter 12.*~~ 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 delineated in the Design Features section of Appendix B to the CoC.*

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 125-ton or 100-ton HI-TRAC 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 125 ton HI-TRAC provides better shielding than the 100 ton HI-TRAC. 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 ~~considerations~~*limits*, or ~~space envelope limitations in the fuel pool or air lock~~*other site-specific considerations*. As with other dose reduction-based plant *activities* ~~modifications~~, individual users who cannot accommodate the 125 ton HI-TRAC ~~due to plant design limitations must~~ *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 ~~modification(s)~~ *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.

Operation

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 ~~in accordance with site and~~ *the* HI-STORM 100 System *CoC.* ~~Technical Specification requirements contained in Chapter 12.~~

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 the CoC, 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 regulatory position with respect to such structures is specified in 10CFR72.122(b):

"(2) Structures, systems, and components important to safety must be designed to withstand the effects of natural phenomena such as earthquakes, tornadoes, lightning, hurricanes, floods, tsunami, and seiches, without impairing their capability to perform safety functions. The design bases for these structures, systems, and components must reflect:

(i) Appropriate consideration of the most severe of the natural phenomena reported for the site and surrounding area, with appropriate margins to take into account the limitations of the data and the period of time in which the data have accumulated, and

(ii) Appropriate combinations of the effects of normal and accident conditions and the effects of natural phenomena."

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 in 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 ~~the design code ACI 349 and~~ 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*

It is noted 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.*

<u>*Normal Events*</u>

$U_c > 1.4D + 1.7\,(L)$

<u>*Off-Normal Events*</u>

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

<u>*Accident-Level Events*</u>

$U_c > D+L+E\ (\text{or } W_t)$

c. <u>*Load Combination for the Anchor Studs*</u>

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*
<u>*Normal Events*</u> *D*	*NF-3322.1, 3324.6*
<u>*Off-Normal Events*</u> *D+F*	*NF-3322.1, 3324.6 with all stress limits increased by 1.33*
<u>*Accident-Level Events*</u> *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. The CoC provides the specific requirements for ISFSI pad design and establishing lift height limits.

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 HI-STORM. 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 ~~& Fabrication~~ 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	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
Design Dead Weights:			
Max. Loaded Canister (dry)	79,987 lb. (MPC-24) *82,389 lb. (MPC-24E)* 87,241 lb. (MPC-68) *88,135 lb. (MPC-32)*	R.G. 3.61	Table 3.2.1
Empty Canister (dry)	39,667 lb. (MPC-24) *42,069 lb. (MPC-24E)* 39,641 lb. (MPC-68) *34,375 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

Table 2.0.1 (continued)
MPC DESIGN CRITERIA SUMMARY

Type	Criteria	Basis	FSAR Reference
Off-Normal:	100 psig	ANSI/ANS 57.9	Section 2.2.2.1
Accident (Internal)	~~125~~ *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
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	ASME Code Section II, Part D	Table 2.2.3
Neutron Poison:			
Boral (normal)	800° F	See Section 4.3.1	Table 2.2.3
Boral (accident)	950° F	See Section 4.3.1	Table 2.2.3
PWR Fuel Cladding *(Moderate/High Burnup Fuel)*:			
5-year cooled	*691° / 679° F* ~~692° F~~	PNL-6189/*Appendix 4.A*	Section 4.3/*Appendix 4.A*
6-year cooled	*676° / 660° F* ~~677° F~~	PNL-6189/*Appendix 4.A*	Section 4.3/*Appendix 4.A*
7-year cooled	*635° / 635° F* ~~636° F~~	PNL-6189/*Appendix 4.A*	Section 4.3/*Appendix 4.A*
10-year cooled	*625° / 621° F* ~~626° F~~	PNL-6189/*Appendix 4.A*	Section 4.3/*Appendix 4.A*
15-year cooled	*614° / 611° F* ~~615° F~~	PNL-6189/*Appendix 4.A*	Section 4.3/*Appendix 4.A*
BWR Fuel Cladding *(Moderate and High Burnup Fuel)*:			
5-year cooled	*740* ~~742~~° F	PNL-6189	Section 4.3/*Appendix 4.A*
6-year cooled	*712* ~~714~~° F	PNL-6189	Section 4.3/*Appendix 4.A*
7-year cooled	*669* ~~671~~° F	PNL-6189	Section 4. /*Appendix 4.A* 3
10-year cooled	*658* ~~660~~° F	PNL-6189	Section 4.3/*Appendix 4.A*

Table 2.0.1 (continued)
MPC DESIGN CRITERIA SUMMARY

Type	Criteria	Basis	FSAR Reference
15-year cooled	*646* ~~648~~° F	PNL-6189	Section 4.3/*Appendix 4.A*
Canister Backfill Gas	Helium	-	Section 12.3.3
Canister Backfill ~~Mass~~	~~Varies by MPC~~ *See CoC Appendix A, Table 3-1*	*Thermal Analysis*	~~*Section 12.3.3*~~
Short-Term Allowable Fuel Cladding Temperature	1058° F	PNL-4835	Sections 2.0.1 and 4.3
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	Multi-pass Partial Penetration		
Port Covers	Full 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

Table 2.0.1 (continued)
MPC DESIGN CRITERIA SUMMARY

Type	Criteria	Basis	FSAR Reference
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	Shell seams, shell-to-baseplate, MPC lid-to-shell, and port covers-to-MPC lid	-	Section 7.1 and Chapters 8, 9, and 12
Medium	Helium	-	Sections 7.2 and Chapter 12
Max. Leak Rate	$5x10^{-6}$ *atm*-cm^3/sec (helium)	-	Chapter ~~8~~ *12 (TS)*
Monitoring System	None	10CFR72.128(a)(1)	Section 2.3.2.1
Hydrostatic Testing:			
Test Pressure	125 psig (+3, -0 psig)	-	Chapters 8 and 9
Welds Tested	MPC Lid-to-Shell, MPC Shell seams, MPC Shell-to-Baseplate	-	Section 8.1 and 9.1
Medium	Water	-	Section 8.1 and Chapter 9
Retrievability:			
Normal and Off-normal: Post (design basis) Accident	No Encroachment on Fuel Assemblies or Exceeding Fuel Assembly Deceleration Limits	10CFR72.122(f),(h)(1), & (l)	Sections 3.4, 3.5, and 3.1.2
Criticality:		10CFR72.124 & 10CFR72.236(c)	
Method of Control	Fixed Borated Neutron Absorber, ~~&~~ Geometry, *and Soluble Boron*	-	Section 2.3.4

Table 2.0.1 (continued)
MPC DESIGN CRITERIA SUMMARY

Type	Criteria	Basis	FSAR Reference
Min. Boron Loading	0.0267 g/cm^2 (MPC-24) 0.0372 g/cm^2 (MPC-68, *MPC-68FF, MPC-24E,MPC-24EF, and MPC-32*) 0.01 g/cm^2 (MPC-68F)	-	Section 2.1.8
Minimum Soluble Boron	~~*Varies By MPC*~~ *See CoC, Appendix A, LCO 3.3.1*	*-Criticality Analysis*	*Section 6.1;~~,~~ CoC, Appendix B*
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)	
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
Storage Mode Position	See Table 2.0.2	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*) *Up to 32 (MPC-32)* Up to 68 (MPC-68, *MPC-68F, & MPC-68FF*)	-	Table 1.2.1

Table 2.0.1 (continued)
MPC DESIGN CRITERIA SUMMARY

Type	Criteria	Basis	FSAR Reference
Type of Cladding	Zircaloy *and Stainless Steel**	-	Table 2.1.6
Fuel Condition	Intact, *Damaged, and Debris**	-	Section 2.1.2 & Table 2.1.6
* ~~*Also designed to accommodate failed fuel, stainless clad fuel, and MOX fuel (Tables 2.1.7 and 2.1.8 and Chapter 12)*~~ *See Appendix B to the CoC for specific fuel condition requirements.*			
PWR Fuel Assemblies:			
Type/Configuration	Various**	-	Table 2.1.3
** ~~No control components are permitted.~~			
Max. Burnup	~~44,700~~ *68,200* MWD/MTU ~~(MPC-24)~~	-	~~*Figure 2.1.6*~~ *CoC, Appendix B*
Max. Enrichment	Varies by fuel design	-	Table 2.1.3
Max. Decay Heat/Assembly†: *(Regionalized fuel loading)*			
5-year cooled	*1470* W (MPC-24) *1540 W (MPC-24E)* *1132 W (MPC-32)*	-	Table*s* ~~*4.4.20 and 2.2.3*~~ *4.4.31*
6-year cooled	*1470* W (MPC-24) *1540 W (MPC-24E)* *1072 W (MPC-32)*	-	Tables ~~*4.4.20 and 2.2.3*~~ *4.4.31*
7-year cooled	*1335* W (MPC-24) *1395 (MPC-24E)* *993 (MPC-32)*	-	Tables ~~*4.4.20 and 2.2.3*~~ *4.4.31*
10-year cooled	*1235* W (MPC-24) *1290 W (MPC-24E)* *950 W (MPC-32)*	-	Table*s* ~~*4.4.20 and 2.2.3*~~ *4.4.31*

† *The Approved Contents Section of Appendix B to the CoC provides the decay heat limits per assembly.*

Table 2.0.1 (continued)
MPC DESIGN CRITERIA SUMMARY

Type	Criteria	Basis	FSAR Reference
15-year cooled	*1165* W (MPC-24) *1215 W (MPC-24E)* *918 W (MPC-32)*	-	Tables ~~4.4.20 and 2.2.3~~ *4.4.31*
Minimum Cooling Time:	5 years (Intact Zr Clad Fuel) 8 years (Intact SS Clad Fuel)		*CoC, Appendix B*
Max. Fuel Assembly Weight: *(including non-fuel hardware and DFC, as applicable)*	1,680 lb.	-	Table 2.1.6
Max. Fuel Assembly Length: (Unirradiated Nominal)	176.8 in.	-	Table 2.1.6
Max. Fuel Assembly Width (Unirradiated Nominal)	8.54 in.	-	Table 2.1.6
Fuel Rod Fill Gas:			
Pressure (max.)	500 psig	-	Section 4.3 & Table 4.3.2
BWR Fuel Assemblies:			
Type	Various	-	Table 2.1.4
Max. Burnup	~~*41,700*~~ *59,900* MWD/MTU	-	~~*Figure 2.1.6*~~ *CoC, Appendix B*
Max. Enrichment	Varies by fuel design	-	Section 6.1, ~~and Chapter 12~~ *Table 2.1.4*
Max. Decay Heat/Assy†. *(Regionalized Fuel Loading)*:			
5-year cooled	~~*314.7*~~ *501* W (MPC-68)	-	Tables ~~4.4.21 and 2.2.3~~ *4.4.31*
6-year cooled	~~*298.7*~~ *468* W (MPC-68)	-	Tables ~~4.4.21 and 2.2.3~~ *4.4.31*
7-year cooled	~~*270.7*~~ *419* W (MPC-68)	-	Tables ~~4.4.21 and 2.2.3~~ *4.4.31*
10-year cooled	~~*264.0*~~ *406* W (MPC-68)	-	Tables ~~4.4.21 and 2.2.3~~ *4.4.31*
15-year cooled	~~*256.6*~~ *392* W (MPC-68)	-	Tables ~~4.4.21 and 2.2.3~~ *4.4.31*

† *The Approved Contents Section of Appendix B to the CoC provides the decay heat limits per assembly.*

Table 2.0.1 (continued)
MPC DESIGN CRITERIA SUMMARY

Type	Criteria	Basis	FSAR Reference
Minimum Cooling Time:	5 yrs ~~*(Intact Zr Clad Fuel)*~~ ~~*18 yrs. (Damaged Zr Clad Fuel)*~~ ~~*18 yrs. (Zr Clad Fuel Debris)*~~ ~~*10 yrs. (Intact SS Clad Fuel)*~~		*CoC, Appendix B*
Max. Fuel Assembly Weight:			
w/channels *and DFC, as applicable*	700 lb.	-	Table 2.1.6
Max. Fuel Assembly Length (Unirradiated Nominal)	~~176.2~~ *176.5*in.	-	Table 2.1.6
Max. Fuel Assembly Width (Unirradiated Nominal)	5.85 in.	-	Table 2.1.6
Fuel Rod Fill Gas:			
End-of-Life Hot Standby Pressure (max.)	147 psig	-	Table 4.3.5
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
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 ~~*or Horizontal*~~	-	Section 1.2.2.2
Storage Orientation	Vertical	-	Section 1.2.2.2
Fuel Rod Rupture Releases:			
Fuel Rod Failures	1%	NUREG-1536	Section 2.2.1.3

Table 2.0.1 (continued)
MPC DESIGN CRITERIA SUMMARY

Type	Criteria	Basis	FSAR Reference
Fill Gases	100%	NUREG-1536	Section 2.2.1.3
Fission Gases	30%	NUREG-1536	Section 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	No Loss of Confinement	ANSI/ANS 57.9	Section 2.2.2.4
Partial Blockage of Overpack Air Inlets	Two Air Inlets Blocked	-	Section 2.2.2.5
Fuel Rod Rupture Releases:			
Fuel Rod Failures	10%	NUREG-1536	Section 2.2.2.1
Fill Gases	100%	NUREG-1536	Section 2.2.2.1
Fission Gases	30%	NUREG-1536	Section 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	Section 2.2.3.8
Fill Gases	100%	NUREG-1536	Section 2.2.3.8
Fission Gases	30%	NUREG-1536	Section 2.2.3.8
Particulates & Volatiles	See Table 7.3.1	-	Sections 2.2.3.9 and 7.3
Confinement Boundary Leakage	7.5×10^{-6} *atm*-cm^3/sec (helium)	*TS leak rate plus test sensitivity*	Sections 2.2.3.9 and 7.3
Explosive Overpressure	60 psig (external)	10CFR72.122(c)	Section 2.2.3.10
Airflow Blockage:			
Vent Blockage	100% of Overpack Air	10CFR72.128(a)(4)	

Table 2.0.1 (continued)
MPC DESIGN CRITERIA SUMMARY

Type	Criteria	Basis	FSAR Reference
	Inlets Blocked		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
~~*Partial Blockage of MPC Basket Vent Holes*~~	~~*Crud Depth (Table 2.2.8)*~~	~~*ESEERCO Project EP91-29*~~	~~*Section 2.2.3.4*~~
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 specified in Appendix 1.D	10CFR72.24(c)(4)	Section 2.0.2 and Appendix 1.D
Fabrication	ACI 349 as specified in Appendix 1.D	10CFR72.24(c)(4)	Section 2.0.2 and Appendix 1.D
Compressive Strength	ACI 318-95 as specified 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
Design Weights:			
Max. Loaded MPC (Dry)	~~87,241~~ *88,135* lb. (MPC-~~68~~ *32*)	R.G. 3.61	Table 3.2.1
Max. Empty Overpack Assembled with Top Cover *(100/100S)*	~~267,190~~ *265,866/252,423* lb. *(Add 2000 lb. for 100A)*	R.G. 3.61	Table 3.2.1
Max. MPC/Overpack *(100/100S)*	~~354,431~~ *345,853/332,410* lb. *(Add 2000 lb. for 100A)*	R.G. 3.61	Table 3.2.1
Design Cavity Pressures	N/A	-	Section 2.2.1.3

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			
Local Maximum (Normal)	200° F	ACI 349 Appendix A	Table 2.2.3
Local Maximum (Accident)	350° F	ACI 349 Appendix A	Table 2.2.3
Steel Structure	350° 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 which precludes Retrieval of MPC or Exceeding Fuel Assembly Deceleration Limits	10CFR72.122(f),(h)(1), & (l)	Sections 3.5 and 3.4
Accident			Sections 3.5 and 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
Beyond Controlled Area During	25 mrem/yr. to whole body	10CFR72.104	Sections 5.1.1, 7.2, and 10.1

