ATTACHMENT 3

M170230

NEDO-33866
Model 2000 Radioactive Material Transport Package
Safety Analysis Report, Revision 1, September 2017

Non-Proprietary Information – Class I (Public)

NOTICE

This is a non-proprietary version of NEDE-33866P, Revision 1, which has the proprietary information removed. Portions of the document that have been removed are indicated by white space with an open and closed bracket as shown here [[ ]].

GE Hitachi Nuclear Energy

NEDO-33866
Revision 1
September 2017

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Model 2000 Radioactive Material Transport Package Safety Analysis Report

INFORMATION NOTICE

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IMPORTANT NOTICE REGARDING CONTENTS OF THIS REPORT

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REVISION SUMMARY

Changes from Revision 0 to Revision 1 are listed here.

Location	Description of Change	Reason for Change
Chapter 1		
Section 1.1	Deleted "fissile materials" from the first paragraph.	Responses to RAIs 5.1, 5.2, and 5.6.
Section 1.1	Deleted Reference 1-1, as 10 CFR 71 does not need to be a chapter reference. Adjusted all other reference numbers accordingly in Chapter 1. Added pointer to Section 5.1.2 for discussion of exclusive use shipment.	Administrative change.
Section 1.1	Reworded last sentence of first paragraph – CSI not applicable due to removal of fissile content from SAR, as stated in the responses to RAIs 5.1, 5.2, and 5.6.	Responses to RAIs 5.1, 5.2, and 5.6.
Section 1.2	Modified third bullet under "Contents" consistent with removal of fissile material from SAR.	Responses to RAIs 5.1, 5.2, and 5.6.
Section 1.2.1.1	Second paragraph – regarding the cask lid seal, deleted the information associated with Configuration 2.	Removing reference to decay heat configurations and Configuration 2 seal material per response to RAI 4.1.
Section 1.2.1.1	Fourth paragraph – regarding the cask lid seal, deleted the information associated with Configuration 2.	Removing reference to decay heat configurations and Configuration 2 seal material per response to RAI 4.1.
Section 1.2.2.1	Added "nominally" for the HPI dimensions, as the supporting drawing lists the dimensions as nominal.	Change made for clarity.
Section 1.2.2.3	Removed "and fissile materials" from the first sentence. Removed irradiated fuel rods and special nuclear material from the second sentence.	Responses to RAIs 5.1, 5.2, and 5.6.
Section 1.2.2.3	Item d) rewritten to remove reference to Configuration 1 and 2 and clarify the decay heat basis for the SAR.	Removing reference to decay heat configurations consistent with the response to RAI 4.1.
Table 1.2-1	Deleted due to the changes to Section 1.2.2.3 Item d).	Removing reference to decay heat configurations consistent with the response to RAI 4.1.

Location	Description of Change	Reason for Change
Section 1.2.2.3	Removed Irradiated [[ ]] Fuel Rods and Special Nuclear Material as contents for shipment. Also, updated the Cobalt-60 Isotope Rods Item c. to reflect consistency with Section 5.5.2.	Responses to RAIs 1.1, 5.1, 5.2, and 5.6.
Section 1.2.3	Reworded to clarify that fissile material is not an approved content.	Responses to RAIs 5.1, 5.2, and 5.6.
Section 1.2.4	Administratively updated wording related to the additional shoring. Deleted last part of last sentence in fourth paragraph, as there are no longer multiple decay heat configuration designs.	Removing reference to decay heat configurations consistent with the response to RAI 4.1.
Section 1.2.4	Updated the reference to the Chapter 3 section that discussed the protective personnel barrier.	Administrative change.
Table 1.3-1	Updated revision numbers for licensing drawings.	Update made because drawings have been revised since SAR Revision 0 was issued.
Section 1.3.1	Provided revised licensing drawings and associated parts lists in accordance with Table 1.3-1.	Update made because drawings have been revised since SAR Revision 0 was issued.
Section 1.3.2.1	Rewritten to only address the one seal material (originally associated with Configuration 1). References 1-3 and 1-5 deleted, as they are specific to the Former Configuration 2 seal material. Reference 1-4 revised to only provide information for the one seal material (and the reference renumbered due to the other reference deletions).	Responses to RAIs 4.1, 4.2, and 4.3.
Section 1.4	Deleted Reference 1-1 as discussed above. Deleted References 1-3 and 1-5 per the changes to Section 1.3.2.1.	Response to RAIs 4.1, 4.2, and 4.3.
Chapter 2		
Chapter 2	Changed the title of Chapter 2 from "Structural Analysis" to "Structural Evaluation".	For strict adherence to Regulatory Guide 7.9.
Section 2	Created paragraph 2 explaining the licensing basis (1500 W) and the Chapter 2 analysis basis (3000 W).	Elimination of Configuration 2.

