TABLE 1.0.1

HI-STORM FW SYSTEM COMPONENTS

Overpack	**Transfer Cask**	**MPC***
HI-STORM FW	HI-TRAC VW	MPC-32ML
		MPC-37
		MPC-44 Version CBS
		MPC-89
		MPC-89 Version CBS
	HI-TRAC VW Version V	MPC-32ML
		MPC-37
		MPC-44 Version CBS
		MPC-89
		MPC-89 Version CBS
	HI-TRAC VW Version V2	MPC-32ML
		MPC-37
		MPC-44 Version CBS
		MPC-89
		MPC-89 Version CBS
HI-STORM FW Version XL	HI-TRAC VW	MPC-32ML
		MPC-37
		MPC-44 Version CBS
		MPC-89
		MPC-89 Version CBS
	HI-TRAC VW Version V	MPC-32ML
		MPC-37
		MPC-44 Version CBS
		MPC-89
		MPC-89 Version CBS
	HI-TRAC VW Version V2	MPC-32ML
		MPC-37
		MPC-44 Version CBS
		MPC-89
		MPC-89 Version CBS
HI-STORM FW Version E	HI-TRAC VW	MPC-32ML
		MPC-37
		MPC-37P Version CBS
		MPC-44 Version CBS

TABLE 1.0.1

HI-STORM FW SYSTEM COMPONENTS

		MPC-89
		MPC-89 Version CBS
	HI-TRAC VW Version V	MPC-32ML
		MPC-37
		MPC-37P Version CBS
		MPC-44 Version CBS
		MPC-89
		MPC-89 Version CBS
	HI-TRAC VW Version V2	MPC-32ML
		MPC-37
		MPC-37P Version CBS
		MPC-44 Version CBS
		MPC-89
		MPC-89 Version CBS
HI-STORM FW UVH	See Table 1.I.0.1	

*It should be assumed that any statement or discussion in the FSAR applies to any basket version designed for use with the identified MPC number as specified in this Table unless the basket version is specifically called out in a particular statement or discussion of an MPC.

~~TABLE 1.0.1~~

~~HI-STORM FW SYSTEM COMPONENTS~~

~~**Item**~~	~~**Designation (Model Number)**~~	
~~Overpack~~	~~HI-STORM FW (Includes Standard, Version XL, & Version E)~~	
~~PWR Multi-Purpose Canister~~	~~MPC-37,~~	
	~~MPC-32ML,~~	
	~~MPC-37P*,~~	
	~~MPC-44~~	
~~BWR Multi-Purpose Canister~~	~~MPC-89 (Includes Standard & Version CBS)~~	
~~Transfer Cask~~	~~HI-TRAC VW(Standard),~~	
	~~HI-TRAC VW Version V,~~	
	~~HI-TRAC VW Version V2~~	

~~*MPC-37P qualified for storage in the HI-STORM FW Version E.~~

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 Design and Service Levels A, B, and D 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 permanent deflection~~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, and it is also used conservatively to inform the criticality analysis model for the MPC fuel baskets, as described in Subsection 6.3.1. 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.

[2.2.7] Regulatory Guide 1.76, “Design Basis Tornado for Nuclear Power Plants,” United States Nuclear Regulatory Commission, April 1974.

[2.2.8] ANSI/ANS 57.9-1992, "Design Criteria for an Independent Spent Fuel Storage Installation (Dry Type)", American Nuclear Society, LaGrange Park, IL, May 1992.

[2.2.9] NUREG-0800, “Standard Review Plan,” United States Nuclear Regulatory Commission, Washington, DC, April 1996

[2.2.10] ASME Boiler & Pressure Vessel Code, Section III, Subsection NB. “Class 1 Components,” American Society of Mechanical Engineers, New York, NY, 2007

[2.2.11] Holtec Proprietary Position Paper DS-331, “Structural Acceptance Criteria for the Metamic-HT Fuel Basket”, Revision 2 ~~(USNRC Docket No. 71-9325)~~.

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

3.1 STRUCTURAL DESIGN

3.1.1 Discussion

The HI-STORM FW system consists of the Multi-Purpose Canister (MPC) and the storage overpack (Figure 1.1.1). The components subject to certification on this docket consist of the HI-STORM FW system components and the HI-TRAC VW transfer cask (please see Table 1.0.1). A complete description of the design details of these three components are provided in Section 1.2. This section discusses the structural aspects of the MPC, the storage overpack, and the HI-TRAC VW (including Versions V and V2) transfer cask. Detailed licensing drawings for each component are provided in Section 1.5.

(i) The Multi-Purpose Canister (MPC)

The design of the MPC seeks to attain three objectives that are central to its functional adequacy:

- Ability to Dissipate Heat: The thermal energy produced by the stored spent fuel must be transported to the outside surface of the MPC to maintain the fuel cladding and fuel basket metal walls below the regulatory temperature limits.

- Ability to Withstand Large Impact Loads: The MPC, with its payload of nuclear fuel, must withstand the large impact loads associated with the non-mechanistic tipover event.

- Differential Thermal Expansion (DTE): The stress arising from the differential thermal expansion between the fuel basket and the MPC shell is mitigated by providing a prescribed nominal gap at their interface locations. The radial gap is selected to produce modest local compatibility stresses at the basket panel-to-shell junction, if not eliminate them. The DTE between various cask components at maximum design basis heat load is evaluated in Section 4.4.6 of Chapter 4. If the DTE between fuel basket and MPC canister exceed the prescribed gap, then the compatibility stresses are further evaluated in Section 3.4.4 to ensure that the stress criteria per ASME, Section III, Subsection NB are satisfied~~ which are classified as peak stresses in NB-3213.11 and NB-3213.13(b) that produce no significant distortion, and are important only in determining the cyclic fatigue life of the component. The magnitude of the peak stress will vary at the different basket panel-to-shell interface locations and with the canister's heat generation rate. At low heat loads and ambient conditions, a positive gap will exist at most interface locations. The progressive reduction in the gap with increasing heat load ensures improved heat transmission across the basket-to-shell interface which enhances the thermal capacity~~.

