i. The finite element discretization of the overpack is sufficiently detailed to accurately articulate the primary membrane and bending stresses as well as the secondary stresses at locations of gross structural discontinuity. The finite element layouts of the HI-STORM FW overpack body and the top lid are pictorially illustrated in Figures 3.4.3A/B and 3.4.5A-D, respectively. The overpack model consists of over 70,000 nodes and 50,000 elements, which exceed the number of nodes and elements in the HI-STORM 100 tipover model utilized in [3.1.4]. Table 3.1.11 summarizes the key input data that is used to create the finite element models of the HI-STORM FW overpack body and top lid.

ii. The overpack baseplate, anchor blocks, and the lid studs are modeled with SOLID45 elements. The overpack inner and outer shells, bottom vent shells, and the lifting ribs are modeled with SHELL63 elements. A combination of SOLID45, SHELL63, and SOLSH190 elements is used to model the steel components in the HI-STORM FW standard lid. A combination of SOLID185 and SOLSH190 elements is used to model the steel components in the HI-STORM FW Version XL lid, HI-STORM FW domed lid, and the HI-STORM FW Version E lid. These element types are well suited for the overpack geometry and loading conditions, and they have been used successfully in previous cask licensing applications [3.1.10, 3.3.2].

iii. All overpack steel members are represented by their linear elastic material properties (at 300ºF) based on the data provided in Section 3.3. The concrete material in the overpack body is not explicitly modeled. Its mass, however, is accounted for by applying a uniformly distributed pressure on the baseplate annular area between the inner and outer shells (see Figure 3.4.26). The plain concrete in the HI-STORM FW lids (standard, Version XL, domed, and Version E) is explicitly modeled in ANSYS using SOLID65 elements along with the input parameters listed in Table 3.1.12.

iv. To implement the ANSYS finite element model in LS-DYNA, the SOLID45, SHELL63, and SOLSH190 elements are converted to solid, shell, and thick shell elements, respectively, in LS-DYNA. The SOLID65 elements used to model the plain concrete in the HI-STORM FW lid are replaced by MAT_PSEUDO_TENSOR (or MAT_016) elements in LS-DYNA. The plain concrete in the overpack body is also modeled in LS-DYNA using MAT_PSEUDO_TENSOR elements.

v.

~~v.~~ In LS-DYNA, all overpack steel members including the MPC are represented by their applicable nonlinear elastic-plastic true stress-strain relationships.

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The concrete material is modeled in LS-DYNA using a non-linear material model (i.e., MAT_PSEUDO_TENSOR or MAT_016) based on the properties listed in Section 3.3.

- ~~➢–~~Drop Height: The operating procedures used in the HI-STORM FW Version E dry storage implementation recommend the loaded cask to be carried at the minimum possible height. However, architectural features such as door thresholds and elevation changes necessitate a greater carry height. Each site has its own unique haul path topography. The licensing basis analysis herein limits the drop height to 11 inches.
- ➢ Drop Orientation: The loaded casks (HI-STORM FW Version E/HI-TRAC VW) are always handled in the vertical orientation. The maximum cask HI-STORM FW Version E overpack and the HI-TRAC VW transfer cask lift height is limited to 11 inches above the ground. [

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  ~~.~~Consequently, the cask impact force and the corresponding stress, strain and deflection results for the cask internals are maximized during a pure vertical end drop.
- ➢ Site Specific Conditions: Many plants, because of their architecture, require the amount and distribution of shielding to be optimized through the 10CFR72.48 change process to optimize operational goals such as minimizing the crew dose. This design adaptation, therefore, often renders the cask structurally distinct from the standard license-basis design.

The above factors make the accidental cask drop problem unique for each site. Therefore, the exposition in this FSAR, presented below in this sub-section, is focused on specifying the essentials of the LS-DYNA model which must be observed when simulating HI-STORM FW Version E storage cask and HI-TRAC VW transfer cask drop events per [3.4.29]. A common attribute of these –simulation models is that they have been implemented on the benchmarked and QA validated versions of LS-DYNA [~~xxxx~~3.1.8]; that they utilize element types that have been previously used in other safety analyses; and that they have been qualified to ensure numerical convergence. To ensure modeling fidelity in site specific applications, the finite elements used to simulate HI-STORM FW Version E overpack, HI-TRAC VW transfer cask and the loaded MPC are benchmarked for their longevity (years of use) and computational fidelity are summarized in the following table.