Location	Description of Change	Reason for Change
Section 2	Removed bullet 5 concerning support of criticality analysis assumptions.	Criticality analysis has been removed from Chapter 6. Fissile material is no longer in content scope.
Section 2.1.1	Removed Configuration 2 seal materials.	Elimination of Configuration 2.
Table 2.1-3	Removed HPI component weights.	Consistent with GEH licensing drawings 001N8425, 001N8427 and 001N8428
Table 2.1-4	Added for overpack base weight.	Response to RAI 7.2.
Section 2.4.3	Changed closure bolt torque from 500 ft-lb to 720±30 ft pound.	Response to RAI 7.2.
Table 2.5.1-1	Updated lifting device bolt stresses and margins of safety.	Response to RAI 7.2.
Section 2.5.1.2	Changed lifting ear bolt expected life from 12.5 to 11 years.	Response to RAI 7.2.
Section 2.5.2.1	Added missing word "shows".	Editorial correction.
Section 2.6.1	Removed "maximum" from description of internal power generation.	1500 W is maximum, 3000 W bounding for structural analysis.
Section 2.6.1.1	Removed references to Configuration 2 and Configuration 1, replaced with 3000W and 1500W.	GE2000 with HPI is licensed for 1500W with 3000W bounding for structural evaluation.
Section 2.6.1.2	Subsection Radial Thermal Expansion, added "worst case" and changed difference in diameters from 0.19" to 0.020".	Worst case dimensions used consistent with GEH licensing drawings 001N8424R2,001N8425R2, 101E8718R17 and 105E9520R9; difference in diameters consistent with revised Table 2.6.1-2.
Section 2.6.1.2	Subsection Axial Thermal Expansion, added "worst case" and changed difference in lengths from 0.23" to 0.13".	Worst case dimensions used consistent with GEH licensing drawings 001N8424R2,001N8425R2, 101E8718R17 and 105E9520R9; difference in diameters consistent with revised Table 2.6.1-3.
Figure 2.6.1-1	Updated to reflect HPI [[ ]] diameter as built condition.	Consistent with GEH licensing drawing 001N8425 R2.
Figure 2.6.1-2	Updated to reflect material basket as built condition.	Consistent with GEH licensing drawing 001N8424 R2.
Figure 2.6.1-3	Updated to reflect HPI inside diameter as built condition.	Consistent with GEH licensing drawing 001N8425 R2.