As stated in Chapter 1, the MPC Enclosure Vessel is a confinement vessel designed to meet the stress limits in ASME Code, Section III, Subsection NB. The enveloping canister shell, baseplate, and the lid system form a complete Confinement Boundary for the stored fuel that is referred to as the "Enclosure Vessel". Within this cylindrical shell confinement vessel is an egg-crate assemblage of Metamic-HT plates that form prismatic cells with square cross-sectional openings for fuel storage, referred to as the fuel basket. All multi-purpose canisters designed for deployment in the HI-STORM FW have identical external diameters. The essential difference between the different MPCs lies in on the MPC lid.

- The MPC fuel baskets consist of an array of interconnecting plates. The number of storage cells formed by this interconnection process varies depending on the type of fuel being stored. Basket configurations designed for both PWR and BWR fuel are explained in detail in Section 1.2. All baskets are designed to fit into the same MPC shell.

- The MPC shell is separated from the basket and its lateral supports (basket shims) by a small, calibrated gap designed to minimize, if not completely eliminate, ~~prevent significant~~ thermal stressing associated with the thermal expansion mismatches between the fuel basket, the basket support structure, and the MPC shell. Refer to discussion on DTE earlier in this subsection.

The MPC fuel basket maintains the spent nuclear fuel in a subcritical arrangement. Its safe operation is assured by maintaining the physical configuration of the storage cell cavities intact in the aftermath of a non-mechanistic tipover event. This requirement is satisfied if the MPC fuel basket plates undergo a minimal deflection (see Table 2.2.11). The fuel basket strains are shown in Subsection 3.4.4.1.4 to remain largely elastic with only localized areas of plastic strain. Moreover, from the stimulation results it is demonstrated that the cross section of the storage cell, throughout the active fuel length, remains essentially unchanged. Therefore, there is no impairment in the recoverability or retrievability of the fuel and the subcriticality of the stored fuel is unchallenged.

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In normal operating condition, these shims are not subject to any significant loadings. The only condition in which this shim configuration experiences significant loads is the non-mechanistic tipover event when the shim extension plates may be subject to cantilever loads. This loading, which bounds all other events including seismic loads, is considered in the tipover analysis presented in Subsection 3.4.4.1.4b.

Similarly, MPC-44 and MPC-37P are evaluated for non-mechanistic tipover in Subsections 3.4.4.1.4c and 3.4.4.1.4d.

The MPC Confinement Boundary contains no valves or other pressure relief devices. In addition, the analyses presented in Subsections 3.4.3, 3.4.4.1.5, and 3.4.4.1.6 show that the MPC Enclosure Vessel meets the stress intensity criteria of the ASME Code, Section III, Subsection NB for all service conditions. Therefore, the demonstration that the MPC Enclosure Vessel meets Subsection NB stress limits ensures that there will be no discernible release of radioactive materials from the MPC.

(ii) Storage Overpack

The HI-STORM FW storage overpack is a steel cylindrical structure consisting of inner and outer low carbon steel shells, a lid, and a baseplate. Between the two shells is a thick cylinder of un-reinforced (plain) concrete. Plain concrete is also installed in the lid to minimize skyshine. The storage overpack serves as a missile and radiation barrier, provides flow paths for natural meaningful load combinations for the fuel basket, Enclosure Vessel, and the overpack. Each component is considered separately.

a. Fuel Basket

Table 3.1.1 summarizes the loading cases (derived from Tables 2.2.6, 2.2.7, and 2.2.13) that are germane to demonstrating compliance of the loaded fuel baskets inside the MPC Enclosure Vessel.

The fuel basket is not a pressure vessel; therefore, the pressure loadings are not meaningful loads for the basket. Further, the basket is physically disconnected from the Enclosure Vessel. The combined radial gap between the basket, the shims, and the Enclosure Vessel is sized to ensure that minimal~~no significant~~ thermal stresses (if any) are developed, which are incapable of~~ that would~~ causing~~e~~ distortion in basket panels. The axial gap between the basket and the Enclosure Vessel is sized to ensure that no constraint of free-end thermal expansion of the basket occurs. The DTE calculations are presented in Chapter 4.

The normal handling of the MPC within the HI-STORM FW system or the HI-TRAC VW transfer cask does not produce any significant stresses in the fuel basket because the operating procedures involve handling evolutions in the vertical orientation. The only departure from a purely vertical orientation of the transfer cask is described in subsection 4.5.1. In such cases, the stresses in the fuel basket must be established on a site-specific basis.

b. Enclosure Vessel

Table 3.1.1 summarizes all load cases that are applicable to structural analysis of the Enclosure Vessel to ensure integrity of the Confinement Boundary.

The Enclosure Vessel is a pressure retaining device consisting of a cylindrical shell, a thick circular baseplate at the bottom, and a thick circular lid at the top. This pressure vessel must be shown to meet the primary stress intensity limits per ASME Section III Class 1 at the design temperature and primary plus secondary stress intensity limits under the combined action of pressure plus thermal loads (Level A service condition in the Code).