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

Type	Criteria	Basis	FSAR Reference
Normal Operation and Anticipated Occurrences	75 mrem/yr. to thyroid 25 mrem/yr. to any *critical* organ		
~~On~~ *At* Controlled Area Boundary from Design Basis Accident	5 rem *TEDE* ~~to whole body or to any organ~~ *or sum of DDE and CDE to any individual organ or tissue (other than lens of eye)* $\leq$ *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
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.)	~~239,877~~ *240,758* lb. (125-ton HI-TRAC w/transfer lid)	R.G. 3.61	Table 3.2.2 Section 2.2.1.2
Dry Loaded MPC (max.)	~~87,241~~ *88,135* 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 ANSI N14.6	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

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

Type	Criteria	Basis	FSAR Reference
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	Two Air Inlet Ducts 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*
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

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

Type	Criteria	Basis	FSAR Reference
Seismic			
~~Resultant~~ Max. ZPA *at top of ISFSI pad* ~~Horizontal Ground~~ ~~(Max. ZPA Vertical Ground)~~	*Free Standing:* $G_H + 0.53G_V = 0.53$ *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 ~~& Fabrication~~ 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
Design Weights:			
Max. Empty Cask:			
W/Pool Lid & No Top Lid	~~140,258~~ *140,246* lb. (125-ton HI-TRAC) ~~99,758~~ *99,246* lb. (100-ton HI-TRAC)	R.G. 3.61	Table 3.2.2
W/Top Lid & Transfer Lid	~~152,636~~ *154,373* lb. (125-ton HI-TRAC) ~~109,470~~ *108,626* lb. (100-ton HI-TRAC)	R.G. 3.61	Table 3.2.2
Max. MPC/HI-TRAC with Yoke (in-pool lift):			
Water Jacket Empty	~~199,394~~ *240,320* lb. (~~100~~ *125*-ton HI-TRAC)	R.G. 3.61	Table ~~3.2.4~~ *8.1.1*
Water Jacket Full	~~248,105~~ *248,601* lb. (125-ton HI-TRAC)	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

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.)	Manufacturer Data	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 or Exceeding Fuel Assembly Deceleration Limits	10CFR72.122(f),(h)(1), & (l)	Sections 3.5 & 3.4
After Design-basis (Postulated) Accident			Section 3.5 & 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 Temperatures:			
Lifetime Average	100° F	ANSI/ANS 57.9	Section 2.2.1.4
Live Load			
Max. Loaded Canister			
Dry	~~*87,241*~~ *88,135* lb.	R.G. 3.61	Table 3.2.1
Wet	~~*103,898*~~ *104,705* 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 ~~*or Horizontal*~~	-	Section 1.2.2.2
Test Loads:			
Trunnions	300% of vertical design load	NUREG-0612 & ANSI N14.6	Section 9.1.2.1
Off-Normal Design Event Conditions:		10CFR72.122(b)(1)	
Ambient Temperature			
Minimum	0° F	ANSI/ANS 57.9	Section 2.2.2.2
Maximum	100° F	ANSI/ANS 57.9	Section 2.2.2.2
Design-Basis (Postulated) Accident Design Events and Conditions:		10CFR72.24(d)(2) & 10CFR72.94	

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

Type	Criteria	Basis	FSAR Reference
Side Drop	42 in.	-	Section 2.2.3.1
Fire			
Duration	4.8 minutes	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
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*	$G_H + \mu G_V \leq \mu$	$G_H \leq 2.12$ *AND* $G_V \leq 1.5$	
6. *Required minimum value of cask to pad static coefficient of friction (μ, must be confirmed by testing).*	*Greater than or equal to 0.53 (per Table 2.2.9).*	*Same as that for free-standing condition*	
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.*	

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 length of the multi-purpose canisters has been set at a dimension which permits storing most types of PWR fuel assemblies and BWR fuel assemblies with or without fuel channels. The *one* exception~~s~~ *is* ~~are~~ 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 length.

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 which 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. Any fuel assembly that has fuel characteristics within the range of Tables 2.1.3 and 2.1.4 is acceptable for storage in the HI-STORM 100 System. 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 decay heat generation. Substantiating results of analyses for the governing assembly types are presented in the respective chapters dealing with the specific qualification topic. 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 zircaloy clad fuel assemblies with the characteristics listed in Table 2.1.6 or intact stainless steel clad fuel assemblies with the characteristics listed in Table 2.1.8. The placement of a single stainless steel clad fuel assembly in a MPC necessitates that all fuel assemblies (stainless steel clad or zircaloy clad) stored in that MPC meet the maximum heat generation requirements for stainless steel clad fuel specified in Table 2.1.8. Intact BWR MOX fuel assemblies shall meet the requirements of Table 2.1.7.

Intact fuel assemblies with missing pins cannot be loaded into the HI-STORM 100 unless dummy fuel pins, which occupy a volume greater than or equal to the original fuel pins, replace the missing pins prior to loading. Any intact fuel assembly which falls within the geometric, thermal, and nuclear limits established for the design basis intact fuel assembly, as defined in the ~~*Technical Specifications of Chapter 12*~~ *Approved Contents section of Appendix B to the CoC* 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.

2.1.3 Damaged SNF and Fuel Debris Specifications

Damaged fuel and fuel debris are defined in Table 1.0.1.

~~Damaged fuel assemblies are defined as fuel assemblies with known or suspected cladding defects,~~ ~~*as determined by a review of records,*~~ ~~greater than pinhole leaks and hairline cracks or~~ ~~*missing empty*~~ ~~fuel rod~~ ~~*locations*~~ ~~that are not replaced with dummy fuel rods,~~ ~~*and which may have mechanical damage which would not allow it to or those that cannot*~~ ~~be handled by normal means; however, there shall be no loose components. No loose fuel debris is allowed with the damaged fuel assembly.~~

~~Fuel debris is defined as~~ ~~*fuel assemblies with known or suspected defects greater than pinhole leaks or hairline cracks such as*~~ ~~ruptured fuel rods, severed fuel rods,~~ ~~*or*~~ ~~loose fuel pellets,~~ ~~*andor fuel assemblies with known or suspected defects*~~ ~~which cannot be handled by normal~~

~~means~~ ~~*due to fuel cladding damage.*~~

To aid in loading and unloading, damaged fuel assemblies and fuel debris will be loaded into stainless steel damaged fuel containers (DFCs) provided with 250 x 250 fine mesh screens, ~~*prior to placement*~~ *for storage* in the HI-STORM 100 System. ~~*This application requests approval of Dresden Unit 1 (UO_2 rods and MOX fuel rods) and Humboldt Bay fuel arrays (Assembly Classes 6x6A, 6x6B, 6x6C, 7x7A, and 8x8A) are approved as damaged fuel assembly contents for storage in the MPC-68 and fuel debris as contents for storage in the MPC-68F. The design characteristics bounding Dresden Unit 1 and Humboldt Bay SNF are given in Table 2.1.7. The placement of a single damaged fuel assembly in an MPC-68 or a single fuel debris damaged fuel container in an MPC-68F necessitates that all fuel assemblies (intact, damaged, or debris) stored in that MPC meet the maximum heat generation requirements specified in Table 2.1.7. The fuel characteristics specified in Table 2.1.4 for Dresden 1 and Humboldt Bay fuel arrays have been evaluated in this*~~ ~~FSAR~~ ~~*and are acceptable for storage as damaged fuel or fuel debris in the HI-STORM 100 System. The DFC design is illustrated in Figure 2.1.1 and the Design Drawings are provided in Section 1.5. Because of the long cooling time, small size, and low weight of spent fuel assemblies qualified as damaged fuel or fuel debris, the DFC and its contents are bounded by the structural, thermal, and shielding analyses performed for the intact BWR design basis fuel. Separate criticality analysis of the bounding fuel assembly for the damaged fuel and fuel debris has been performed in Chapter 6.*~~ *The MPC-24E is designed to accommodate PWR damaged fuel. The MPC-24EF is designed to accommodate PWR damaged fuel and fuel debris. The MPC-68 is designed to accommodate BWR damaged fuel. The 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 authorized for loading in the HI-STORM 100 System are provided in Table 2.1.7. Restrictions on the number and location of damaged fuel containers authorized for loading in each MPC model are provided in the Approved Contents section of Appendix B to the CoC. 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).*

2.1.4 Deleted

2.1.5 Structural Parameters for Design Basis SNF

The main physical parameters of a 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 listed in Tables 2.1.6, 2.1.7, and 2.1.8. 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 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 Tables 2.1.6, 2.1.7, or 2.1.8.

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, the allowable fuel cladding temperature based on cooling time, and the decay heat removal capabilities of the HI-STORM 100 System. The maximum heat generation rate per assembly for the design basis fuel assembly is based on the fuel assembly type with the highest decay heat for a given enrichment, burnup, and cooling time. This decay heat design basis fuel assembly is listed in Table 2.1.5. Section 5.2 describes the method used to determine the design basis fuel assembly type and calculate the decay heat load.

~~*To ensure the allowable fuel cladding temperature limits are not exceeded, Table 2.0.1 specifies the allowable decay heat per assembly versus cooling time for zircaloy clad fuel in each MPC type. Tables 2.1.7 and 2.1.8 provide the maximum heat generation for damaged zircaloy clad fuel assemblies and stainless steel clad fuel assemblies, respectively. Due to the conservative thermal assessment and the long cooling time of the damaged and stainless steel clad fuel, a reduction in decay heat load is not required as the cooling time increases beyond the minimum specified.*~~

To ensure the permissible fuel cladding temperature limits are not exceeded, the Approved Contents section of Appendix B to the CoC specifies the allowable decay heat per assembly for each MPC model. For both uniform and regionalized loading of moderate and high burnup Zircaloy clad fuel assemblies, the allowable decay heat per assembly is a function of cooling time and is presented in Appendix B to the CoC in Tables 2.1-5 and 2.1-7. For stainless steel clad fuel assemblies, the allowable decay heat per assembly is not dependent upon cooling time and is specified in Table 2.1-1 of Appendix B to the CoC. Due to the large conservatisms in the thermal evaluations and the relatively long cooling times and corresponding low decay heats for stainless steel clad, an age-dependent allowable decay heat limit is not necessary.

The specified decay heat load can be attained by varying burnups and cooling times. ~~*Figure 2.1.6*~~ *The Approved Contents section of Appendix B to the CoC* provides the burnup and cooling time ~~*characteristics*~~ *limits* for intact zircaloy clad fuel to meet the thermal requirements for the *various* MPC's. ~~*Any intact zircaloy clad fuel assembly with a burnup and cooling time which lies on or below the curve of Figure 2.1.6 is thermally acceptable for loading into the HI-STORM 100 System. Each point on the curve produces a decay heat equal to or below the value specified in Table 2.0.1.*~~

The Approved Contents section of Appendix B to the CoC 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.*

~~*Figure 2.1.6 does not extend beyond 15 years of cooling time. For fuel assemblies with cooling times greater than 15 years, the maximum allowed burnup will be limited to maximum burnup value specified for 15 years. As shown in Figure 2.1.6 the allowable burnup increases as the cooling time increases due to the decay of radioactivity over time. Therefore, limiting the maximum burnup for fuel assemblies with more than 15 years of cooling time to the corresponding burnup value for 15 years ensures that the decay heat load from these older fuel assemblies will be less than the values analyzed in this* FSAR.~~

The fuel rod cladding temperature is also affected by other factors. A governing geometry which maximizes the impedance to the transmission of heat out of the fuel rods has been defined. The governing thermal parameters to ensure that the range of SNF discussed previously are bounded by the thermal analysis are discussed in detail and specified in Chapter 4. By utilizing these bounding thermal parameters, the calculated peak fuel rod cladding temperatures are conservative for actual spent fuel assemblies which have greater thermal conductivities.

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.

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 specified in the CoC for preferential fuel loading and 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 the central core basket storage locations with lower heat emitting fuel assemblies in the peripheral 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 and the associated burnup, cooling time, and decay heat limits are found in Appendix B to the CoC.

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.* ~~at the maximum burnup, minimum cooling time, and a conservative enrichment corresponding to the burnup~~. 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. *The Approved Contents section of Appendix B to the CoC provides the burnup and cooling time limits for all of the authorized fuel assembly array/classes for both uniform fuel loading and regionalized loading.* ~~Table 2.1.7 provides the burnup and cooling time values which meet the radiological source term requirements for damaged BWR fuel in the MPC-68 and fuel debris in the MPC-68F. Table 2.1.8 provides the burnup and cooling time values which meet the radiological source term requirements for intact stainless steel clad fuel. Figure 2.1.6 provides illustrative burnup and cooling time values which meet the radiological source term requirements for zircaloy clad fuel in each MPC type.~~

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 Appendix B to the CoC.

Non-fuel hardware, including BPRAs, TPDs, CRAs, and APSRs and other similarly designed hardware with different names has been evaluated and is authorized for storage in the PWR MPCs as specified in Appendix B to the CoC.

2.1.8 Criticality Parameters for Design Basis SNF

As discussed earlier, the MPC-68, *MPC-68F, MPC-68FF, and MPC-32* feature~~s~~ a basket without flux traps. In the *aforementioned* ~~MPC-68~~ baskets, there is one panel of neutron absorber between two adjacent fuel assemblies. The MPC-24, *MPC-24E, and MPC-24EF* employ~~s~~ 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 for each MPC model is shown in Table 2.1.15.

~~The MPC-24 Boral ^{10}B areal density is specified at a minimum loading of 0.0267 g/cm^2. The MPC-68, *MPC-68FF, MPC-24E, MPC-24EF, and MPC-32* Boral ^{10}B areal density is specified at a minimum loading of 0.0372 g/cm^2. The MPC-68F Boral ^{10}B areal density is specified at a minimum loading of 0.01 g/cm^2.~~

For all MPCs, the ^{10}B areal density used for analysis is conservatively established at 75% of the minimum ^{10}B areal density to demonstrate that the reactivity under the most adverse accumulation of tolerances and biases is less than 0.95. This complies with NUREG-1536 [2.1.5] which requires a 25% reduction in ^{10}B areal density credit. A large body of sampling data accumulated by Holtec from thousands of manufactured Boral panels indicates the average ^{10}B areal densities to be approximately 15% greater than the specified minimum.

The criticality analyses for the MPC-24, MPC-24E and MPC-24EF (all with higher enriched fuel) and for the MPC-32 were performed with credit taken for soluble boron in the MPC water during wet loading and unloading operations. Table 2.1.14 provides the required soluble boron concentrations for these MPCs. Minimum soluble boron concentration is also included as Limiting Condition for Operation (LCO)3.3.1 in the Technical Specifications found in Appendix A to the CoC.

2.1.9 Summary of SNF Design Criteria

~~*An intact zircaloy clad fuel assembly is acceptable for storage in a HI-STORM 100 System if it fulfills the following criteria :*~~

~~*a. It satisfies the physical characteristics listed in Tables 2.1.3 or 2.1.4, and 2.1.6.*~~

~~*b. Its initial enrichment is less than that indicated by Table 2.1.6 for the fuel assembly and MPC type.*~~

~~*c. The period from discharge is greater than or equal to the minimum cooling time listed in Table 2.1.6, and the decay heat is equal to or less than the maximum value stated in Table 2.0.1 for a given cooling time.*~~

~~*d. The average burnup of the fuel assembly is less than or equal to the burnup specified in Figure 2.1.6 for a given cooling time.*~~

~~*A damaged fuel assembly shall meet the characteristics specified in Table 2.1.7 for storage in the MPC-68. A fuel assembly classified as fuel debris shall meet the characteristics specified in Table 2.1.7 for storage in the MPC-68F.*~~

~~*Stainless steel clad fuel assemblies shall meet the characteristics specified in Table 2.1.8 for storage in the MPC-24 and MPC-68.*~~

~~*MOX BWR fuel assemblies shall meet the requirements of Tables 2.1.6 and 2.1.7 for intact and damaged fuel/fuel debris, respectively.*~~

~~No PWR control components are to be included with the fuel assembly.~~

Tables 2.1.1 through 2.1.8 and Table 2.1.12 provide the design characteristics for spent fuel and non-fuel hardware authorized for storage in the HI-STORM 100 System. Much of this information is repeated in the Approved Contents section of Appendix B to the CoC. Only fuel meeting the specifications in the CoC is authorized for storage. Fuel classified as damaged fuel assemblies or fuel debris must be stored in damaged fuel containers for storage in the HI-STORM 100 System.

