CHAPTER 2[†]: PRINCIPAL DESIGN CRITERIA

2.0 INTRODUCTION

The design characteristics of the HI-STORM FW System are presented in Chapter 1, Section 1.2. This chapter contains a compilation of loadings and design criteria applicable to the HI-STORM FW System. The loadings and conditions prescribed herein for the MPC, particularly those pertaining to mechanical accidents, are consistent with those required for 10CFR72 compliance. 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 structural design criteria are presented in the subsequent chapters of this FSAR.

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

The design criteria for the MPCs, HI-STORM FW overpack, and HI-TRAC VW transfer cask are summarized in Subsections 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 engineered for a 60 year design life, while satisfying the requirements of 10CFR72. The adequacy of the MPC to meet the above design life is discussed in Section 3.4. The design characteristics of the MPC are described in Section 1.2.

Structural

The MPC is classified as important-to-safety. The MPC structural components include the fuel basket and the enclosure vessel. The fuel basket is designed and fabricated to meet a more stringent displacement limit under mechanical loadings than those implicit in the stress limits of the ASME code (see Section 2.2). The MPC enclosure vessel is designed and fabricated as a Class 1 pressure vessel in accordance with Section III, Subsection NB of the ASME Code, with

† This chapter has been prepared in the format and section organization set forth in Regulatory Guide 3.61. 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. All terms-of-art used in this chapter are consistent with the terminology of the Glossary.

certain necessary alternatives, as discussed in Section 2.2. The principal exception to the above Code pertains to the MPC lid, vent and drain port cover plates, and closure ring welds to the MPC lid and shell, as discussed in Section 2.2. In addition, Threaded Anchor Locations (TALs) in the MPC lid are designed in accordance with the requirements of NUREG-0612 for critical lifts to facilitate handling of the loaded MPC.

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

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

Compliance with the ASME Code, with respect to the design and fabrication of the MPC, and the associated justification are discussed in Section 2.2. The MPC design is analyzed for all design basis normal, off-normal, and postulated accident conditions, as defined in Section 2.2. The required characteristics of the fuel assemblies to be stored in the MPC are limited in accordance with Section 2.1.

Thermal

The thermal design and operation of the MPC in the HI-STORM FW System meets the intent of the review guidance contained in ISG-11, Revision 3 [2.0.1]. Specifically, the ISG-11 provisions that are explicitly invoked and satisfied are:

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

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

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

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

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

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

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

iii. The off-normal and accident condition PCT limit remains unchanged at 570 ºC (1058ºF).

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

The normal condition design temperatures for the stainless steel components in the MPC are provided in Table 2.2.3.

Each MPC model allows for regionalized storage where the basket is segregated into three regions as shown in Figures 1.2.1 and 1.2.2. Decay heat limits for regionalized loading are presented in Tables 1.2.3 and 1.2.4 for MPC-37 and MPC-89, respectively. Specific requirements, such as approved locations for DFCs and non-fuel hardware are given in Section 2.1.

Shielding

The dose limits for an ISFSI using the HI-STORM FW System are delineated in 10CFR72.104 and 72.106. Compliance with these regulations for any particular array of casks at an ISFSI is necessarily site-specific and must be demonstrated by the licensee. Dose for a single cask and a representative cask array is illustrated in Chapter 5.

The MPC provides axial shielding at the top and bottom ends to maintain occupational exposures ALARA during canister closure and handling operations. The HI-TRAC VW bottom lid also contains shielding. The occupational doses are controlled in accordance with plant-specific procedures and ALARA requirements (discussed in Chapter 9).

The dose evaluation is performed for a reference fuel (Table 1.0.4) as described in Section 5.2. Calculated dose rates for each MPC are provided in Section 5.1. These dose rates are used to perform an occupational exposure (ALARA) evaluation, as discussed in Chapter 11.

Criticality

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

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

Confinement

The MPC provides for confinement of all radioactive materials for all design basis normal, off-normal, and postulated accident conditions. As discussed in Section 7.1, the HI-STORM FW MPC design meets the guidance in Interim Staff Guidance (ISG)-18 so that leakage of radiological matter from the confinement boundary is non-credible. Therefore, no confinement dose analysis is required or performed. The confinement function of the MPC is verified through pressure testing, helium leak testing of the MPC shell, base plate, and lid material along with the shell to base plate and shell to shell seam welds, and a rigorous weld examination regimen executed in accordance with the acceptance test program in Chapter 10.

Operations

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

Generic operating procedures for the HI-STORM FW System are provided in Chapter 9. Detailed operating procedures will be developed by the licensee using the information provided in Chapter 9 along with the site-specific requirements that comply with the 10CFR50 Technical Specifications for the plant, and the HI-STORM FW System Certificate of Compliance (CoC).

Acceptance Tests and Maintenance

The acceptance criteria and maintenance program to be applied to the MPC are described in Chapter 10. The operational controls and limits to be applied to the MPC are discussed in

Chapter 13. Application of these requirements will assure that the MPC is fabricated, operated, and maintained in a manner that satisfies the design criteria defined in this chapter.

Decommissioning

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

2.0.2 HI-STORM FW Overpack Design Criteria

General

The HI-STORM FW overpack is engineered for a 60 year Design Life while satisfying the requirements of 10CFR72. The adequacy of the overpack to meet the required design life is discussed in Subsection 3.4.7. The design characteristics of the HI-STORM FW overpack are summarized in Subsection 1.2.1.

Structural

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

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

The HI-STORM FW overpack plain concrete is enclosed in steel inner and outer shells connected to each other by radial ribs, and top and bottom plates. As the HI-STORM FW overpack concrete is not reinforced, the structural analysis of the overpack only credits the compressive strength of the concrete in the analysis to provide an appropriate simulation of the accident conditions postulated in this FSAR. The technical requirements on testing and qualification of the HI-STORM FW overpack plain concrete are in Appendix 1.D of the HI-STORM 100 FSAR. Appendix 1.D is incorporated in this FSAR by reference.

There is no U.S. or international code that is sufficiently comprehensive to provide a completely prescriptive set of requirements for the design, manufacturing, and structural qualification of the overpack. The various sections of the ASME Codes, however, contain a broad range of specifications that can be assembled to provide a complete set of requirements for the design, analysis, shop manufacturing, and final field construction of the overpack. The portions or whole of the Codes and Standards that are invoked for the various elements of the overpack design, analysis, and manufacturing activities (viz., materials, fabrication and inspection) are summarized in Tables 1.2.6, and 1.2.7.

The ASME Boiler and Pressure Vessel Code (ASME Code) Section III, Subsection NF Class 3, [2.0.3], is the applicable code to determine stress limits for the load bearing components of the overpack when required by the acceptance criteria set down in this chapter. The material types used in the components of the HI-STORM FW System are listed in the licensing drawings.

ACI 318-05 [2.0.4] is the applicable reference code to establish the limits on unreinforced concrete (in the Closure Lid), which is subject to secondary structural loadings. Appendix 1.D contains the design, construction, and testing criteria applicable to the plain concrete in the overpack lid.

As mandated by 10CFR72.24(c)(3) and §72.44(d), Holtec International's quality assurance (QA) program requires all constituent parts of an SSC subject to NRC certification under 10CFR72 to be assigned an ITS category appropriate to its function in the control and confinement of radiation. The ITS designations (ITS or NITS) for the constituent parts of the HI-STORM FW System are provided in the licensing drawings. The QA categorization level (A, B, or C) for ITS parts is provided in Tables 2.0.1 through 2.0.8. A table exists for each licensing drawing and provides the QA level for the parts designated as ITS on the licensing drawings.

The excerpts from the codes, standards, and generally recognized industry publications invoked in this FSAR, supplemented by the commitments in Holtec's QA procedures, provide the necessary technical framework to ensure that the as-installed system would meet the intent of §72.24(c), §72.120(a) and §72.236(b). As required by Holtec's QA Program (discussed in Chapter 14), all operations on ITS components must be performed under QA validated written procedures and specifications that are in compliance with the governing citations of codes, standards, and practices set down in this FSAR.

The overpack is designed for all normal, off-normal, and design basis accident condition loadings, as defined in Section 2.2.

Thermal

The thru-thickness temperature limits for the plain concrete in the overpack for long term and short term temperatures are in Table 2.2.3. 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 Subsection 2.2.2. The brittle fracture assessment of structural steel materials used in the storage cask is considered in Section 3.1.

The overpack is designed to dissipate the maximum allowable heat load (shown in Tables 1.2.3 and 1.2.4) from the MPC. The thermal characteristics of the MPC stored inside the overpack are evaluated in Chapter 4.

Shielding

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

The overpack is designed to limit the calculated surface dose rates on the cask for all MPC designs as defined in Subsection 2.3.5. The overpack is also designed to maintain occupational exposures ALARA during MPC processing, 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 operations and a site boundary dose assessment for a typical ISFSI, as described in Chapter 11.

Confinement

The overpack does not perform any confinement function. Confinement during storage is provided by the MPC. The overpack provides physical protection and radiation shielding of the MPC contents during dry storage operations.

Operations

There are no radioactive effluents that result from MPC operations after the MPC is sealed or during storage operations. 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 FW System are provided in Chapter 9. The licensee is required to develop detailed operating procedures based on Chapter 9 with due consideration of site-specific conditions including the applicable 10CFR50 technical specification requirements for the site, and the HI-STORM FW System CoC.

Acceptance Tests and Maintenance

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

Decommissioning

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

2.0.3 HI-TRAC VW Transfer Cask Design Criteria

General

The HI-TRAC VW transfer cask is engineered for a 60 year design life. The adequacy of the HI-TRAC VW to meet the above design life commitment is discussed in Section 3.4. The design characteristics of the HI-TRAC VW cask are presented in Subsection 1.2.1.

Structural

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

The HI-TRAC VW transfer cask design is analyzed for all normal, off-normal, and design basis accident condition loadings, as defined in Section 2.2. Under accident conditions, the HI-TRAC VW transfer cask must protect the MPC from unacceptable deformation, provide continued shielding, and remain in a condition such that the MPC can be removed from it. The loads applicable to the HI-TRAC VW transfer cask are defined in Tables 2.2.6 and 2.2.13 and Table 3.1.1. The physical characteristics of each MPC for which the HI-TRAC VW is designed are presented in Subsection 1.2.1.

Thermal

The allowable temperatures for the HI-TRAC VW transfer cask structural steel components are based on the maximum temperature for material properties and allowable stress values provided in Section II of the ASME Code. The allowable temperatures for the structural steel and shielding components of the HI-TRAC VW are provided in Table 2.2.3. The HI-TRAC VW is designed for off-normal environmental cold conditions, as discussed in Subsection 2.2.2. The evaluation of the potential for brittle fracture in structural steel materials is presented in Section 3.1.

The HI-TRAC VW is designed and evaluated for the maximum heat load analyzed for storage operations. The maximum allowable temperature of water in the HI-TRAC jacket is a function of the internal pressure. To preclude over- pressurization of the water jacket due to boiling of the neutron shield liquid (water), the maximum temperature of the water is restricted to be less than the saturation temperature at the shell design pressure. Even though the analysis shows that the water jacket will not over-pressurize, a relief device is placed at the top of the water jacket shell. In addition, the water is precluded from freezing during off-normal cold conditions by limiting the minimum allowable operating temperature and by adding ethylene glycol. The thermal characteristics of the fuel for each MPC for which the transfer cask is designed are defined in Section 2.1. The working area ambient temperature limit for loading operations is limited in accordance with Table 2.2.2.

Shielding

The HI-TRAC VW 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 the rated capacity of the crane. As discussed in Subsection 1.2.1, the shielding in HI-TRAC VW is maximized within the constraint of the allowable weight at a plant site. The HI-TRAC VW calculated dose rates for a set of reference conditions 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 11. A postulated HI-TRAC VW accident condition, which includes the loss of the liquid neutron shield (water), is also evaluated in Chapter 5.

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

Confinement

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

Operations

There are no radioactive effluents that result from MPC transfer operations using HI-TRAC VW. 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 FW System are provided in Chapter 9. The licensee will develop detailed operating procedures based on Chapter 9 along with plant-specific requirements including the Part 50 Technical Specification and SAR, and the HI-STORM FW System CoC.

Acceptance Tests and Maintenance

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

Decommissioning

Decommissioning considerations for the HI-STORM FW Systems, including the HI-TRAC VW 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 FW cask system is classified as "important-to-safety" (ITS). This FSAR explicitly recognizes the HI-STORM FW 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 "not important to safety" (NITS) structure because of a lack of a physical connection between the cask and the pad.

Because the geological conditions vary widely across the United States, it is not possible to, *a'priori*, define the detailed design of the ISFSI pad. Accordingly, in this FSAR, the limiting requirements on the design and installation of the pad are provided. The user of the HI-STORM FW 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 FSAR.
- The material of construction of the pad (viz., the additives used in the pad concrete) are compatible with the ambient environment at the ISFSI site.
- Appropriate structural evaluations are performed pursuant to 10CFR72.212 to demonstrate that the pad is structurally competent to permit the cask to withstand the seismic and other credible inertial loadings at the site.