Normal handling of the Enclosure Vessel is considered in Section 2.2; the handling loads are independent of whether the Enclosure Vessel is within the storage overpack or HI-TRAC VW cask.

c. Storage Overpack

Table 3.1.1 identifies the load cases to be considered for the overpack. The following acceptance criteria apply:

3.4.3.3 Safety Evaluation of Lifting Scenarios

As can be seen from the above, the computed factors of safety have a large margin over the allowable (of 1.0) in every case. In the actual fabricated hardware, the factors of safety will likely be much greater because of the fact that the actual material strength properties are generally substantially greater than the Code minimums. Minor variations in manufacturing, on the other hand, may result in a small subtraction from the above computed factors of safety. A part 72.48 safety evaluation will be required if the cumulative effect of manufacturing deviation and use of the CMTR (or CoC) material strength in a manufactured hardware renders a factor of safety to fall below the above computed value. Otherwise, a part 72.48 evaluation is not necessary. The above criterion applies to all lift calculations covered in this FSAR.

3.4.4 Heat

The thermal evaluation of the HI-STORM FW system is reported in Chapter 4.

a. Summary of Pressures and Temperatures

Design pressures and design temperatures for all conditions of storage are listed in Tables 2.2.1 and 2.2.3, respectively.

Differential Thermal Expansion

The effect of differential thermal expansion among the constituent components in the HI-STORM FW system is considered in Chapter 4 wherein the temperatures necessary to perform the differential thermal expansion analyses for the MPC in the HI-STORM FW and HI-TRAC VW casks are computed. The material presented in Section 4.4 demonstrates that a constraint to free expansion due to differential growth between discrete components of the HI-STORM FW system (e.g., storage overpack and enclosure vessel) will either not develop or not lead to significant thermal stresses.

i. Normal Hot Environment

Results presented in Section 4.4 demonstrate that initial gaps between the HI-STORM FW storage overpack or the HI-TRAC VW transfer cask and the MPC canister, and between the MPC canister and the fuel basket, will not lead to significant thermal stresses in any components due to DTE under normal operating conditions. In most cases, the initial gap is greater than the calculated DTE, which eliminates the possibility of thermal stresses related to restraint of thermal expansion. Only the DTE results for the MPC-37 CBS and MPC-89 CBS fuel baskets exceed the minimum combined radial gap at maximum design basis heat load. The interference, however, is quite small, as reported in Table 4.4.6, and it causes only modest local compatibility stresses at the basket panel-to-shell junction and no significant distortion. Per NB-3213.11 and NB-3213.13(b), such stresses are classified as peak stresses, and are important only in determining the cyclic fatigue life of the component. Since the temperature fluctuations inside the cask storage cavity are relatively minor, as discussed in Paragraph 3.1.2.5, fatigue failure is not a credible concern for the MPC canister or the CBS basket.

The magnitude of the peak stress will vary at the different basket panel-to-shell interface locations and with the canister’s heat generation rate. At low heat loads and ambient conditions, a positive gap will exist at most interface locations. The progressive reduction in the gap with increasing heat load ensures improved heat transmission across the basket-to-shell interface, which enhances the thermal capacity and mitigates the interference stresses. Therefore, the DTE between the MPC canister and the MPC-37 CBS and MPC-89 fuel baskets is not a significant structural concern.

ii. Fire Accident

It is shown in Chapter 4 that the fire accident has a small effect on the MPC temperatures because of the short duration of the fire accidents and the large thermal inertia of the storage overpack. Therefore, a structural evaluation of the MPC under the postulated fire event is not required. The conclusions reached in item (i) above are also appropriate for the fire accident with the MPC housed in the storage overpack. Analysis of fire accident temperatures of the MPC housed within the HI-TRAC VW for thermal expansion is unnecessary, as the HI-TRAC VW, directly exposed to the fire, expands to increase the gap between the HI-TRAC VW and MPC.

As expected, the external surfaces of the HI-STORM FW storage overpack that are directly exposed to the fire event experience maximum rise in temperature. The outer shell and top plate in the top lid are the external surfaces that are in direct contact with heated air from fire. Table 4.6.2 provides the maximum temperatures attained at the key locations in HI-STORM FW storage overpack under the postulated fire event.

The following conclusions are evident from the above table.

- The maximum metal temperature of the carbon steel shell most directly exposed to the combustion air is well below the applicable short-term temperature limit per Table 2.2.3. 700°F is the permissible temperature limit in the ASME Code for the outer shell material.

- The local concrete temperature is below its short term temperature limit specified in Table 2.2.3.

- The metal temperature of the inner shell does not exceed 300°F at any location, which is well below the accident condition temperature specified in Table 2.2.3 for the inner shell.

- The presence of a vented space at the top of the overpack body ensures that there will be no pressure buildup in the concrete annulus due to the evaporation of vapor and gaseous matter from the shielding concrete.

Thus, it is concluded that the postulated fire event will not jeopardize the structural integrity of the HI-STORM FW overpack or significantly diminish its shielding effectiveness.

The above conclusions, as relevant, also apply to the HI-TRAC VW fire considered in Chapter 4. Water jacket over-pressurization is prevented by the pressure relief devices. The non-structural effects of loss of water have been evaluated in Chapter 5 and shown to meet regulatory limits.

results of these analyses are summarized at the end of this subsection.

The objectives of the analyses are to demonstrate that the plastic deformation in the fuel basket is sufficiently limited to permit the stored SNF to be retrieved by normal means and that there is no significant loss of radiation shielding in the storage system. Furthermore, the maximum permanent lateral deflection of the lateral surface of the fuel basket is within the limit assumed in the criticality analyses (Chapter 6), and therefore, the lateral deflection does not have an adverse effect on criticality safety.

The tipover event is an artificial construct wherein the HI-STORM FW overpack is assumed to be perched on its edge with its C.G. directly over the pivot point A (Figure 3.4.8). In this orientation, the overpack begins its downward rotation with zero initial velocity. Towards the end of the tip-over, the overpack is horizontal with its downward velocity ranging from zero at the pivot point (point A) to a maximum at the farthest point of impact. The angular velocity at the instant of impact defines the downward velocity distribution along the contact line.