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*^{TM}
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 ~~(except 8x8 WE (QUAD+))~~	All 9x9	All 10x10
Humboldt Bay	All 6x6	All 7x7 (Zircaloy 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 *43*)	~~≤ 402~~ *≤ 407*	~~≤ 402~~ *≤ 407*	~~≤ 410~~ *≤ 425*	≤ 400	*≤ 206*
Initial Enrichment *(MPC-24, 24E, and 24EF without soluble boron credit)* (wt % ^{235}U) *(Note 7)*	≤ 4.6 *(24)* *≤ 5.0 (24E/24EF)*	≤ 4.6 *(24)* *≤ 5.0 (24E/24EF)*	≤ 4.6 *(24)* *≤ 5.0 (24E/24E F)*	≤ 4.0 *(24)* *≤ 5.0 (24E/24EF)*	*≤ 5.0 (24)* *≤ 5.0 (24E/24EF)*
Initial Enrichment (MPC-24, 24E, 24EF, or 32 with soluble boron credit - see Notes 5 and 7) (wt % ^{235}U)	*≤ 5.0*	*≤ 5.0*	*≤ 5.0*	*≤ 5.0*	*≤ 5.0*
No. of Fuel Rod *Locations*	179	179	176	180	*173*
Fuel Clad O.D. (in.)	≥ 0.400	≥ 0.417	≥ 0.440	≥ 0.422	*≥ 0.3415*
Fuel Clad I.D. (in.)	≤ 0.3514	≤ 0.3734	~~≤ 0.3840~~ *≤ 0.3880*	≤ 0.3890	*≤ 0.3175*
Fuel Pellet Dia. (in.)	≤ 0.3444	≤ 0.3659	~~≤ 0.3770~~ *≤ 0.3805*	≤ 0.3835	*≤ 0.3130*
Fuel Rod Pitch (in.)	≤ 0.556	≤ 0.556	≤ 0.580	≤ 0.556	*Note 6*
Active Fuel Length (in.)	≤ 150	≤ 150	≤ 150	≤ 144	*≤ 102*
No. of Guide *and/or Instrument* Tubes	17	17	5 (see Note ~~3~~ *4*)	16	*0*
Guide/*Instrument* Tube Thickness (in.)	≥ 0.017	≥ 0.017	~~≥ 0.040~~ *≥ 0.038*	≥ 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)	~~≤ 420~~ *≤ 464*	≤ 464	≤ 464	≤ 475	≤ 475	≤ 475
Initial Enrichment *(MPC-24, 24E, and 24EF without soluble boron credit)* (wt % ^{235}U) *(See 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, or 32 with soluble boron credit - see Notes 5 and 7) (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.)	≤ 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***	**16x16 A**	**17x17A**	**17x17 B**	**17x17 C**
Clad Material (Note 2)	SS	*Zr*	Zr	Zr	Zr	Zr
Design Initial U (kg/assy.) (Note *43*)	≤ 420	*≤ 475*	~~≤ 430~~ *≤ 443*	~~≤ 450~~ *≤ 467*	~~≤ 464~~ *≤ 467*	~~≤ 460~~ *≤ 474*
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)*	≤ 4.6 *(24)* *≤ 5.0 (24E/24EF)*	≤ 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, or 32 with soluble boron credit - see Notes 5 and 7) (wt % ^{235}U)	*≤ 5.0*	*≤ 5.0*	*≤ 5.0*	*≤ 5.0*	*≤ 5.0*	*≤ 5.0*
No. of Fuel Rod *Locations*	204	*208*	236	264	264	264
Fuel Clad O.D. (in.)	≥ 0.422	*≥ 0.414*	≥ 0.382	≥ 0.360	≥ 0.372	≥ 0.377
Fuel Clad I.D. (in.)	≤ 0.3890	*≤ 0.3700*	≤ 0.3320	≤ 0.3150	≤ 0.3310	≤ 0.3330
Fuel Pellet Dia. (in.)	≤ 0.3825	*≥ 0.3622*	≤ 0.3255	≤ 0.3088	≤ 0.3232	≤ 0.3252
Fuel Rod Pitch (in.)	≤ 0.563	*≤ 0.568*	≤ 0.506	≤ 0.496	≤ 0.496	≤ 0.502
Active Fuel length (in.)	≤ 144	*≤ 150*	≤ 150	≤ 150	≤ 150	≤ 150
No. of Guide *and/or Instrument* Tubes	21	*17*	5 (see note ~~3~~ *4*)	25	25	25
Guide/*Instrument* Tube Thickness (in.)	≥ 0.0145	*≥ 0.140*	≥ 0.0400	≥ 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. Zr designates cladding material made of zirconium or zirconium alloys.

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 Technical Specification LCO 3.3.1.*

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.*

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 ~~*4*~~ *3*)	~~*≤ 108*~~ *≤ 110*	~~*≤ 108*~~ *≤ 110*	~~*≤ 108*~~ *≤ 110*	≤ 100	≤ 195	≤ 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*	~~*≤ 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.)	~~*≤ 0.4945*~~ *≤ 0.5105*	≤ 0.4945	≤ 0.4990	~~*≤ 0.4200*~~ *≤ 0.4204*	≤ 0.4990	≤ 0.3620
Fuel Pellet Dia. (in.)	~~*≤ 0.4940*~~ *≤ 0.4980*	≤ 0.4820	≤ 0.4880	≤ 0.4110	~~*≤ 0.4880*~~ *≤ 0.4910*	≤ 0.3580
Fuel Rod Pitch (in.)	~~*0.694*~~ *≤ 0.710*	~~*0.694*~~ *≤ 0.710*	≤ 0.740	≤ 0.631	≤ 0.738	≤ 0.523
Active Fuel Length (in.)	~~*≤ 110*~~ *≤ 120*	~~*≤ 110*~~ *≤ 120*	≤ 77.5	~~*≤ 79*~~ *≤ 80*	≤ 150	~~*≤ 110*~~ *≤ 120*
No. of Water Rods *(see note 11)*	*1 or* 0	*1 or* 0	0	0	0	*1 or* 0
Water Rod Thickness (in.)	~~*N/A*~~ *> 0*	~~*N/A*~~ *> 0*	N/A	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 ~~6~~ *3*)	~~≤ 185~~ *≤ 191*	~~≤ 185~~ *≤ 191*	~~≤ 185~~ *≤ 191*	~~≤ 180~~ *≤ 191*	*≤ 191*	~~≤ 173~~ *≤ 179*
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 ~~3~~ *5*)
Fuel Clad O.D. (in.)	≥ 0.4840	≥ 0.4830	≥ 0.4830	≥ 0.4930	*≥ 0.4576*	≥ 0.4400
Fuel Clad I.D. (in.)	~~≤ 0.4250~~ *≤ 0.4295*	≤ 0.4250	~~≤ 0.4190~~ *≤ 0.4230*	≤ 0.4250	*≤ 0.3996*	≤ 0.3840
Fuel Pellet Dia. (in.)	~~≤ 0.4160~~ *≤ 0.4195*	≤ 0.4160	~~≤ 0.4110~~ *≤ 0.4140*	≤ 0.4160	*≤ 0.3913*	≤ 0.3760
Fuel Rod Pitch (in.)	~~0.636 - 0.641~~ *≤ 0.642*	~~0.636 -~~ ≤ 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 *(see note 11)*	1 *or 0*	2	1 - 4 (see note ~~5~~ *7*)	5	*N/A (see 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	*≤ 0.100*	≤ 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 *4 3*)	~~≤ 173~~ *≤ 179*	~~≤ 173~~ *≤ 179*	~~≤ 170~~ *≤ 179*	~~≤ 170~~ *≤ 179*	~~≤ 170~~ *≤ 179*	*≤ 179*
Maximum Planar-Average Initial Enrichment (wt.% ^{235}U) (Note 14)	*≤ 4.2*	*≤ 4.2*	*≤ 4.2*	~~≤ 4.2~~ *≤ 4.0*	~~≤ 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*	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	~~≤ 0.3590~~ *≤ 0.3640*	~~≤ 0.3810~~ *≤ 0.3860*	*≤ 0.3640*
Fuel Pellet Dia. (in.)	≤ 0.3740	≤ 0.3565	≤ 0.3565	~~≤ 0.3525~~ *≤ 0.3530*	≤ 0.3745	*≤ 0.3565*
Fuel Rod Pitch (in.)	~~0.569~~ *≤ 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 *(see note 11)*	1 (see note *4 6*)	1	2	5	5	*1 (see note 6)*
Water Rod Thickness (in.)	> 0.00	≥ 0.020	~~≥ 0.0305~~ *≥ 0.0300*	~~≥ 0.0305~~ *≥ 0.0120*	~~≥ 0.0305~~ *≥ 0.0120*	*≥ 0.0320*
Channel Thickness (in.)	≤ 0.120	≤ 0.100	≤ 0.100	~~≤ 0.100~~ *≤ 0.120*	~~≤ 0.100~~ *≤ 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 ~~6~~ *3*)	~~≤ 182~~ *≤ 188*	~~≤ 182~~ *≤ 188*	~~≤ 180~~ *≤ 188*	≤ 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 ~~3~~ *8*)	91/83 (Note ~~3~~ *9*)	96	100	96
Fuel Clad O.D. (in.)	≥ 0.4040	≥ 0.3957	~~≥ 0.3790~~ *≥ 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 *(see note 11)*	2	1 (Note ~~4~~ *6*)	5 (Note ~~5~~ *10*)	0	4
Water Rod Thickness (in.)	≥ 0.030	> 0.00	~~≥ 0.034~~ *≥ 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. Zr designates cladding material made of zirconium or zirconium alloys.

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	**MPC-68/*68F/68FF***	**MPC-24**	***MPC-24E/24EF***	***MPC-32***
Reactivity (Criticality)	GE12/14 10x10 with Partial Length Rods (Class 10x10A)	B&W 15x15 (Class 15x15F)	*B&W 15x15 (Class 15x15F)*	*B&W 15x15 (Class 15x15F)*
Source Term (Shielding)	GE 7x7 (Class 7x7B)	B&W 15x15 (Class 15x15F)	*B&W 15x15 (Class 15x15F)*	*B&W 15x15 (Class 15x15F)*
Decay Heat (Thermal-Hydraulic)	GE 7x7 (Class 7x7B)	B&W 15x15 (Class 15x15F)	*B&W 15x15 (Class 15x15F)*	*B&W 15x15 (Class 15x15F)*

Table 2.1.6

DESIGN CHARACTERISTICS FOR ~~*DESIGN BASIS*~~ INTACT ZIRCALOY CLAD FUEL ASSEMBLIES[1]

	MPC-68/*68FF*	*MPC-68F*	MPC-24	*MPC-24E/24EF*	*MPC-32*
PHYSICAL PARAMETERS:					
Max. assembly width (in.)	5.85	*4.70*	8.54	*8.54*	*8.54*
Max. assembly length (in.)	~~176.2~~ *176.5*	*135.0*	176.8	*176.8*	*176.8*
Max. assembly weight[2] (lb.)	700	*550*	1680	*1680*	*1680*
Max. active fuel length (in.)	150	*120*	150	*150*	*150*
~~*Fuel rod clad material*~~	~~*zircaloy*~~		~~*zircaloy*~~		
RADIOLOGICAL AND THERMAL CHARACTERISTICS:					
	MPC-68/*68FF*	*MPC-68F*	MPC-24	*MPC-24E/24EF*	*MPC-32*
Max. initial enrichment (wt% ^{235}U)	See Table 2.1.4	*See Table 2.1.4*	See Table 2.1.3	*See Table 2.1.3*	*See Table 2.1.3*
Max. heat generation (W)	Table 2.0.1 ~~*115 (Assembly Classes 6x6A, 6x6B, 6x6C, 7x7A, 8x8A)*~~	*Table 2.0.1*	Table 2.0.1	*Table 2.0.1*	*Table 2.0.1*
Max. average burnup (MWD/MTU)	~~*See Figure 2.1.6*~~ ~~*30,000 (Assembly Classes 6x6A, 6x6B, 6x6C, 7x7A, 8x8A)*~~ *59,900*	*30,000*	~~*See Figure 2.1.6*~~ *66,200*	*68,200*	*54,700*
Min. cooling time (years)	~~*See Figure 2.1.6*~~ ~~*18 (Assembly Classes 6x6A, 6x6B, 6x6C, 7x7A, 8x8A)*~~ *5*	*18*	~~*See Figure 2.1.6*~~ *5*	*5*	*5*

1 *These are limiting values for all authorized fuel assembly array/classes. Refer to the Approved Contents section of Appendix B to the CoC for specific limits for each fuel assembly array/class.*

2 Fuel assembly weight including *non-fuel* hardware, *and channels, as applicable,* based on DOE MPC DPS [2.1.6].

Table 2.1.7
DESIGN CHARACTERISTICS FOR DAMAGED
~~*ZIRCALOY CLAD*~~ FUEL ASSEMBLIES[1]

	MPC-68/*68FF* (Damaged Fuel *and Fuel Debris*)	MPC-68F (*Damaged Fuel and* Fuel Debris)	*MPC-24E/24EF (Damaged Fuel and Fuel Debris)*
PHYSICAL PARAMETERS:			
Max. assembly width (in.)	~~4.7~~ *5.5*	4.7	*8.54*
Max. assembly length (in.)	~~135~~ *176.5*	135.0	*176.8*
Max. assembly weight[2] (lb.)	~~400~~ *700*	400	*1680*
Max. active fuel length (in.)	~~110~~ *150*	110	*150*
Fuel rod clad material	zircaloy/*SS*	zircaloy	*zircaloy/SS*
RADIOLOGICAL AND THERMAL CHARACTERISTICS:			
Max. heat generation (W)	~~115~~ *356*	115	*927*
Min. cooling time (yr)	~~18~~ *5*	18	*5*
Max. initial enrichment (wt.% ^{235}U) for UO_2 rods	~~2.7~~ *4.0*	2.7	*4.0*
Max. initial enrichment for MOX rods	~~0.612~~ *0.635* wt.% ^{235}U 1.578 wt. % Total Fissile Plutonium	~~0.612~~ *0.635* wt.% ^{235}U 1.578 wt. % Total Fissile Plutonium	*N/A*
Max. average burnup (MWD/MTU)	~~30,000~~ *58,800*	30,000	*68,200*

Note: ~~*A maximum of four (4) damaged fuel containers with BWR zircaloy clad fuel debris may be stored in the MPC-68F with the remaining locations filled with undamaged or damaged fuel assemblies meeting the maximum heat generation specifications of this table.*~~ *Refer to the Approved Contents section of Appendix B to the CoC for restrictions on the number and location of damaged fuel assemblies and fuel debris authorized for loading in the HI-STORM 100 System.*

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1 *These are limiting values for all authorized fuel assembly array/classes. Refer to the Approved Contents section of Appendix B to the CoC for specific limits for each fuel assembly array/class.*

2 Fuel assembly weight including *non-fuel* hardware, *channels, and DFC, as applicable,* based on DOE MPC DPS [2.1.6].

Table 2.1.8

DESIGN CHARACTERISTICS FOR INTACT STAINLESS STEEL CLAD FUEL ASSEMBLIES[1]