2.0.4.2 Load Combinations and Applicable Codes

Factored load combinations for ISFSI pad design are provided in NUREG-1536 [1.0.3]. 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).

The factored load combinations presented in Table 3-1 of NUREG 1536 are reduced in number by eliminating loading types that are not germane or controlling in a HI-STORM ISFSI pad design. The applicable factored load combinations are accordingly adapted from the HI-STORM 100 FSAR and presented below.

a. Definitions

D = Dead load
L = Live load
T = Thermal load
E = DBE seismic load
U_c= Reinforced concrete available strength

b. Load Combinations for the Concrete Pad

Normal Events

$U_c > 1.4\ D + 1.7\ L$

Off-Normal Events

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

Accidents

$U_c > D + L + T + E$

As an interfacing structure, the ISFSI pad and its underlying substrate must possess the structural strength to satisfy the above inequalities. As discussed in the HI-STAR 100 FSAR, thermal gradient loads are generally small; therefore, the Off-Normal Event does not generally provide a governing load combination.

Table 2.2.9 provides a reference set of parameters for the ISFSI pad and its foundation that are used solely as input to the non-mechanistic tipover analysis. Analyses in Chapter 3 show that this reference pad design does not violate the design criterion applicable to the non-mechanistic tip-over of the HI-STORM FW storage system. The pad design may be customized to meet the requirements of a particular site, without performing a site-specific tipover analysis, provided that all ISFSI pad strength properties are less than or equal to the values in Table 2.2.9.

Applicable sections of industry codes such as ACI 318-05, “Building Code Requirements for Structural Concrete”; 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” may be used in the design, structural evaluation, and construction of the concrete pad. However, load combinations in ACI 318-05 are not applicable to the ISFSI pad structural evaluation, and are replaced by the load combinations stated in subparagraph 2.0.4.2.b.

Table 2.0.1 – HI-STORM FW Assembly (Drawing # 6494)		
Item Number*	Part Name	ITS QA Safety Category
1	Assembly, Lid, HI-STORM Ø 113 B.C.	B
2	Lid-Stud	B
3	Heavy Hex Nut, 3 ¼" – 4 UNC	B
5	Plate, HI-STORM FW Heat Shield	B
6	Shielding, HI-STORM FW Body	B
8	Block, HI-STORM FW Cask Anchor	B
11	Plate, HI-STORM FW Body Base	B
15	Shell, HI-STORM FW Outer Shell	B
16	Shell, HI-STORM FW Inner Shell	B
17	Rib, HI-STORM FW Lifting Rib	B
18	Plate, HI-STORM FW Cask Body Top	B
20	Plate, Gamma Shield	C
21	Tube, MPC Guide	C
22	Tube, MPC Guide	C
23	Tube, MPC Guide	C
24	Closure Bolt	B

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

Table 2.0.2 – MPC-37 Enclosure Vessel (Drawing # 6505)		
Item Number*	Part Name	ITS QA Safety Category
1	Shell, Enclosure Vessel	A
2	Plate, Enclosure Vessel Base	A
3	Plate, Enclosure Vessel Lift Lug	C
4	Plate, Enclosure Vessel Upper Lid	A
5	Plate, Enclosure Vessel Lower Lid	B
6	Ring, Enclosure Vessel Closure	A
7	Block, Enclosure Vessel Vent/Drain Upper	B
8	Port, Enclosure Vessel Vent/Drain	C
9	Plug, Enclosure Vessel Vent /Drain	C
10	Block, Enclosure Vessel Lower Drain	C
12	Block, Enclosure Vessel Vent Shielding	C
13	Plate, Enclosure Vessel Vent/Drain Port Cover	A
16	Purge Tool Port Plug	C
21	Shim, Enclosure Vessel Type 1 PWR Fuel Basket	C
22	Shim, Enclosure Vessel Type 2 PWR Fuel Basket	C

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

Table 2.0.3 – Assembly, MPC-37 Fuel Basket (Drawing # 6506)		
Item Number	Part Name	ITS QA Safety Category
1	Panel, Type 1 Cell Wall	A
2	Panel, Type 2 Cell Wall	A
3	Panel, Type 3 Cell Wall	A
4	Panel, Type 4 Cell Wall	A
5	Panel, Type 5 Cell Wall	A
6	Panel, Type 6 Cell Wall	A

Table 2.0.4 – Assembly, MPC-89 Fuel Basket (Drawing # 6507)		
Item Number	Part Name	ITS QA Safety Category
1	Panel, Type 1 Cell Wall	A
2	Panel, Type 2 Cell Wall	A
3	Panel, Type 3 Cell Wall	A
4	Panel, Type 4 Cell Wall	A
5	Panel, Type 5 Cell Wall	A
6	Panel, Type 6 Cell Wall	A
7	Panel, Type 7 Cell Wall	A
8	Panel, Type 8 Cell Wall	A

Table 2.0.5 – Assembly, Lid, HI-STORM Ø113 B.C. (Drawing # 6508)		
Item Number*	Part Name	ITS QA Safety Category
1	Plate, HI-STORM Lid Base	B
2	Plate, HI-STORM Lid Type 1 Round	B
3	Plate, HI-STORM Lid Type 2 Round	B
4	Plate, HI-STORM Lid Type 1 Ring	B
5	Plate, HI-STORM Lid Type 2 Ring	B
6	Plate, HI-STORM Lid Type 3 Ring	B
7	Plate, HI-STORM Lid Type 4 Ring	B
8	Plate, HI-STORM Lid Type 5 Ring	B
9	Plate, HI-STORM Lid Type 6 Ring	B
10	Plate, HI-STORM Lid Upper Shim	B
11	Plate, HI-STORM Lid Lower Shim	B
13	Gusset, HI-STORM Lid	B
16	Shielding, HI-STORM Lid Lower	B
17	Shielding, HI-STORM Lid Upper	B
18	Plate, Heat Shield	B
20	Block, HI-STORM Lid Lifting Anchor	B

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

Table 2.0.6 – MPC-89 Enclosure Vessel (Drawing # 6512)		
Item Number*	Part Name	ITS QA Safety Category
1	Shell, Enclosure Vessel	A
2	Plate, Enclosure Vessel Base	A
3	Plate, Enclosure Vessel Lift Lug	C
4	Plate, Enclosure Vessel Upper Lid	A
5	Plate, Enclosure Vessel Lower Lid	B
6	Ring, Enclosure Vessel Closure	A
7	Block, Enclosure Vessel Vent/Drain Upper	B
8	Port, Enclosure Vessel Vent/Drain	C
9	Plug, Enclosure Vessel Vent/Drain	C
10	Block, Enclosure Vessel Lower Drain	C
12	Block, Enclosure Vessel Vent Shielding	C
13	Plate, Enclosure Vessel Vent/Drain Port Cover	A
16	Purge Tool Port Plug	C
21	Shim, Enclosure Vessel Type 1 BWR Fuel Basket	C
22	Shim, Enclosure Vessel Type 2 BWR Fuel Basket	C
23	Shim, Enclosure Vessel Type 3 BWR Fuel Basket	C

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

Table 2.0.7 – HI-TRAC VW – MPC-37 (Drawing # 6514)		
Item Number*	Part Name	ITS QA Safety Category
1	Flange, Bottom	B
3	Hex Bolt, 2-4 ½ UNC X 6” LG.	B
4	Shell, Inner	B
5	Shielding, Gamma	B
6	Flange, Top	A
7	Shell, Water Jacket	B
10	Pipe, Bolt Recess	B
11	Cap, Bolt Recess	B
12	Bottom Lid	B
13	Shell, Outer	B
14	Rib, Extended	B
15	Rib, Short	B

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

Table 2.0.8 – HI-TRAC VW – MPC-89 (Drawing # 6799)		
Item Number*	Part Name	ITS QA Safety Category
1	Flange, Bottom	B
3	Hex Bolt, 2-4 ½ UNC X 6” LG.	B
4	Shell, Inner	B
5	Shielding, Gamma	B
6	Flange, Top	A
7	Shell, Water Jacket	B
10	Pipe, Bolt Recess	B
11	Cap, Bolt Recess	B
12	Bottom Lid	B
13	Shell, Outer	B
14	Rib, Extended	B
15	Rib, Short	B

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

2.1 SPENT FUEL TO BE STORED

2.1.1 Determination of the Design Basis Fuel

A central object in the design of the HI-STORM FW System is to ensure that all SNF discharged from the U.S. reactors and not yet loaded into dry storage systems can be stored in a HI-STORM FW MPC. Publications such as references [2.1.1] and [2.1.2] provide a comprehensive description of fuel discharged from U.S. reactors.

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

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

2.1.2 Undamaged SNF Specifications

Undamaged fuel is defined in the Glossary.

2.1.3 Damaged SNF and Fuel Debris Specifications

Damaged fuel and fuel debris are defined in the Glossary.

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

2.1.4 Structural Parameters for Design Basis SNF

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

2.1.5 Thermal Parameters for Design Basis SNF

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

To ensure the permissible PCT limits are not exceeded, Subsection 1.2 specifies the maximum allowable decay heat per assembly for each MPC model in the three-region configuration (see also Table 1.2.3 and 1.2.4).

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

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

2.1.6 Radiological Parameters for Design Basis SNF

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

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

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

2.1.7 Criticality Parameters for Design Basis SNF

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

2.1.8 Summary of Authorized Contents

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

Table 2.1.1 MATERIAL TO BE STORED		
PARAMETER	**VALUE (Note 1)**	
	MPC-37	MPC-89
Fuel Type	Uranium oxide undamaged fuel assemblies, damaged fuel assemblies, and fuel debris meeting the limits in Table 2.1.2 for the applicable array/class.	Uranium oxide undamaged fuel assemblies, damaged fuel assemblies, with or without channels, fuel debris meeting the limits in Table 2.1.3 for the applicable array/class.
Cladding Type	ZR (see Glossary for definition)	ZR (see Glossary for definition)
Maximum Initial Rod Enrichment	Depending on soluble boron levels and assembly array/class as specified in Table 2.1.6	≤ 5.0 wt. % U-235
Post-irradiation cooling time and average burnup per assembly	Minimum Cooling Time: 3 years Maximum Assembly Average Burnup: 68.2 GWd/mtU	Minimum Cooling Time: 3 years Maximum Assembly Average Burnup: 65 GWd/mtU
Non-fuel hardware post-irradiation cooling time and burnup	Minimum Cooling Time: 3 years Maximum Burnup†: - BPRAs, WABAs and vibration suppressors: 60 GWd/mtU - TPDs, NSAs, APSRs, RCCAs, CRAs, CEAs, water displacement guide tube plugs and orifice rod assemblies: 630 GWd/mtU - ITTRs: not applicable	N/A
Decay heat per fuel storage location	Regionalized Loading: See Table 1.2.3	Regionalized Loading: See Table 1.2.4

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

Table 2.1.1 MATERIAL TO BE STORED		
PARAMETER	**VALUE (Note 1)**	
	MPC-37	MPC-89
Fuel Assembly Nominal Length (in.)	Minimum: 157 (with NFH) Reference: 167.2 (with NFH) Maximum: 199.2 (with NFH and DFC)	Minimum: 171 Reference: 176.5 Maximum: 181.5 (with DFC)
Fuel Assembly Width (in.)	≤ 8.54 (nominal design)	≤ 5.95 (nominal design)
Fuel Assembly Weight (lb)	Reference: 1600 (without NFH) 1750 (with NFH), 1850 (with NFH and DFC) Maximum: 2050 (including NFH and DFC)	Reference: 750 (without DFC), 850 (with DFC) Maximum: 850 (including DFC)
Other Limitations	▪ Quantity is limited to 37 undamaged ZR clad PWR fuel assemblies with or without non-fuel hardware. Up to 12 damaged fuel containers containing PWR damaged fuel and/or fuel debris may be stored in the locations denoted in Figure 2.1.1 with the remaining basket cells containing undamaged ZR fuel assemblies, up to a total of 37. ▪ One NSA. ▪ Up to 30 BPRAs. ▪ BPRAs, TPDs, WABAs, water displacement guide tube plugs, orifice rod assemblies, and/or vibration suppressor inserts may be stored with fuel assemblies in any fuel cell location. ▪ CRAs, RCCAs, CEAs, NSAs, and/or APSRs may be stored with fuel assemblies in fuel cell locations specified in Figure 2.1.5.	▪ Quantity is limited to 89 undamaged ZR clad BWR fuel assemblies. Up to 16 damaged fuel containers containing BWR damaged fuel and/or fuel debris may be stored in locations denoted in Figure 2.1.2 with the remaining basket cells containing undamaged ZR fuel assemblies, up to a total of 89.