Finite Element Types used in the Dynamic Analysis of HI-STORM FW Version E System and HI-TRAC VW Components using LS-DYNA

Element I.D.	HI-STORM FW overpack	All MPC models	HI-TRAC VW transfer cask
Solid Element	Yes	Yes	Yes
Thick shell Element	Yes	Yes	Yes

(a) <u>Key Attributes of the Dynamic Model for HI-STORM FW</u>:

The finite element model summarized herein corresponds to drawing listed in Section 1.5.

Results for HI-STORM FW Version E Cask – Free Drop Event

Part	Strain from Simulation (in/in)	Material Failure Strain (in/in)	Strain at Necking[note1]
Fuel Basket	4.020×10^{-3}	1.97×10^{-1}	PROPRIETARY INFORMATION WITHHELD PER 10CFR2.390
MPC Enclosure Vessel	5.035×10^{-3}	0.2	
Cask Overpack Body	8.125×10^{-2}	3.72×10^{-1}	
[PROPRIETARY INFORMATION WITHHELD PER 10 CFR 2.390]			

It is also noted that the effective (Von-mises) stress in the HI-STORM FW Version E closure lid bolts (see Figure 3.4.56B) remain well below its material yield strength.

Results for HI-TRAC VW – Free Drop Event			
Part	Strain from Simulation (in/in)	Material Failure Strain (in/in)	Strain at Necking[note1]
Fuel Basket	1.588×10^{-3}	1.97×10^{-1}	PROPRIETARY INFORMATION WITHHELD PER 10CFR2.390
MPC Enclosure Vessel	4.752×10^{-3}	0.2	
Cask Overpack	5.920×10^{-4}	3.34×10^{-1}	
[PROPRIETARY INFORMATION WITHHELD PER 10 CFR 2.390]			
Maximum axial deceleration for fuel - (g's)	19.15		
Minimum safety factor for MPC Lid weld	3.26		

Fuel Deceleration – Cask Vertical Drop Event		
Cask Drop	Demand Deceleration - g	Limit Deceleration - g
HI-STORM FW VERSION E Cask Drop	18.92	70 (Per Table 2.1.9)
HI-TRAC VW Drop	19.52	

As can be seen from the above, both drop simulations meet each of the three acceptance criteria set forth in subsection 2.2.3, namely:

- No breach of the MPC Confinement Boundary is indicated.
- The HI-STORM FW Version E overpack suffered no loss of its shielding materialThe shell enclosure structures maintained their physical integrity.
- The stresses in the HI-STORM FW Version E closure lid bolts remain well below its material yield strength and it is demonstrated that the closure lid remains connected to the overpack body subsequent to the drop event.
- The transfer cask suffered no lead slump or loss of its neutron or gamma shield. The shell enclosure structures maintained their physical integrity.
- The maximum axial deceleration experienced by the fuel rods is less than the limit set down in Table 2.1.9.

During the cask handling accidents, the fuel baskets are predominantly subject to axial (or dynamic) loading from basket self-weight independent from the stored fuel assemblies. In other words, the fuel baskets are not subject to significant loading from the fuel assemblies during the HI-STORM cask vertical end drops as opposed to the non-mechanistic tipover event. Since there is no substantial lateral loading on the fuel baskets, and the inertial load from the basket panel self-weight being insignificant as compared to the weight of the stored fuel assemblies, the basket panel is not structurally challenged during the cask handling drops. The basket lateral deflection criterion, as discussed in Section 2.2.8, is not critical for the vertical end drop scenario. The basket panel lateral deflection criterion is critical for non-mechanistic tipover event, which is addressed earlier in this section.

