

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.

~~The environmental loads and handling evolutions for a specific site during Part 72 short term operations are influenced by both the architectural layout as well as the geological and meteorological characteristics of the site, and therefore, are apt to be different from the standard handling steps summarized in the chapter on Operations. To perform the site-specific safety analysis of the handling evolutions, the magnitude of the incident load should be informed by its frequency of likely occurrence and the mitigative measures employed. All short-term operations, except the transitional transitory steps (such as upending or down-ending of the cask, placement of the Closure Lid on HI STORM), shall be subject to safety analysis under the postulated environmental loads. The method of analysis shall follow prior established precedent where available.~~

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

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

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

ii. Prevention against “edging” of the cask:

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

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

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

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.

With respect to short term operations in dry storage campaigns, a probabilistic risk assessment (PRA) may be employed at a geologically stable and low return frequency site, characterized by a small number of annual loadings, to evaluate the risk associated with a simultaneous earthquake event. However, for defense in depth, regardless of the loading campaign’s seismic PRA metric, it is necessary to demonstrate a positive margin against overturning of the cask transporter during the translocation of the cask to the ISFSI pad. For this purpose, a static equilibrium analysis of the cask transporter assemblage shall be performed in which it is subject to the site’s DBE with its acceleration magnified as suggested in NUREG-0800 (i.e., factor of 1.1). For kinematic stability analysis, the haul path may be simulated as an unyielding surface, and the limiting grade in the haul path incorporated in the solution for conservatism. Safety against potential sliding of the assemblage leading to an impact with a safety significant structure proximate to the haul path shall also be ascertained.

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., H³, 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.

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9.1 TECHNICAL AND SAFETY BASIS FOR LOADING AND UNLOADING PROCEDURES

The procedures herein are developed for the loading, storing, and unloading of spent fuel in the HI-STORM FW system. The activities involved in loading of spent fuel in a canister system, if not carefully performed, may present physical risk to the operations staff. The design of the HI-STORM FW system, including these procedures, the ancillary equipment and the Technical Specifications, serve to minimize potential risks and mitigate consequences of potential events.

The primary objective of the information presented in this chapter is to identify and describe the sequence of significant operations and actions that are important to safety for cask loading, cask handling, storage operations, and cask unloading to adequately protect health and minimize danger to life or property, protect the fuel from significant damage or degradation, and provide for the safe performance of tasks and operations.

~~The safety evaluation of the various loading configurations and ancillaries is outside the scope of this FSAR because such equipment and analyses must, of necessity, be site specific to accord with the exigencies of the architecture of each plant. However, to ensure consistency, a series of generic reports [9.1.4 thru 9.1.7] that address various loading scenarios have been adopted in Holtec's configuration control system to standardize the analysis methodologies to the extent possible, where none exists in the plant's existing design basis.~~

In the event of an extreme abnormal condition the appropriate procedural guidance to respond to the situation must be available and ready for implementation. As a minimum, the procedures shall address establishing emergency action levels, implementation of emergency action program, establishment of personnel exclusions zones, monitoring of radiological conditions, actions to mitigate or prevent the release of radioactive materials, and recovery planning and execution and reporting to the appropriate regulatory agencies, as required.

9.5 REFERENCES

- [9.0.1] U.S. Nuclear Regulatory Commission, "Standard Review Plan for Dry Cask Storage Systems", NUREG-1536, Final Report, January 1997.
- [9.1.1] U.S. Code of Federal Regulations, Title 10 "Energy", Part 72, "Licensing Requirements for Independent Storage of Spent Nuclear Fuel and High-Level Radioactive Waste,"
- [9.1.2] American National Standards Institute, Institute for Nuclear Materials Management, "American National Standard for Radioactive Materials – Leakage Tests on Packages for Shipment," ANSI N14.5-1997.
- [9.1.3] American Society of Mechanical Engineers "Boiler and Pressure Vessel Code".
- ~~[9.1.4] Holtec Report HI-2135841, "Methodology for Determining Cask to ISFSI Pad Dynamic Response with Consideration of SSI and Nonlinear Effects", Latest Revision.~~
- ~~[9.1.5] Holtec Report HI-2135869, "Site Specific Tornado Missile Analysis for HI-STORM FW System", Latest Revision.~~
- ~~[9.1.6] Holtec Report HI-2146258, "VCT Stability Analysis on Haul Path and ISFSI Pad for Multiple Nuclear Power Plants", Latest Revision.~~
- ~~[9.1.7] Holtec Report HI-2167059, "Analysis Methodology for ANSI N14.6 Special Lifting Devices", Latest Revision.~~
- [9.5.1] U.S. Code of Federal Regulations, Title 10 "Energy", Part 20, "Standards for Protection Against Radiation,"

CHAPTER 3.I: STRUCTURAL EVALUATION

3.I.0 Overview

This chapter contains the structural safety analysis of the HI-STORM FW storage system containing the Version UVH overpack (hereafter referred to as the *Storage System* for brevity) illustrated in Figure 1.I.1.1 and in the Licensing drawing package in Section 1.I.5. The structural evaluation for Version UVH under all applicable loadings, including pressure and the non-mechanistic tip-over event, are discussed in Chapter 2.I and evaluated in Section 3.I.3. The loading scenarios for Version UVH overpack that are bounded by the existing analyses in Chapter 3 of this FSAR are presented in Table 2.I.2.1 and Section 3.I.3.

3.I.1 Structural Design

The design information provided in Section 3.1 remains applicable except that the storage cask has no inlet or outlet vents and the space between the cask cavity and the MPC is confined. To ensure a sequestered space outside the MPC, the interface between the closure lid and the cask body is equipped with a weather-resistant gasket.

The absence of vents confers additional structural resistance to Version UVH to certain mechanical loadings such as the Design Basis penetrant missiles considered in Subsection 3.4.4 of this report. Indeed, as the evaluation narrative in Table 2.I.2.1 and Section 3.I.3 demonstrates, from the structural standpoint, the Version UVH is either similar or better in terms of the safety margins established for the system components in the main FSAR except for the cask internal pressure and the non-mechanistic tip-over evaluations which are distinct. All evaluations to demonstrate structural integrity of various components are discussed in Section 3.I.3.

As this chapter envisages no change to the MPCs or their contents or to the HI-TRAC transfer casks, all safety information on them in Chapter 3 remains fully applicable. The only new calculations for MPC are limited to ensuring that the temperature field in the enclosure vessel is bounded by those used in the Subsection 3.4.3 evaluations under normal and off-normal conditions. The safety evaluation of the Design Basis Loadings (DBLs) for Version UVH overpack is limited to ensuring that the overpack's response remains acceptable under the design criteria and features unique to Version UVH, which, as stated in Section 2.I.2, consists of Design Basis internal pressure loadings and cask stability evaluations. In addition, since the Version UVH overpack lid is different from those designs evaluated in Subsections 3.4.3 and 3.4.4, a separate lid evaluation is performed under all applicable loadings as described in Section 3.I.3.

3.I.2 Structural Model

The cask body is simulated as dual shell structure with discrete radial connectors, the shielding concrete serves no structural function except to keep the two shells from deflecting laterally into the space occupied by the concrete. The baseplate of the cask is modeled as a flat plate buttressed by radial ribs and held from lateral deflection at its connection with the edges of the two shells.