Location	Description of Change	Reason for Change
Table 2.6.1-2	Updated for worst case as built dimensions and corrected maximum component temperatures consistent with supporting calculations.	Consistent with as built condition per GEH licensing drawing 001N8425R2 and temperature error correction.
Table 2.6.1-3	Updated for worst case as built dimensions for MB height and corrected maximum component temperatures consistent with supporting calculations.	Consistent with as built condition per GEH licensing drawings 001N1824R2, 001N8425R2, 101E8718 and 105E9520 and temperature error correction.
Table 2.6.1-5	Updated stress component $P_m + P_b + Q$ values and margins of safety as appropriate, deleted stress component Q for all cases because there is no acceptance criteria secondary stress.	Response to RAI 7.2; additional analysis for cask body stresses due to increase in cask lid bolt preload.
Section 2.6.7.1.1	Under subsection "Closure Lid Bolt Preload", replace 32,000 lb preload with 48,000 lb preload consistent with a maximum torque of 750 ft-lb.	Response to RAI 7.2.
Figure 2.6.7-2	Updated for 48,000 lb cask closure bolt preload.	Response to RAI 7.2; additional analysis for cask body stresses due to increase in cask lid bolt preload.
Figure 2.6.7-4	Updated for 48,000 lb cask closure bolt preload.	Response to RAI 7.2; additional analysis for cask body stresses due to increase in cask lid bolt preload.
Section 2.6.7.1.2	Updated paragraph 2 & 3 margin of safety for $P_m + P_b + Q$ consistent with changes to Table 2.6.1-5.	Response to RAI 7.2; additional analysis for cask body stresses due to increase in cask lid bolt preload.
Figure 2.6.7-6	Updated consistent with 48,000 lb cask closure bolt preload.	Response to RAI 7.2; additional analysis for cask body stresses due to increase in cask lid bolt preload.
Table 2.6.7-3	Updated consistent with 48,000 lb cask closure bolt preload.	Response to RAI 7.2; additional analysis for cask body stresses due to increase in cask lid bolt preload.
Figure 2.6.7-8	Updated consistent with 48,000 lb cask closure bolt preload.	Response to RAI 7.2; additional analysis for cask body stresses due to increase in cask lid bolt preload.
Table 2.6.7-5	Updated consistent with 48,000 lb cask closure bolt preload.	Response to RAI 7.2; additional analysis for cask body stresses due to increase in cask lid bolt preload.
Section 2.6.7.1.3	Updated paragraph 3 and 4 margin of safety for $P_m + P_b + Q$ consistent with changes to Tables 2.6.7-9 and Table 2.6.7-10.	Response to RAI 7.2; additional analysis for cask body stresses due to increase in cask lid bolt preload.

Location	Description of Change	Reason for Change
Figure 2.6.7-10	Updated consistent with 48,000 lb cask closure bolt preload.	Response to RAI 7.2; additional analysis for cask body stresses due to increase in cask lid bolt preload.
Table 2.6.7-7	Updated consistent with 48,000 lb cask closure bolt preload.	Response to RAI 7.2; additional analysis for cask body stresses due to increase in cask lid bolt preload.
Figure 2.6.7-12	Updated consistent with 48,000 lb cask closure bolt preload.	Response to RAI 7.2; additional analysis for cask body stresses due to increase in cask lid bolt preload.
Table 2.6.7-9	Updated consistent with 48,000 lb cask closure bolt preload.	Response to RAI 7.2; additional analysis for cask body stresses due to increase in cask lid bolt preload.
Figure 2.6.7-14	Updated consistent with 48,000 lb cask closure bolt preload.	Response to RAI 7.2; additional analysis for cask body stresses due to increase in cask lid bolt preload.
Table 2.6.7-11	Updated consistent with 48,000 lb cask closure bolt preload.	Response to RAI 7.2; additional analysis for cask body stresses due to increase in cask lid bolt preload.
Section 2.6.7.1.6	Added new section for cask overpack NCT end drop bolt evaluation.	Response to RAI 7.2.
Section 2.6.7.3	Deleted 2nd sentence in paragraph 1, added NCT end drop case to material basket evaluation.	Response to RAI 2.1.
Section 2.7.1.2.5	Added new section for cask overpack HAC end drop bolt evaluation.	Response to RAI 7.2.
Section 2.7.1.3	Added material basket HAC end drop evaluation.	Response to RAI 2.2.
Section 2.7.1.3	Added subsection title “HAC Side Drop”.	Editorial change.
Section 2.7.1.3	Corrected “NCT side drop. . .” to “HAC side drop. . .” in G definition.	Editorial correction.
Section 2.7.5	Changed paragraph to state that the Model 2000 Transport Package is not licensed to transport fissile material.	Criticality analysis has been removed from Chapter 6. Fissile material is no longer in content scope.
Section 2.12.3.1	Subsection “Bolt Preload”, updated for 600±20 ft-lb lifting ear bolt torque.	Response to RAI 7.2.
Figure 2.12.3-7	Label added to figure showing lifting ear contact bearing stresses.	Editorial change
Table 2.12.3-2	Added new table for summarizing lifting ear bolt percent preload.	Response to RAI 7.2.