In the following, an explicit expression for calculating the angular velocity of the cask at the instant when it impacts on the ISFSI pad is derived. Referring to Figure 3.4.8, let r be the length AC where C is the cask centroid. Therefore,

$$r = \left(\frac{d^2}{4} + h^2 \right)^{1/2}$$

The mass moment of inertia of the HI-STORM FW system, considered as a rigid body, can be written about an axis through point A, as

$$I_A = I_c + \frac{W}{g} r^2$$

where I_c is the mass moment of inertia about a parallel axis through the cask centroid C, and W is the weight of the cask (W = Mg).

Let $\theta_1(t)$ be the rotation angle between a vertical line and the line AC. The equation of motion for rotation of the cask around point A, during the time interval prior to contact with the ISFSI pad, is

$$I_A \frac{d^2 \theta_1}{dt^2} = \text{Mgr} \sin \theta_1$$

This equation can be rewritten in the form

$$\frac{I_A}{2}\,\frac{d\,(\dot{\theta}_1)^2}{d\,\theta_1} = Mgr\,\sin\theta_1$$

which can be integrated over the limits $\theta_1 = 0$ to $\theta_1 = \theta_{2f}$ (Figure 3.4.8). The final angular velocity θ_1 at the time instant just prior to contact with the ISFSI pad is given by the expression

$$\dot{\theta}_1\,(t_B) = \sqrt{\frac{2\,Mgr}{I_A}\,(1 - \cos\theta_{2f})}$$

where, from Figure 3.4.8,

$$\theta_{2f} = \cos^{-1}\left(\frac{d}{2r}\right)$$

This equation establishes the initial conditions for the final phase of the tip-over analysis; namely, the portion of the motion when the cask is decelerated by the resistive force at the ISFSI pad interface. Using the data germane to HI-STORM FW (Table 3.4.11) and the above equations, the angular velocity of impact is calculated as

$$\dot{\theta}_1\,(t_B) = 1.45\ \text{rad/sec}$$

The LS-DYNA analysis to characterize the response of the HI-STORM FW system under the non-mechanistic tipover event is focused on two principal demonstrations, namely:

(i) The permanent lateral deflection~~deformation~~ of the basket panels in the active fuel region is less than the limiting value in Table 2.2.11.

(ii) The impact between the MPC guide tubes and the MPC does not cause a thru-wall penetration of the MPC shell.

Three~~Four~~ LS-DYNA finite element models are developed to simulate the postulated tipover event of HI-STORM FW storage cask with loaded MPC-37~~, MPC-44,~~ MPC-89 and MPC-32ML with standard fuel baskets~~, respectively~~.~~-~~ The ~~three~~ LS-DYNA models are constructed according to the dimensions specified in the licensing drawings included in Section 1.5; the tallest configuration for each MPC enclosure type is considered to ensure a bounding tipover analysis. Because of geometric and loading symmetries, a half model of the loaded cask and impact target (i.e., the ISFSI pad) is considered in the analysis. The LS-DYNA models of the HI-STORM FW overpack and the MPC are described in Subsections 3.1.3.1 and 3.1.3.2, respectively. ~~The tipover analysis for MPC-44 is postulated only in the HI-STORM FW Version E overpack.~~

For the ISFSI pad, t~~T~~he bounding target foundation properties per Table 2.2.9 are utilized.

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The complete details of the finite element model, input data and results are archived in the calculation package [3.4.11]. In summary, the results of the tipover analysis ~~The following conclusions~~ demonstrate that all safety criteria are satisfied for the cask system with MPC-89 CBS basket design, which means:~~.~~

i. The permanent lateral deflection of the most heavily loaded basket panel in the active fuel region complies with the deflection criterion in Table 2.2.11.

ii. **[**
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iii. The plastic strains in the MPC enclosure vessel remain below the allowable material plastic strain limit.

iv. The cask closure lid does not dislodge after the tipover event, i.e., the closure lid bolts remain in-tact.
v. The structural analyses of cask closure lids are performed in [3.4.13] using bounding peak deceleration values; therefore, the lids do not suffer any gross loss of shielding.

3.4.4.1.4c Load Case 4: Non-Mechanistic Tipover of MPC-44 Basket Design

The tipover analysis for MPC-44 is postulated only in the HI-STORM FW Version E overpack. The same modelling approach described in subparagraph 3.4.4.1.4a is used to construct the tipover model in LS-DYNA, except that the standard HI-STORM FW overpack is replaced by the Version E overpack, and the MPC-44 replaces the MPC-37. The fully assembled tipover model for the MPC-44 inside the HI-STORM FW Version E overpack is shown in Figure 3.4.9D. ~~The tipover analysis is performed for the MPC-44 basket design using the existing design basis tipover model in LS-DYNA where the MPC-37 standard basket and aluminum shims are replaced with a fully articulated MPC-44 basket.~~ The finite element model of the MPC-44 CBS basket is shown in Figure 3.4.12E. The continuous basket shims are modelled using the same approach employed for the MPC-89 CBS, which is described in subparagraph 3.4.4.1.4b. Lastly, the finite element model of the ISFSI is the same as described above in subparagraph 3.4.4.1.4a. For the ISFSI pad, the bounding target foundation properties per Table 2.2.9 are utilized.

Like other basket designs, the response of the MPC-44 CBS basket during the tipover event is predominantly elastic with very localized areas of plasticity, as shown in Figure 3.4.15E. Nonetheless, to insure compliance with the allowable limit in Subsection 2.2.8, the maximum lateral deformation of the most heavily loaded CBS basket panel, at any elevation within the active fuel region, is obtained from the LS-DYNA solution and reported in Table 3.4.19.