Table 2.1.2

PWR FUEL ASSEMBLY CHARACTERISTICS (Note 1)

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

Table 2.1.2 (continued)

PWR FUEL ASSEMBLY CHARACTERISTICS (Note 1)

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

Table 2.1.2 (continued) PWR FUEL ASSEMBLY CHARACTERISTICS (Note 1)						
Fuel Assembly Array and Class	**16x16 A**	**17x17A**	**17x17 B**	**17x17 C**	**17x17 D**	**17x17 E**
No. of Fuel Rod Locations	236	264	264	264	264	265
Fuel Clad O.D. (in.)	≥ 0.382	≥ 0.360	≥ 0.372	≥ 0.377	≥ 0.372	≥ 0.372
Fuel Clad I.D. (in.)	≤ 0.3350	≤ 0.3150	≤ 0.3310	≤ 0.3330	≤ 0.3310	≤ 0.3310
Fuel Pellet Dia. (in.) (Note 3)	≤ 0.3255	≤ 0.3088	≤ 0.3232	≤ 0.3252	≤ 0.3232	≤ 0.3232
Fuel Rod Pitch (in.)	≤ 0.506	≤ 0.496	≤ 0.496	≤ 0.502	≤ 0.496	≤ 0.496
Active Fuel length (in.)	≤ 150	≤ 150	≤ 150	≤ 150	≤ 170	≤ 170
No. of Guide and/or Instrument Tubes	5 (Note 2)	25	25	25	25	24
Guide/Instrument Tube Thickness (in.)	≥ 0.0350	≥ 0.016	≥ 0.014	≥ 0.020	≥ 0.014	≥ 0.014

Notes:

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

Table 2.1.3

BWR FUEL ASSEMBLY CHARACTERISTICS (Note 1)

Fuel Assembly Array and Class	**7x7 B**	**8x8 B**	**8x8 C**	**8x8 D**	**8x8 E**
Maximum Planar-Average Initial Enrichment (wt.% ^{235}U) (Note 14)	≤ 4.8	≤ 4.8	≤ 4.8	≤ 4.8	≤ 4.8
No. of Fuel Rod Locations	49	63 or 64	62	60 or 61	59
Fuel Clad O.D. (in.)	≥ 0.5630	≥ 0.4840	≥ 0.4830	≥ 0.4830	≥ 0.4930
Fuel Clad I.D. (in.)	≤ 0.4990	≤ 0.4295	≤ 0.4250	≤ 0.4230	≤ 0.4250
Fuel Pellet Dia. (in.)	≤ 0.4910	≤ 0.4195	≤ 0.4160	≤ 0.4140	≤ 0.4160
Fuel Rod Pitch (in.)	≤ 0.738	≤ 0.642	≤ 0.641	≤ 0.640	≤ 0.640
Design Active Fuel Length (in.)	≤ 150	≤ 150	≤ 150	≤ 150	≤ 150
No. of Water Rods (Note 10)	0	1 or 0	2	1 - 4 (Note 6)	5
Water Rod Thickness (in.)	N/A	≥ 0.034	> 0.00	> 0.00	≥ 0.034
Channel Thickness (in.)	≤ 0.120	≤ 0.120	≤ 0.120	≤ 0.120	≤ 0.100

Table 2.1.3 (continued) BWR FUEL ASSEMBLY CHARACTERISTICS (Note 1)					
Fuel Assembly Array and Class	**8x8F**	**9x9 A**	**9x9 B**	**9x9 C**	**9x9 D**
Maximum Planar-Average Initial Enrichment (wt.% ^{235}U) (Note 14)	≤ 4.5 (Note 12)	≤ 4.8	≤ 4.8	≤ 4.8	≤ 4.8
No. of Fuel Rod Locations	64	74/66 (Note 4)	72	80	79
Fuel Clad O.D. (in.)	≥ 0.4576	≥ 0.4400	≥ 0.4330	≥ 0.4230	≥ 0.4240
Fuel Clad I.D. (in.)	≤ 0.3996	≤ 0.3840	≤ 0.3810	≤ 0.3640	≤ 0.3640
Fuel Pellet Dia. (in.)	≤ 0.3913	≤ 0.3760	≤ 0.3740	≤ 0.3565	≤ 0.3565
Fuel Rod Pitch (in.)	≤ 0.609	≤ 0.566	≤ 0.572	≤ 0.572	≤ 0.572
Design Active Fuel Length (in.)	≤ 150	≤ 150	≤ 150	≤ 150	≤ 150
No. of Water Rods (Note 10)	N/A (Note 2)	2	1 (Note 5)	1	2
Water Rod Thickness (in.)	≥ 0.0315	> 0.00	> 0.00	≥ 0.020	≥ 0.0300
Channel Thickness (in.)	≤ 0.055	≤ 0.120	≤ 0.120	≤ 0.100	≤ 0.100

Table 2.1.3 (continued)

BWR FUEL ASSEMBLY CHARACTERISTICS (Note 1)

Fuel Assembly Array and Class	**9x9 E (Note 3)**	**9x9 F (Note 3)**	**9x9 G**	**10x10 A**	**10x10 B**
Maximum Planar-Average Initial Enrichment (wt.% ^{235}U) (Note 14)	≤ 4.5 (Note 12)	≤ 4.5 (Note 12)	≤ 4.8	≤ 4.8	≤ 4.8
No. of Fuel Rod Locations	76	76	72	92/78 (Note 7)	91/83 (Note 8)
Fuel Clad O.D. (in.)	≥ 0.4170	≥ 0.4430	≥ 0.4240	≥ 0.4040	≥ 0.3957
Fuel Clad I.D. (in.)	≤ 0.3640	≤ 0.3860	≤ 0.3640	≤ 0.3520	≤ 0.3480
Fuel Pellet Dia. (in.)	≤ 0.3530	≤ 0.3745	≤ 0.3565	≤ 0.3455	≤ 0.3420
Fuel Rod Pitch (in.)	≤ 0.572	≤ 0.572	≤ 0.572	≤ 0.510	≤ 0.510
Design Active Fuel Length (in.)	≤ 150	≤ 150	≤ 150	≤ 150	≤ 150
No. of Water Rods (Note 10)	5	5	1 (Note 5)	2	1 (Note 5)
Water Rod Thickness (in.)	≥ 0.0120	≥ 0.0120	≥ 0.0320	≥ 0.030	> 0.00
Channel Thickness (in.)	≤ 0.120	≤ 0.120	≤ 0.120	≤ 0.120	≤ 0.120

Table 2.1.3 (continued) BWR FUEL ASSEMBLY CHARACTERISTICS (Note 1)			
Fuel Assembly Array and Class	**10x10 C**	**10x10 F**	**10x10 G**
Maximum Planar-Average Initial Enrichment (wt.% ^{235}U) (Note 14)	≤ 4.8	≤ 4.7 (Note 13)	≤ 4.6 (Note 12)
No. of Fuel Rod Locations	96	92/78 (Note 7)	96/84
Fuel Clad O.D. (in.)	≥ 0.3780	≥ 0.4035	≥ 0.387
Fuel Clad I.D. (in.)	≤ 0.3294	≤ 0.3570	≤ 0.340
Fuel Pellet Dia. (in.)	≤ 0.3224	≤ 0.3500	≤ 0.334
Fuel Rod Pitch (in.)	≤ 0.488	≤ 0.510	≤ 0.512
Design Active Fuel Length (in.)	≤ 150	≤ 150	≤ 150
No. of Water Rods (Note 10)	5 (Note 9)	2	5 (Note 9)
Water Rod Thickness (in.)	≥ 0.031	≥ 0.030	≥ 0.031
Channel Thickness (in.)	≤ 0.055	≤ 0.120	≤ 0.060

Table 2.1.3 (continued)

BWR FUEL ASSEMBLY CHARACTERISTICS

NOTES:

1. All dimensions are design nominal values. Maximum and minimum dimensions are specified to bound variations in design nominal values among fuel assemblies within a given array/class.

2. This assembly is known as “QUAD+.” It has four rectangular water cross segments dividing the assembly into four quadrants.

3. For the SPC 9x9-5 fuel assembly, each fuel rod must meet either the 9x9E or the 9x9F set of limits or clad O.D., clad I.D., and pellet diameter

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

5. Square, replacing nine fuel rods.

6. Variable.

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

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

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

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

11. Not Used

12. When loading fuel assemblies classified as damaged fuel assemblies, all assemblies in the MPC are limited to 4.0 wt.% U-235.

13. When loading fuel assemblies classified as damaged fuel assemblies, all assemblies in the MPC are limited to 4.6 wt.% U-235.

14. In accordance with the definition of undamaged fuel assembly, certain assemblies may be limited to 3.3 wt.% U-235. When loading these fuel assemblies, all assemblies in the MPC are limited to 3.3 wt.% U-235.

Table 2.1.4

DESIGN BASIS FUEL ASSEMBLY FOR EACH DESIGN CRITERION

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

Table 2.1.5 NORMALIZED DISTRIBUTION BASED ON BURNUP PROFILE		
PWR DISTRIBUTION[1]		
Interval	**Axial Distance From Bottom of Active Fuel (% of Active Fuel Length)**	**Normalized Distribution**
1	0% to 4-1/6%	0.5485
2	4-1/6% to 8-1/3%	0.8477
3	8-1/3% to 16-2/3%	1.0770
4	16-2/3% to 33-1/3%	1.1050
5	33-1/3% to 50%	1.0980
6	50% to 66-2/3%	1.0790
7	66-2/3% to 83-1/3%	1.0501
8	83-1/3% to 91-2/3%	0.9604
9	91-2/3% to 95-5/6%	0.7338
10	95-5/6% to 100%	0.4670
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 2.1.6

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

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

Note:

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

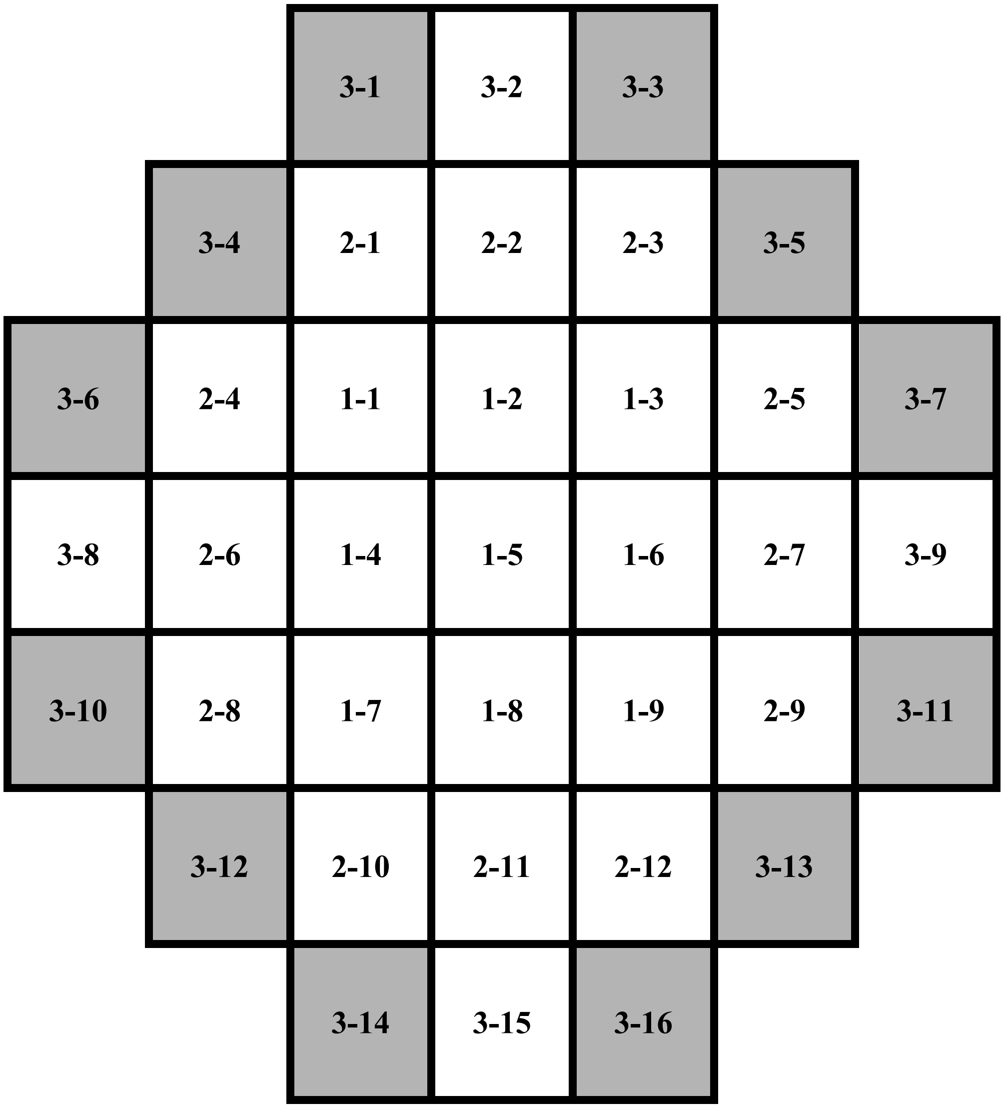

Figure 2.1.1 Location of DFCs for Damaged Fuel or Fuel Debris
in the MPC-37(Shaded Cells)