	BWR MPC-68/*68FF*	PWR MPC-24/*24E/24EF*	*PWR MPC-32*
PHYSICAL PARAMETERS:			
Max. assembly width[2] (in.)	5.62	~~8.42~~ *8.54*	*8.54*
Max. assembly length[2] (in.)	102.5	~~138.8~~ *176.8*	*176.8*
Max. assembly weight[3] (lb.)	~~400~~ *700*	~~1421~~ *1680*	*1680*
Max. active fuel length[2] (in.)	83	~~122~~ *144*	*144*
RADIOLOGICAL AND THERMAL CHARACTERISTICS :			
Max. heat generation (W)	95	710	*500*
Min. cooling time (yr)	10	8	*9/20*
Max. initial enrichment *without soluble boron credit* (wt.% ^{235}U)	4.0	~~4.0~~ *See Table 2.1.3*	*N/A*
Max. initial enrichment with soluble boron credit (wt.% ^{235}U)	*N/A*	*5.0*	*5.0*
Max. average burnup (MWD/MTU)	22,500	40,000	*30,000/40,000*

1 *These are limiting values for all authorized fuel assembly array/classes. Refer to the Approved Contents section of Appendix B to the CoC for specific limits for each fuel assembly array/class.*

2 Unirradiated nominal dimensions are shown.

3 Fuel assembly weight including *non-fuel* hardware *and channels, as applicable,* based on DOE MPC DPS [2.1.6].

Table 2.1.9

SUGGESTED PWR UPPER AND LOWER FUEL SPACER LENGTHS

Fuel Assembly Type	**Assembly Length w/o** ~~C.C.~~*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 inch gap under the MPC lid.*

1 ~~C.C.~~ *NFH* is an abbreviation for ~~Control Components~~ *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 for Reactor 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	23.6
Humboldt Bay	95.0	8.0	79	40.5	40.5
Dresden 1 Damaged Fuel or Fuel Debris	144.5[1]	11.2	110	17.0	14.5
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 inch gap under the MPC lid.*

1 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 D1 THORIA ROD CANISTERS

PARAMETER	***MPC-68 or MPC-68F***
Cladding Type	*Zircaloy (Zr)*
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*

Table 2.1.13
MPC Fuel Loading Regions

MPC MODEL	REGION 1 FUEL STORAGE LOCATIONS	REGION 2 FUEL STORAGE LOCATIONS
MPC-24, 24E and 24EF	9, 10, 15, and 16	All Other Locations
MPC-32	7, 8, 12 through 15, 18 through 21, 25, and 26	All Other Locations
MPC-68/68F/68FF	11 through 14, 18 through 23, 27 through 32, 37 through 42, 46 through 51, 55 through 58	All Other Locations

Note: Refer to Figures 1.2.2 through 1.2.4A

Table 2.1.14

Soluble Boron Requirements for PWR 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	*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-32	*All fuel assemblies with initial enrichment ≤ 4.1 wt. %*	*≥ 1900*
MPC-32	*One or more fuel assemblies with an initial enrichment > 4.1 and ≤ 5.0 wt. %*	*≥ 2600*

[1] *Refer to Table 2.1.3 for these enrichments.*

Table 2.1.15

MINIMUM BORAL ^{10}B LOADING

MPC MODEL	***MINIMUM B-10 LOADING (g/cm²)***
MPC-24	*0.0267*
MPC-24E and MPC-24EF	*0.0372*
MPC-32	*0.0372*
MPC-68 and MPC-68FF	*0.0372*
MPC-68F	*0.01*

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 which 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 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

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

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.

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 100 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 100 overpack is limited to *working area* ambient temperatures ~~above~~ *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 100 Overpack for use during handling operations at a minimum service temperature of 0° F.

Lifting attachments and devices shall meet the requirements of ANSI N14.6[†] [2.2.3].

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† 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.

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.

Table 2.2.1 provides the design pressures for the HI-STORM 100 System.

For the storage of damaged ~~*Dresden Unit 1 or Humboldt Bay BWR*~~ fuel assemblies or fuel debris ~~*(Assembly Classes 6x6A, 6x6B, 6x6C, 7x7A, and 8x8A)*~~ 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 ~~*68*~~ of the ~~*BWR*~~ fuel assemblies. It is shown in Chapter 4 that the ~~normal~~ *accident* condition design pressure is not exceeded with 100% of the fuel rods ruptured in all ~~*68*~~ of the design basis ~~*BWR*~~ 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 ~~normal~~ *accident* design pressure.

The MPC internal design pressure under accident conditions is discussed in Subsection 2.2.3.

The HI-STORM 100 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 100 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 which 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 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 maximum fuel rod cladding temperature limits for normal conditions are calculated by the DCCG (Diffusion Controlled Cavity Growth) methodology outlined in the LLNL report [2.2.14] in accordance with NUREG-1536. However, for conservatism, the PNL methodology outlined in PNL report [2.0.3] produces a lower fuel cladding temperature, which is used to establish the *permissible* fuel cladding temperature limits, which are used to determine the allowable fuel decay heat load. Maximum fuel rod stainless steel cladding temperature limits recommended in EPRI report [2.2.13] are greater than the long-term allowable zircaloy fuel cladding temperature limits. However, in this FSAR the long-term zircaloy fuel cladding temperature limits are conservatively applied to the stainless steel clad fuel. The short term temperature limits for zircaloy and stainless steel cladding are taken from references [2.2.15] and [2.2.13], respectively. A detailed description of the maximum fuel rod cladding temperature limits determination is provided in Section 4.3.

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.

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. For conservatism, the MPC normal internal design pressure bounds both normal and off-normal conditions. Therefore, the normal and off-normal condition MPC internal pressures are set equal for analysis purposes.

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 design temperature, 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 short-term temperature which may exist during a transition state or a transient event (examples of such instances are short-term temperature excursion during canister vacuum drying and backfilling operations (transition state) and fire (transient event)). 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 structural or non-structural part, as applicable, during a short-term event. These enveloping values, therefore, will bound the maximum temperature reached anywhere in the part, excluding skin effects during or immediately after, a short-term event.

2.2.2.4 Leakage of One Seal

The HI-STORM 100 System must withstand leakage of one seal in the radioactive material confinement boundary.

The confinement boundary is defined by the MPC shell, baseplate, MPC lid, port cover plates, and closure ring. Most confinement boundary welds are inspected by radiography or ultrasonic examination. Field welds are examined by the liquid penetrant method on the root and final pass. In addition to liquid penetrant examination, the MPC lid-to-shell weld is leakage tested, hydrostatic tested, and volumetrically examined or multi-pass liquid penetrant examined. The vent and drain port cover plates are leakage tested in addition to the liquid penetrant examination. These inspection and testing techniques are performed to verify the integrity of the confinement boundary.

Although leakage of one seal is not a credible accident, it is analyzed in Chapter 11.

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 conservatively defined as a complete blockage of ~~one-half~~ *two* (2) of the four air inlets. Because the overpack air inlets and outlets are covered by fine mesh steel screens, located 90° apart, and inspected routinely (or alternatively, exit vent air temperature monitored), it is unlikely that all vents could become blocked by blowing debris, animals, etc. during normal and off-normal operations. ~~One-half~~ *Two* of the air inlets are conservatively assumed to be completely blocked to demonstrate the inherent thermal stability of the HI-STORM 100 System.

2.2.2.6 Off-Normal HI-TRAC Handling

During upending and/or downending of the HI-TRAC 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.

If the lifting device ~~is allowed~~ *cables begin* to "go slack", *the eccentricity of the pocket trunnions would immediately cause the cask to pivot, restoring tension on the cables.* ~~the total weight would be applied to the lower pocket trunnions only~~. *Nevertheless,* ~~Under this off-normal condition~~, the pocket trunnions *are conservatively analyzed* ~~would each be required~~ to support one-half of the total weight, doubling the load per trunnion. This condition is analyzed to demonstrate that the pocket trunnions 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 ~~will~~ *may* use lifting equipment 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 100 ~~O~~*o*verpack 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 ~~O~~*o*verpack falls freely from the vertical lift limit height before impacting a thick reinforced concrete pad. The deceleration of the ~~MPC~~ *cask* must be maintained below ~~60~~ *45* g's. ~~under axial loading to ensure the analysis performed in the HI-STAR Safety Analysis Reports [2.2.4 and 2.2.5] bounds the HI-STORM 100 overpack vertical handling accident.~~ Additionally, the overpack must continue to suitably shield the radiation emitted from the loaded MPC. The use of lifting ~~equipment with redundant drop protection and lifting devices designed in accordance with the requirements specified in Section 2.3.3.1~~ *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 side of the cask 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. Analysis is provided which 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) remain attached. Furthermore, the HI-TRAC inner shell is demonstrated by analysis to not deform sufficiently to ~~affect~~ *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 analyses in Appendix 3.AN 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~~, of lifting equipment with redundant drop protection and lifting devices designed in accordance with the requirements specified in Section 2.3.3.1, will~~ eliminate the need for a horizontal lift height limit.

The loaded HI-TRAC, when lifted in the vertical position outside of the ~~reactor~~ *Part 50* facility shall be lifted ~~by lifting equipment with redundant drop protection features and~~ *with* ~~lifting~~ 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.* ~~Therefore,~~ *For vertical lifts of HI-TRAC with suitably designed lift devices,* a vertical drop or tip-over is not a credible accident for the HI-TRAC transfer cask and no vertical lift height limit is ~~provided~~ *required to be established.* Likewise, while the loaded HI-TRAC is positioned atop the HI-STORM 100 ~~O~~*o*verpack 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 ~~O~~*o*verpack is not a credible accident for the HI-TRAC transfer cask. ~~This~~ *These* condition*s* of use for MPC transfer operations from the HI-TRAC transfer cask to the HI-STORM 100 ~~O~~*o*verpack ~~is~~ *are* specified in *the HI-STORM 100 CoC,* ~~*the Technical Specifications in Chapter 12 and*~~ Subsection 2.3.3.1, and ~~is~~ *are* included in the operating procedures of Chapter 8.

The loaded MPC is lowered into the HI-STORM or HI-STAR ~~O~~*o*verpack or raised from the overpack using the HI-TRAC transfer cask and a MPC lifting system ~~designed to be single failure proof and lifting devices~~ 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 ~~O~~*o*verpacks 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. ~~The~~ *Two "pre-approved"* concrete pad design*s* for storing the HI-STORM 100 System ~~shall comply with~~ *are presented in* Table 2.2.9. *Other ISFSI pad designs may be used provided the designs are* ~~and shall be~~ 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 ~~those~~ *the design basis limits when analyzed using the methodologies established in this* FSAR. ~~calculated by the dynamic models used in the structural qualifications.~~

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 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 100 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-STAR 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 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. 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 *cask 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 ~~also~~ be designed to minimize ~~secured against~~ 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.

The HI-STORM 100 System must withstand temperatures due to a fire event. The HI-STORM 100 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 100 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 100 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 short-term temperature limit specified in reports [2.2.13 and 2.2.15].

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 prior to placement in the MPC. The damaged fuel container is equipped with fine 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 100 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 which deforms on impact (large missile); a rigid missile to test penetration resistance (penetrant missile); and a small rigid missile of 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 ~~shields~~ *protection* shall be *provided* ~~placed at either end of the HI-TRAC~~ to prevent tornado missiles from impacting either end of the HI-TRAC. The tornado missile ~~shield~~ *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 ~~shield positioned to protect~~ *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 ~~shields~~ *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 ~~and the resultant differential pressure on the overpack is stated in Table 2.2.1~~. 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 100 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 HI-STORM 100 Overpack. Blockage of the air inlets is addressed in Subsection 2.2.3.12.

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 kinematic stability. An evaluation for tsunamis† for certain coastal sites should also

† 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.

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 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 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. To demonstrate the overall safety of the HI-STORM 100 System, the largest test leakage rate for the confinement boundary plus 50% for conservatism is assumed as the maximum credible confinement boundary leakage rate and 100 percent of the fuel rods are assumed to have failed. Under this accident condition, doses to an individual located at the boundary of the controlled area are calculated.

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 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. The MPC is composed of stainless steel, Boral, and aluminum alloy 1100, all of which have a long proven history of use in fuel pools at nuclear power plants. For these materials there is no credible cause for an 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 is 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 short term 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 100 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 Anchored HI-STORM

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.

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. 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 318-95 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 318-95 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 which 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 exceptions to the ASME Code for the HI-STORM 100 System and the justification for those exceptions.

The MPC utilized in the HI-STORM 100 System is identical to the MPC described in the applications for the HI-STAR 100 System for storage (Docket 72-1008) and transport (Docket 71-9261) certification. To avoid unnecessary repetition of the large numbers of stress analyses, attention is directed in this document to establish that the MPC loadings for storage in the HI-STORM 100 System do not exceed those computed in the referenced applications. 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.

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.

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 100 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 which primarily affect kinematic stability, and (ii) those which produce significant stresses. The loadings in the former category are principally applicable to the overpack. Wind (W), earthquake (E), tornado (W□), 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 which demonstrate that the overpack structure remains unbreached by the postulated missiles are provided in Chapter 3.

Loadings in the second category produce global stresses which 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 100 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 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. Table 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 towards reinforced concrete structures. Those load combinations applicable to steel structures are directed towards 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 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

S_y: Minimum yield strength at temperature

S_u: Minimum ultimate strength at temperature

Table 2.2.1

DESIGN PRESSURES

Pressure Location	Condition	Pressure (psig)
MPC Internal Pressure	Normal	100
	Off-Normal	100
	Accident	~~125~~ *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)

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)	100	
Off-Normal (3-Day Average)	0 and 100	0° F with no insolation 100° F with insolation

Note:

1. Handling operations with the loaded HI-STORM 100 overpack and HI-TRAC transfer cask are limited to *working area ambient* ~~environmental~~ temperatures greater than *or equal to* 0°F as specified in Subsection 2.2.1.2 and the *Design Features section of Appendix B to the CoC.* ~~Technical Specifications in Chapter 12~~.

Table 2.2.3

DESIGN TEMPERATURES

HI-STORM 100 Component	Normal Condition Design Temp. (Long-Term Events) (° F)	Off-Normal and Accident Condition Temp. Limits (Short-Term Events)† (° F)
MPC shell	450	775
MPC basket	725	950
MPC Boral	800	950
MPC lid	550	775
MPC closure ring	400	775
MPC baseplate	400	775
MPC Heat Conduction Elements	725	950
HI-TRAC inner shell	400	600
HI-TRAC pool lid/transfer lid	350	700
HI-TRAC top lid	400	700
HI-TRAC top flange	400	700
HI-TRAC pool lid seals	350	N/A
HI-TRAC bottom lid bolts	350	700
HI-TRAC bottom flange	350	700
HI-TRAC top lid neutron shielding	300	300
HI-TRAC radial neutron shield	307	N/A
HI-TRAC radial lead gamma shield	350	600
Remainder of HI-TRAC	350	700
Zircaloy fuel cladding (5-year cooled)[1]	~~692~~ *691*(PWR) ~~742~~ *740*(BWR)	1058
Zircaloy fuel cladding (6-year cooled)[1]	~~677~~ *676*(PWR) ~~714~~ *712*(BWR)	1058
Zircaloy fuel cladding (7-year cooled)[1]	~~636~~ *635*(PWR) ~~671~~ *669*(BWR)	1058
Zircaloy fuel cladding (10-year cooled)[1]	~~626~~ *625*(PWR) ~~660~~ *658*(BWR)	1058
Zircaloy fuel cladding (15-year cooled)[1]	~~615~~ *614*(PWR) ~~648~~ *646*(BWR)	1058
Zircaloy fuel cladding (5-year cooled)[2]	*679 (PWR) 740 (BWR)*	*1058*

† *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).*

Table 2.2.3 (continued)

DESIGN TEMPERATURES

HI-STORM 100 Component	**Normal Condition Design Temp. (Long-Term Events) (° F)**	**Off-Normal and Accident Condition Temp. Limits (Short-Term Events)† (° F)**
Zircaloy fuel cladding (6-year cooled)[2]	*660 (PWR) 712 (BWR)*	*1058*
Zircaloy fuel cladding (7-year cooled)[2]	*635 (PWR) 669 (BWR)*	*1058*
Zircaloy fuel cladding (10-year cooled)[2]	*621 (PWR) 658 (BWR)*	*1058*
Zircaloy fuel cladding (15-year cooled)[2]	*611 (PWR) 646 (BWR)*	*1058*
Overpack outer shell	350	600
Overpack concrete	200	350
Overpack inner shell	350	400
Overpack Lid Top Plate	350	550
Remainder of overpack steel structure	350	400