Location	Description of Change	Reason for Change
Section 2.12.3.1	Subsection "Bolt Fatigue Analysis", updated for 600±20 ft-lb lifting ear bolt torque.	Response to RAI 7.2.
Table 2.12.2-3	Updated bolt and thread stresses and margins of safety.	Response to RAI 7.2.
Section 2.12.4.1	Updated based on a cask lid closure bolt torque of 720±30 ft-lbs.	Response to RAI 7.2.
Section 2.12.4.1	Removed soft steel and stainless steel gasket retainer options.	Elimination of Configuration 2.
Table 2.12.4-1	Updated removing carbon steel and stainless steel parameters.	Elimination of Configuration 2.
Table 2.12.4-2	Deleted – Bolt torque sizing analysis removed.	Response to RAI 7.2 and elimination of Configuration 2.
Table 2.12.4-3	Deleted – Cask lid bolt torque sizing analysis removed.	Response to RAI 7.2 and elimination of Configuration 2.
Table 2.12.4-4	Deleted– Cask lid bolt torque sizing analysis removed.	Response to RAI 7.2 and elimination of Configuration 2.
Table 2.12.4-7 (now Table 2.12.4-4)	Updated existing parameters consistent with cask lid bolt torque and low temperature aluminum cask seal, added additional parameters from deleted Table 2.12.4-2 required for the bolt load and stress evaluation.	Response to RAI 7.2 and elimination of Configuration 2.
Table 2.12.4-8 (now Table 2.12.4-5)	Updated consistent with revised cask closure bolt load analysis.	Response to RAI 7.2 and elimination of Configuration 2.
Table 2.12.4-9 (now Table 2.12.4-6)	Updated consistent with revised cask closure bolt load analysis.	Response to RAI 7.2 and elimination of Configuration 2.
Table 2.12.4-10 (now Table 2.12.4-7)	Updated consistent with revised cask closure bolt load analysis.	Response to RAI 7.2 and elimination of Configuration 2.
Table 2.12.4-11 (now Table 2.12.4-8)	Updated consistent with revised cask closure bolt load analysis.	Response to RAI 7.2 and elimination of Configuration 2.
Section 2.12.4.2.16	Updated results consistent with revised cask closure bolt load analysis.	Response to RAI 7.2 and elimination of Configuration 2.
Section 2.12.4.2.17	Updated results consistent with revised with cask closure bolt load analysis.	Response to RAI 7.2 and elimination of Configuration 2.
Table 2.12.4-12 (now Table 2.12.4-9)	Updated consistent with revised cask closure bolt load analysis.	Response to RAI 7.2 and elimination of Configuration 2.

Location	Description of Change	Reason for Change
Chapter 3		
Section 3	Removed Configurations 1 and 2, added 2nd paragraph explaining the licensing basis (1500W) and the Chapter 3 analysis basis (3000W).	Elimination of Configuration 2.
Section 3.1.1	Updated 3rd paragraph, cask lid seal discussion.	Elimination of Configuration 2.
Section 3.1.2	Removed “configurations” from first sentence, removed irradiated fuel as a content, deleted last sentence.	Elimination of Configuration 2 and revised content scope.
Section 3.1.3	Removed Configuration 2.	Elimination of Configuration 2.
Table 3.1.3-1	Changed note c to “See Chapter 4 for additional discussion”.	Chapter 4 provides the 1500 W decay heat licensing basis temperatures for the seal locations.
Section 3.1.3.1	Removed Configuration 2.	Elimination of Configuration 2.
Table 3.1.3-2	Added note c callouts to lid seal and O-ring allowable temperatures and added note c “See Chapter 4 for additional discussion”.	Chapter 4 provides the 1500 W decay heat licensing basis temperatures for the seal locations.
Section 3.1.3.2	Removed Configuration 2.	Elimination of Configuration 2.
Table 3.1.3-3	Added note b callouts to lid seal and O-ring allowable temperatures and added note b “See Chapter 4 for additional discussion”.	Chapter 4 provides the 1500 W decay heat licensing basis temperatures for the seal locations.
Section 3.2.2	Removed Configuration 2, updated description of seal, O-ring and retainer materials.	Elimination of Configuration 2.
Section 3.3	Removed Configuration 2.	Elimination of Configuration 2.
Figure 3.3-1	Removed Configuration 2 from title.	Elimination of Configuration 2.
Figure 3.3-2	Removed Configuration 2 from title.	Elimination of Configuration 2.
Figure 3.3-3	Removed Configuration 2 from title.	Elimination of Configuration 2.
Section 3.3.1.1.2	Removed Configuration 2.	Elimination of Configuration 2.
Figure 3.3.1-2	Removed Configuration from title.	Elimination of Configuration 2.
Section 3.3.1.1.3	Removed Configuration 2.	Elimination of Configuration 2.
Figure 3.3.1-3	Removed Configuration from title.	Elimination of Configuration 2.
Section 3.4	Removed Configuration 2.	Elimination of Configuration 2.
Section 3.4.3	Removed Configuration 2.	Elimination of Configuration 2.
Table 3.4.3-1	Removed Configuration 2 from title.	Elimination of Configuration 2.
Figure 3.4.3-1	Removed Configuration 2 from title.	Elimination of Configuration 2.