The cask lid is secured to the body using four large anchor bolts similar to the standard FW design, and it has shielding concrete to keep the top and bottom plates and outer shell from deflecting into the space occupied by the concrete. In addition, there are diagonal stiffener plates through the thickness of the lid to reinforce the structure and to provide interfacing lift points for handling of the lid.

3.I.3 Safety Analyses

As discussed in Chapter 2.I and Section 3.I.1, multiple evaluations are performed to demonstrate structural integrity of HI-STORM FW Version UVH Storage System, namely,

- a) Evaluation of MPC **confinement** boundary under normal and off-normal conditions using pressure limits from Table 2.2.1 and temperature profiles from thermal analyses supporting Chapter 4.I.
- b) Evaluation of Version UVH cask under internal and external pressure loads.
- c) Evaluation of Version UVH closure lid under lifting and snow load conditions.
- d) Evaluation of Version UVH cask's stability in the event of flood.
- e) Evaluation of Version UVH cask's stability in the event of explosion or blast.
- f) Evaluation of Version UVH cask's stability in the event of earthquake.
- g) Evaluation of Version UVH cask in the event of tornado (wind and missile impacts).
- h) Evaluation of Version UVH cask in the event of non-mechanistic tip-over.

3.I.3.1 MPC **Confinement** Boundary Evaluation

Using the ANSYS finite element model of **the MPC** described in **Paragraphs 3.1.3.2 and 3.4.3.2**, two separate analyses **for normal and off-normal conditions** are added to demonstrate structural integrity **of the confinement boundary in Supplement 1 of [3.4.13]** as described below. **The analyses under handling, design, short-term normal and accident conditions are not explicitly performed for the Version UVH system as they are bounded by those presented in Paragraph 3.4.3.2 and Subparagraphs 3.4.4.1.5 and 3.4.4.1.6, respectively.**

- i) **Normal Condition:** The long-term normal condition internal pressure limit in Table 2.2.1 is applied to MPC lid, shell and baseplate along with **a conservatively bounding** temperature contour obtained from normal condition thermal analysis in **Chapter 4.I Section 4.I.4**. The primary and secondary stresses in MPC lid, shell and baseplate are then compared against ASME NB Level A stress limits obtained at bounding component temperatures. **The analysis methodology and acceptance criteria are the same as those described in Subparagraph 3.4.4.1.5 for the MPC confinement boundary evaluation under normal condition. Additional analysis details are presented in Case 7 of Supplement 1 of [3.4.13]. The key results are presented in Table 3.I.3.2 and Figure 3.I.3.1 which demonstrate that all safety factors are greater than 1.0. It is demonstrated in Supplement 1 of [3.4.13] that all safety factors are greater than 1.0.**
- ii) **Off-normal Condition:** The off-normal condition internal pressure limit in Table 2.2.1 is applied to MPC lid, shell and baseplate along with **a conservatively bounding** temperature contour **obtained from based on the** off-normal condition thermal analysis in **Chapter 4.I Subsection 4.I.6.1**. The primary and secondary stresses in MPC lid, shell and baseplate are then compared against ASME NB Level B stress limits obtained at bounding component temperatures. **The analysis**

methodology and acceptance criteria are the same as those described in Subparagraph 3.4.4.1.5 for the MPC confinement boundary evaluation under off-normal condition. Additional analysis details are presented in Case 8 of Supplement 1 of [3.4.13]. The key results are presented in Table 3.I.3.3 and Figure 3.I.3.2 which demonstrate that all safety factors are greater than 1.0. It is demonstrated in Supplement 1 of [3.4.13] that all safety factors are greater than 1.0.

3.I.3.2 HI-STORM FW Version UVH Cask Pressure Loading

A 3-D finite element model of the HI-STORM FW Version UVH overpack is constructed in ANSYS [3.4.26] as shown in Supplement 43 of [3.4.13]. All plate and shell components are modeled using ANSYS solid elements (SOLID185 with at least three elements through thickness) and concrete is modeled using ANSYS solid element (SOLID65).

A total of six (6) pressure loading cases (four normal, including lifting, and two accident) are evaluated in Supplement 43 of [3.4.13] to envelope all design basis internal and external pressure loadings in Table 2.I.2.3. Three bounding normal condition (that also envelope off-normal condition) pressure loading cases, two bounding accident condition pressure loading cases and one lifting load case are analyzed in Supplement 43 of [3.4.13]. The cask base plate edge is fixed under normal, off-normal and accident pressure loadings. The cask anchor is constrained vertically under lifting load case. The six pressure loading cases are further described below.

In pressure loading case 1, 20 psi internal pressure is applied with the weight of a fully loaded MPC applied on the cask base plate as a uniform pressure. In pressure loading case 2, -14.7 psi internal pressure and 10 psi external pressure are applied without the MPC. In pressure loading case 3, 25 psi external pressure is applied without the MPC. In pressure loading case 4, 25 psi internal pressure is applied with the weight of a fully loaded MPC applied on the cask base plate as a uniform pressure. In pressure loading case 5, 75 psi external pressure is applied without the MPC. In pressure loading case 6 (lifting load case), 20 psi internal pressure is applied with the weight of a fully loaded MPC applied on the cask base plate as a uniform pressure. The self-weight of the overpack is simulated by applying a constant acceleration in the vertical direction. The finite element model of the HI-STORM FW Version UVH overpack is shown in Figure 3.I.3.10.

The primary membrane and membrane plus bending stresses in Version UVH overpack shells, base plate and lid are compared against ASME NF Level A (under normal and off-normal (conservative) pressure loadings) stress limits in Table 3.1.4 and Level D (under accident pressure loadings) stress limits in Table 3.1.6 obtained at bounding temperatures. The allowable stresses for the load bearing members are taken at 500°F for normal and off-normal conditions and 600°F for accident conditions, which exceed the maximum calculated temperatures for the overpack under normal, off-normal and accident conditions in Supplement 4.I. It is demonstrated in Supplement 43 of [3.4.13] that all safety factors are greater than 1.0. In addition, it is demonstrated that outer shell of overpack does not collapse or buckle under the accident external pressure loading. The governing stress plots for the UVH overpack and lid among the six pressure cases are presented in Figures 3.I.3.11 and 3.I.3.12, respectively, and the governing safety factors are summarized in Table 3.I.3.11.

2.

~~The primary membrane and membrane plus bending stresses in Version UVH overpack shells, base plate and lid are compared against ASME NF Level A (under normal and off-normal (conservative) pressure loadings) and Level D (under accident pressure loadings) stress limits obtained at bounding temperatures. It is demonstrated in Supplement 43 of [3.4.13] that all safety factors are greater than 1.0. In addition, it is demonstrated that outer shell of overpack does not collapse or buckle under the accident external pressure loading.~~

3.I.3.3 HI-STORM FW Version UVH Cask Closure Lid

The Version UVH closure lid is evaluated under the following load conditions in Supplement 46 of [3.4.13] using the same methodology and acceptance criteria used to evaluate standard, XL, domed and Version E closure lids in Subsections 3.4.3 and 3.4.4.