NOTES: 1. *Moderate Burnup Fuel*
2. *High Burnup Fuel (see Table 4.A.2)*

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

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

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)
~~Helium Retention~~ *Confinement*	Shell	A	ASME Section III; Subsection NB	Alloy X [5]	See Appendix 1.A	NA	NA
~~Helium Retention~~ *Confinement*	Baseplate	A	ASME Section III; Subsection NB	Alloy X	See Appendix 1.A	NA	NA
~~Helium Retention~~ *Confinement*	Lid	A	ASME Section III; Subsection NB	Alloy X	See Appendix 1.A	NA	NA
~~Helium Retention~~ *Confinement*	Closure Ring	A	ASME Section III; Subsection NB	Alloy X	See Appendix 1.A	NA	NA
~~Helium Retention~~ *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	Alloy X	See Appendix 1.A	NA	NA
Criticality Control	Boral	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	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 Chapter 13. 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)
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	Alloy X	See Appendix 1.A	NA	NA
Structural Integrity	Basket Supports (Angled Plates)	A	ASME Section III; Subsection NG	Alloy X	See Appendix 1.A	NA	NA
Structural Integrity	Basket Supports (Flat Plates)	B	ASME Section III; Subsection NG	Alloy X	See Appendix 1.A	NA	NA
Structural Integrity	Lift Lug	C	Non-code	Alloy X	See Appendix 1.A	NA	NA
Structural Integrity	Lift Lug Baseplate	C	Non-code	Alloy X	See Appendix 1.A	NA	NA
Structural Integrity	Upper Fuel Spacer Bolt	NITS	Non-code	A193-B8	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)	~~Alloy X~~ *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

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 Chapter 13. 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)
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	304 S/S	Per ASME Section II	Thread area surface hardened	NA
Operations	Vent & Drain Cap	C	Non-code	304 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
Operations	Damaged Fuel Container	C	ASME Section III; Subsection NG	Primarily 304 S/S	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 Chapter 13. 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 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	4	NA	NA
Shielding	Shield Block Ring & Shell	B	See Note 6	SA516-70	See Table 3.3.2	See Note 5	NA
Shielding	Pedestal Shield	B	ACI 349, App. 1-D	Concrete	4	NA	NA
Shielding	Lid Shield	B	ACI 349, App. 1-D	Concrete	4	NA	NA
Shielding	Shield Shell	B	See Note 6	SA516-70	See Table 3.3.2	NA	NA
Shielding	Shield Block	B	ACI 349, App. 1-D	Concrete	4	NA	NA
Shielding	Gamma Shield Cross Plates & Tabs	C	Non-code	SA240-304	NA	NA	NA
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
Structural Integrity	Lid Bottom 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 Chapter 13. NITS stands for Not Important to Safety.
5) All exposed steel surfaces (except threaded holes) to be painted with Carboline 890.
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	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 Vertical & Horizontal Plates	B	See Note 6	SA516-70	See Table 3.3.2	See Note 5	
Structural Integrity	Top Plate	B	ASME Section III; Subsection NF	SA516-70	See Table 3.3.2	See Note 5	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	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 III; Subsection NF	SA564-630 *(stud)* *SA 194-2H (nut)*	See Table 3.3.4	Threads to have cadmium coating (or similar)	NA
Structural Integrity	Bolt Anchor Block	~~A~~ *B*	ASME Section III; Subsection NF ANSI N14.6	SA350-LF3 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 Bill of Materials in Chapter 1.
4) A, B, and C denote important to safety classifications as described in Chapter 13. NITS stands for Not Important to Safety.
5) All exposed steel surfaces (except threaded holes) to be painted with Carboline 890.
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	See Table 3.3.2	See Note 5	NA
Structural Integrity	Pedestal Platform	B	ASME Section III; Subsection NF	SA516-70	See Table 3.3.2	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	~~Thermocouple~~ *Temperature Element &* Associated Temperature Monitoring Equipment	B	Non-code	NA	NA	NA	NA
Operations	Screen	NITS	Non-code	Mesh Wire	NA	NA	NA
Operations	Paint	C	Non-code	Carboline 890	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 Chapter 13. NITS stands for Not Important to Safety.
5) All exposed steel surfaces (except threaded holes) to be painted with Carboline 890.
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	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 Channels	B	ASME Section III; Subsection NF	SA516-70	See Table 3.3.2	See Note 5	NA
Structural Integrity	Enclosure Shell Panels	B	ASME Section III; Subsection NF	SA516-70	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 (SA203E)	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
Structural Integrity	Bottom Flange	B	ASME Section III; Subsection NF	SA350-LF3 (SA516-70)	See Table 3.3.3 (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 Chapter 13. NITS stands for Not Important to Safety.
5) All external surfaces to be painted with Carboline 890. Inside surface of ~~overpack~~ *transfer cask* to be painted with Thermaline 450.

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	*SA 516 Gr. 70 or SA 203E, or* SA350-LF3	See 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 Caps	C	ASME Section III; Subsection NF	SA516-70	See Table 3.3.2	See Note 5	NA
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 ANSI 14.6	SA350-LF3	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 Bill of Materials in Chapter 1.
4) A, B, and C denote important to safety classifications as described in Chapter 13. NITS stands for Not Important to Safety.
5) All external surfaces to be painted with Carboline 890. Inside surface of ~~overpack~~ *transfer cask* to be painted with Thermaline 450.

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	Lifting Trunnion	A	ANSI N14.6	SB637 (N07718)	See Table 3.3.4	NA	NA
Structural Integrity	Pocket Trunnion	B	ASME Section III; Subsection NF ~~ANSI 14.6~~	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
Structural Integrity	Thermal Expansion Foam	NITS	Non-code	Silicone or similar	NA	NA	NA
Operations	Top Lid Stud	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	~~SA193-2H~~ *SA194-2H*	NA	NA	NA
Operations	Pool Lid Gasket	NITS	Non-code	Elastomer	NA	NA	NA
Operations	Pool Lid & Top Lid Tongues	B	ASME Section III; Subsection NF	SA516-70	See Table 3.3.2	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 Chapter 13. NITS stands for Not Important to Safety.
5) All external surfaces to be painted with Carboline 890. Inside surface of ~~overpack~~ *transfer cask* to be painted with Thermaline 450.

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)
Operations	Lifting Trunnion Locking Pad	C	Non-code	SA516-70	See Table 3.3.2	See Note 5	NA
Operations	Lifting Trunnion End Cap	C	Non-code	SA516-70	See Table 3.3.2	See Note 5	NA
Operations	End Cap Bolts	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	Lifting Trunnion Pad Bolt	NITS	Non-code	SA193-B7	See Table 3.3.4	NA	NA
Operations	Couplings, Valves and Vent Plug	NITS	Non-code	Steel or Bronze	NA	NA	Bronze/Steel

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 Chapter 13. NITS stands for Not Important to Safety.
5) All external surfaces to be painted with Carboline 890. Inside surface of ~~overpack~~ *transfer cask* to be painted with Thermaline 450.

TABLE 2.2.6

MATERIALS AND COMPONENTS OF THE HI-STORM 100 SYSTEM
HI-TRAC TRANSFER LID [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 Chapter 13. NITS stands for Not Important to Safety.
5) All external surfaces to be painted with Carboline 890. Top surface of doors to be painted with Thermaline 450.

TABLE 2.2.6

MATERIALS AND COMPONENTS OF THE HI-STORM 100 SYSTEM
HI-TRAC TRANSFER LID [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-36~~ *SA 193-B7*	36 (yield)	See Note 5	NA
Structural Integrity	Shaft Cover Plate	C	Non-code	SA516-70	See Table 3.3.2	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	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 Chapter 13. NITS stands for Not Important to Safety.
5) All external surfaces to be painted with Carboline 890. Top surface of doors to be painted with Thermaline 450.

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	Section III, Subsection NG, NG-3300 and NG-3200	Section III, Subsection NG, NG-4000	Section III, Subsection NG, NG-5000 and Section V
HI-TRAC Trunnions	Section II, Section III, Subsection NF, NF-2000	ANSI 14.6	Section III, Subsection NF, NF-4000	See Chapter 9
MPC basket supports	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
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 318-95 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)
Cask Environment During the Postulated Fire Event (*Deg*. F)	Accident	1475
HI-STORM 100 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 ZPA (Zero Period Acceleration) for HI-STORM‡	Accident	$G_H + 0.53G_V = 0.53$†† (HI-STORM 100 *and 100S*) $G_H = 2.12$; $G_V = 1.5$ (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†††

~~‡ The maximum horizontal ZPA is specified as the vector sum of the ZPA g-loading in two orthogonal directions.~~

†† See Subsection 3.4.7.1 for definition of G_H and G_V. The coefficient of 0.53 may be increased 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)*	≤ 36	*≤ 28*
Concrete Compressive Strength *(at 28 days), f_c', (psi)*	≤ 4,200	*≤ 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)*	≤ 28,000	*≤ 16,000*

NOTE: A static coefficient of friction of ≥ 0.53 between the ISFSI pad and the bottom of the overpack 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)[H]	P_i
Off-Normal Pressure (External)[H]	P_o
Off-Normal Temperature	T'
Off-Normal HI-TRAC Handling	H'

† Internal Design Pressure P_i bounds the normal and off-normal condition internal pressures. External Design Pressure P_o bounds off-normal external pressures. Similarly, Accident pressures P_i^* and P_o^*, respectively, bound actual internal and external pressures under all postulated environment phenomena and accident events.

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 EXCEPTIONS FOR HI-STORM 100 SYSTEM

Component	Reference ASME Code Section/Article	Code Requirement	Exception, 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	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 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.

Table 2.2.15 (continued)

LIST OF ASME CODE EXCEPTIONS FOR HI-STORM 100 SYSTEM

Component	Reference ASME Code Section/Article	Code Requirement	Exception, Justification & Compensatory Measures
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 MPC vent and drain cover plate welds are leak tested. The closure ring provides independent redundant closure for vent and drain cover plates.
MPC Lid 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 hydrostatically tested as defined in Chapter 8. Accessibility for leakage inspections preclude a Code compliant hydrostatic test. All MPC vessel welds (except closure ring and vent/drain cover plate) are inspected by RT or UT. The vent/drain cover plate welds are confirmed by helium leakage testing and liquid penetrant examination and the closure ring weld is confirmed by liquid penetrant.

Table 2.2.15 (continued)

LIST OF ASME CODE EXCEPTIONS FOR HI-STORM 100 SYSTEM

Component	Reference ASME Code Section/Article	Code Requirement	Exception, Justification & Compensatory Measures
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.	HI-STORM 100 System 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.
MPC Basket Assembly	NG-8000	States requirements for nameplates, stamping and reports per NCA-8000.	The HI-STORM 100 System will be marked and identified in accordance with 10CFR71 and 10CFR72 requirements. No Code stamping is required. The MPC basket data package will be in conformance with Holtec's QA program.

Table 2.2.15 (continued)

LIST OF ASME CODE EXCEPTIONS FOR HI-STORM 100 SYSTEM

Component	Reference ASME Code Section/Article	Code Requirement	Exception, Justification & Compensatory Measures
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 large margins of safety in these welds under loads experienced during lifting operations or accident conditions are quite large and warrant an exemption. The overpack baseplate welds to the inner shell, pedestal shell, and radial plates are only loaded during lifting conditions and have a minimum safety factor of greater than 12 during lifting. The top lid plate to lid shell weld has a safety factor greater than 6 under 45g's.

Table 2.2.15 (continued)

LIST OF ASME CODE EXCEPTIONS FOR HI-STORM 100 SYSTEM

Component	Reference ASME Code Section/Article	Code Requirement	Exception, Justification & Compensatory Measures
Overpack Steel Structure	NF-3256	Provides requirements for welded joints.	Welds for which no structural credit is taken are identified as ANon-NF@ welds in the design drawings by an A*@. These non-structural welds are specified in accordance with the prequalified 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.

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.
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 HI-STAR ~~applications~~ *SARs* under Docket Numbers 71-9261 and 72-1008.

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 hydrostatically tested, helium leakage tested and inspected by the liquid penetrant method.

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.* ~~Chapter 12~~.

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 to the maximum extent practical, 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, hydrostatic testing, and helium leak testing are performed to verify the confinement function ~~*in accordance with the Technical Specifications contained in Chapter 12.*~~ 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. The decay heat value in Table 2.1.6 is developed by computing the decay heat from the design basis fuel assembly which produces the highest heat generation rate for a given burnup. Additional margin is built into the calculated cask cooling rate by using a design basis fuel assembly which offers maximum resistance to the transmission of heat (minimum thermal conductivity).

- 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 a 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. ITS ancillary equipment utilized in activities which occur outside the 10CFR Part 50 structure shall be engineered ~~*using a written specification which describes*~~ *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 ~~*specification document shall contain*~~ *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 standards5. 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 outside of a facility 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 is a stand-alone facility located on-site, near the ISFSI that incorporates or is compatible with lifting devices designed to lift a loaded or unloaded HI-TRAC transfer cask, place it atop the overpack, and transfer the loaded MPC to or from the overpack. 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 100 overpack
- Transfer between a HI-TRAC transfer cask and a HI-STAR 100 overpack

In both scenarios, HI-TRAC is mounted on top of the overpack (HI-STAR 100 or HI-STORM 100) 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. 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.

1. 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).

      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)

      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).

      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).

      e. MPC transfer between the HI-TRAC transfer cask and the HI-STORM 100 overpack.

      f. MPC transfer between the HI-TRAC transfer cask and the HI-STAR 100 overpack.

ii. Other Functional Requirements:

The CTF should possess facilities and capabilities to support cask operations such as :

a. Devices and areas to support installation and removal of the HI-STORM 100 lid.

b. Devices and areas to support installation and removal of the HI-STORM 100 shield block inserts.

c. Devices and areas to support installation and removal of the HI-STAR 100 closure plate.

d. Devices and areas to support installation and removal of the HI-STAR 100 transfer collar.

e. Features to support positioning and alignment of the HI-STORM 100 overpack and the HI-TRAC transfer cask.

f. Features to support positioning and alignment of the HI-STAR 100 overpack and the HI-TRAC transfer cask.

g. Areas to support jacking of a loaded HI-STORM 100 overpack for insertion of a translocation device underneath.

h. Devices and areas to support placement of an empty MPC in the HI-TRAC transfer cask or HI-STAR 100 overpack

i. Devices and areas to support receipt inspection of the MPC, HI-TRAC transfer cask, HI-STORM overpack, and HI-STAR overpack.

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 key terms not defined elsewhere in this FSAR and used in this specification are provided below. The following terms are used to define key components of the CTF.

- 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.

- 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).

- 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.†

- Lifter Mount: A beam-like structure (part of the CTF structure) that supports the HI-TRAC and MPC lifter(s).

- 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.

- Mobile crane: A mobile crane is a device defined in ASME B30.5-1994, Mobile and Locomotive Cranes. A mobile crane 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.

- 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.

- Pier: The portion of the reinforced concrete foundation which projects above the concrete floor of the CTF.

† The term overpack is used in this specification as a generic term for the HI-STAR 100 and *the various* HI-STORM 100 overpacks.

- 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.

- 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.

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 Chapter 13 of this FSAR.

B. Environmental and Design Conditions

i. Lowest Service Temperature (LST): The LST for the CTF is ~~100°F~~ *0°F* (consistent with the specification for the HI-TRAC transfer cask in Subsection 3.1.2.3).

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.

iii. Tornado Missile, M, and Wind,W': The tornado 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 structure 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 structure 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 structure.

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 structure analysis:

- The missile has a planform area of 20 sq. ft. and impact force characteristics set forth in Appendix 3.AN (Section 3.AN.3).

- The large missile can strike the CTF structure 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 structure 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 structure and, therefore, need not be considered.

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.

v. Lightning: Meteorological data for the region surrounding the ISFSI site shall be used to specify the applicable lightning input to the CTF structure for personnel safety evaluation purposes.