Location	Description of Change	Reason for Change
Figure 3.4.3-2	Removed Configuration 2 from title.	Elimination of Configuration 2.
Figure 3.4.3-3	Removed Configuration 2 from title.	Elimination of Configuration 2.
Figure 3.4.3-4	Removed Configuration 2 from title.	Elimination of Configuration 2.
Figure 3.4.3-5	Removed Configuration 2 from title.	Elimination of Configuration 2.
Table 3.4.3-2	Removed Configuration 2 from title.	Elimination of Configuration 2.
Figure 3.4.3-6	Removed Configuration 2 from title.	Elimination of Configuration 2.
Section 3.5.1	Removed Configuration 1 and Configuration 2 from section title and text.	Elimination of Configuration 2.
Figure 3.5.1-1	Removed Configuration 1 from title.	Elimination of Configuration 2.
Table 3.5.1-1	Removed Configuration 1 from title.	Elimination of Configuration 2.
Table 3.5.1-2	Removed Configuration 1 from title.	Elimination of Configuration 2.
Table 3.5.1-3	Removed Configuration 1 from title.	Elimination of Configuration 2.
Figure 3.5.1-2	Removed Configuration 1 from title.	Elimination of Configuration 2.
Figure 3.5.1-3	Removed Configuration 1 from title.	Elimination of Configuration 2.
Table 3.5.1-4	Removed Configuration 1 from title.	Elimination of Configuration 2.
Table 3.5.1-5	Removed Configuration 1 from title, updated note a, deleted note b.	Elimination of Configuration 2.
Table 3.5.1-6	Removed Configuration 1 from title.	Elimination of Configuration 2.
Table 3.5.1-7	Removed Configuration 1 from title.	Elimination of Configuration 2.
References	Updated References 3-4 and 3-7.	Response to RAI 3.1.
Chapter 4		
Section 4	Removed "primary" from 4th sentence in response to RAI 8.2. Reference 4-1 has been deleted – see basis in description of change for Section 4.6.	Response to RAI 8.2.
Section 4.1	Reworded section to clarify thermal decay heat basis for Chapter 4.	Removes reference to decay heat configurations and establishes the basis for Chapter 4.
Section 4.1.2	Revised the cask lid closure torque, consistent with the response to RAI 7.2.	Response to RAI 7.2.
Section 4.1.3	Deleted Reference 4-2 – see basis in description of change for Section 4.6.	Administrative change.
Section 4.1.3.2	Eliminated reference to the configuration numbers, as well as the lid seal for the 3000 W case, as the 1500 W decay heat case forms the basis for Chapter 4 as stated in Section 4.1.	Removes reference to decay heat configurations and establishes the basis for Chapter 4. Changes are consistent with the responses to RAIs 4.2 and 4.3.