i) Lid lifting: It is demonstrated in Supplement 46 of [3.4.13] that the stresses in lid lifting points are less than NUREG-0612 and Regulatory Guide 3.61 stress limits obtained at bounding temperatures for the heaviest lid (bounded by maximum lid weight in Table 3.2.5). Also, the primary stresses in the remainder of lid structure, including welds, are shown to be less than ASME Code Subsection NF Level A stress limits obtained at bounding temperature. The primary failure modes for the lifting lug and the welds are evaluated using strength of materials based approach. A more rigorous finite element analysis is conducted to evaluate the global stresses in the plates and shells of the HI-STORM FW Version UVH lid. Figure 3.I.3.7 shows the finite element model of the Version UVH lid. Figure 3.I.3.8 shows the resulting stress distribution of Version UVH cask lid under normal handling. For conservatism, the maximum calculated stresses at any location in the lid, including secondary stress contributions, are compared against the primary membrane and primary bending stress limits per Subsection NF of the ASME Code for Level A conditions. The maximum stresses and the corresponding safety factors for Version UVH lid are summarized in Table 3.I.3.10.

ii) Snow load: It is demonstrated in Supplement 46 of [3.4.13] that under a bounding snow load, applied as pressure on top surface of closure lid, all primary stresses in the lid structure are less than ASME Code Subsection NF Level A stress limits obtained at bounding temperature. Figure 3.I.3.9 shows the resulting stress distribution of Version UVH cask lid under snow load. For conservatism, the maximum calculated stresses at any location in the lid, including secondary stress contributions, are compared against the primary membrane and primary bending stress limits per Subsection NF of the ASME Code for Level A. The safety factors for Version UVH lid under snow loading are bounded by the safety factors summarized in Table 3.I.3.10 for normal handling.

3.I.3.4 HI-STORM FW Version UVH Cask Stability During Flood

The Version UVH cask's stability in the event of a flood is evaluated in Supplement 45 of [3.4.13] using Version UVH cask's dimensions and corresponding minimum weight following the same methodology and acceptance criteria used to evaluate standard FW cask in Subparagraph 3.4.4.1.1. The analysis demonstrates that the de-stabilizing flood velocity for Version UVH cask is greater

~~(see Table 3.I.3.4) than the conservatively established limit (see Table 3.I.3.4) for standard FW cask in Subparagraph 3.4.4.1.1. guidance in Subparagraph 3.4.4.1.1 for standard FW cask. The analysis demonstrates that the maximum flood water velocity established in Subparagraph 3.4.4.1.1 remains governing for Version UVH cask.~~

3.I.3.5 HI-STORM FW Version UVH Cask Stability During Explosion

The Version UVH cask's stability in the event of an explosion is evaluated in Supplement 44 of [3.4.13] following the same methodology and acceptance criteria used for Standard FW cask in Subparagraph 3.1.2.1.d and with guidance in Subparagraph 3.1.2.1.d using Version UVH cask's dimensions and corresponding minimum weight. The analysis in Supplement 44 of [3.4.13] establishes the maximum static pressure that the cask can withstand without sliding or rocking (i.e., no incipient loss of kinematic stability). The maximum allowable static external pressure for the UVH cask is listed in Table 3.I.3.5. In case the blast pressures are greater at a Plant, a time-history based site-specific analysis using the applicable pressure-time pulse will be required to demonstrate that the cask will not slide excessively or overturn.

3.I.3.6 HI-STORM FW Version UVH Cask Stability During Earthquake

The discussion in Subparagraph 3.4.4.1.2 remains applicable to Version UVH cask. The combination of vertical and horizontal ZPAs of the earthquake that would cause Version UVH cask's incipient loss of kinematic stability are derived using static inequalities defined in Paragraph 2.2.3(g) in Supplement 47 of [3.4.13] using cask's dimensions and corresponding minimum weight. The limiting combination of vertical (a_v) and horizontal (a_h) ZPAs (Zero Period Accelerations) for UVH cask is presented in Table 3.I.3.6. For earthquakes with greater ZPAs than those in Table 3.I.3.6, it is necessary to perform a dynamic analysis per Subparagraph 3.4.4.1.2. For earthquakes stronger than that defined by the inequalities in Subsection 2.2.3(g), it is necessary to perform a dynamic analysis per Subparagraph 3.4.4.1.2.

3.I.3.7 HI-STORM FW Version UVH Cask During Tornado

The Version UVH cask's stability in the event of a tornado (wind and missiles) is evaluated ~~following the guidance in Subparagraph 3.4.4.1.3 for standard FW cask in Appendix I of [3.4.15]~~ using Version UVH cask's dimensions and corresponding minimum weight. The analysis for the UVH cask follows the same methodology and acceptance criteria used for the standard FW cask in Subparagraph 3.4.4.1.3. The results from the analysis (summarized in Table 3.I.3.7) demonstrate that the maximum cask displacements are governed by the results for the standard FW cask discussed in Subparagraph 3.4.4.1.3. The analysis demonstrates that the maximum cask displacements due to sliding and rocking are governed by the results for standard FW cask.

The penetration analysis for Version UVH cask using the wind and missile characteristics defined in Tables 2.2.4 and 2.2.5 is presented in Appendix J of [3.4.15]. The penetration analysis for the UVH cask follows the same methodology and acceptance criteria used for the standard FW cask in Subparagraph 3.4.4.1.3. The results presented in Table 3.I.3.8 demonstrate that the penetrations from small and intermediate missiles in UVH cask are acceptable.

~~demonstrating all results are acceptable.~~

3.I.3.8 Non-Mechanistic Tip-over

Non-mechanistic tip-over of the freestanding HI-STORM FW system consisting of the Version UVH overpack and three variants of MPC (MPC-37, MPC-44 and MPC-89) is considered herein. The solution uses the same methodology that was employed in the system's original certification documented in Subparagraph 3.4.4.1.4. The physical problem subject to the present analysis is different from the original problem in two respects; they are:

(a) As ascertained in Chapter 4.I, there is smaller clearance between the MPC and the overpack under the design basis heat load and as a result, there are no MPC guide tubes that participate in the cask's dynamics during its impact with pad.

(b) The top lid-to-cask body connectivity has been improved such that the lid strikes the ISFSI pad without applying any shear load on the anchor bolts. Thus, the impact of the lid is decoupled from that of the cask body which materially reduces the angular momentum of the cask as it collides with the pad during tip-over. The anchor bolts still serve the safety function of keeping the MPC confined within the cask's radiation shield against the centrifugal force generated by the tip-over event.

The LS-DYNA model of the system, therefore, considers the cask body and its MPC with a small annular clearance between them striking the pad as an assemblage with limited lateral kinematic freedom. The ability of the closure lid to constrain the MPC within the confines of the overpack is also evaluated. The target foundation properties per Tables 2.2.9 and 2.I.0.1 are utilized. In case the target properties are not bounded by those in Table 2.2.9 and 2.I.0.1, a site-specific analysis using the model described in [3.4.31] will be required to demonstrate satisfaction of acceptance criteria in Paragraph 2.2.3(b).

The details of the finite element model, input data and results are archived in the calculation package [3.4.31]. The ISFSI pad LS-DYNA model, which consists of a 320"×100"×36" concrete pad plus 4" thick mudmat and the underlying subgrade (800"×250"×470" in size) with non-reflective lateral and bottom surface boundaries, is identical to that used for standard FW cask in Subparagraph 3.4.4.1.4. All structural members of the loaded cask are explicitly modeled so that any violation of the acceptance criteria can be found by examining the LS-DYNA simulation results (note: the fuel assembly, which is not expected to fail in a tipover event, is modeled as an elastic rectangular body).