3.4.4.1.10 Load Case 10: Snow Load

In accordance with Table 3.1.1, the HI-STORM FW lid is analyzed using ANSYS to demonstrate that the design basis snow load (Table 2.2.8) does not cause stress levels in the overpack lid to exceed ASME Subsection NF stress limits for Level A. The finite element model is identical to the one used in Subsection 3.4.3 to simulate a vertical lift of the HI-STORM FW lid (see Figures 3.4.5A and 3.4.5B). For conservatism, a pressure load of 10 psig is used in the finite element analysis. The stress distribution in the lid under the bounding snow load is shown in Figure 3.4.25A for the standard lid, Figure 3.4.25B for the Version XL lid, and Figure 3.4.25C for the Version E lid. The maximum stress results are summarized in Table 3.4.10. For conservatism, the maximum calculated stress at any point on the lid, including secondary stress contributions, is compared against the primary membrane and primary bending stress limits per ASME Subsection NF. Since the domed lid has similar configuration but is much thicker compared to the XL lid, the results from XL lid are bounding for domed lid.

3.4.4.1.11 Load Case 11: MPC Reflood Event

During a MPC reflood event, water is introduced to the MPC cavity through the lid drain line to cooldown the MPC internals and support fuel unloading. This quenching operation induces thermal stresses and strains in the fuel rod cladding, which are maximum at the boundary interface between the rising water and the dry (gaseous) cavity. The following analysis demonstrates that the maximum total strain in the fuel cladding due to the reflood event is well below the failure strain limit of the material. Thus, the fuel rod cladding will not be breached due to the MPC reflood event.

The analysis is carried out using the finite element code ANSYS [3.4.1]. The model, which is shown in Figure 3.4.37, is constructed using 4-node plastic large strain elements (SHELL43) based on the cladding dimensions of the PWR reference fuel type. The overall length of the model is equal to 30 times the outside diameter of the fuel cladding. As seen in Figure 3.4.37, the mesh size is reduced at the boundary between the wetted fuel rod and the dry fuel rod, where the highest stresses and strains occur. To account for the gas pressure inside the fuel rod, the top end of the fuel rod is fixed in the vertical direction, and an equivalent axial force is applied at the bottom end. A radial pressure is also applied to the inside surface of the fuel cladding (see Figure 3.4.38). The fuel cladding material is modeled as a bi-linear isotropic hardening material with temperature dependent properties. The key input data used to develop the finite element model are summarized in Table 3.4.14.

[3.4.27] Carette and Malhotra, Performance of Dolostone and Limestone Concretes at Sustained High Temperatures, Temperature Effects on Concrete, ASTM STP 858, 1985, p. 38-67.

[3.4.28] Holtec Report HI- 2188720~~R0~~, “Structure Calculation Package for HI-STORM FW Anchor System”, Revision 1~~0~~.

[3.4.29] Holtec Report HI- 2200647, “Analysis of the Postulated Drop and Missile Impact Events for the Loaded HI-STORM FW Version E Cask and the Loaded HI-TRAC VW System”, Revision 3~~0~~.

[3.4.30] Topical report of Bechtel Power Corporation, BC-TOP-9A, "Design of structures for missile impact", Revision 2.

[3.4.31] Holtec Report HI-2210251, "Benchmarking of Material Stress-Strain Curves in LS-DYNA", Revision 0.

[3.6.1] Visual Nastran 2004, MSC Software, 2004.

BASES

ACTIONS (continued)

C.2.3

In lieu of implementing Required Action C.2.2, an engineering evaluation may be performed to demonstrate that all component and content temperatures remain below accident condition temperature limits in Table 2.2.3 and the MPC internal pressure remains below the accident condition pressure limits in Table 2.2.1. The evaluation would be performed either (1) by using the cask thermal model described in Chapter 4 of this FSAR or (2) by comparison to a previously-evaluated similar condition (i.e., a previous evaluated bounding blockage event). If performing a new evaluation (Option 1 above) the model inputs would be modified to reflect actual or bounding expected site conditions including bounding expected amount of blockage, actual decay heat load, and actual or expected ambient temperature. If a similar evaluation is not available for reference, or an evaluation cannot be performed within the stipulated time, required action C.2.1 or C.2.2 must be implemented. Efforts must continue to restore the SFSC heat removal system to operable status by removing the air flow obstruction(s). If the evaluation shows none of the components exceed the temperatures determined above, the MPC can remain in the OVERPACK. Once the air flow obstructions have been cleared, the SFSC heat removal system is declared operable, and compliance with LCO 3.1.2 is then restored.

(continued)