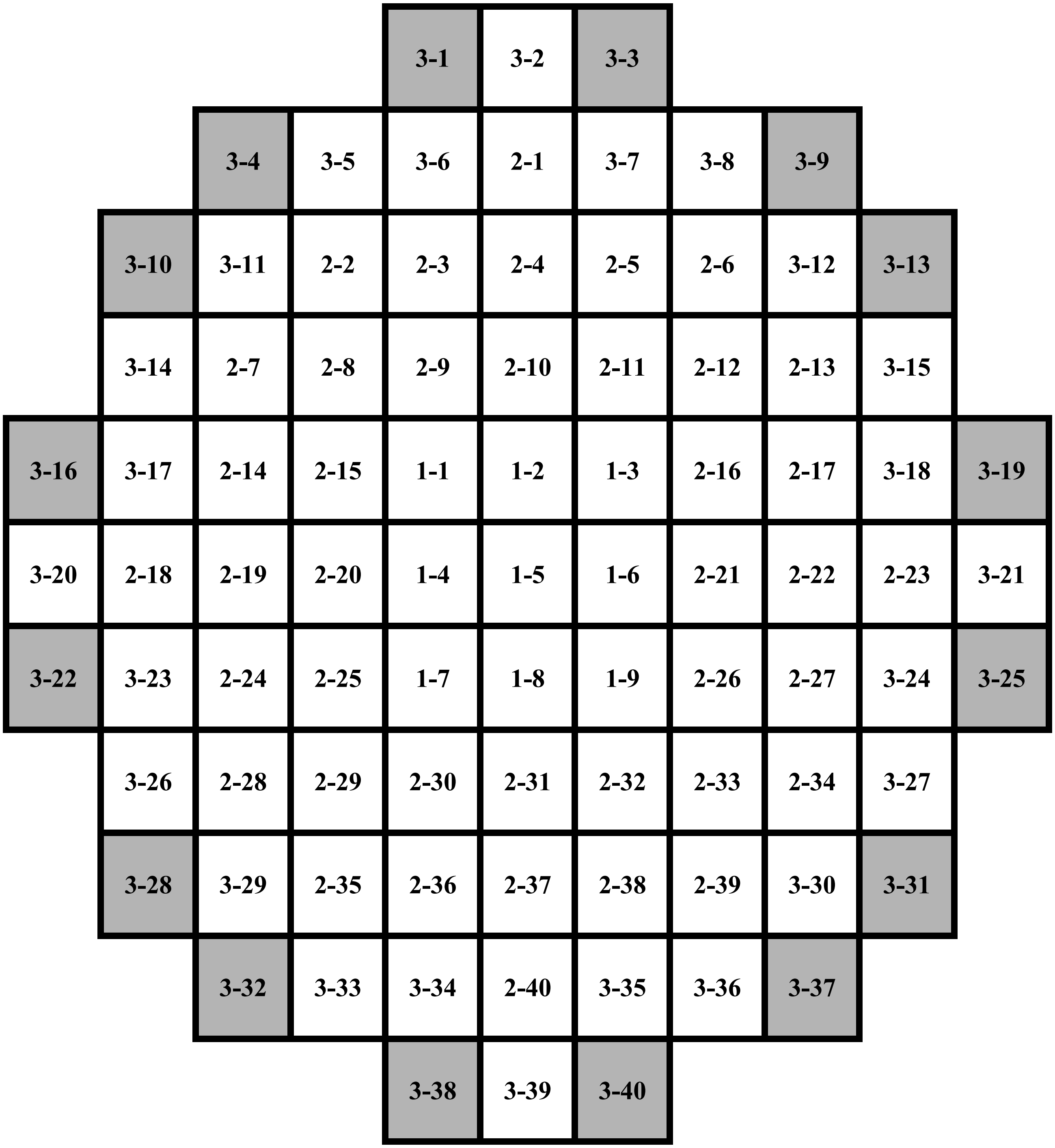

Figure 2.1.2 Location of DFCs for Damaged Fuel or Fuel Debris
in the MPC-89 (Shaded Cells)

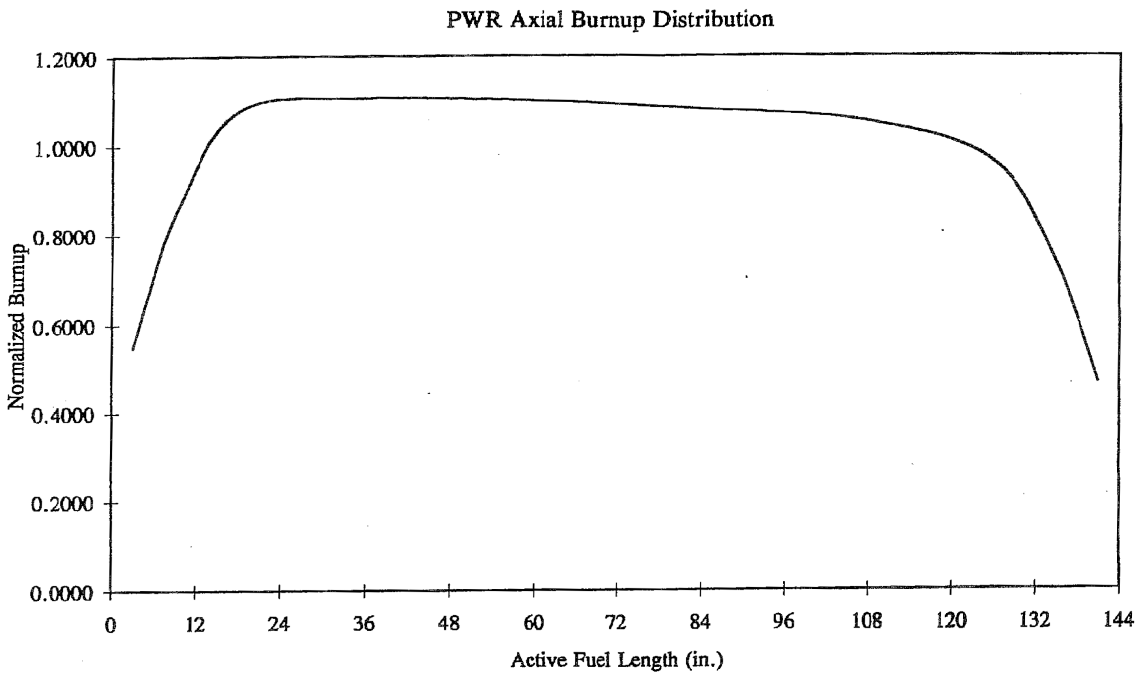

Figure 2.1.3 PWR Axial Burnup Profile with Normalized Distribution

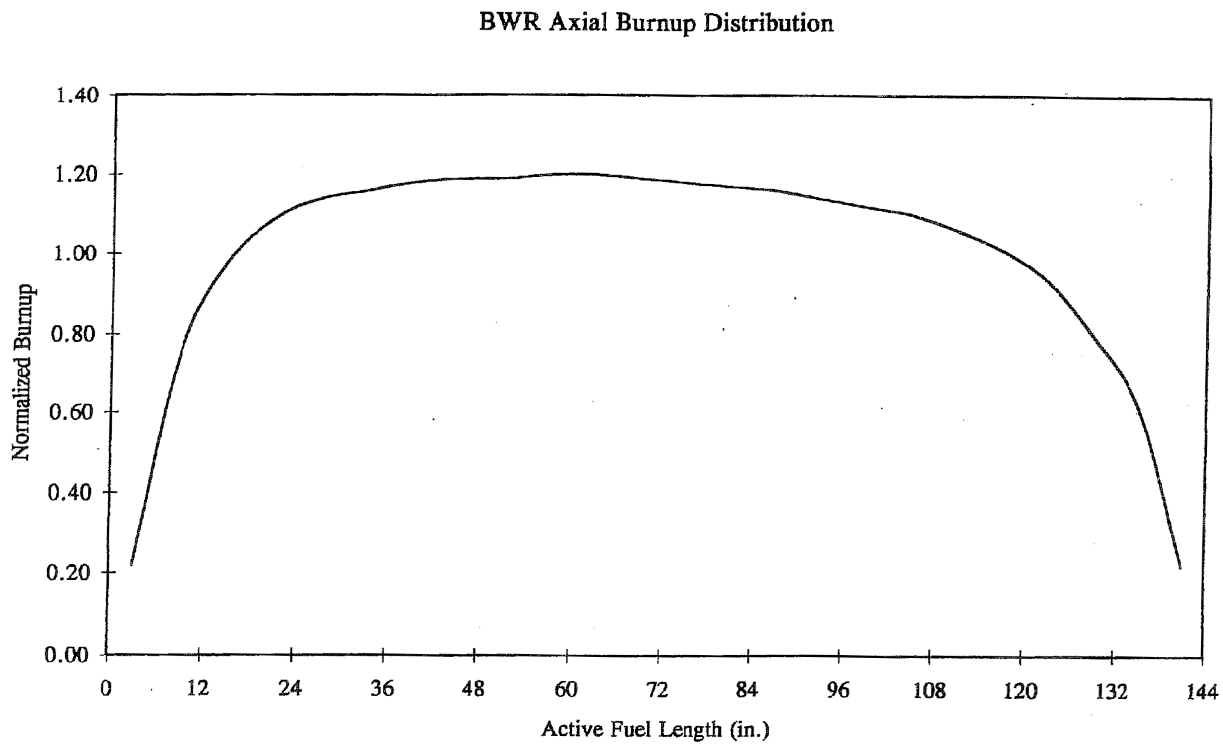

Figure 2.1.4 BWR Axial Burnup Profile with Normalized Distribution

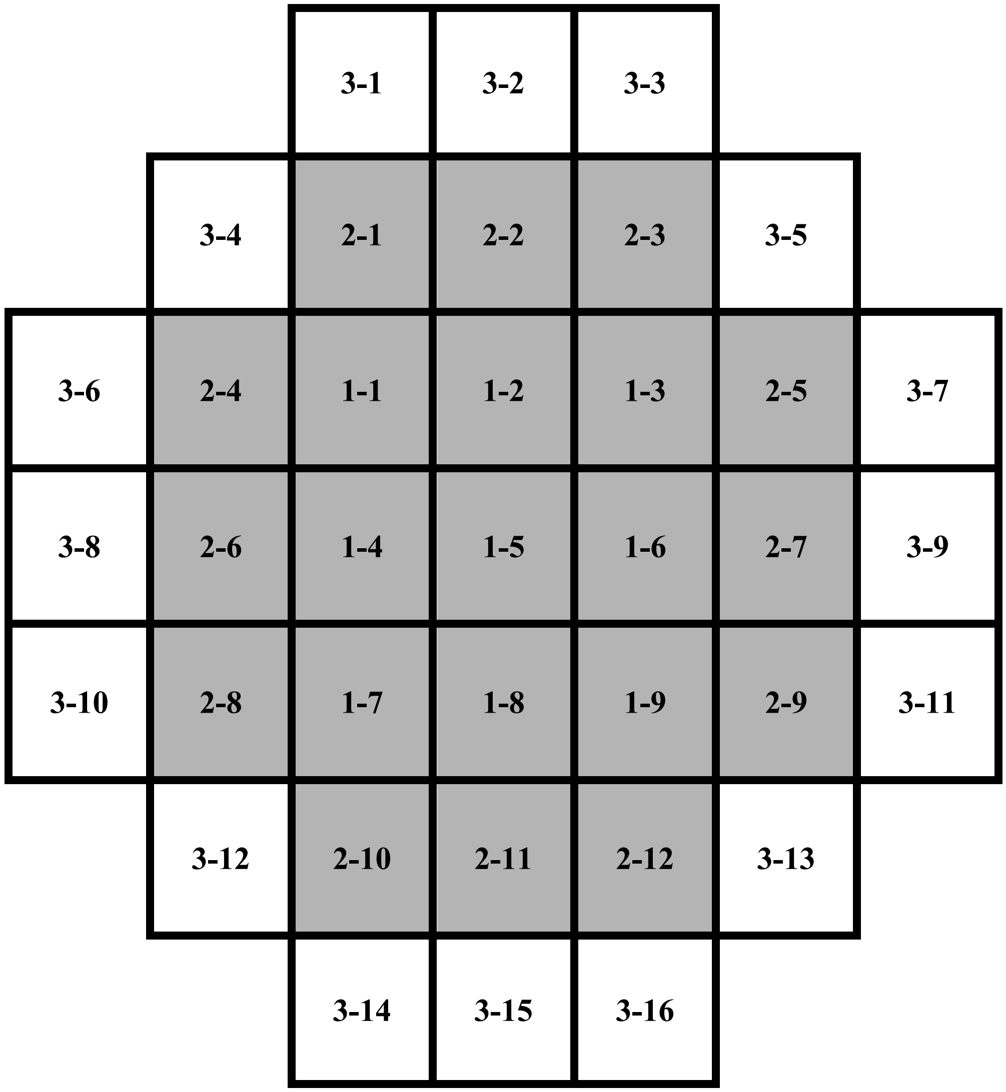

Figure 2.1.5: Location of NSAs, APSRs, RCCAs, CEAs, and CRAs in the MPC-37 (Shaded Cells)

Withheld in Accordance with 10 CFR 2.390

Figure 2.1.6: Damaged Fuel Container (Typical)

2.2 HI-STORM FW DESIGN LOADINGS

The HI-STORM FW System is engineered for unprotected outside storage for the duration of its design life. Accordingly, the cask system is designed to withstand normal, off-normal, and environmental phenomena and accident conditions of storage. Normal conditions include the conditions that are expected to occur regularly or frequently in the course of normal operation. Off-normal conditions include those infrequent events that could reasonably be expected to occur during the lifetime of the cask system. Environmental phenomena and accident conditions include events that are postulated because their consideration establishes a conservative design basis.