Except for the fuel basket, which is divided into four parts based on the temperature distribution of the basket, each structural member of the cask is modeled as an independent part in the LS-DYNA model. Note that the critical weld connection between the MPC shell and the MPC lid is treated as a separate part and modeled with solid elements. Each of the three LS-DYNA models, for different basket types, are discretized with sufficiently high mesh density; very fine grids are used in modeling the MPC enclosure vessel, especially in the areas where high stress gradients are expected (e.g., initial impact location with the overpack). To ensure numerical accuracy, thick shell elements with 10 through-thickness integration points or multi-layer solid elements are used. In all three LS-DYNA models, the HI-STORM FW Version UVH cask is rotated by 1 degree (in the counter clockwise direction) leading to a vertical gap of approximately 4.34 inches between

the ISFSI pad and top impact location of the storage cask. This is done to ensure that all loads are applied prior to cask's impact with the ground.

The same ISFSI concrete pad material model used for the standard HI-STORM FW tipover analysis in Subparagraph 3.4.4.1.4 is adopted for the HI-STORM FW Version UVH tipover analysis. Specifically, the concrete pad behavior is characterized using the same LS-DYNA material model (i.e., MAT_PSEUDO_TENSOR or MAT_016) as for the tipover analysis of the standard HI-STORM FW cask in Subparagraph 3.4.4.1.4. Similarly, the subgrade is also conservatively modeled as an elastic material. Note that this ISFSI pad material modeling approach was originally taken in the USNRC approved storage cask tipover and end drop LS-DYNA analyses [3.4.5] where a good correlation was obtained between the analysis results and the test results.

To assess the potential damage of the cask caused by the tipover accident, an LS-DYNA nonlinear material model with strain rate effect is used to model the responses of all HI-STORM FW Version UVH cask structural members based on the true stress-strain curves of corresponding materials. Note that the strain rate effect for the fuel basket material, i.e., Metamic-HT, is not considered for conservatism.

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 following conclusions demonstrate that all safety criteria are satisfied for the Version UVH cask with MPC-37, MPC-44 and MPC-89 basket designs.

- 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 shims in MPC-44 basket remain attached to it maintaining its physical integrity.
- 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.

Table 3.I.3.1: ON-ISFSI WEIGHTS OF LOADED HI-STORM FW VERSION UVH

Scenario	Weight (kilo-pounds)
Shortest cask loaded with minimum fuel	283
Tallest cask fully loaded	450

Table 3.I.3.2: STRESS INTENSITY RESULTS FOR MPC ENCLOSURE VESSEL – NORMAL CONDITION

Item	Calculated Value (ksi)	Allowable Limit (ksi)	Safety Factor
Lid – Primary Membrane Stress Intensity	10.61	17.00	1.60
Lid – Local Membrane Plus Primary Bending Stress Intensity	15.67	25.52	1.63
Baseplate – Primary Membrane Stress Intensity	9.32	18.05	1.94
Baseplate – Local Membrane Plus Primary Bending Stress Intensity	23.36	27.10	1.16
Shell – Primary Membrane Stress Intensity	12.60	17.00	1.35
Shell – Local Membrane Plus Primary Bending Stress Intensity	20.76	25.52	1.23
Shell – Local Membrane Plus Primary Bending Plus Secondary Stress Intensity	37.08	54.98	1.48

Table 3.I.3.3: STRESS INTENSITY RESULTS FOR MPC ENCLOSURE VESSEL – OFF-NORMAL CONDITION

Item	Calculated Value (ksi)	Allowable Limit (ksi)	Safety Factor
Lid – Primary Membrane Stress Intensity	11.71	18.15	1.55
Lid – Local Membrane Plus Primary Bending Stress Intensity	17.34	27.22	1.57
Baseplate – Primary Membrane Stress Intensity	11.04	19.86	1.80
Baseplate – Local Membrane Plus Primary Bending Stress Intensity	26.36	29.81	1.13
Shell – Primary Membrane Stress Intensity	15.88	18.70	1.18
Shell – Local Membrane Plus Primary Bending Stress Intensity	20.98	28.08	1.34
Shell – Local Membrane Plus Primary Bending Plus Secondary Stress Intensity	46.44	54.15	1.17

Table 3.I.3.4: MAXIMUM FLOOD WATER VELOCITY

Item	Calculated Value (feet/sec) [3.4.13]	Established Limit for Standard FW Cask (feet/sec)
Velocity	37.5	30.5

Table 3.I.3.5: MAXIMUM ALLOWABLE STATIC EXTERNAL PRESSURE

Static External Pressure Limit for UVH Cask	5.45 psi
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Table 3.I.3.6: LIMITING COMBINATION OF HORIZONTAL ZPA AND VERTICAL ZPA FOR UVH CASK

Horizontal ZPA (a_h)	Vertical ZPA (a_v)
0.356	0.237

Table 3.I.3.7: CASK ROTATIONS DUE TO LARGE MISSILE IMPACT

Event	Calculated Value (deg)	Allowable Limit (deg)	Safety Factor
Missile Impact plus Tornado Wind on UVH Cask	2.6	29.25	11.25
Missile Impact plus Pressure Drop on UVH Cask	3.02	29.25	9.69

Table 3.I.3.8: MISSILE PENETRATION RESULTS – SMALL AND INTERMEDIATE MISSILES

Missile Type – Impact Location	Calculated Value (in)	Allowable Limit (in)	Safety Factor
Small Missile – All Impact Locations	< 0.4 in	> 0.5 in (MPC shell thickness)[†]	> 1.25
Intermediate Missile – Side Strike on UVH Cask Outer Shell (away from optional jacking assembly region)*	16.02	28.00	1.75
Intermediate Missile – Side Strike on UVH Cask Outer Shell (near optional jacking assembly region)*	18.01	28.00	1.55
Intermediate Missile – End Strike on UVH Cask Lid*	15.06	15.50	1.03
*For conservatism, the minimum concrete compressive strength per Table 3.3.5 is further decreased by a factor of 2 to account for concrete strength degradation due to exposure to high temperatures (>300°F) from short-term normal, off-normal, or accident conditions. The 50% reduction in strength is a conservative estimate based on the data provided in [3.4.27].			

Table 3.I.3.9: MAXIMUM LOCAL TRUE PLASTIC STRAIN RESULTS – NON-MECHANISTIC TIPOVER

Part	MPC-37	MPC-89	MPC-44	Material Failure Strain
Fuel Basket Within the Active Fuel Region*	1.00x10⁻¹	1.20x10⁻¹	1.16x10⁻¹	1.97x10⁻¹ (MPC-37) 1.53x10⁻¹ (MPC-89) 1.21x10⁻¹ (MPC-44)
MPC Enclosure Vessel	4.80x10⁻²	5.10x10⁻²	4.80x10⁻²	1.05[§]
Cask Overpack (including lid)	3.30x10⁻¹	1.52x10⁻¹	2.32x10⁻¹	3.72x10⁻¹
Cask Lid Bolts	3.18x10⁻³	3.27x10⁻³	2.87x10⁻³	6.10x10⁻¹
*Active fuel region is conservatively considered to be 6” and 14.5” below the top of the basket for the PWR and BWR baskets respectively. Larger strains occur locally at sharp edges but with no failed (eroded) elements.				
[§] MPC plastic strain design limit is conservatively considered to be 0.2 per recommendation in [3.4.6].				