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 structure, then such a loading, with due consideration of the short duration of CTF operations, shall be defined for the CTF structure.

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.

viii. Design Temperature: All material properties used in the stress analysis of the CTF structure shall utilize a reference design temperature of 150°F.

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*.

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:

1. Mobile cranes at the CTF shall conform to the guidelines of Section 5.1.1 of NUREG-0612 with the exception that mobile cranes 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 crane used shall have a minimum safety factor of two over the allowable load table for the crane 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. Section 5.1.6(2) of NUREG-0612 specifies that new cranes should be designed to meet the requirements of NUREG-0554. For mobile cranes, the guidance of Section 5.1.6(2) of NUREG-0612 does not apply.

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.

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.

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.

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.

e. The design of the lifting system shall ensure that the lift platform (or lift frame) is held horizontal at all times and that the symmetrically situated axial members are symmetrically loaded.

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.

g. The HI-TRAC lifter and MPC lifter shall possess design features to avoid side-sway of the payload during lifting operations.

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.

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.

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.

v. Specific Requirements for Mobile Cranes:

A mobile crane, 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).

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 mobile crane is prevented from lifting loads in excess of 110% of the loaded MPC weight.

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 experiencing a deceleration in excess of its design basis deceleration specified in this FSAR.

vi. Lift Height Limitation: The HI-TRAC lift heights shall be governed by the Technical Specifications.

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.

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).

E. Materials and Failure Modes

i. Acceptable Materials and Material Properties: All materials used in the design of the CTF shall be ASTM approved or equal, consistent with the ITS category of the part. Reinforced concrete, if used, shall comply with the provisions of ACI 318 (89). The material property and allowable stress values for all steel structurals 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.

ii. Brittle Fracture: All structural components in the CTF structure and the lift platform designated as primary load bearing shall have an NDTT equal to 0^{o}F or lower (consistent with the ductile fracture requirements for ASME Section III, Subsection NF, Class 3 structures).

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.

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.

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).

G. Miscellaneous Components

Hoist rings, turnbuckles, slings, and other appurtenances which are in the load path during heavy load handling at the CTF shall be single-failure-proof.

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.

I. Foundation

The design of the CTF structure foundation and piers, including load combinations, shall be in accordance with ACI-318(89).

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.

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.

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).

iii. Exterior aprons shall be of a material that will not be damaged by the vertical cask crawler tracks, if a crawler is used.

L. Facility Floor

i. The facility floor shall be sufficiently flat to allow optimum handling of casks with a translocation device.

ii. Any floor penetrations, in areas where translocation device operations may occur, shall be equipped with flush inserts.

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.

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.

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.

iii. The design of the connector brackets shall ensure that the HI-TRAC transfer cask is fully secured against slippage during MPC transfer operations.

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 100 or HI-STAR 100).

O. Design Life

The Cask Transfer Facility shall be constructed to have a minimum design life of 40 years.

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].

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 Chapter 13 of this FSAR.

R. Documentation Requirements

i. O&M Manual: An Operations and Maintenance Manual shall be prepared which contains, at minimum, the following items of information:

- Maintenance Drawings
- Operating Procedures

ii. Design Report: 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 Chapter 13 of this FSAR.

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, ~~*thermocouples*~~ *temperature elements* may be installed in two of the overpack exit vents to continuously monitor the air temperature. If the ~~*thermocouples*~~ *temperature elements* and associated temperature monitoring instrumentation are used, they shall be designated important to safety as specified in Table 2.2.6.

The ~~thermocouples~~ *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 ~~thermocouples~~ *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 (Boral™) 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 are the following:

1. Loading of PWR fuel assemblies must be performed in water with a minimum boron content as specified in Table 2.1.14.

2. Prevention of fresh water entering the MPC internals.

Administrative controls specified as Technical Specifications *and Approved Contents* are provided in *Appendices A and B to the CoC, respectively,* ~~Chapter 12~~ 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.* ~~*an annual dose equivalent greater than the values stated below for normal and off-normal conditions. Further, an individual located at the site boundary must not receive a dose to the whole body or any organ from any design basis accident greater than the values listed in Table 2.3.1.*~~

The objective of shielding is to assure that radiation dose rates at key locations are below acceptable levels for those locations. 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. A design objective for the maximum average radial surface dose rate has been established as ~~*40*~~ *60* mrem/hr. Areas adjacent to the inlet and exit vents which pass through the radial shield are limited to 60 mrem/hr. The average dose rate at the top of the overpack is limited to below ~~*10*~~ *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, 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 two transfer cask designs are provided (i.e.,125 ton HI-TRAC and 100 ton HI-TRAC). The 125 ton HI-TRAC provides better shielding than the 100 ton HI-TRAC 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.* ~~considerations, or space envelope limitations in the fuel pool or air lock~~. As with other dose reduction-based plant *activities,* ~~modifications~~, individual users who cannot accommodate the 125 ton HI-TRAC ~~due to plant design limitations must~~ *should* perform a cost-benefit analysis of the *actions (e.g., plant modifications) that* ~~modifications which~~ would be necessary to use the 125 ton HI-TRAC. The cost of the *action(s)* ~~modification(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 meets the above radiation dose limits and design objectives.

2.3.5.3 Radiological Alarm System

There are no credible events which could result in release of radioactive materials or increases in direct radiation above the requirements of 10CFR72.106. In addition, the non-mechanistic release as the result of a hypothetical accident is described in Chapter 7, and results in a dose to an individual at the controlled area boundary of a very small magnitude. Therefore, radiological alarm systems are not necessary.

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:	
~~Whole Body~~ *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*
~~*Any Organ (rem)*~~	~~5~~

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 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.

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. 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, 3.7% enrichment, 47,500 MWD/MTU, and eight-year cooling time) stored for 40 years.

- Material quantities based on the Design 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	~~6.65e-4~~ *2.20e-3*
^{55}Fe	~~1.07e-3~~ *3.53e-3*
^{59}Ni	~~8.79e-7~~ *2.91e-6*
^{60}Co	~~9.39e-5~~ *3.11e-4*
^{63}Ni	~~2.98e-5~~ *9.87e-5*
Total	~~1.86e-3~~ *6.15e-3*

HI-STORM OVERPACK ACTIVATION

Nuclide	Activity After 40-Year Storage (Ci/m^3)
Overpack Steel	
^{54}Mn	~~1.09e-4~~ *3.62e-4*
^{55}Fe	~~2.06e-3~~ *7.18e-3*
Total	~~2.17e-3~~ *7.18e-3*
Overpack Concrete	
^{39}Ar	~~9.11e-7~~ *3.02e-6*
^{41}Ca	~~7.36e-8~~ *2.44e-7*
^{54}Mn	~~4.79e-7~~ *1.59e-7*
^{55}Fe	~~8.90e-6~~ *2.95e-5*
Total	~~1.04e-5~~ *3.43e-5*

2.6 REFERENCES

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

[2.0.3] Levy, et al., "Recommended Temperature Limits for Dry Storage of Spent Light Water Reactor Zircaloy - Clad Fuel Rods in Inert Gas," Pacific Northwest Laboratory, PNL-6189, 1987.

[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, "Classificaation of Transportation Packaging and Dry Spent Fuel Storage Syystem Component According to Important to Safety," Idaho Engineering Laboratory, NUREG/CR-6407, INEL-95-0551, 1996.

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[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.

[2.1.4] Deleted.

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

[2.1.5] NUREG-1536, SRP for Dry Cask Storage Systems, USNRC, Washington, DC, January 1997.

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[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.

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[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-~~941184~~*2012610*, "Final Safety Analysis Report for the HI-STAR 100 Cask System", NRC Docket No. 72-1008, *latest* ~~R~~revision ~~9~~, ~~1998~~.

[2.2.5] Holtec Report HI-951251, "Safety Analysis Report for the HI-STAR 100 Cask System", NRC Docket No. 71-9261, *latest revision*~~Revision 7, 1998~~.

[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).

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[2.2.14] M.W. Schwartz and M.C. Witte, Lawrence Livermore National Laboratory, "Spent Fuel Cladding Integrity During Dry Storage", UCID-21181, September 1987.

[2.2.15] PNL-4835, "Technical Basis for Storage of Zircaloy-Clad Spent Fuel in Inert Gases", A.B. Johnson and E.R. Gilbert, Pacific Northwest Laboratories, September 1983.

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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 reacttor site parameters, including earthquake intensity and large missiles, are enveloped by the cask deesign 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-349-97 [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 349-97 [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 349-97 [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-349-97 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.*

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 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).*

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 (Figure 2.A.1)***	
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_o (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, or equiv.*
Embedment ring:	*Low carbon steel such as A-36, A-516-Gr. 70, or equiv.*

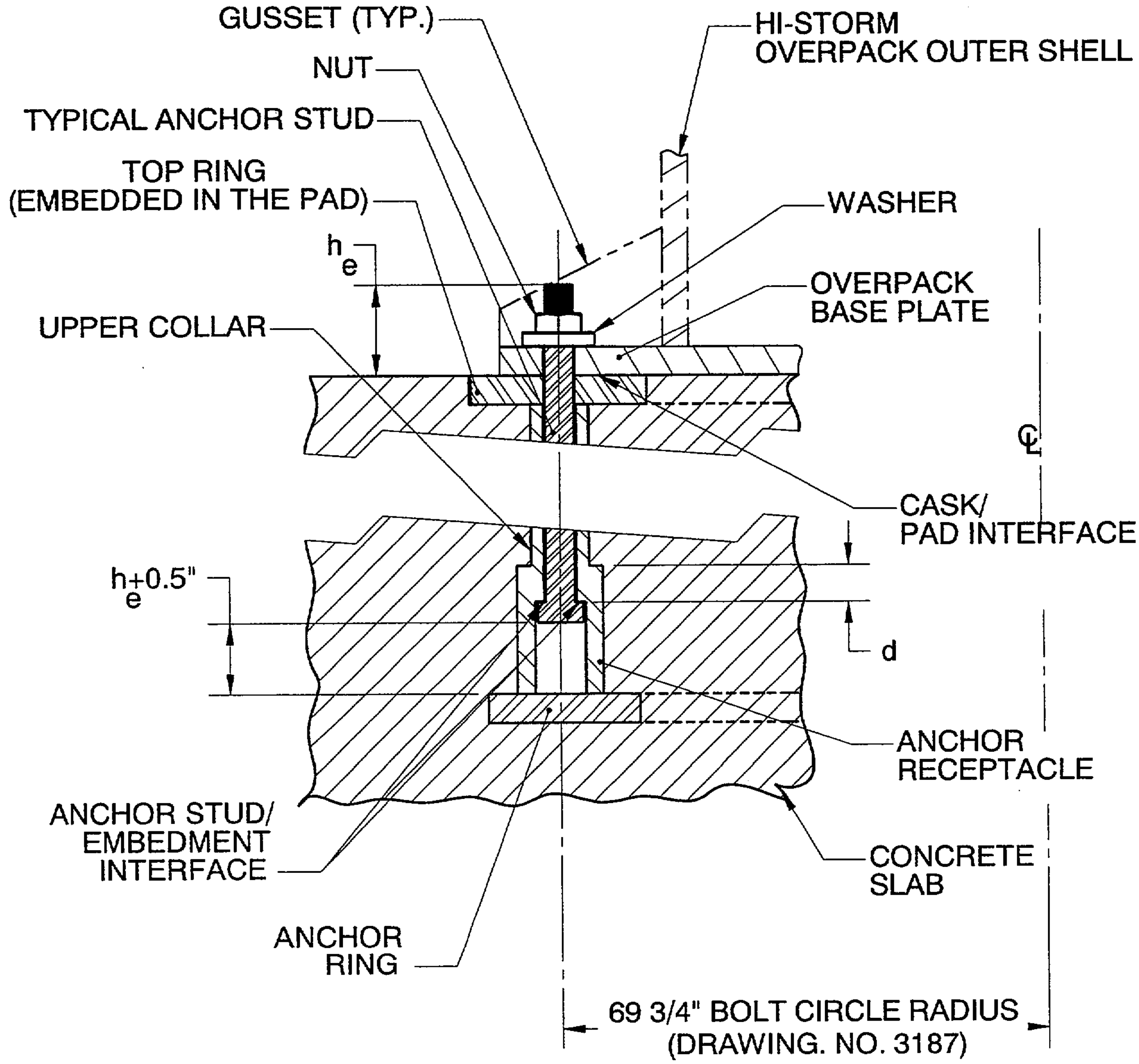

Figure 2.A.1;
Typical HI-STORM/ISFSI pad Fastening Detail

Note: Rebars in the ISFSI pad and sub-surface soil/rock continuum not shown.

CHAPTER 3: STRUCTURAL EVALUATION†

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 conservatism's 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.

Detailed numerical computations supporting the conclusions in the main body of this chapter are presented in a series of appendices. Where appropriate, the subsections make reference to results in the appendices. Section 3.6.3 contains the complete list of appendices that support this chapter.

This revision to the HI-STORM Safety Analysis Report, the first since the HI-STORM 100 System was issued a Part 72 Certificate-of-Compliance, incorporates several features into the structural analysis to respond to the changing needs of the U.S. nuclear power generation industry. The most significant changes to this chapter for this revision are:

- *The incorporation of structural results associated with the MPC-32 and the MPC-24E/24EF fuel baskets. In the case of the MPC-32, this revision simply returns results of analyses that were contained in this chapter prior to the initial CoC. In the case of the 24E basket, the new results are based on the same structural analysis model used for all the other baskets evaluated.*

- *The revision of the analyses of free thermal expansion and MPC canister shell to incorporate the changed temperature distribution from the inclusion of the thermosiphon* effect *(convective heat transfer inside the canister).*

- *The introduction of new analyses that permit the use of additional damaged fuel canisters in the HI-STORM 100.*

† 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 inclusion of a short version of the HI-STORM overpack (designated as HI-STORM 100S) to accommodate plants with reduced clearances. In general, we show that the HI-STORM 100S is bounded by results previously obtained.*

- *Revisions to approved HI-TRAC analyses to accommodate fabrication enhancements.*

- *Enhancement of the handling accident and tipover analyses to provide an additional qualified reference ISFSI pad configuration with higher strength concrete.*

- *Introduction of an anchored HI-STORM (designated as HI-STORM 100A). This enhancement permits use of a HI-STORM at sites in high seismic zones where a free standing cask is not acceptable.*

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 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;3.D;3.E;3.AC	
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 plus Appendices	
"	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; 3.F	
"	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; 3.U; *3.V;* 3.W; 3.I;3.AF*; 3.AQ*	Tables 4.4.15, 4.5.4

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; 3.Z; 3.AL*; 3.AN*	2.2.3.1
V.1.d.i.(3).(b)	Explosive Overpressure	3.1.2.1.1.4;3AK	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; 3.C	
"	Load Combination	3.4.8; 3.C	

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; 3.C	
"	Damage	3.B; 3.G; 3.H; 3Z; 3.AM	
"	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; 3B	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; 3.D;3.E; 3.AC; 3.AE	72-1008(3.4.3)
"	Other Lift Analyses	3.4.3.7-3.4.3.9; 3.D; 3.AB; 3.AC; 3.AE; 3.AD; 3.AI; 3.AJ	
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; 3.U; 3.W; 3.I; ~~3.N 3.T;~~ 3.Y	72-1008(3.4.4.3.1.2; 3.4.4.3.1.6; 3.AA; 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.X	
"	Stability	3.4.4.3; 3.4.4.4; 3.AK	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.AC	
"	Analyses	3.L	
"	Engagement Length	3.AC; 3.D	
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; 3.D; ~~3.N 3.T~~	72-1008(3.E; 3.K; 3.I; 3.AA 3.4.4.3.1.5)
"	Dynamic Amplifiers	3.X; 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.B; 3.D; 3.L; 3.M; 3.AC; 3.D;3.4.4.3; 3.K; 3.AK*; 3.AR; 3.AS*	

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; 3.X	
"	Stability	3.4.4.3; Table 3.1.1; 3.4.4.5; 3.AK	
"	Transfer Cask		
"	Requirements	3.1.2.1.2; Table 3.1.5	
"	Specific Analyses	3.4.4.3; 3.6.3; 3.E; 3.H; 3.I; 3.Z; 3.AD; 3.AE; 3.AA; 3.AI; 3.AB; 3.AD; 3.AG; 3.F; 3.AH; 3.AJ; 3.AL; 3.AM	
"	Dynamic Amplifiers	3.X	
"	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

Appendices 3.N-3.T have been relocated to the Calculation Package, HI-2002481 as of this revision.