Normal condition loads act in combination with all other loads (off-normal or environmental phenomena/accident). Off-normal condition loads and environmental phenomena and accident condition loads are not applied in combination. However, loads that occur as a result of the same phenomena are applied simultaneously. For example, the tornado winds loads are applied in combination with the tornado missile loads.

In the following subsections, the design criteria are established for normal, off-normal, and accident conditions for storage. The following conditions of storage and associated loads are identified:

i. Normal (Long-Term Storage) Condition: Dead Weight, Handling, Pressure, Temperature, Snow.

ii. Off-Normal Condition: Pressure, Temperature, Leakage of One Seal, Partial Blockage of Air Inlets.

iii. Accident Condition: Handling Accident, Non-Mechanistic Tip-Over, Fire, Partial Blockage of MPC Basket Flow Holes, Tornado, Flood, Earthquake, Fuel Rod Rupture, Confinement Boundary Leakage, Explosion, Lightning, Burial Under Debris, 100% Blockage of Air Inlets, Extreme Environmental Temperature.

iv. Short-Term Operations: This loading condition is defined to accord with ISG-11, Revision 3 [2.0.1] guidance. This includes those normal operational evolutions necessary to support fuel loading or unloading activities. These include, but are not limited to MPC cavity drying, helium backfill, MPC transfer, and on-site handling of a loaded HI-TRAC VW transfer cask.

Each of these conditions and the applicable loads are identified herein with their applicable design criteria. A design criterion is deemed to be satisfied if the allowable limits for the specific loading conditions are not exceeded.

2.2.1 Loadings Applicable to Normal Conditions of Storage

a. Dead Weight

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

b. Handling Evolutions

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

i. Vertical lifting and transfer to the ISFSI of the HI-STORM FW overpack containing a loaded MPC.
ii. Vertical lifting and handling of the HI-TRAC VW transfer cask containing a loaded MPC.
iii. Lifting of a loaded MPC.

The dead load of the lifted component is increased by 15% in the stress qualification analyses (to meet ANSI N14.6 guidance) to account for dynamic effects from lifting operations as suggested in CMAA #70 [2.2.1].

Handling operations of the loaded HI-TRAC VW transfer cask or HI-STORM FW overpack are limited to working area ambient temperatures specified in Table 2.2.2. This limitation is specified to ensure a sufficient safety margin against brittle fracture during handling operations.

Table 2.2.6 summarizes the analyses required to qualify all threaded anchor locations in the HI-STORM FW System.

c. Pressure

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

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

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

The MPC internal pressure under the normal condition of storage must remain below the design pressure specified in Table 2.2.1.

The MPC external pressure is a function of environmental conditions, which may produce a pressure loading. The normal condition external design pressure is specified in Table 2.2.1.

The HI-STORM FW 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 VW transfer cask is not capable of retaining internal pressure due to its open design. Therefore, no analysis is required for the internal pressure loading in HI-TRAC VW transfer cask. However, the HI-TRAC VW transfer cask water jacket may experience an internal vapor pressure due to the heat-up of the water contained in the water jacket. Analysis is performed in Chapter 3 of this report to demonstrate that the water jacket can withstand the design pressure in Table 2.2.1 without a structural failure and that the water jacket design pressure will not be exceeded. To provide an additional layer of safety, a pressure relief device is used to ensure that the water jacket design pressure will not be exceeded.

d. Environmental Temperatures and Pressures

To evaluate the long-term effects of ambient temperatures on the HI-STORM FW System, an upper bound value on the annual average ambient temperature for the continental United States is used. The annual average temperature is termed the normal ambient temperature for storage. The normal ambient temperature specified in Table 2.2.2 is bounding for all reactor sites in the contiguous United States. The normal ambient temperature set forth in Table 2.2.2 is intended to ensure that it is greater than the annual average of ambient temperature at any location in the continental United States. In the northern region of the U.S., the design basis normal ambient temperature 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^{o} 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^{o}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. Insolation based on 10CFR71.71 input averaged over 24 hours shall be used as the additional heat input under the normal and off-normal conditions of storage.

The ambient pressure shall be assumed to be 760mm of Hg coincident with the normal condition temperature, whose bounding value is provided in Table 2.2.2. For sites located substantially above sea level (elevation > 1500 feet), it will be necessary to perform a site specific evaluation of the peak cladding temperature using the site specific ambient temperature (maximum average annual temperature based on 40 year meteorological data for the site). ISG 11, Revision 3 [2.0.1] temperature limits will continue to apply.

All of the above requirements are consistent with those in the HI-STORM 100 FSAR.

e. 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 FW System. The ASME Code (Section III, Paragraph NCA-2142) requires the design temperature to be set at or above the maximum through thickness mean metal temperature of the pressure part under normal service (Level A) condition. Consistent with the terminology of NUREG-1536, this temperature is referred to as the "Design Temperature for Normal Conditions". Conservative calculations of the steady-state temperature field in the HI-STORM FW System, under assumed environmental normal temperatures with the maximum decay heat load, result in HI-STORM FW component temperatures at or below the normal condition design temperatures for the HI-STORM FW System defined in Table 2.2.3.

Maintaining fuel rod cladding integrity is also a design consideration. The fuel rod peak cladding temperature (PCT) limits for the long-term storage and short-term operating conditions shall meet the intent of the guidance in ISG-11, Revision 3 [2.0.1]. For moderate burnup fuel the PCT limit for short-term operations is higher than for high burnup fuel [2.0.2].

f. Snow and Ice

The HI-STORM FW System must be capable of withstanding pressure loads due to snow and ice. Section 7.0 of ANSI/ASCE 7-05 [2.2.3] 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 FW System range from 50 to 70 pounds per square foot. For conservatism, the snow pressure load (Table 2.2.8) is set to bound the ANSI/ASCE 7-05 recommendation.

2.2.2 Loadings Applicable to Off-Normal Conditions

As the HI-STORM FW 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 this subsection.

A discussion of the effects of each off-normal condition and the corrective action for each off-normal condition is provided in Section 12.1. Table 2.2.7 contains a list of all normal and off-normal loadings and their applicable acceptance criteria.

a. <u>Pressure</u>

The HI-STORM FW System must withstand loads due to off-normal pressure. The off-normal condition for the MPC internal design pressure, defined herein in Table 2.2.1, 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 as suggested in NUREG-1536.

b. <u>Environmental Temperatures</u>

The HI-STORM FW 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 sufficient duration to allow the system to reach steady-state temperatures.

Limits on the peaks in the time-varying ambient temperature at an ISFSI site are recognized in the FSAR in the specification of the off-normal temperatures. The lower bound off-normal temperature is defined as the minimum of the 72-hour average of the ambient temperature at an ISFSI site. Likewise, the upper bound off-normal temperature is defined by the maximum of 72-hour average of the ambient temperature. The lower and upper bound off-normal temperatures listed in Table 2.2.2 are intended to cover all ISFSI sites in the continental U.S. The 72-hour average of temperature used in the definition of the off-normal temperature recognizes the considerable thermal inertia of the HI-STORM FW storage system which essentially flattens the effect of daily temperature variations on the internals of the MPC.

c. <u>Design Temperatures</u>

In addition to the normal condition design temperatures, which apply to long-term storage and short-term normal operating conditions (e.g., MPC drying operations and onsite transport operations), an off-normal/accident condition temperature pursuant to the provisions of NUREG-1536 and Regulatory Guide 3.61 is also defined. This is the temperature which may exist during a transient event (examples of such an instance is the blockage of the overpack inlet vents or the fire accident). The off-normal/accident condition temperatures of Table 2.2.3 are given 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 the transient event. These enveloping values, therefore, will bound the maximum temperature reached anywhere in the part, excluding skin effects, during or immediately after, a transient event.

The off-normal/accident condition temperatures for stainless steel and carbon steel components are chosen such that the material's ultimate tensile strength does not fall below 30% of its room temperature value, based on data in published references [2.2.4 and 2.2.5]. This ensures that the material will not be subject to significant creep rates during these short duration transient events.

d. Leakage of One Seal

The MPC enclosure vessel does not contain gaskets or seals: All confinement boundary closure locations are welded. Because the material of construction (Alloy X, see Appendix 1.A) is known from extensive industrial experience to lend to high integrity, high ductility and high fracture strength welds, the MPC enclosure vessel welds provide a secure barrier against leakage.

The confinement boundary is defined by the MPC shell, MPC baseplate, MPC lid, port cover plates, closure ring, and associated welds. Most confinement boundary welds are inspected by radiography or ultrasonic examination. Field welds are examined by the liquid penetrant method on the root (if more than one weld pass is required) and final weld passes. In addition to multi-pass liquid penetrant examination, the MPC lid-to-shell weld is pressure tested. The vent and drain port cover plates are also subject to proven non-destructive evaluations for leak detection such as liquid penetrant examination. These inspection and testing techniques are performed to verify the integrity of the confinement boundary. Therefore, leakage of one seal is not evaluated for its consequence to the storage system.

e. Partial Blockage of Air Inlets

The loaded HI-STORM FW overpack must withstand the partial blockage of the air inlets. Because the overpack air inlets and outlets are covered by screens and inspected routinely (or alternatively, equipped with temperature monitoring devices), significant blockage of all vents by blowing debris, critters, etc., is very unlikely. Nevertheless, the inherent thermal stability of the HI-STORM FW System shall be demonstrated by assuming all air inlets are partially blocked as an off-normal event.

f. Malfunction of FHD

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

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

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

2.2.3 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 continues to confine the radioactive material, the MPC fuel basket structure maintains the configuration of the contents, the canister can be recovered from the overpack, and the system continues to provide adequate shielding.

A discussion of the effects of each environmental phenomenon and accident condition is provided in Section 12.2. The consequences of each accident or environmental phenomenon are evaluated against the requirements of 10CFR72.106 and 10CFR20. Section 12.2 also provides the corrective action for each event.

a. Handling Accident

A handling accident in the Part 72 jurisdiction is precluded by the requirements and provisions specified in this FSAR. The loaded HI-STORM FW components will be lifted in the Part 72 operations jurisdiction in accordance with written and Q.A. validated procedures and shall use special lifting devices which comply with ANSI N14.6-1993 [2.2.2]. Also, the lifting and handling equipment (typically the cask transporter) is required to have a built-in redundancy against uncontrolled lowering of the load. Further, the HI-STORM FW is a vertically deployed system, and the handling evolutions in *short term operations*, as discussed in Chapter 9, do not involve downending of the loaded cask to the horizontal configuration (or upending from the horizontal state) at any time (with the rare handling exception of the transfer cask as described in Subsection 4.5.1). In particular, the loaded MPC shall be lowered into the HI-STORM FW overpack or raised from the overpack using the HI-TRAC VW transfer cask and a MPC lifting system designed in accordance with ANSI N14.6. Therefore, analysis of a handling accident event involving a HI-STORM system component is not required.

b. Non-Mechanistic Tip-Over

The freestanding loaded HI-STORM FW overpack is demonstrated by analysis to remain kinematically stable under all design basis environmental phenomena (tornado, earthquake, etc.) and postulated accident conditions. The cask tip-over is not an outcome of any environmental phenomenon or accident condition and the cask tip-over is considered a *non-mechanistic* event. Nevertheless, the HI-STORM FW overpack and MPC is analyzed for a hypothetical tip-over event, and the structural integrity of a loaded HI-STORM FW System after a tip-over onto a reinforced concrete pad is demonstrated by analysis to show compliance with 10 CFR 72.236(m) with regards to the future transportability of the MPC.