**Table 3.I.3.10: STRESS RESULTS FOR HI-STORM FW VERSION UVH LID –
NORMAL HANDLING**

Item	Calculated Value (ksi)	Allowable Limit (ksi)	Safety Factor
Maximum Primary Membrane Stress	6.6 (conservative)	19.6	2.97
Maximum Primary Membrane Plus Bending Stress	6.6	29.4	4.45
Lift Lug-to-Base Plate Weld	0.474	7	14.76
Lift Lug – Tear Out	2.177	4.20	1.93

**Table 3.I.3.11: GOVERNING STRESS RESULTS FOR HI-STORM FW VERSION UVH
– NORMAL HANDLING AND PRESSURE LOADING**

Item	Calculated Value (ksi)*	Allowable Limit (ksi)	Safety Factor
Maximum Primary Membrane Stress (Overpack)	17.17	34.9	2.03
Maximum Primary Membrane Plus Bending Stress (Overpack)	30.89	52.4	1.70
Maximum Primary Membrane Stress (Lid)	9.56	34.9	3.65
Maximum Primary Membrane Plus Bending Stress (Lid)	17.16	52.4	3.05
*All the tabulated stresses correspond to the governing load case i.e., pressure case 5 in Subsection 3.I.3.2			

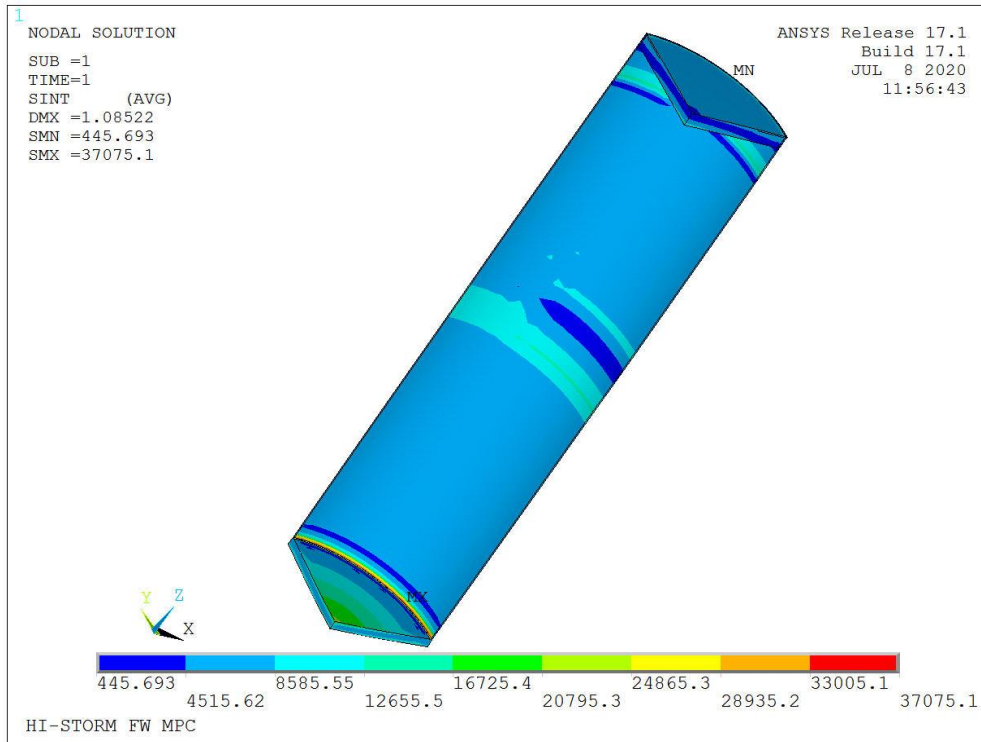


Figure 3.I.3.1: Stress Intensity in MPC Enclosure Vessel – Normal Condition

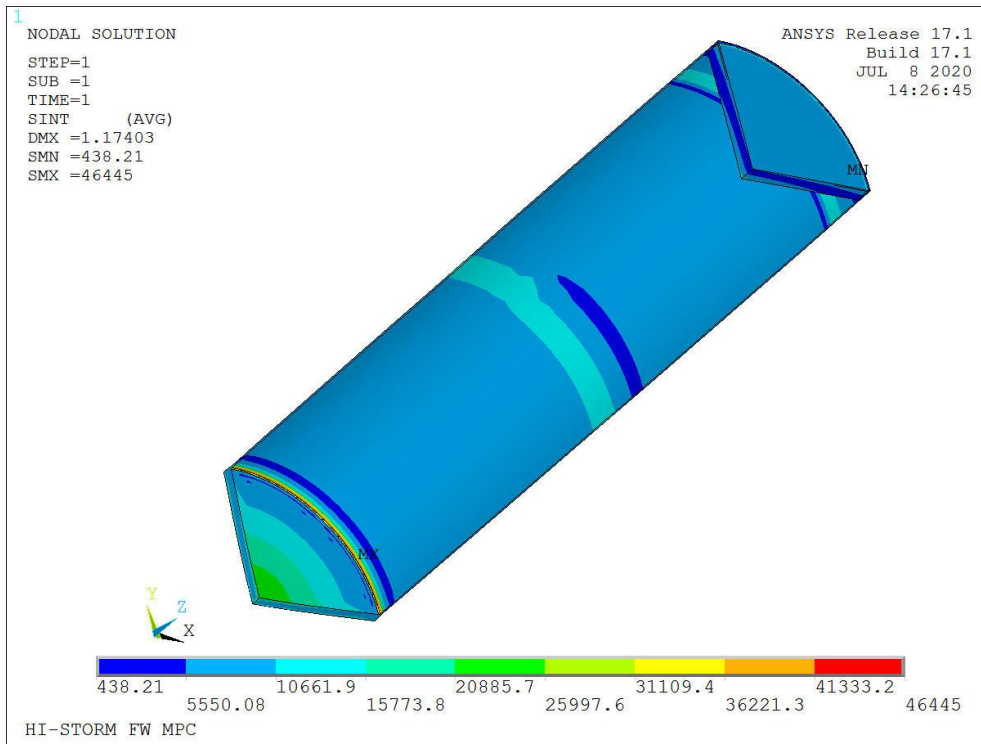


Figure 3.I.3.2: Stress Intensity in MPC Enclosure Vessel – Off-Normal Condition

□ HISTORM FW UVH TIPOVER

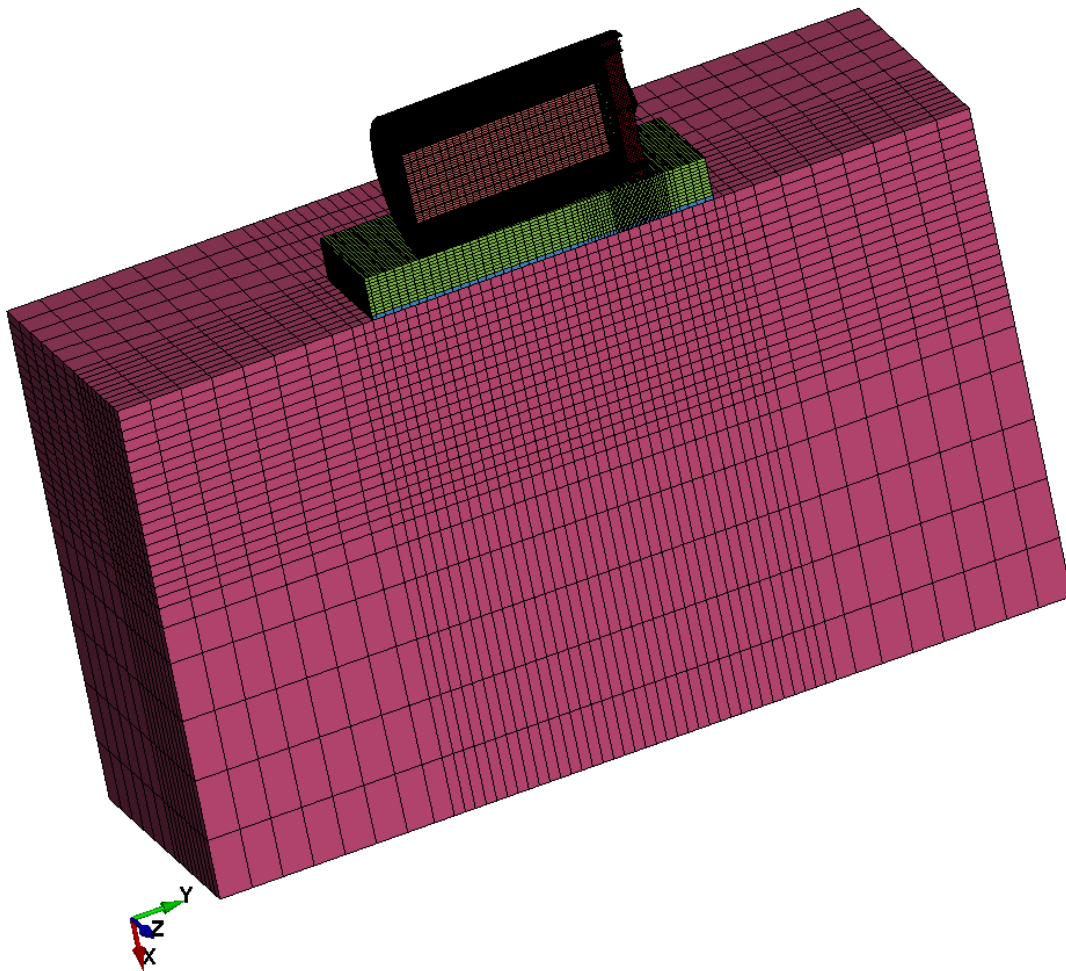


Figure 3.I.3.3: LS-DYNA Tipover Model – HI-STORM FW Version UVH Loaded with MPC-37