The complete details of the finite element model, input data and results are archived in the calculation package [3.4.30]. In summary, the results of the tipover analysis ~~The following conclusions~~ demonstrate that all safety criteria are satisfied for the cask system with MPC-44 basket design, which means:

i. The permanent lateral deflection of the most heavily loaded basket panel in the active fuel region complies with the deflection criterion in Table 2.2.11.
ii. The CBS remain attached to the basket maintaining their physical integrity. The stresses in the basket shims are mainly below the yield strength with only limited permanent deformation, as shown in Figure 3.4.46B.
iii. The plastic strains in the MPC enclosure vessel remain below the allowable material plastic strain limit.
iv. The cask closure lid does not dislodge after the tipover event, i.e., the closure lid bolts remain in-tact.
v. The structural analyses of cask closure lids are performed in [3.4.13] using bounding peak deceleration values; therefore, the lids do not suffer any gross loss of shielding.

3.4.4.1.4d Load Case 4: Non-Mechanistic Tipover of MPC-37P Basket Design

A non-mechanistic tipover of HI-STORM FW Version E cask with MPC-37P basket inside is not explicitly analyzed because it is bounded by the tipover analysis of MPC-37 CBS basket. The reasons are~~The tipover analysis of HI-STORM FW Version E cask with MPC-37P basket is not explicitly performed because of the following reasons~~:

a. -MPC-37P basket panels are thicker than that of MPC-37 CBS basket per licensing drawings in Section 1.5.
b. -MPC-37P basket cell width is smaller than that of MPC-37 CBS basket per licensing drawings in Section 1.5.
c. -Weight of MPC-37P fuel assemblies is conservatively bounded by MPC-37 fuel assemblies per Table 2.1.1.
d. -Temperature distribution of MPC-37P basket panels is bounded by MPC-37 CBS basket panels per thermal analyses supporting Chapter 4.

The details of the comparative evaluation, as well as the calculated results for the MPC-37 CBS tipover analysis, are documented in [3.4.30]. The maximum permanent deflection of the heaviest loaded fuel basket panel for the MPC-37/37P CBS basket is reported in Table 3.4.19. The stress distribution in the basket shims is plotted in Figure 3.4.46C, which shows that the stresses in the CBS are mainly below the material yield strength with only limited permanent deformation. Therefore, as the results demonstrate, the acceptance criteria defined in Paragraph 2.2.3(b) are satisfied for HI-STORM FW Version E cask with MPC-37P basket.

3.4.4.1.5 Load Case 5: Design, Short-Term Normal and Off-Normal MPC Internal Pressure

The MPC Enclosure Vessel, which is designed to meet the stress intensity limits of ASME Subsection NB [3.4.4], is analyzed for a bounding normal (design, long-term and short-term) internal pressure (Table 2.2.1) of 120 psig using the ANSYS finite element code [3.4.1]. Except for the applied loads and the boundary conditions, the finite element model of the MPC Enclosure Vessel used for this load case is identical to the model described in Subsections 3.1.3.2 and 3.4.3.2 for the MPC lifting analysis.

The only load applied to the finite element model for this load case is the bounding MPC design internal pressure for normal conditions (Table 2.2.1). All internal surfaces of the MPC storage cavity are subjected to the design pressure. The center node on the top surface of the MPC upper lid is fixed against translation in all directions. Symmetric boundary conditions are applied to the two vertical symmetry planes. This set of boundary conditions allows the MPC Enclosure Vessel to deform freely under the applied pressure load. Figure 3.4.31 graphically depicts the applied pressure load and the boundary conditions for Load Case 5.

The stress intensity distribution in the MPC Enclosure Vessel under design internal pressure is shown in Figure 3.4.23. Figures 3.4.32 and 3.4.33 plot the thru-thickness variation of the stress intensity at the baseplate center and at the baseplate-to-shell juncture, respectively. The maximum

Table 3.4.19

PERMANENT LATERAL DEFLECTION OF FUEL BASKET PANELS DUE TO NON-MECHANISTIC TIPOVER

Fuel Basket Type	Max. Calculated Deflection[†] (in)	Allowable Limit[††] (in)	Safety Factor
MPC-89 CBS	0.021	0.030	1.43
MPC-44 CBS	0.011	0.0405	3.68
MPC-37/37P CBS[†††]	0.036	0.045	1.25

[†] The following steps are taken to calculate the maximum permanent deflection of fuel basket panel from the results of the non-mechanistic tipover simulation for each basket type:

1) The effective stress and the plastic strain contours for the fuel basket are plotted in LS-DYNA at the time instant of maximum loading. The maximum load demand essentially corresponds to the time instant when the top end of the MPC and stored fuel assemblies “bottom out” inside the HI-STORM cavity after primary impact and begin to rebound in the upward direction.
2) The contour plots are visually examined to identify the specific panel locations and fuel basket elevations where the stresses/strains are maximum. Both horizontally and vertically oriented panels are considered.
3) At each of the identified locations, a row of elements spanning the width of the cell is selected.
4) For the selected row of elements, the total lateral displacement (elastic + plastic) at the middle of the span and at both ends of the span are obtained from the LS-DYNA solution. The relative deflection between the midspan of the panel and its two support ends is taken as the largest difference between the three absolute displacement measurements.
5) To separate the permanent deflection from the combined deflection, step (4) is repeated for the same row of elements for an earlier solution time step when the maximum stress in the limiting element (among the row of selected elements) is just below the yield strength of the material.
6) The maximum permanent deflection, for each panel location identified in step (3), is conservatively computed by subtracting the elastic deflection determined in step (5) from the total deflection (elastic + plastic) determined in step (4).

[††] Equal to 0.005 times the cell inner dimension per Subsection 2.2.8 and Table 2.2.11. Cell inner dimension obtained from drawing package in Section 1.5.