The following requirements and acceptance criteria apply to the HI-STORM FW overpack under the tipover event:

i. In order to maximize the target stiffness (based on experience with ISFSI pad designs), the ISFSI pad and underlying soil are conservatively modeled using the data in Table 2.2.9.
ii. The tipover is simulated as a gravity-directed rotation of the cask from rest with its CG above its edge on the pad as the system's initial condition. The tipover begins when the cask is given an infinitesimal outward displacement in the radial plane of its tilted configuration.
iii. The MPC will remain in the HI-STORM FW overpack after the tipover event and the overpack will not suffer any ovalization which would preclude the removal of the MPC.
iv. The maximum plastic deformation sustained by the fuel basket panels is limited to the value given in Table 2.2.11.
v. The HI-STORM FW overpack will not suffer a significant loss of shielding.
vi. The confinement boundary will not be breached.

c. Fire

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

The HI-STORM FW System must withstand elevated temperatures due to a fire event. The HI-STORM FW overpack and HI-TRAC VW 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 FW overpack and HI-TRAC VW 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 FW overpack and HI-TRAC VW transfer cask based on the amount of flammable materials assumed. The temperature of fire is assumed to be 1475^{o} F to accord with the provisions in 10CFR71.73.

The following acceptance criteria apply to the fire accident:

i. The peak cladding temperature during and after a fire accident shall not exceed the ISG-11 [2.0.1] permissible limit (see Table 2.2.3).
ii. The through-thickness average temperature of concrete at any section shall not exceed its short-term limit in Table 2.2.3.
iii. The steel structure of the overpack shall remain physically stable; i.e., no risk of structural instability such as gross buckling.

d. Partial Blockage of MPC Basket Flow Holes

The HI-STORM FW MPC is designed to prevent reduction of thermosiphon action due to partial blockage of the MPC basket flow holes by fuel cladding failure, fuel debris and crud. The HI-STORM FW 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 of fuel classified as undamaged during storage in the HI-STORM FW. Fuel classified as damaged fuel or fuel debris are placed in damaged fuel containers. The damaged fuel container is equipped with mesh screens which ensure that the damaged fuel and fuel debris will not escape to block the MPC basket flow holes. The MPC is loaded once for long-term storage and, therefore, buildup of crud in the MPC due to numerous loadings is precluded. Using crud quantities for fuel assemblies reported in an Empire State Electric Energy Research Corporation Report [2.2.6] determines a layer of crud of conservative depth that is assumed to partially block the MPC basket flow holes. The crud depth is listed in Table 2.2.8. The flow holes in the bottom of the fuel basket are designed (as can be seen on the licensing drawings) to ensure that this amount of crud does not block the internal helium circulation.

e. Tornado

The HI-STORM FW System must withstand pressures, wind loads, and missiles generated by a tornado. The prescribed design basis tornado and wind loads for the HI-STORM FW System are consistent with NRC Regulatory Guide 1.76 [2.2.7], ANSI 57.9 [2.2.8], and ASCE 7-05 [2.2.3]. Table 2.2.4 provides the wind speeds and pressure drops the HI-STORM FW overpack can 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 FW overpack, and continued integrity of the MPC confinement boundary, within the storage overpack or HI-TRAC VW transfer cask, must be demonstrated under impact from tornado-generated missiles in conjunction with the wind loadings. Standard Review Plan (SRP) 3.5.1.4 of NUREG-0800 [2.2.9] stipulates that the postulated missiles include at least three objects: a massive high kinetic energy missile that deforms on impact (large missile); a rigid missile to test penetration resistance (penetrant missile); and a small rigid missile of 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 penetrating 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.

f. Flood

The HI-STORM FW System must withstand pressure and water forces associated with deep and moving flood waters. Resultant loads on the HI-STORM FW 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 FW 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 is 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 moving. The maximum allowable flood water velocity (Table 2.2.8) is established so that the pressure loading from the water is less than the pressure loading which would cause the HI-STORM FW System to slide or tip over. Site-specific safety reviews by the licensee must confirm that flood parameters at the proposed ISFSI site do not exceed the flood depth or water velocity given in Table 2.2.8.

If the flood water depth exceeds the elevation of the top of the HI-STORM FW overpack inlet vents, then the cooling air flow would be blocked. The flood water may also carry debris which may act to block the air inlets of the overpack. Blockage of the air inlets is addressed in 2.2.3 (l).

The hydrological conditions at most reactor sites are 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 FW System for kinematic stability, if necessary. An evaluation for tsunamis[†] for certain coastal sites should also be performed to demonstrate that the maximum flood depth in Table 2.2.8 will not be exceeded. The factor of safety against sliding or overturning of the cask under the moving flood waters shall be equal to or greater than the value in Table 2.2.8.

The scenario where the flood water raises high enough to block the inlet ducts (and thus cut-off ventilation) and remains stagnant is the most adverse flood condition (thermally) for the storage system. As discussed in Chapter 1, the HI-STORM FW System inlet vent design makes it resistant to such adverse flood scenarios. The results of this analysis are presented in Chapter 4.

g. Earthquakes

The principal effect of an earthquake on the loaded HI-STORM FW overpack is the movement of the MPC inside the overpack cavity causing impact with the cavity inner wall, and, if the

† 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.

earthquake is sufficiently strong, the potential sliding and tilting of the storage system. The acceptance criteria for the storage system under the site's Design Basis Earthquake (DBE) are as follows:

i. The loaded overpacks will not impact each other during the DBE event.
ii. The loaded overpack will not slide off the ISFSI.
iii. The loaded overpack will not tip over.
iv. The confinement boundary will not be breached.

To minimize the need for a seismic analysis at each ISFSI site, the approach utilized in Docket No. 72-1014 is adopted for HI-STORM FW, which divides the DBE into two categories, labeled herein as (i) low intensity and (ii) high intensity. A low intensity earthquake is one whose ZPA is low enough to pass the "static equilibrium test". A high intensity earthquake is one that cannot pass the "static equilibrium test". The limiting value of the static friction coefficient, μ, has been set at 0.53 for freestanding HI-STORM overpack on a reinforced concrete pad in Docket No. 72-1014. The same limit is observed for HI-STORM FW overpack in this report. The criterion for static equilibrium is derived from elementary statics with the simplifying assumption that the cask and its contents are fixed and emulate a rigid body with six degrees-of-freedom. The earthquake is represented by its ZPA in horizontal (the vector sum of the two horizontal ZPAs for a 3-D earthquake site) and vertical directions. The limits on a_H and a_v for HI-STORM FW are readily derived as follows:

i. Prevention of sliding: Assuming the vertical ZPA to be acting to reduce the weight of the cask, horizontal force equilibrium yields:

$$W \cdot a_H \leq \mu \cdot W \cdot (1-a_v)$$

Or $$a_H \leq (1-a_v) \cdot \mu$$

ii. Prevention against "edging" of the cask:

Balancing the moment about the cask's pivot point for edging yields:

$$W \cdot a_H \cdot h \leq W \cdot (1-a_v) \cdot r$$

Or $$a_H \leq (1-a_v) \cdot \frac{r}{h}$$

Where:

r: radius of the footprint of the cask's base
h: height of the CG of the cask
μ: Static friction coefficient between the cask and the ISFSI pad.

The above two inequalities define the limits on a_H and a_v for a site if the earthquake is to be considered of "low intensity." For low intensity earthquake sites, additional analysis to demonstrate integrity of the confinement boundary is not required.

However, if the earthquake's ZPAs do not satisfy either of the above inequalities, then a dynamic analysis using the methodology specified in Chapter 3 shall be performed as a part of the §72.212 safety evaluation.

h. 100% Fuel Rod Rupture

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

i. Confinement Boundary Leakage

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

j. External Pressure on the MPC Due to Explosion

The loaded HI-STORM FW overpack 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 Subsection 3.4.1, or appropriate preventive measures are taken to preclude internal explosive events (see Subsection 1.2.1). The MPC is composed of non explosive materials and maintains an inert gas environment. Thus explosion during long term storage is not credible. Likewise, the mandatory use of the protective measures at nuclear plants to prevent fires and explosions and the absence of any need for an explosive material during loading and unloading operations eliminates the scenario of an explosion as a credible event. Furthermore, because the MPC is internally pressurized, any short-term external pressure from explosion or even submergence in flood waters will act to reduce the tensile state of stress in the enclosure vessel. Nevertheless, a design basis external pressure (Table 2.2.1) has been defined as a design basis loading event wherein the internal pressure is non-mechanistically assumed to be absent.

k. Lightning

The HI-STORM FW System must withstand loads due to lightning. The effect of lightning on the HI-STORM FW System is evaluated in Chapter 12.

l. Burial Under Debris and Duct Blockage

Debris may collect on the HI-STORM FW overpack vent screens as a result of floods, wind storms, or mud slides. Siting of the ISFSI pad shall ensure that the storage location is not located over shifting soil. However, if burial under debris is a credible event for an ISFSI, then a thermal analysis to analyze the effect of such an accident condition shall be performed for the site using the analysis methodology presented in Chapter 4. The duration of the burial-under-debris scenario will be based on the ISFSI owner's emergency preparedness program. The following acceptance criteria apply to the burial-under-debris accident event:

i. The fuel cladding temperature shall not exceed the ISG-11, Revision 3 [2.0.1] temperature limits.
ii. The internal pressure in the MPC cavity shall not exceed the accident condition design pressure limit in Table 2.2.1.

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

m. Extreme Environmental Temperature

The HI-STORM FW System must withstand extreme environmental temperatures. The extreme accident level temperature is specified in Table 2.2.2. The extreme accident level temperature is assumed to occur with steady-state insolation. This temperature is assumed to persist for a sufficient duration to allow the system to reach steady-state temperatures. The HI-STORM FW overpack and MPC have a large thermal inertia; therefore, extreme environmental temperature is a 3-day average for the ISFSI site.

All accident events and extreme environmental phenomena loadings that require analysis are listed in Table 2.2.13 along with the applicable acceptance criteria.

The loadings listed in Table 2.2.13 fall into two broad categories; namely, (i) those that primarily affect kinematic stability, and (ii) those that produce significant stresses and strains. The loadings in the former category are principally applicable to the overpack. Tornado wind (W), earthquake (E), and tornado-borne missile (M) are essentially loadings which can destabilize a cask. Analyses reported in Chapter 3 show that the HI-STORM FW overpack structure will remain kinematically stable under these loadings. Additionally, for the tornado-borne missile (M), analyses that demonstrate that the overpack structure remains unbreached by the postulated missiles are provided in Chapter 3.

Loadings in the second category produce global deformations that must be shown to comply with the applicable acceptance criteria. The relevant loading combinations for the fuel basket, the MPC, the HI-TRAC VW transfer cask and the HI-STORM FW 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.

2.2.4 Applicability of Governing Documents

Section III Subsection NB of the ASME Boiler and Pressure Vessel Code (ASME Code), [2.2.10], is the governing code for the structural design of the MPC. The alternatives to the ASME Code, Section III Subsection NB, applicable to the MPC in Docket Nos. 72-1008 and 72-1014 are also applicable to the MPC in the HI-STORM FW System, as documented in Table 2.2.14.

The stress limits of ASME Section III Subsection NF [2.0.3] are applied to the HI-STORM FW and HI-TRAC VW structural parts where the applicable loading is designated as a code service condition.

The fuel basket, made of Metamic-HT, is subject to the requirements in Chapter 1, Section 1.2.1.4 and is designed to a specific (lateral) deformation limit of its walls under accident conditions of loading (credible and non-mechanistic) (see Table 2.2.11). The basis for the lateral deflection limit in the active fuel region, θ, is provided in [2.2.11].

ACI 318 is the reference code for the plain concrete in the HI-STORM FW overpack. ACI 318.1-85(05) is the applicable code utilized to determine the allowable compressive strength of the plain concrete credited in strength analysis.

Each structure, system and component (SSC) of the HI-STORM FW System that is identified as important-to-safety is shown on the licensing drawings.

Tables 1.2.6 and 1.2.7 provide the information on the applicable Codes and Standards for material procurement, design, fabrication and inspection of the components of the HI-STORM FW System. In particular, the ASME Code is relied on to define allowable stresses for structural analyses of Code materials.

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:

i. Level A Service Limits are used to establish allowables for normal condition load combinations.

ii. Level B Service Limits are used to establish allowables for off-normal conditions.

iii. Level C Service Limits are not used.

iv. Level D Service Limits are used to establish allowables for certain accident conditions.

The ASME Code service limits are used in the structural analyses for definition of allowable stresses and allowable stress intensities, as applicable. 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. Table 2.2.12 lists allowable stress limits for the steel structure of the HI-STORM FW overpack and HI-TRAC VW transfer cask which are analyzed to meet the stress limits of Subsection NF, Class 3 for loadings defined as service levels A, B, and D 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. The loads are listed in Tables 2.2.7 and 2.2.13, along with the applicable acceptance criteria.