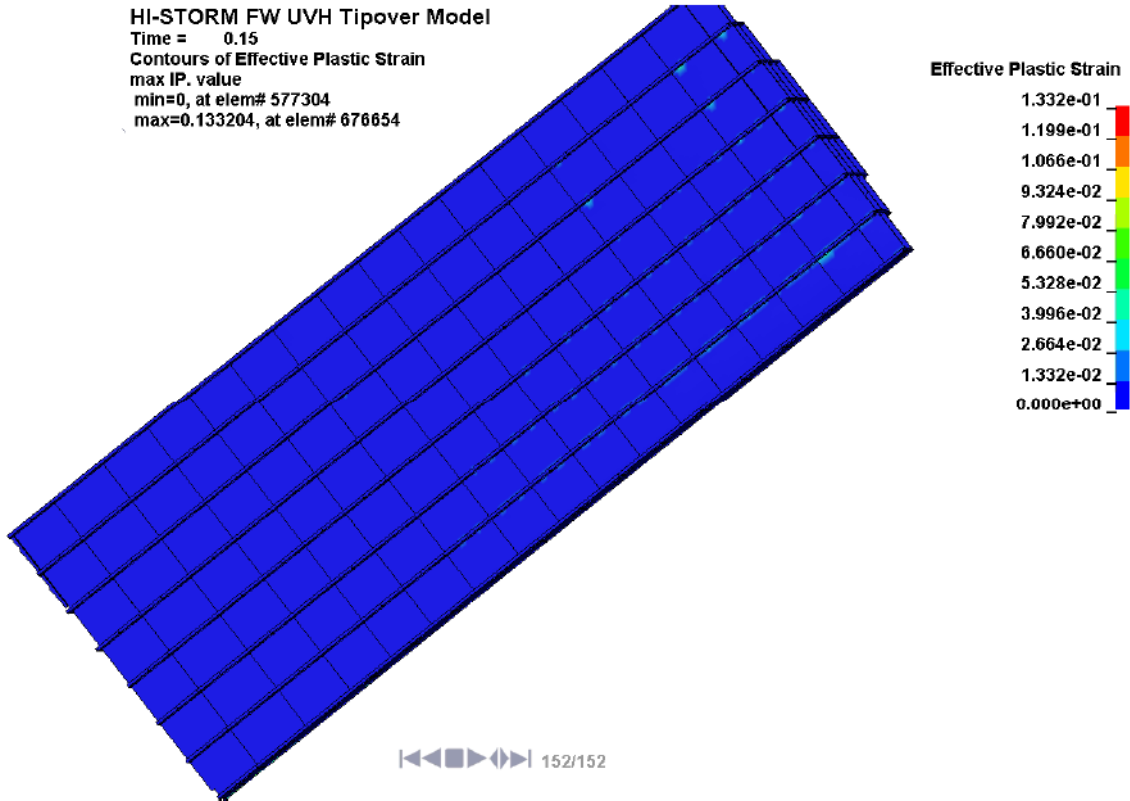


Figure 3.I.3.4: Maximum Plastic Strain –MPC-37 Fuel Basket

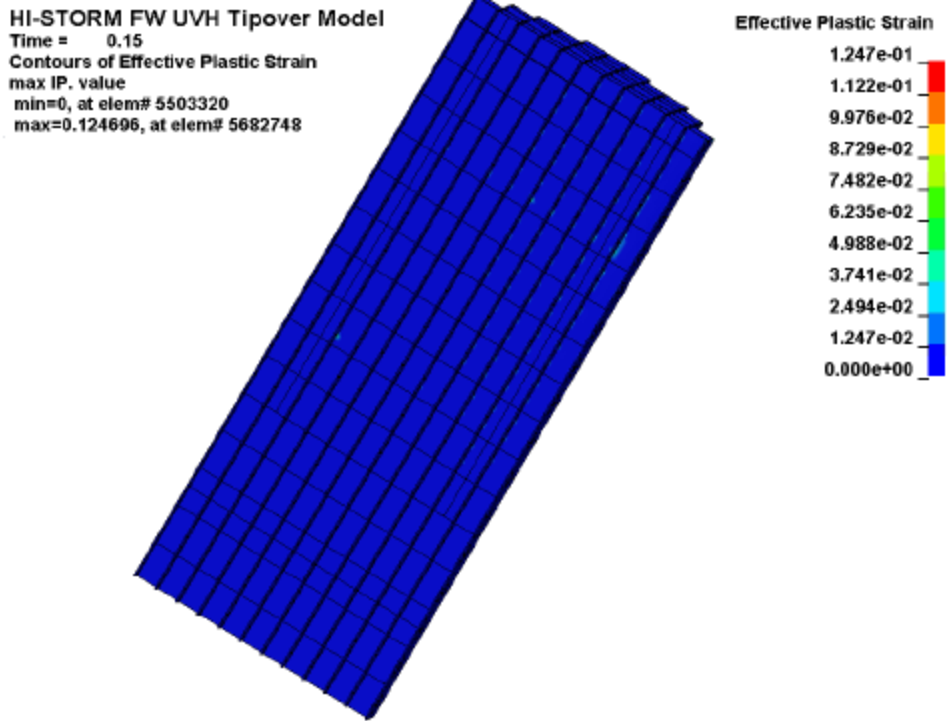


Figure 3.I.3.5: Maximum Plastic Strain –MPC-89 Fuel Basket

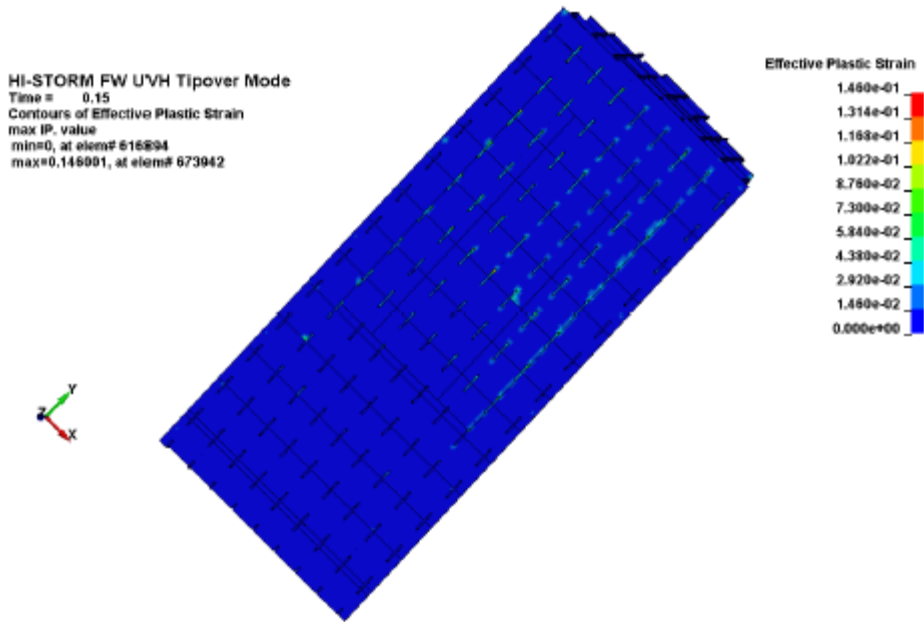