[†††] Tipover analysis performed based on MPC-37 CBS basket geometry. Results are also bounding for MPC-37P CBS basket per discussion in subparagraph 3.4.4.1.4d.

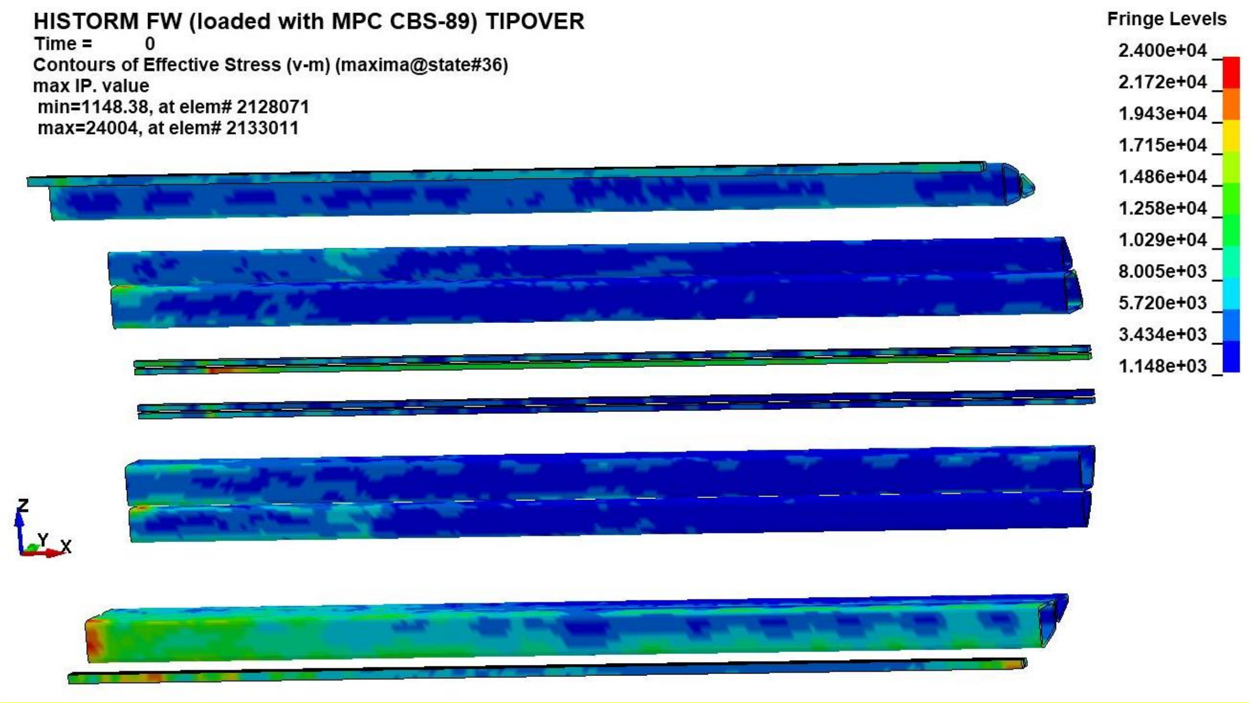

Figure 3.4.46A: Stress Distribution in Basket Shims for MPC-89 CBS

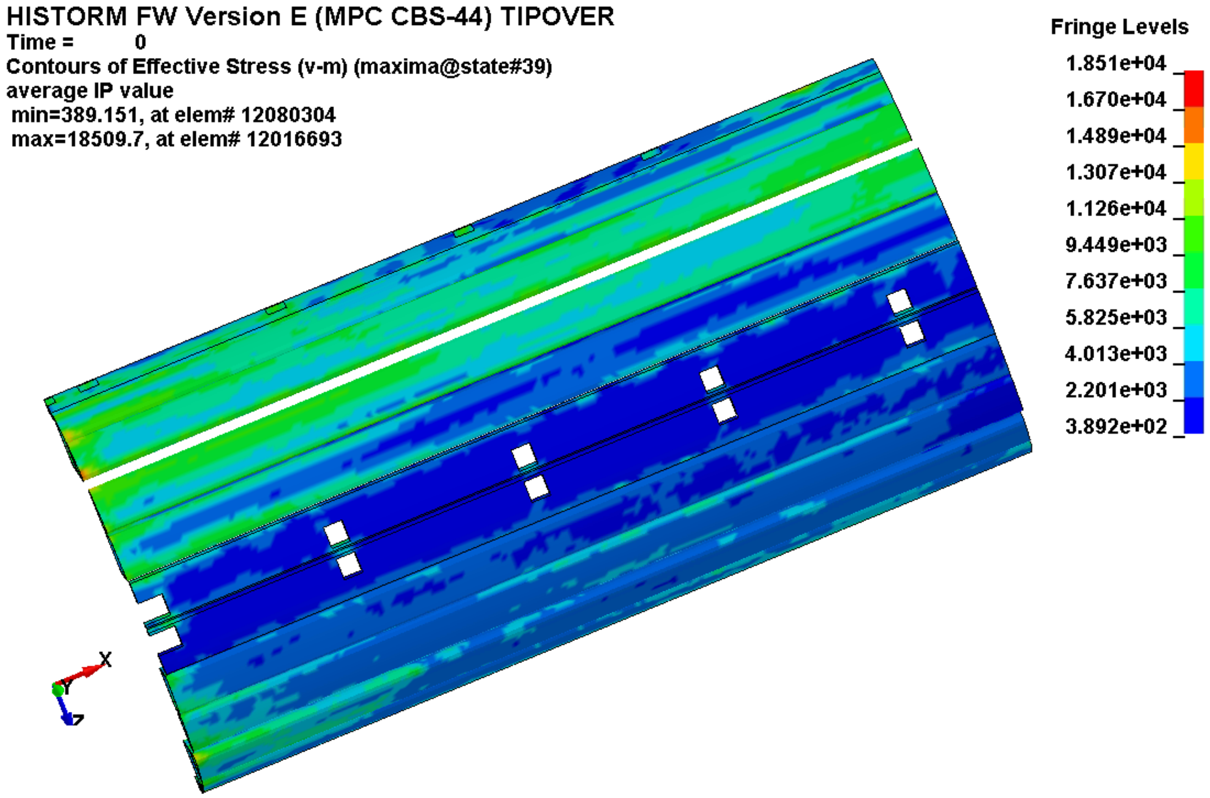

Figure 3.4.46B: Stress Distribution in Basket Shims for MPC-44 CBS

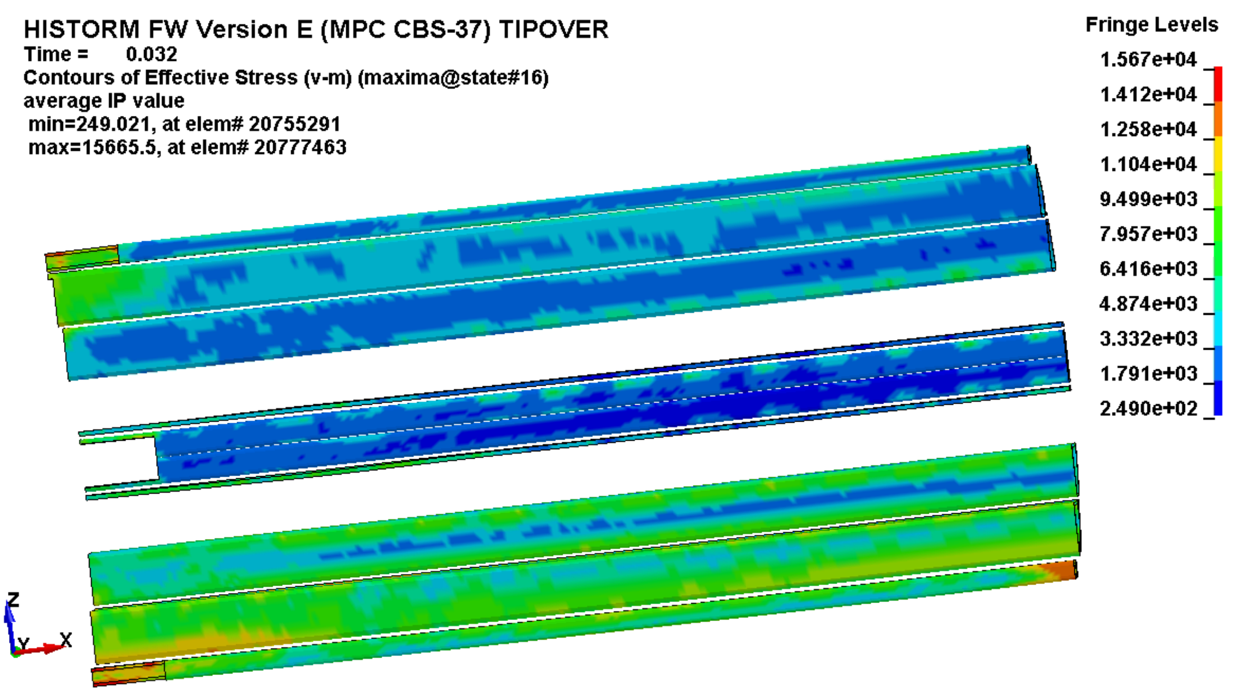

Figure 3.4.46C: Stress Distribution in Basket Shims for MPC-37/37P CBS

- The structural design and fabrication details of the fuel baskets whose safety function in the HI-STORM FW system is to maintain nuclear criticality safety, are provided in the drawings in Section 1.5. The structural factors of safety, summarized in Section 3.4 for all credible load combinations under normal, off-normal, accident, and natural phenomenon events demonstrate that the acceptance criteria are satisfied in all cases. In particular, the maximum permanent lateral deflection in the fuel basket panels under accident events has been determined to be within the limit used in the criticality analysis (see Subsection 3.4.4.1.4). Thus, the requirement of 10CFR72.124(a), with respect to structural margins of safety for SSCs important to nuclear criticality safety are fully satisfied.