2.2.7 Design Basis Loads

Where appropriate, for each loading type, a bounding value is selected in this FSAR to impute an additional margin for the associated loading events. Such bounding loads are referred to as Design Basis Loads (DBL) in this FSAR. For example, the Design Basis External Pressure on the MPC, set down in Table 2.2.1, is a DBL, as it grossly exceeds any credible external pressure that may be postulated for an ISFSI site.

2.2.8 Allowable Limits

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 displacement limit for the MPC fuel basket is expressed as a dimensionless parameter θ defined as [2.2.11]

$$\theta = \frac{\delta}{w}$$

where δ is defined as the maximum total deflection sustained by the basket panels under the loading event and *w* is the nominal inside (width) dimension of the storage cell. The limiting value of θ is provided in Table 2.2.11. Finally, the steel structure of the overpack and the HI-

TRAC VW must meet the stress limits of Subsection NF of ASME Code, Section III for the applicable service conditions.

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/Short-Term	120
	Accident	200
MPC External Pressure	Normal	(0) Ambient
	Off-Normal/Short-Term	(0) Ambient
	Accident	55
HI-TRAC Water Jacket Internal Pressure	Accident	65
Overpack External Pressure	Normal	(0) Ambient
	Off-Normal/Short-Term	(0) Ambient
	Accident	See Paragraph 3.1.2.1.d

Table 2.2.2

ENVIRONMENTAL TEMPERATURES

HI-STORM FW Overpack		
Condition	Temperature (ºF)	Comments
Normal Ambient Temperature	80	Bounding annual average from the contiguous United States
Soil Temperature	77	Bounding annual average from the contiguous United States
Off-Normal Ambient Temperature	-40 (min) 100 (max)	Lower bound does not consider insolation. Upper bound is a 3-day daily average and analysis includes insolation.
Extreme Ambient Temperature	125	3-day daily average and analysis includes insolation
Short-Term Operations	0 (min)	Limit is specified in the technical specifications.
HI-TRAC VW Transfer Cask		
Condition	Temperature (ºF)	Comments
Short-Term Operations	0 (min.) 90 (max.)	The lower bound limit is specified in the technical specifications. The upper bound limit is a 3-day daily average with insolation and can be increased for a specific site if justified by the appropriate thermal analysis.

Table 2.2.3 DESIGN TEMPERATURES		
HI-STORM FW Component	**Normal Condition Design Temperature Limits (°F)**	**Off-Normal and Accident Condition Temperature Limits † (°F)**
MPC shell	600	800
MPC basket	752	932
MPC basket shims	752	932
MPC lid	600	800
MPC closure ring	500	800
MPC baseplate	400	800
HI-TRAC VW inner shell	500	700
HI-TRAC VW bottom lid	350	700
HI-TRAC VW top flange	400	650
HI-TRAC VW bottom lid seals	350	N/A
HI-TRAC VW bottom lid bolts	350	800
HI-TRAC VW bottom flange	350	700
HI-TRAC VW radial neutron shield	311	N/A
HI-TRAC VW radial lead gamma shield	350	600
Fuel Cladding	752 (Storage) 752 or 1058 (Short Term Operations)††	1058 (Off-Normal and Accident Conditions)
Overpack concrete	300	350
Overpack Lid Top and Bottom Plate	450	700
Remainder of overpack steel structure	350	700

† 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 fire event, the structure is required to remain physically stable (no specific temperature limits apply)

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

Table 2.2.4 CHARACTERISTICS OF REFERENCE TORNADO	
Condition	**Value**
Rotational wind speed (mph)	290
Translational speed (mph)	70
Maximum wind speed (mph)	360
Pressure drop (psi)	3.0

Table 2.2.5

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 LIFTING ANALYSIS CASES					
Loading Case	Item	Location of Threaded Anchor (Material)	Bounding Weight	Dynamic Amplification Factor	Permissible Stress (psi) (Note 1)
HA.	Loaded MPC	Top Lid (stainless steel)	Section 3.2	1.15	Lesser of 0.1 S_u or $S_y/3$
HB.	Loaded HI-TRAC Transfer Cask	Top Flange of the Cask (C.S. forging)	Section 3.2	1.15	Lesser of 0.1 S_u or $S_y/3$
HC.	Loaded HI-STORM 100 Module with Lid	Threaded cylinder embedded and welded to the radial connectors near the top of the cask (carbon steel forging)	Section 3.2	1.15	$S_y/3$
Note 1: The permissible stress applies to the material of the part in which the lift anchor location is tapped. Minimum threaded length of the top shall be used in the analysis. S_u = ultimate strength; S_y = yield strength					

Table 2.2.7

LOADS APPLICABLE TO THE NORMAL AND OFF-NORMAL CONDITIONS OF STORAGE

Loading Case	Loading	Affected Item and Part	Magnitude of Loading	Acceptance Criterion
NA.	Snow and Ice	Top lid of HI-STORM FW overpack	Table 2.2.8	The stress in the steel structure must meet NF Class 3 limits for linear structures
NB.	Internal Pressure[1]	MPC Enclosure Vessel	Table 2.2.1	Meet "NB" stress intensity limits
	a. Normal Condition	MPC Enclosure Vessel	Table 2.2.1	Level A condition limit on primary plus secondary stress intensities
	b. Off-Normal Condition	MPC Enclosure Vessel	Table 2.2.1	Level B limits on primary and secondary stress intensities.

1 Normal condition internal pressure is bounded by the Design Internal Pressure in Table 2.2.1. Because the top and bottom extremities of the MPC Enclosure Vessel are each at a uniform temperature due to the recirculating helium, thermal stresses are minimal. Therefore, the Design Internal Pressure envelops the case of the Normal Service condition for the MPC. The same remark applies to the Off-Normal Service condition.

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
Assumed Blockage of MPC Basket Flow Opening by Crud Settling (Depth of Crud, in.)	Accident	1
Cask Environment During the Postulated Fire Event (Deg. F)	Accident	1475
HI-STORM FW Overpack Fire Duration (seconds)	Accident	208
HI-TRAC VW Transfer Cask Fire Duration (minutes)	Accident	4.64
Maximum Submergence Depth due to Flood (ft)	Accident	125
Factor of safety against sliding or overturning from moving flood waters	Accident	1.1

Table 2.2.9 ISFSI PAD DATA FOR NON-MECHANISTIC TIP-OVER ANALYSIS	
Thickness (inch)	36
Concrete Pad Compressive Strength (psi)	6,000
Modulus of elasticity of the subgrade (psi)	28,000

Table 2.2.10

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

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

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

Table 2.2.11

STRUCTURAL DESIGN CRITERIA FOR THE FUEL BASKET

PARAMETER	VALUE
Minimum service temperature	-40ºF
Maximum total (lateral) deflection in the active fuel region - dimensionless	0.005

Table 2.2.12
STRESS AND ACCEPTANCE LIMITS FOR DIFFERENT LOADING CONDITIONS FOR THE STEEL STRUCTURE OF THE HI-STORM FW OVERPACK AND HI-TRAC VW

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

Definitions:

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

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

Table 2.2.13 LOADING EVENTS AND ACCEPTANCE CRITERIA APPLICABLE TO ACCIDENT CONDITIONS AND EXTREME ENVIRONMENTAL PHENOMENA				
Loading Case	Loading or Event	Affected Item or Part	Characteristics of Loading	Notes and Acceptance Criterion
AA.	Non-Mechanistic Tip-Over	HI-STORM FW overpack, Fuel Basket and Enclosure Vessel	Impactive load from the slap-down of the loaded overpack	See Paragraph 2.2.3(b)
AB.	Fire	Fuel Cladding, Shielding Concrete, and FW overpack steel structure	Significant radiant heat input over a short time	See Paragraph 2.2.3(c)
AC.	Tornado-Borne Missile	HI-STORM FW overpack	Impactive loading (Table 2.2.5)	See Paragraph 2.2.3(e)
	a. Large Missile	HI-STORM FW overpack	Acting to tip-over the loaded overpack	Use lower bound cask weight, demonstrate kinematic stability
	b. Medium Missile	HI-STORM FW overpack	May damage shielding concrete	Use lower bound cask weight, demonstrate kinematic stability
	c. Small Missile	HI-STORM FW overpack	Penetration	Prevent penetration of the cask and access to the MPC
AD.	Moving Floodwaters	Loaded Storage Module	Acting to tip-over the loaded overpack (Table 2.2.8)	See Paragraph 2.2.3 (f). Use both lower bound and upper bound cask height and weight to demonstrate kinematic stability.
AE.	Design Basis Earthquake	Loaded Storage Module	Acting to destabilize the cask	See Paragraph 2.2.3(g).
AF.	100% Rod Rupture	MPC confinement boundary	Acts to overpressure the MPC and raise the temperature of the fuel cladding	See Paragraph 2.2.3(h). Demonstrate that the equilibrium pressure in the MPC remains below the Accident Condition Design Pressure (Table 2.2.1) and ISG-11 temperature limits are met by the fuel cladding.

Table 2.2.13 LOADING EVENTS AND ACCEPTANCE CRITERIA APPLICABLE TO ACCIDENT CONDITIONS AND EXTREME ENVIRONMENTAL PHENOMENA				
AG.	Burial Under Debris	Stored SNF	Blocks convection and retards conduction as means for heat dissipation	See Paragraph 2.2.3(l). Determine the permissible time elapsed under debris so that the pressure in the MPC does not exceed the Accident Condition Design Pressure and the fuel cladding temperature remains below the ISG-11 limit.
AH	Design Basis External Pressure	MPC Enclosure Vessel	An assumed non-mechanistic load from deep submergence in flood water or explosion in the vicinity of the ISFSI	Demonstrate that the MPC Enclosure Vessel will not buckle, i.e., become structurally unstable
AJ.	Internal pressure developed in the HI-TRAC water jacket	HI-TRAC Water Jacket	A non-mechanistic (postulated) event	The water jacket will meet Level D stress limits for “NF” components.

TABLE 2.2.14
List of ASME Code Alternatives for Multi-Purpose Canisters (MPCs)

MPC Enclosure Vessel	Subsection NCA	General Requirements. Requires preparation of a Design Specification, Design Report, Overpressure Protection Report, Certification of Construction Report, Data Report, and other administrative controls for an ASME Code stamped vessel.	Because the MPC is not an ASME Code stamped vessel, none of the specifications, reports, certificates, or other general requirements specified by NCA are required. In lieu of a Design Specification and Design Report, the HI-STORM FSAR includes the design criteria, service conditions, and load combinations for the design and operation of the MPCs as well as the results of the stress analyses to demonstrate that applicable Code stress limits are met. Additionally, the fabricator is not required to have an ASME-certified QA program. All important-to-safety activities are governed by the NRC-approved Holtec QA program. Because the cask components are not certified to the Code, the terms “Certificate Holder” and “Inspector” are not germane to the manufacturing of NRC-certified cask components. To eliminate ambiguity, the responsibilities assigned to the Certificate Holder in the Code, as applicable, shall be interpreted to apply to the NRC Certificate of Compliance (CoC) holder (and by extension, to the component fabricator) if the requirement must be fulfilled. The Code term “Inspector” means the QA/QC personnel of the CoC holder and its vendors assigned to oversee and inspect the manufacturing process.
MPC Enclosure Vessel	NB-1100	Statement of requirements for Code stamping of components.	MPC Enclosure Vessel is designed and will be fabricated in accordance with ASME Code, Section III, Subsection NB to the maximum practical extent, but Code stamping is not required.
MPC basket supports and lift lugs	NB-1130	NB-1132.2(d) requires that the first connecting weld of a non-pressure retaining structural attachment to a component shall be considered part of the component unless the weld is more than 2t from the pressure retaining portion of the component, where t is the	The lugs that are used exclusively for lifting an empty MPC are welded to the inside of the pressure-retaining MPC shell, but are not designed in accordance with Subsection NB. The lug-to-Enclosure Vessel Weld is required to meet the stress limits of Reg. Guide 3.61 in lieu of Subsection NB of the Code.