Figure 3.I.3.6: Maximum Plastic Strain –MPC-44CBS Fuel Basket

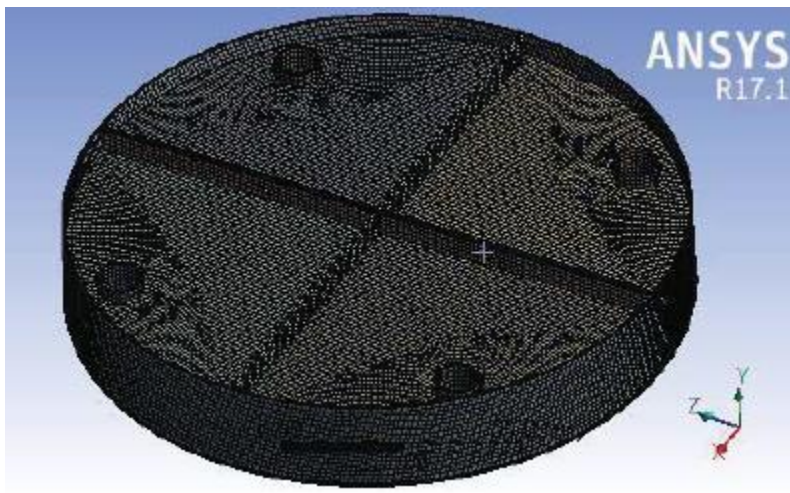


Figure 3.I.3.7: ANSYS Model of HI-STORM FW Version UVH Lid

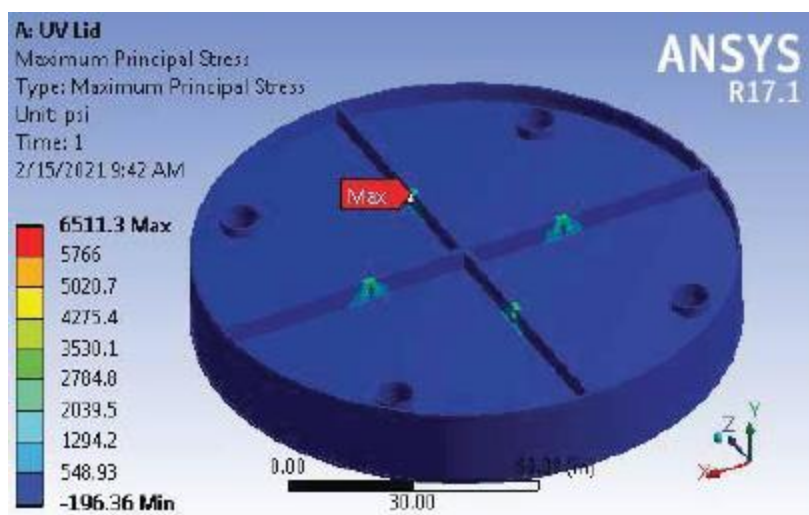


Figure 3.I.3.8: Stress Distribution in HI-STORM FW Version UVH Lid – Normal Handling