- Structural margins of safety during handling, packaging, and transfer operations, under the provisions of 10CFR Part 72.236(b), imply that the lifting and handling devices be engineered to comply with the stipulations of ANSI N14.6 and NUREG-0612, as applicable. The requirements of the governing standards for handling operations are summarized in Subsection 3.4.3 herein. Factors of safety for all ITS components under lifting and handling operations are summarized in tables in Section 3.4, which show that adequate structural margins exist in all cases.

- Consistent with the provisions of 10CFR72.236(i), the Confinement Boundary for the HI-STORM FW system has been engineered to maintain confinement of radioactive materials under normal, off-normal, and postulated accident conditions. This assertion of confinement integrity is made on the strength of the following information provided in this FSAR.

  i. The MPC Enclosure Vessel which constitutes the Confinement Boundary is designed and fabricated in accordance with Section III, Subsection NB (Class 1 nuclear components) of the ASME Code to the maximum extent practicable.

  ii. The primary lid of the MPC Enclosure Vessel is welded using a strength groove weld and is subjected to multiple liquid penetrant examinations and pressure testing to establish a maximum confidence in weld joint integrity.

  iii. The closure system of the MPC Enclosure Vessel consists of *two* independent isolation barriers.

  iv. The Confinement Boundary is constructed from stainless steel alloys with a proven history of material integrity under the environmental conditions of an ISFSI.