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 is a thick circular plate continuously welded to the MPC shell along its circumference. 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.

- 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. 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. A short version of the HI-STORM 100 *overpack, designated as the HI-STORM 100S, is introduced 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. Therefore, 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 100 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. The HI-STORM 100S can carry all MPC's 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 ACI 318.1(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.

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 air flow shall remain available under normal and off-normal conditions of storage and after a natural phenomenon or accident event.

    ~~9.~~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 ~~free-~~*standing* 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 has 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.* 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~~is~~ controlled by the ISFSI structural design and, therefore, may result in a reduced "carry height" from that specified for a free-standing 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*~~postulable~~ 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

Explosion, by definition, is a transient event. Explosive materials (except for the short duration when a limited quantity of motive fuel for placing the loaded MPC on the ISFSI pad is present in the tow vehicle) are prohibited in the controlled area by specific stipulation in the HI-STORM 100 Technical Specification. However, pressure waves emanating from explosions in areas outside the ISFSI are credible.

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 was 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 warraented. 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 by the HI-STORM Technical Specification to be equal to or less than the accident condition design external pressure or external pressure differential specified in Table 2.2.1. The design external pressure differential is applied as a component of the load combinations.

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* ~~which~~ may prevent ready retrievability of the MPC.
- Excessive storage overpack *permanent* deformation *that*~~which~~ 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 HI-STORM 100S 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*~~which~~ 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*~~which~~ are relevant to the stability analyses *of free-standing 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)* 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.

Fuel Basket

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 the-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 SAR.

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 SAR 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 steel rib plates, and by the concrete columns away from the vent regions.

- 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, *free-standing* 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; 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 both a 125-ton HI-TRAC and a 100-ton HI-TRAC as detailed 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, and the lower dead weight loading. Therefore, all structural analyses performed for the 125 ton HI-TRAC are repeated for the 100-ton HI-TRAC only if it cannot be clearly demonstrated that the 125-ton unit 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*~~which~~ 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 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 *that*~~which~~ are upper bound*s* 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 ~~local~~ primary stress~~e~~ *required to*~~s~~ *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*~~eliminates the potential~~ *section* ~~of local~~ 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 normal storage mode, the lowest service temperature (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 parts used to lift the overpack or transfer cask (see Table 2.2.2 and Chapter 12). This includes the anchor block in the HI-STORM 100 Overpack, and pocket trunnions, lifting trunnions and the lifting trunnion block in HI-TRAC. Such items will henceforth be referred to as "significant-to-handling" (STH) parts. The applicable code for these elements of the structure is ANSI N14.6.

LST = -40°F for all HI-STORM "NF" components and 0°F for all HI-TRAC "NF" components. This includes all "NF" items not identified as an STH part.

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.

From the standpoint of protection against brittle fracture, it should be recognized that setting the LST equal to the NDT temperature ensures that the fracture strength of the material containing small flaws is equal to its yield strength. In fact, as the stress calculations in this chapter (and associated appendices) would attest, the maximum primary tensile stress in the HI-STORM 100 Overpack is below 6,000 psi in all normal conditions of storage operating modes. Even in extreme environmental phenomena events, tensile stresses are below 6,000 psi, except for localized regions under postulated missile impacts or non-mechanistic tip-over. For ferritic steels (please see NF-2311(b)(7)), 6,000 psi is the threshold stress, at or below which crack propagation will not take place, no matter how low the metal temperature [3.1.3, p. 13]. (The threshold stress is the horizontal extension of the crack arrest temperature (CAT) curve in the fracture mechanics literature.)

The generally low value of tensile stress in the HI-STORM 100 storage overpack and in the HI-TRAC cask parts suggest that an NDT temperature requirement is not essential to ensure safety from crack growth. However, the aforementioned NDT temperature requirement of -40°F has been imposed to incorporate an additional layer of conservatism in the design.

The STH components (bolt anchor block (HI-STORM), lifting trunnion (HI-TRAC), lifting trunnion block (HI-TRAC), and pocket trunnion (HI-TRAC) 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 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 SA516-70 (with some components having an option for SA203E or SA350-LF3 depending on material availability).

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* ~~which~~ 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.	Appendix 3.C
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.	Appendices 3.I, 3.J, 3.U, *3.V*, 3.W; 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.	Appendix 3.AA of Docket 72-1008
F3			
F3.a (Note 2)	D + H'	Vertical axis drop event	Docket Number 72-1008, Subsection 3.4.4.3.1.6
F3.b (Note 3)	D + H'	Side Drop, 0 degree orientation (Figure 3.1.2)	*Table 3.4.6*~~Appendix 3.T~~
F3.c (Note 3)	D + H'	Side Drop, 45 degree orientation (Figure 3.1.3)	*Table 3.4.6*~~Appendix 3.T~~

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 3.4.4.3.1.6. 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.I.8.1 Shell 3.4.4.3.1.2 SupportsN/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 3.H (Case 4) 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 Docket 72-1008 3.I.8.2 Shell Docket 72-1008 3.AA (stress) Docket 72-1008 3.H (Case 4) (buckling) Supports Docket 72-1008 3.AA

† 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 72-10083.E.8.2.1-2 Baseplate: Docket 72-10083.I.8.3 Shell: Docket 72-10083.H (Case 5) (Buckling) 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*~~Appendix 3.T~~ Supports: *Table 3.4.6*~~Appendix 3.T~~, 3.Y
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*~~Appendix 3.T~~ Supports: *Table 3.4.6* ~~Appendix 3.T~~, 3.Y
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 (Note 1)	P_i^* or P_o^* + D + T^*	Demonstrate compliance with level D stress limits – buckling stability.	Lid	Docket 72-1008	3.E.8.2.1.3
			Baseplate	Docket 72-1008	3.I.8.4
			Shell	Docket 72-1008	3.H (Case 6) (buckling)
				Docket 72-1008	3.4.4.3.1.5 (thermal stress)
			Supports	N/A	

Notes:

1. Load Cases E1.a, E1.b, E2, and E5 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, Appendix 3.AA. 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 Where this Case is Analyzed
01	D + H + T + (P_o,P_i)	Vertical load handling of HI-STORM 100 Overpack/HI-TRAC.	Overpack 3.D HI-TRAC Shell 3.AE Pool lid 3.AB Transfer lid 3.AD
02			
02.a	D + H' + (P_o,P_i)	Storage Overpack: End drop; primary stress intensities must meet level D stress limits.	Overpack 3.M
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.Z Transfer Lid 3.AD Slapdown 3.AN
02.c	D + H'	Storage Overpack: Tip-over; any permanent deformations must not preclude ready retrieval of the MPC.	Overpack 3.A,3.B

† 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 Where this Case is Analyzed
03	D (water jacket)	Satisfy primary membrane plus bending stress limits for water jacket (This case is only applicable to HI-TRAC).	3.AG
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.G HI-TRAC 3.AN 3.H
05	P_o	Explosion: must not produce buckling or exceed primary stress levels in the overpack structure.	3.B,3.AK

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.

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† 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.

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† 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	450	18.1	27.2	54.3
E2	Alloy X	450	18.1	27.2	54.3
E3	Alloy X	450	43.4	65.2	NL††
E4	Alloy X	450	18.1	27.2	54.3
E5	Alloy X	775	36.15	54.25	NL

Note:

1. Q, P_m, P_L, and P_b are defined in Table 3.1.6.

† Values for reference temperatures are taken as the design temperatures (Table 2.2.3)

†† 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	$P_L + P_b$	$P_L + P_b + Q$
01	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
02	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
03	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
04	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

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† Values for reference temperatures are taken as the design temperatures (Table 2.2.3).

†† 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 (A193 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)	-	-
SA516, Gr. 70 (normalized) (thickness less than or equal to 0.75 inch)	Not required per NF-2311(b)(13) and curve D in Figure NF-2311(b)-1	-	-
SA203, SA516 Gr. 70, SA350-LF3 (greater than 0.75" thick)	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)
Weld material	Test per NF-2430 for welds when base metal impact testing is required.	-40 deg.F (HI-STORM) 0 deg.F (HI-TRAC) ("NF" parts) -40 deg.F (HI-TRAC)("STH" parts)	Per NF-2330

Note:

1. Required NDT temperature = -40 deg.F for all parts in the HI-STORM 100 Overpack, -40 deg.F for HI-TRAC "STH" parts, and 0 deg.F for HI-TRAC "NF" parts.

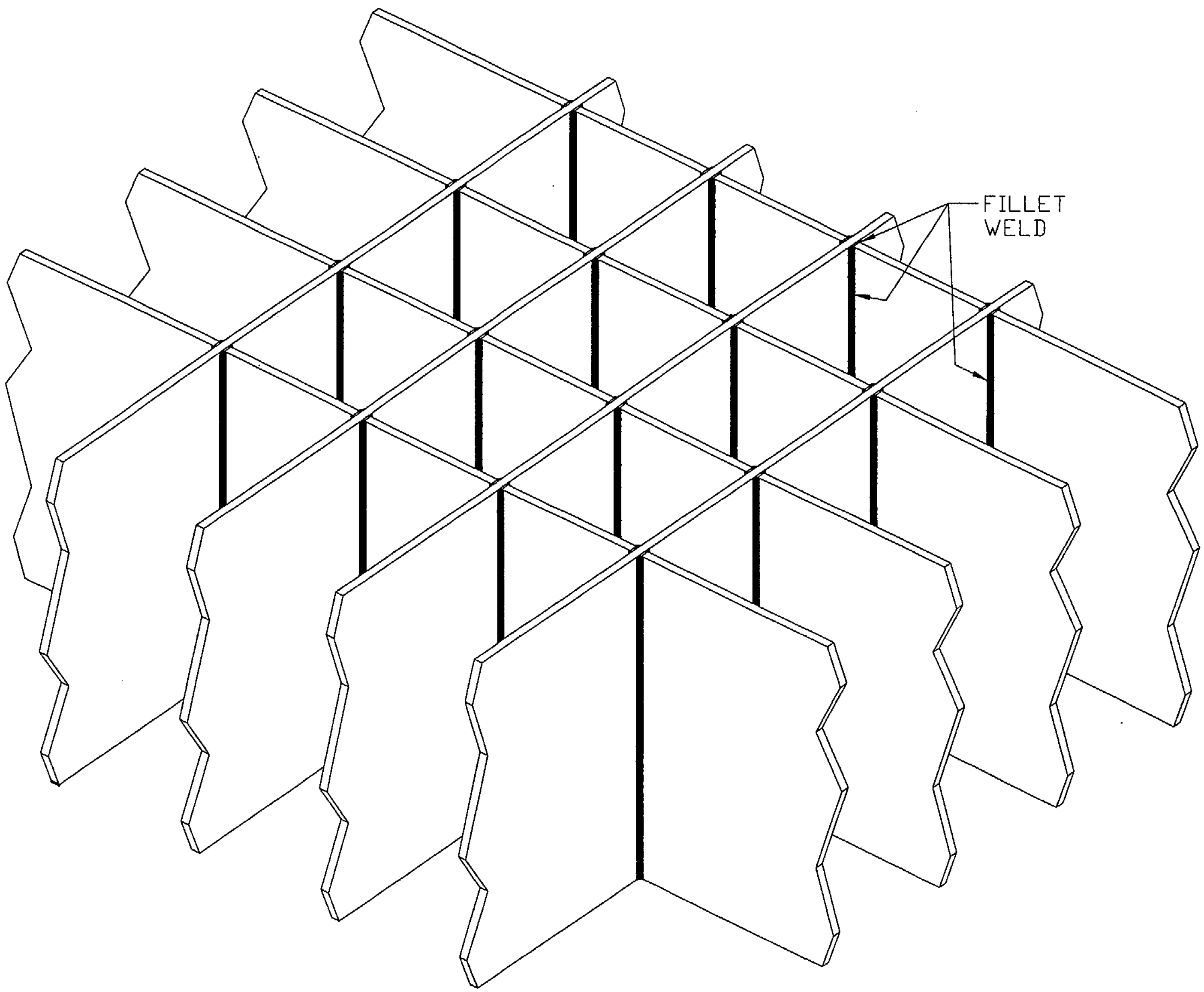


FIGURE 3.1.1; MPC-68 AND MPC-32 FUEL BASKET GEOMETRY

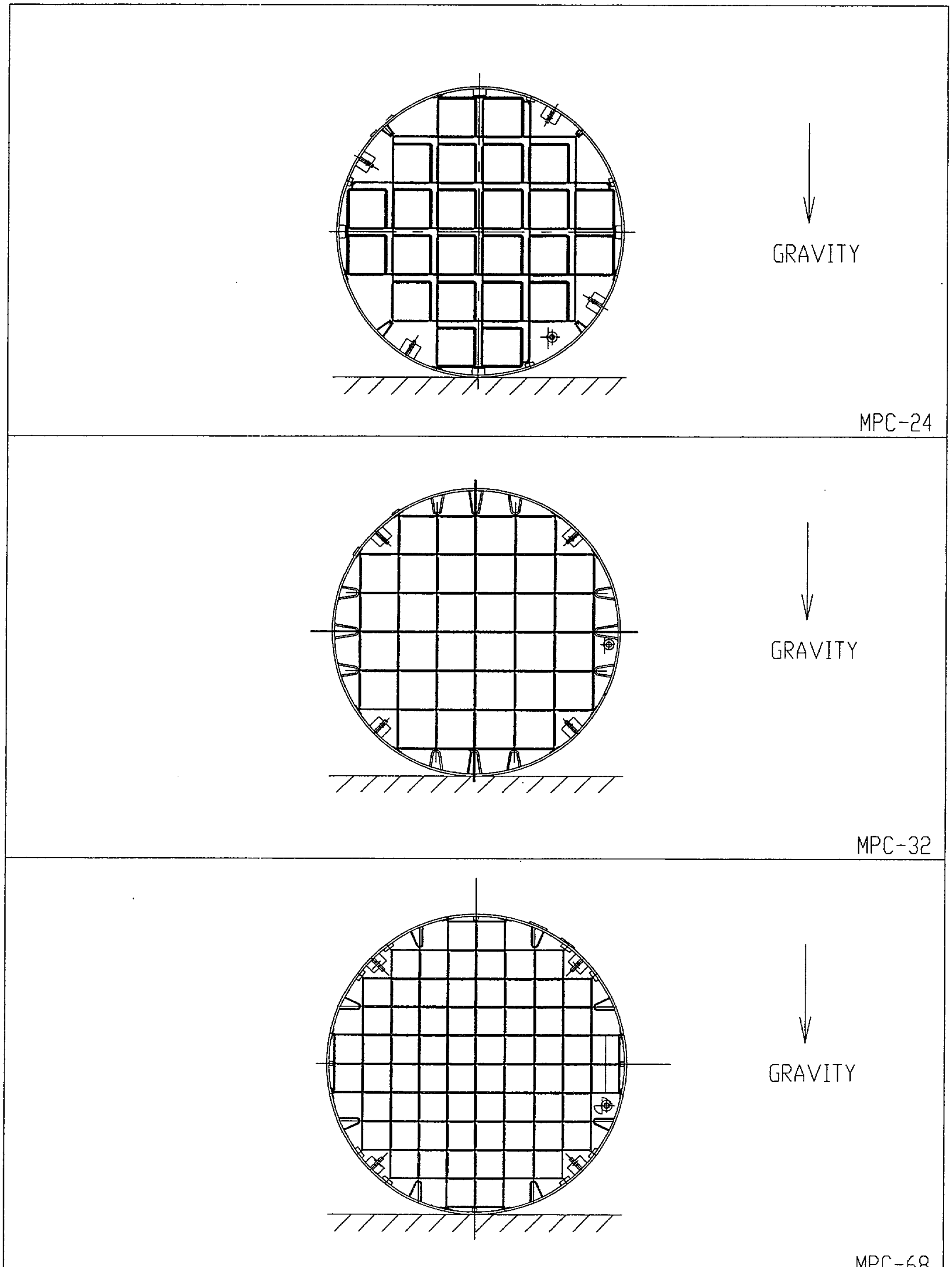
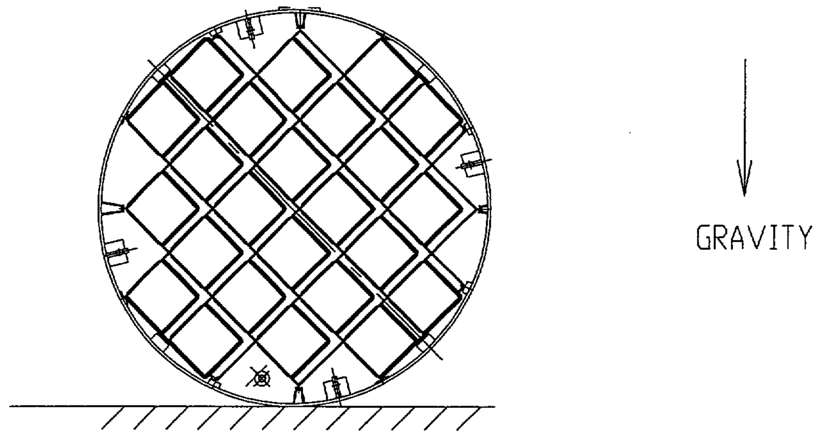
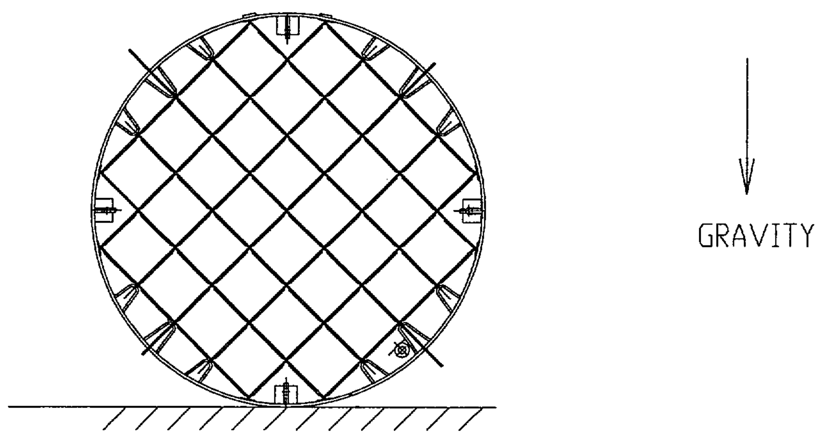