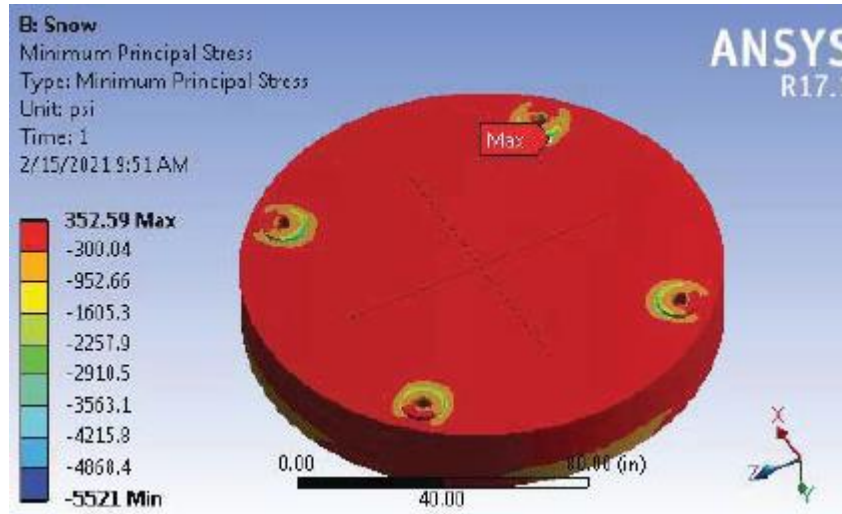


Figure 3.I.3.9: Stress Distribution in HI-STORM FW Version UVH Lid – Snow Load

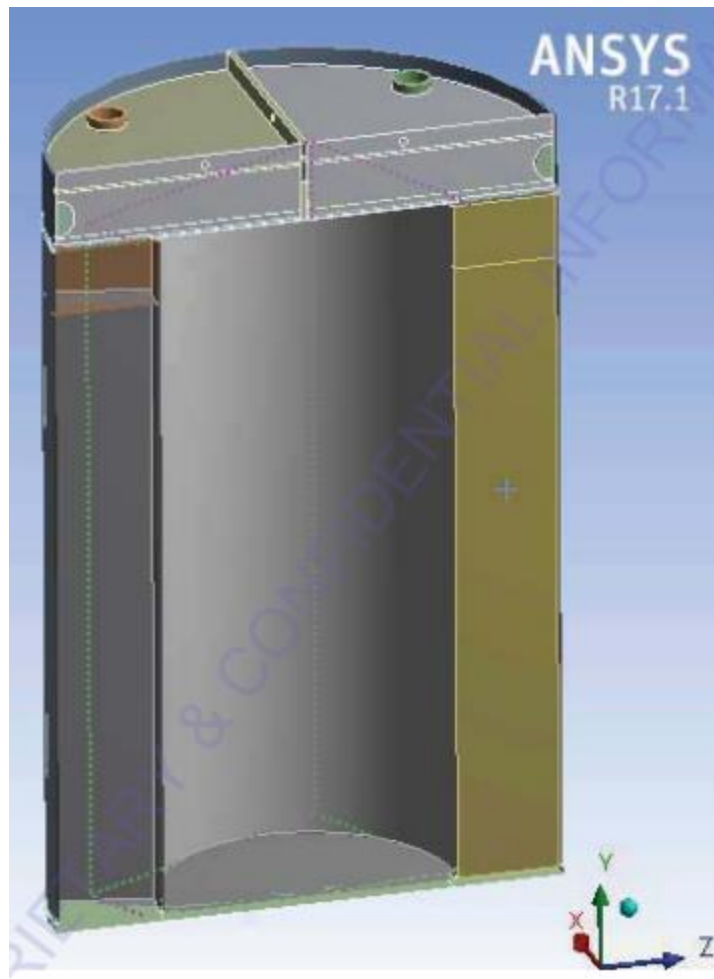


Figure 3.I.3.10: ANSYS Model of HI-STORM FW UVH Overpack

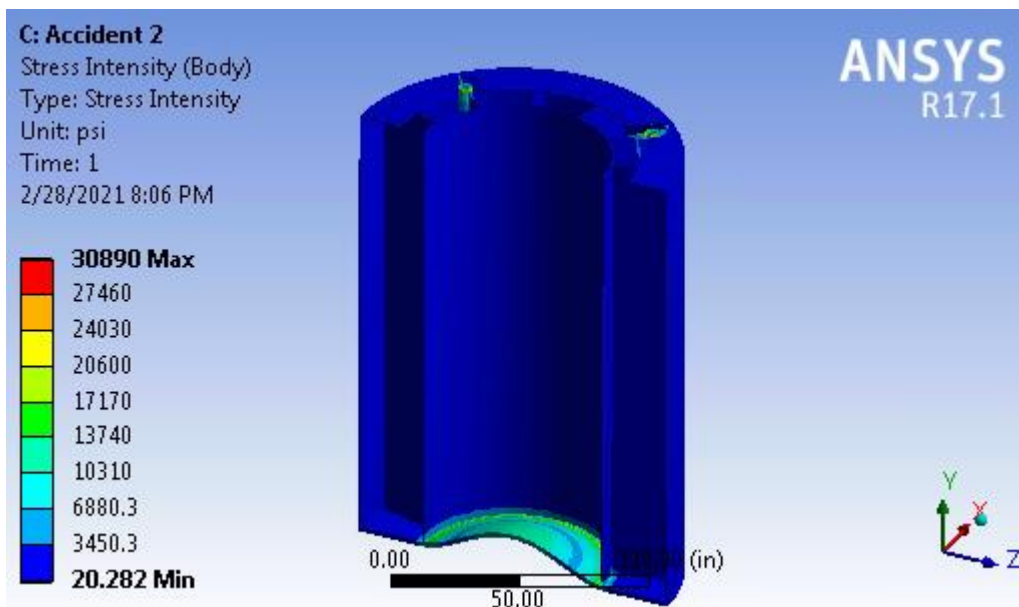


Figure 3.I.3.11: Stress Distribution in HI-STORM FW Version UVH Overpack – Governing Pressure Loading Case (Case 5 in Subsection 3.I.3.2)

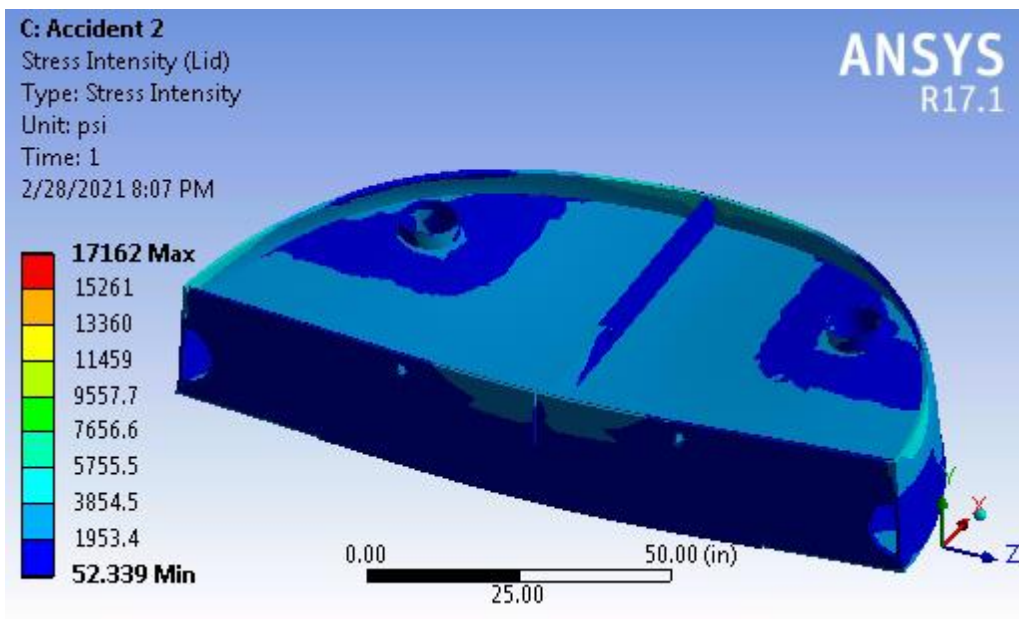


Figure 3.I.3.12: Stress Distribution in HI-STORM FW Version UVH Lid – Governing Pressure Loading Case (Case 5 in Subsection 3.I.3.2)

3.I.4 Safety Conclusions

The structural evaluation of the Version UVH storage cask under the loading conditions unique to it, described in Section 3.I.3, demonstrates that the stresses in all cask components, namely the base plate, the dual shell structure and the closure lid weldments are below the ASME Code limits with significant margins. The structural analysis of the HI-STORM Version UVH closure lid demonstrates that the stresses in lid components are below the stress limits in ASME Code under all loading conditions. In addition, the MPC confinement boundary continues to satisfy the established acceptance criteria under temperature profiles unique to Version UVH Storage System under all loading conditions.

The stability evaluations of the Version UVH storage cask under tornado wind and missile impacts, explosion, earthquake and flood are also performed.

The structural integrity of the Version UVH cask system (with MPC-37, MPC-44 and MPC-89 baskets) is also demonstrated in the event of a non-mechanistic tip-over.

The structural safety of the Storage System under all other loadings germane to the ventilated cask model treated in the main body of this FSAR is established in Table 2.I.2.1. Therefore, the Version UVH overpack is proven to meet all structural criteria applicable to the HI-STORM FW Canister Storage System in this FSAR.