only a negligibly small plastic strain is observed in the bolt.~~Figure 3.I.3.3 depicts the finite-element tipover analysis model developed for the HI-STORM FW Version UVH cask configurations with loaded MPC-37. Identical models are prepared for the HI-STORM FW Version UVH cask loaded with MPC-89 and MPC-44. Table 3.I.3.9 summarizes the maximum plastic strain results, along with the corresponding material failure strains.~~

~~From Figures 3.I.3.4 to 3.I.3.6 and Table 3.I.3.9, it is observed that the strains within the active fuel region are below the material failure strain limit. Local plastic deformation essentially develops only in a couple of peripheral cells of all three baskets (MPC-37, MPC-89 and MPC-44) near the top of the basket or in the bottom mouse hole region beyond the active fuel region. All three fuel baskets are structurally safe since they can continue maintaining appropriate spacing between fuel assemblies after the tipover event. The MPC enclosure vessel also experiences minor plastic deformation at the impact location with overpack inner shell; the maximum local plastic strain is well below the failure strain of the material and also smaller than the conservatively established plastic strain design limit (i.e., at least 0.2 for stainless steel) recommended by [3.4.6] for ASME NB components. Local plastic deformation occurs in the overpack inner shell due to the interaction with the MPC closure lid. Similar local plastic deformation occurs in the top region of the overpack outer shell and in the overpack lid outer shell at the impact location with the ISFSI pad. The strains in the overpack (including the lid) remain below the material failure strain limit. Furthermore, the shielding capacity of overpack (including the lid) is not compromised by the tipover accident and there is no gross plastic deformation in the overpack inner shell to affect the retrievability of the MPC. In addition, the cask closure lid bolts are demonstrated to be structurally safe after the tipover event, only a negligibly small plastic strain is observed in the bolt.~~

The complete details of the finite element model, input data and results are archived in the calculation package [3.4.31]. In summary, the results of the tipover analyses ~~The following conclusions~~ demonstrate that all safety criteria are satisfied for the Version UVH cask with MPC-37, MPC-44 and MPC-89 basket designs, which means:~~.~~

i. The lateral deflection of the most heavily loaded basket panel in the active fuel region complies with the deflection criterion in Table 2.2.11.
ii. The CBS~~shims in MPC-44 basket~~ remain attached to the MPC-44 fuel basket ~~it~~ maintaining their~~its~~ physical integrity. The stresses in the basket shims are mainly below the yield strength with only limited permanent deformation, as shown in Figure 3.I.3.13.
iii. The plastic strains in the MPC enclosure vessel remain below the allowable material plastic strain limit.
iv. The cask closure lid does not dislodge after the tipover event, i.e., the closure lid bolts remain in-tact.
v. The lid or the cask body do not suffer any gross loss of shielding.

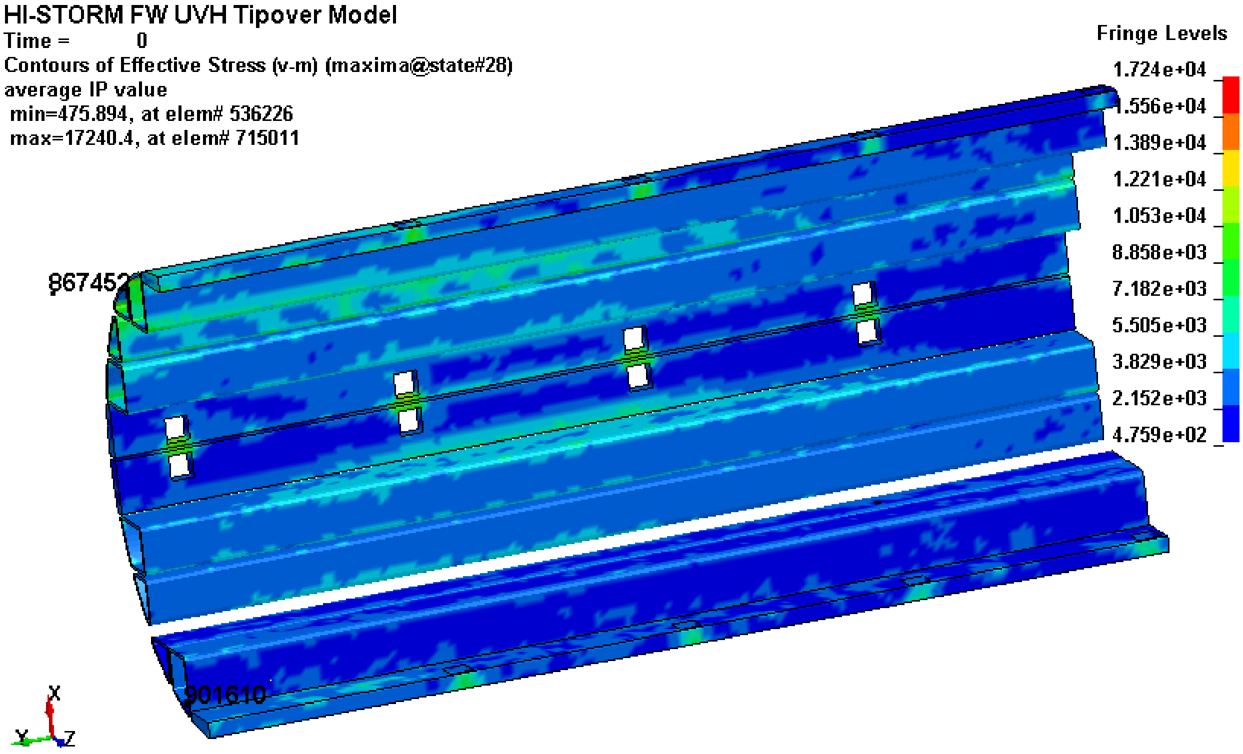

Figure 3.I.3.13: Stress Distribution in Basket Shims for MPC-44 CBS