FIGURE 3.1.2; 0° DROP ORIENTATIONS FOR THE MPCs





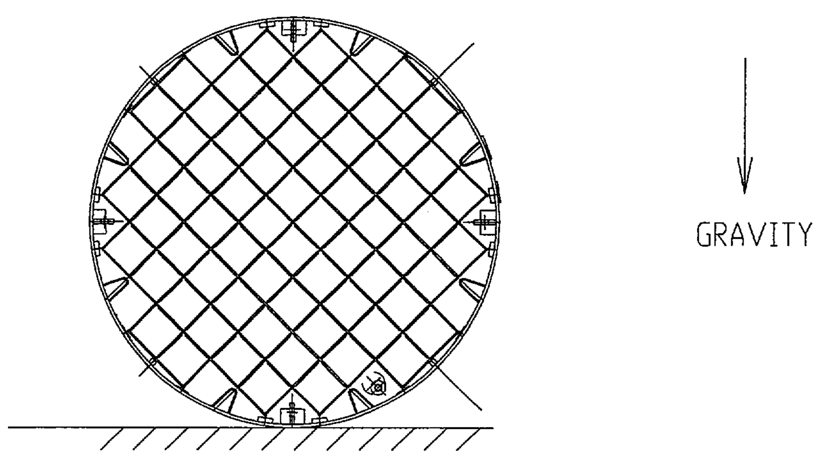


FIGURE 3.1.3; 45° DROP ORIENTATIONS FOR THE MPCs

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-axisymetric 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 100 OVERPACK WEIGHT DATA

	WEIGHT (lb)†		
Item	**Component (lb.)**	**Assembly (lb.)**	**Bounding Weight†† (lb.)**
HI-STORM 100 Overpack · Overpack top lid	 21,638	*265,866*~~8,334~~	270,000 23,000
HI-STORM 100S Overpack · Overpack top lid	 24,*771*~~498~~	*252,423*	270,000 25,500
HI-STORM 100A		*add 2000 lb. to above weights*	*270,000*
MPC-24 · Without SNF · Fully loaded with SNF		 39,667 79,987	 90,000
Overpack (100) with fully loaded MPC-24 *(100S) with loaded MPC-24*		345,*853*~~8,321~~ *332,410*	360,000 *360,000*
MPC-68 · Without SNF · Fully loaded with SNF		 39,641 87,241	 90,000
Overpack (100) with fully loaded MPC-68 *(100S) with loaded MPC-68*		353,*107*~~5,575~~ *339,664*	360,000 *360,000*
Overpack (100) with *empty MPC-68*~~lower bound weight~~~~minimum weight MPC without SNF~~		*304,507*~~307,975~~	30~~303~~,000 (Lower Bound)
MPC-32 · Without SNF · Fully loaded with SNF		 34,375 88,135	 90,000
Overpack (100) with *fully* loaded MPC-32 *(100S) with loaded MPC-32*		354,*001*~~6,469~~ *340,558*	360,000 *360,000*
MPC-24E · Without SNF · Fully loaded with SNF		 42,069 82,389	 90,000
Overpack (100) with *fully* loaded MPC-24E *(100S) with loaded MPC-24E*		*348,255-* *334,812*~~350,723~~	360,000 *360,000*

† All calculated weights are rounded up to the nearest pound

†† Bounding weights or calculated weights may be used for analytical calculations, as appropriate, to ensure conservatism in the results. *All bounding weights are applicable to HI-STORM 100A.*

TABLE 3.2.2
125-TON HI-TRAC TRANSFER CASK WEIGHT DATA

	WEIGHT (lb)†		
ITEM	Component	Assembly	Bounding Weight††
125-Ton HI-TRAC Transfer Cask with Pool Lid · Pool Lid · Top Lid	 12,031~~1~~ 2,730	142,976~~88~~	143,500 12,500 2,750
125-Ton HI-TRAC Transfer Cask with Transfer Lid · Transfer Lid · Top Lid	 23,428~~1,679~~ 2,730	154,373~~2,636~~	155~~3~~,000 24,5~~2,0~~00 2,750
MPC-24 · Without SNF · Fully loaded with SNF		 39,667 79,987	 80,000
125-Ton HI-TRAC with Pool Lid with loaded MPC-24		222,963~~75~~	223,500
125-Ton HI-TRAC with Transfer Lid w/ loaded MPC-24		234,359~~2,623~~	235~~3~~,000
MPC-68 · Without SNF · Fully loaded with SNF		 39,641 87,241	 90,000
125-Ton HI-TRAC with Pool Lid with loaded MPC-68		230,217~~29~~	233,500
125-Ton HI-TRAC with Transfer Lid w/ loaded MPC-68		241,613~~39,877~~	243,000
MPC-32 · Without SNF · Fully loaded with SNF		 34,375 88,135	 90,000
125-Ton HI-TRAC with Pool Lid with loaded MPC-32		231,11~~23~~	233,500
125-Ton HI-TRAC with Transfer Lid w/ loaded MPC-32		242,507~~0,771~~	243,000
MPC-24E · Without SNF · Fully loaded with SNF		 42,069 82,389	 90,000
125-Ton HI-TRAC with Pool Lid with loaded MPC-24E		225,365~~77~~	226,000
125-Ton HI-TRAC with Transfer Lid w/ loaded MPC-24E		236,761~~5,035~~	237~~6~~,5~~0~~00

† All calculated weights are rounded up to the nearest pound

†† Bounding weights or calculated weights may be used for analytical calculations, as appropriate, to insure conservatism in the results.

TABLE 3.2.2 (CONTINUED)
100-TON HI-TRAC TRANSFER CASK WEIGHT DATA†

ITEM	WEIGHT (lb) Component	Assembly	Bounding Weight††
100-Ton HI-TRAC Transfer Cask with Pool Lid • Removable trunnion · Pool Lid · Top Lid	 255 7,915 1,203~~2~~	100,*449*~~960~~	102,000 8,000 *1,5*~~2,~~400
100-Ton HI-TRAC Transfer Cask with Transfer Lid • Removable trunnion · Transfer Lid · Top Lid	 255 16,*092*~~425~~ 1,203~~2~~	108,*626*~~267~~	111,000 17~~8~~,000 *1,5*~~2,~~400
MPC-24 · Without SNF · Fully loaded with SNF		 39,667 79,987	 80,000
100-Ton HI-TRAC with Pool Lid with loaded MPC-24		183,*636*~~0,947~~	1*84*~~82~~,000
100-Ton HI-TRAC with Transfer Lid w/ loaded MPC-24		1*91,812*~~89,457~~	192~~1~~,000
MPC-68 · Without SNF · Fully loaded with SNF		 39,641 87,241	 90,000
100-Ton HI-TRAC with Pool Lid with loaded MPC-68		1*90,890*~~88,201~~	192,000
100-Ton HI-TRAC with Transfer Lid w/ loaded MPC-68		199,*066*~~6,711~~	201,000
MPC-32 · Without SNF · Fully loaded with SNF		 34,375 88,135	 90,000
100-Ton HI-TRAC with Pool Lid with loaded MPC-32		1*91,784*~~89,095~~	192,000
100-Ton HI-TRAC with Transfer Lid w/ loaded MPC-32		199,*960*~~6,402~~	201,000
MPC-24E · Without SNF · Fully loaded with SNF		 42,069 82,389	 90,000
100-Ton HI-TRAC with Pool Lid with loaded MPC-24E		186,*038*~~3,349~~	187~~4~~,000
100-Ton HI-TRAC with Transfer Lid w/ loaded MPC-24E		194,*214*~~0,656~~	195~~2~~,000

† All calculated weights are rounded up to the nearest pound.

†† Bounding weights or calculated weights may be used for analytical calculations, as appropriate, to ensure conservatism in the results.

TABLE 3.2.3
CENTERS OF GRAVITY OF HI-STORM 100 CONFIGURATIONS

Component	Height of CG Above Datum, inches
HI-STORM 100 Overpack empty	116.8
HI-STORM 100S Overpack empty	*111.4*
125-Ton HI-TRAC with Pool Lid empty	90.56~~1~~
125-Ton HI-TRAC with Transfer Lid empty	88.*24*~~19~~
MPC-24 Empty (See Note 2.)	108.9
MPC-68 Empty (See Note 2.)	109.9
MPC-32 Empty (See Note 2.)	109.3
MPC-24E Empty (See Note 2.)	107.9
MPC-24 with Fuel in Overpack *(100)*	118.*47*~~39~~
MPC-68 with Fuel in Overpack *(100)*	118.*51*~~38~~
MPC-32 with Fuel in Overpack *(100)*	118.*50*~~42~~
MPC-24E with Fuel in Overpack *(100)*	*118.44*
MPC-24 with Fuel in Overpack (100S)	*113.05*
MPC-68 with Fuel in Overpack (100S)	*113.09*
MPC-32 with Fuel in Overpack (100S)	*113.07*
MPC-24E with Fuel in Overpack (100S)	*113.01*
125-Ton HI-TRAC w/Pool Lid and MPC-24 w/fuel	93.*91*~~88~~
125-Ton HI-TRAC w/Pool Lid and MPC-68 w/fuel	93.98~~5~~
125-Ton HI-TRAC w/Pool Lid and MPC-32 w/fuel	*93.97*
125-Ton HI-TRAC w/Pool Lid and MPC-24E w/fuel	*93.86*
125-Ton HI-TRAC w/Transfer Lid and MPC-24 w/fuel	91.*01*~~66~~
125-Ton HI-TRAC w/Transfer Lid and MPC-68 w/fuel	*91.74*~~2.34~~
125-Ton HI-TRAC w/Transfer Lid and MPC-32 w/fuel	*91.74*
125-Ton HI-TRAC w/Transfer Lid and MPC-24E w/fuel	*91.10*
100-Ton HI-TRAC w/Pool Lid Empty	85.*99*~~57~~
100-Ton HI-TRAC w/Transfer Lid Empty	8*6.35*~~5.73~~
100-Ton HI-TRAC w/Pool Lid and MPC-24 w/fuel	90.*55*~~31~~

TABLE 3.2.3 CENTERS OF GRAVITY OF HI-STORM 100 CONFIGURATIONS	
Component	***Height of CG Above Datum, Inches***
100-Ton HI-TRAC w/Pool Lid and MPC-68 w/fuel	90.*77*~~54~~
100-Ton HI-TRAC w/Pool Lid and MPC-32 w/fuel	*90.76*
100-Ton HI-TRAC w/Pool Lid and MPC-24E w/fuel	*90.54*
100-Ton HI-TRAC w/Transfer Lid and MPC-24 w/fuel	91.*62*~~24~~
100-Ton HI-TRAC w/Transfer Lid and MPC-68 w/fuel	9*2.29*~~1.92~~
100-Ton HI-TRAC w/Transfer Lid and MPC-32 w/fuel	*92.27*
100-Ton HI-TRAC w/Transfer Lid and MPC-24E w/fuel	*91.60*

Note:

1. The datum used for calculations involving the overpack 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.

2. The datum used for calculations involving only the MPC is the bottom of the MPC baseplate.

TABLE 3.2.4
LIFT WEIGHT ABOVE POOL WITH 125-TON HI-TRAC

Item	Weight (lb.)	Bounding Weight†
Total weight of 125-Ton HI-TRAC w/Pool Lid	142,9*76*~~88~~	
Total weight of MPC-32 + fuel	88,135††	
125-Ton HI-TRAC Top Lid	-2,730†††	
Water in MPC and 125-Ton HI-TRAC	16,*570*~~956~~	17,000
Lift yoke	3,600	
Inflatable annulus seal	50	
TOTAL	248,*601*~~999~~	250,000

† Bounding weights or calculated weights may be used for analytical calculations, as appropriate, to ensure conservatism in the results.

†† Includes MPC closure ring.

††† HI-TRAC top lid weight is included in total weight. However, the top lid is not installed during in-pool operations.

Table 3.2.4 (continued)
LIFT WEIGHT ABOVE POOL WITH 100-TON HI-TRAC

Item	Weight (lb.)	Bounding Weight[†]
Total weight of 100-Ton HI-TRAC w/Pool Lid	100,*194*~~960~~	
Total weight of MPC-*32*~~68~~ + fuel	88,135[††]	
100-Ton HI-TRAC Top Lid	-1,20*3*~~2~~[†††]	
Water in MPC and 100-Ton HI-TRAC	16,*570*~~956~~	17,000
Water in Water Jacket	-7,556[††††]	
Lift yoke	3,*2*~~6~~00	
Inflatable annulus seal	50	
TOTAL	*199,390*~~200,~~ ~~5943~~	201,*000*~~250~~

Note: HI-TRAC 100 body weight is without removable portion of pocket trunnion

† Bounding weights or calculated weights may be used for analytical calculations, as appropriate, to ensure conservatism in the results.

†† Includes MPC closure ring.

††† HI-TRAC top lid weight is included in total weight. However, the top lid is not installed during in-pool operations.

†††† Total weight of 100-Ton HI-TRAC includes water in water jacket, but during removal from fuel pool, no water is in the water jacket as the water within the MPC cavity provides sufficient shielding.