TABLE 2.2.14 List of ASME Code Alternatives for Multi-Purpose Canisters (MPCs)			
		nominal thickness of the pressure retaining material. NB-1132.2(e) requires that the first connecting weld of a welded nonstructural attachment to a component shall conform to NB-4430 if the connecting weld is within 2t from the pressure retaining portion of the component.	
MPC Enclosure Vessel	NB-2000	Requires materials to be supplied by ASME-approved material supplier.	Materials will be supplied by Holtec approved suppliers with Certified Material Test Reports (CMTRs) in accordance with NB-2000 requirements.
MPC Enclosure Vessel	NB-3100 NF-3100	Provides requirements for determining design loading conditions, such as pressure, temperature, and mechanical loads.	These requirements are subsumed by the HI-STORM FW FSAR, serving as the Design Specification, which establishes the service conditions and load combinations for the storage system.
MPC Enclosure Vessel	NB-4120	NB-4121.2 and NF-4121.2 provide requirements for repetition of tensile or impact tests for material subjected to heat treatment during fabrication or installation.	In-shop operations of short duration that apply heat to a component, such as plasma cutting of plate stock, welding, machining, and coating are not, unless explicitly stated by the Code, defined as heat treatment operations.
MPC Enclosure Vessel	NB-4220	Requires certain forming tolerances to be met for cylindrical, conical, or spherical shells of a vessel.	The cylindricity measurements on the rolled shells are not specifically recorded in the shop travelers, as would be the case for a Code-stamped pressure vessel. Rather, the requirements on inter-component clearances (such as the MPC-to-transfer cask) are guaranteed through fixture-controlled manufacturing. The fabrication specification and shop procedures ensure that all dimensional design objectives, including inter-component annular clearances are satisfied. The dimensions required to be met in fabrication are chosen to meet the functional requirements of the dry storage components. Thus, although the post-forming Code cylindricity requirements are not evaluated for compliance directly, they are indirectly satisfied (actually exceeded) in the final manufactured components.

TABLE 2.2.14
List of ASME Code Alternatives for Multi-Purpose Canisters (MPCs)

MPC Enclosure Vessel	NB-4122	Implies that with the exception of studs, bolts, nuts and heat exchanger tubes, CMTRs must be traceable to a specific piece of material in a component.	MPCs are built in lots. Material traceability on raw materials to a heat number and corresponding CMTR is maintained by Holtec through markings on the raw material. Where material is cut or processed, markings are transferred accordingly to assure traceability. As materials are assembled into the lot of MPCs being manufactured, documentation is maintained to identify the heat numbers of materials being used for that item in the multiple MPCs being manufactured under that lot. A specific item within a specific MPC will have a number of heat numbers identified as possibly being used for the item in that particular MPC of which one or more of those heat numbers (and corresponding CMTRS) will have actually been used. All of the heat numbers identified will comply with the requirements for the particular item.
MPC Lid and Closure Ring Welds	NB-4243	Full penetration welds required for Category C Joints (flat head to main shell per NB-3352.3)	MPC lid and closure ring are not full penetration welds. They are welded independently to provide a redundant seal.
MPC Closure Ring, Vent and Drain Cover Plate Welds	NB-5230	Radiographic (RT) or ultrasonic (UT) examination required.	Root (if more than one weld pass is required) and final liquid penetrant examination to be performed in accordance with NB-5245. The closure ring provides independent redundant closure for vent and drain cover plates. Vent and drain port cover plate welds are helium leakage tested.
MPC Lid to Shell Weld	NB-5230	Radiographic (RT) or ultrasonic (UT) examination required.	Only progressive liquid penetrant (PT) examination is permitted. PT examination will include the root and final weld layers and each approx. 3/8" of weld depth.
MPC Enclosure Vessel and Lid	NB-6111	All completed pressure retaining systems shall be pressure tested.	The MPC vessel is seal welded in the field following fuel assembly loading. The MPC vessel shall then be pressure tested as defined in Chapter 10. Accessibility for leakage inspections preclude a Code compliant pressure test. All MPC enclosure vessel welds (except closure ring and vent/drain cover plate) are inspected by volumetric examination. MPC shell and shell to baseplate welds are subject to a fabrication helium leak test prior to loading.

TABLE 2.2.14
List of ASME Code Alternatives for Multi-Purpose Canisters (MPCs)

			The MPC lid-to-shell weld shall be verified by progressive PT examination. PT must include the root and final layers and each approximately 3/8 inch of weld depth. The inspection results, including relevant findings (indications) shall be made a permanent part of the user's records by video, photographic, of other means which provide an equivalent record of weld integrity. The video or photographic records should be taken during the final interpretation period described in ASME Section V, Article 6, T-676. The vent/drain cover plate and the closure ring welds are confirmed by liquid penetrant examination. The inspection of the weld must be performed by qualified personnel and shall meet the acceptance requirements of ASME Code Section III, NB-5350.
MPC Enclosure Vessel	NB-7000	Vessels are required to have overpressure protection.	No overpressure protection is provided. Function of MPC enclosure vessel is to contain radioactive contents under normal, off-normal, and accident conditions of storage. MPC vessel is designed to withstand maximum internal pressure considering 100% fuel rod failure and maximum accident temperatures.
MPC Enclosure Vessel	NB-8000	States requirements for nameplates, stamping and reports per NCA-8000.	The HI-STORM FW System is to be marked and identified in accordance with 10CFR71 and 10CFR72 requirements. Code stamping is not required. QA data package to be in accordance with Holtec approved QA program.

2.3 SAFETY PROTECTION SYSTEMS

2.3.1 General

The HI-STORM FW System is engineered to provide for the safe long-term storage of spent nuclear fuel (SNF). The HI-STORM FW will withstand all normal, off-normal, and postulated accident conditions without release of radioactive material or excessive radiation exposure to workers or members of the public. Special considerations in the design have been made to ensure long-term integrity and confinement of the stored SNF throughout all cask normal and off-normal operating conditions and its retrievability for further processing or ultimate disposal in accordance with 10 CFR 72.122(l) and ISG-2 [2.3.1].

2.3.2 Protection by Multiple Confinement Barriers and Systems

2.3.2.1 Confinement Barriers and Systems

The radioactivity which the HI-STORM FW System must confine originates from the spent fuel assemblies and, to a lesser extent, any radioactive particles from contaminated water in the fuel pool which may remain inside the MPC. This radioactivity is confined by multiple engineered barriers.

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

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

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

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

2.3.2.2 Cask Cooling

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

- The MPC fuel basket is formed by a honeycomb structure of Metamic-HT plates which allows the unimpeded conduction of heat from the center of the basket to the periphery. The MPC cavity is equipped with the capability to circulate helium internally by natural buoyancy effects and transport heat from the interior region of the canister to the peripheral region (Holtec Patent 5,898,747).
- The MPC confinement boundary ensures that the inert gas (helium) atmosphere inside the MPC is maintained during normal, off-normal, and accident conditions of storage and transfer. The MPC confinement boundary maintains the helium confinement atmosphere below the design temperatures and pressures stated in Table 2.2.3 and Table 2.2.1, respectively.
- The MPC thermal design maintains the fuel rod cladding temperatures below the ISG-11 limits such that fuel cladding does not experience degradation during the long term storage period.
- The HI-STORM FW is optimally designed, with cooling vents and an MPC to overpack annulus, which maximize air flow by ensuring a turbulent flow regime at maximum heat loads.
- Eight inlet ducts located circumferentially around the bottom of the overpack and the outlet vent which circumscribes the entire lid of HI-STORM FW render the ventilation action insensitive to shifting wind conditions.

2.3.3 Protection by Equipment and Instrumentation Selection

2.3.3.1 Equipment

Design criteria for the HI-STORM FW System are described in Section 2.2. The HI-STORM FW System may include use of ancillary or support equipment for ISFSI implementation. Ancillary equipment and structures utilized outside of the reactor facility 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 provides guidance for the determination of a component's safety classification [1.1.4].

Users may perform the MPC transfer between the HI-TRAC VW transfer cask and the HI-STORM FW overpack in a location of their choice, depending upon site-specific needs and capabilities. For those users choosing to perform the MPC transfer using devices not integral to structures governed by the regulations of 10 CFR Part 50 (e.g., fuel handling or reactor building), a Canister Transfer Facility (CTF) is required. The CTF is typically a concrete lined cavity of a suitable depth to stage the overpack inside it so that the top of the cask is near grade level (Holtec Patent 7,139,358B2). With the overpack staged inside the cavity, the mating device is installed on top and the HI-TRAC VW is mounted on top of the mating device. The MPC transfer is carried out by actuating the mating device and moving the MPC vertically to the cylindrical cavity of the recipient cask. The mating device is actuated by removing the bottom lid of the HI-TRAC VW transfer cask (see Figure 1.1.2). The device utilized to lift the HI-TRAC VW transfer cask to place it on the overpack and to vertically transfer the MPC may be of stationary or mobile type, but it must have redundant drop protection features. The cask transporter can be the load handling device at the CTF.

2.3.3.2 Instrumentation

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

However, in lieu of performing the periodic inspection of the HI-STORM FW overpack vent screens, temperature elements may be installed in the overpack exit vents to continuously monitor the air temperature. If the temperature elements and associated temperature monitoring instrumentation are used, they shall be designated important to safety.

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:

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

Administrative controls shall be used to ensure that fuel placed in the HI-STORM FW 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 security fence surrounded by a physical barrier fence with an appropriate locking and monitoring system is a standard approach to limit access if the ISFSI is located outside the controlled area. The details of the access control systems and procedures, including division of the site into radiation protection areas, will be developed by the licensee (user) of the ISFSI utilizing the HI-STORM FW System.

2.3.5.2 Shielding

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

The HI-STORM FW is designed to limit dose rates in accordance with 10CFR72.104 and 10CFR72.106 which provide radiation dose limits for any real individual located at or beyond the nearest boundary of the controlled area. The individual must not receive doses in excess of the limits given in Table 2.3.1 for normal, off-normal, and accident conditions.

Three locations are of particular interest in the storage mode:

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

Dose rates in the immediate vicinity of the loaded overpack are important in consideration of occupational exposure. Conservative evaluations of dose rate have been performed and are described in Chapter 5 based on Reference BWR and PWR fuel (Table 1.0.4).

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

Design objective dose rates for the HI-STORM FW overpack surfaces are presented in Table 2.3.2.

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

The analyses and discussions presented in Chapters 5, 9, and 11 demonstrate that the HI-STORM FW System is capable of meeting the radiation dose limits set down in Table 2.3.1.

2.3.5.3 Radiological Alarm System

The HI-STORM FW does not require a radiological alarm system. There are no credible events that could result in release of radioactive materials from the system and direct radiation exposure from the ISFSI is monitored using the plant's existing dose monitoring system.

2.3.6 Fire and Explosion Protection

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

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

Table 2.3.1 RADIOLOGICAL SITE BOUNDARY REQUIREMENTS	
MINIMUM DISTANCE TO BOUNDARY OF CONTROLLED AREA (m)	100
NORMAL AND OFF-NORMAL CONDITIONS: -Whole Body (mrem/yr) -Thyroid (mrem/yr) -Any Other Critical Organ (mrem/yr)	 25 75 25
DESIGN BASIS ACCIDENT: -TEDE (rem) -DDE + CDE to any individual organ or tissue (other than lens of the eye) (rem) -Lens dose equivalent (rem) -Shallow dose equivalent to skin or any extremity (rem)	 5 50 15 50

Table 2.3.2 – Design Objective Dose Rates for HI-STORM FW Overpack Surfaces	
Area of Interest	Dose Rate (mrem/hr)
Radial Surface Excluding Vents	300
Inlet and Outlet Vents	300
Top of the Lid (Horizontal Surface at approximate center)	30

2.4 DECOMMISSIONING CONSIDERATIONS

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

Towards that end, the MPC has been designed with the objective to transport it in a HI-STAR 190 transportation cask (Figure 2.4.1). Since the loaded MPC is a self-contained "Waste Package", no further handling of the SNF stored in the MPC is required prior to transport to a licensed centralized storage facility or repository.

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

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

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 FW System may pose is slight activation of the HI-STORM FW materials caused by irradiation over the storage period.

Due to the design of the HI-STORM FW 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.

The long-lived radionuclides produced by the irradiation of the HI-STORM FW System components are listed in Table 2.4.1. The activation of the HI-STORM FW components shall be limited to a cumulative activity of 10 Ci per cubic meter before decommissioning and disposal of the activated item can be carried out.

In any case, the HI-STORM FW System would not impose any additional decommissioning requirements on the licensee of the ISFSI facility per 10CFR72.30, since the HI-STORM FW System could eventually be shipped from the site.

Table 2.4.1

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

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

Withheld in Accordance with 10 CFR 2.390

Figure 2.4.1: HI-STAR 190 Transportation Overpack and MPC Shown in Exploded, Cut-Away View

2.5 REGULATORY COMPLIANCE

Chapter 2 provides the principal design criteria and applicable loading related to HI-STORM FW structures, systems, and components designated as important-to-safety. These criteria include specifications regarding the fuel, as well as, external conditions that may exist in the operating environment during normal and off-normal operations, accident conditions, and natural phenomena events. The chapter has been written to provide sufficient information to allow verification of compliance with 10CFR72, NUREG-1536, and Regulatory Guide 3.61. A detailed evaluation of the design criteria and an assessment of compliance with those criteria are provided in Chapters 3 through 12.

2.6 REFERENCES

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

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[2.3.1] ISG-2, “Fuel Retrievability”, Revision 0, USNRC, Washington DC