Location	Description of Change	Reason for Change
Figure 4.1.3-3	Replaced the figure by removing the material options for the lid gasket.	Removes Configuration 2 seal material.
Section 4.1.3.3	Added wording to note that the cask port O-rings and covers are outside the containment boundary, consistent with the response to RAI 4.1. Eliminated reference to the configuration numbers, as well as the O-ring material for the 3000 W case, as the 1500 W decay heat case forms the basis for Chapter 4 as stated in Section 4.1.	Removes reference to decay heat configurations and establishes the basis for Chapter 4. Changes are consistent with the responses to RAIs 4.2 and 4.3.
Section 4.2.1	Section heading has been deleted, and the text has been moved to Section 4.2. Maximum pressure during NCT has been updated in the second paragraph to reflect the 1500 W case.	Removes reference to decay heat configurations and establishing the basis for Chapter 4.
Section 4.2.2	Section has been deleted in its entirety.	The 1500 W case forms the basis for Chapter 4 as stated in Section 4.1, and Configuration 2 has been removed per the response to RAI 4.2.
Section 4.3.1	Section heading 4.3.1 has been deleted. Maximum pressure during HAC has been updated to reflect the 1500 W case. Clarification has been added for the cask drain and test ports exceeding the 400°F seal material design temperature consistent with the response in RAI 4.1.	Response to RAI 4.1.
Section 4.3.2	Section has been deleted in its entirety.	The 1500 W case forms the basis for Chapter 4 as stated in Section 4.1, and Configuration 2 has been removed per the response to RAI 4.2.
Section 4.4	Eliminated reference to the configuration numbers and stated the values for the 1500 W decay heat thermal basis. Clarified the conditions used in the acceptance testing.	Removes reference to decay heat configurations and establishes the basis for Chapter 4.
Section 4.5	Section in its entirety has been deleted, as it refers to Configuration 2 results.	Removes reference to decay heat configurations and establishes the basis for Chapter 4.

Location	Description of Change	Reason for Change
Section 4.6	Renumbered to Section 4.5 based on the change above. References 4-1 and 4-2 have been deleted. Reference 4-1 points to 10 CFR 71, which does not need a reference, and Reference 4-2 is redundant to the licensing drawings listed in Section 1.3.1. Remaining references have been renumbered.	Administrative change.
Chapter 5		
Section 5.1.1	Removed “and solid fissile materials”.	Fissile material is no longer an approved shipping content per responses to RAI 5.1, RAI 5.2 and RAI 5.6.
Section 5.1.2	Changed from three content types to two content types.	Fissile material is no longer an approved shipping content per responses to RAI 5.1, RAI 5.2 and RAI 5.6.
Table 5.1-2	Removed row of Content 1 and updated dose rates; changed note from 1 and 2 to a and b.	Fissile material is no longer an approved shipping content per responses to RAI 5.1, RAI 5.2 and RAI 5.6. Update the dose rates due to the elimination of Configuration 2 (3000W) per response to RAI 5.5.
Table 5.1-3	Removed row of Content 1 and updated dose rates; changed note from 1 and 2 to a and b.	Fissile material is no longer an approved shipping content per responses to RAI 5.1, RAI 5.2 and RAI 5.6. Update the dose rates due to the elimination of Configuration 2 (3000W) per response to RAI 5.5.
Section 5.2	In first paragraph, removed the content regarding irradiated fuel and special nuclear material.	Fissile material is no longer an approved shipping content per responses to RAI 5.1, RAI 5.2 and RAI 5.6.
Section 5.2	Removed description of Irradiated Fuel.	Fissile material is no longer an approved shipping content per responses to RAI 5.1, RAI 5.2 and RAI 5.6.
Section 5.2	Removed description of Special Nuclear Material.	Fissile material is no longer an approved shipping content per responses to RAI 5.1, RAI 5.2 and RAI 5.6.

Location	Description of Change	Reason for Change
Section 5.2.1.1	Deleted Section 5.2.1.1.	Fissile material is no longer an approved shipping content per responses to RAI 5.1, RAI 5.2 and RAI 5.6.
Section 5.2.1.2 (now 5.2.1.1)	Added ORIGEN-S description.	Carry over from deleted Section 5.2.1.1.
Section 5.2.1.3 (now 5.2.1.2)	Changed from 3000W to 1500W and from 194,500 Ci to 97,250 Ci.	Configuration 2 (3000W) is no longer an approved configuration per response to RAI 5.5.
Table 5.2-4 (now 5.2-2)	Changed from 194,500 Ci to 97,250 Ci and reduce source strength to half.	Configuration 2 (3000W) is no longer an approved configuration per response to RAI 5.5.
Section 5.2.2.1	Deleted Section 5.2.2.1.	Fissile material is no longer an approved shipping content per responses to RAI 5.1, RAI 5.2 and RAI 5.6.
Section 5.3.1.1	Removed description of Irradiated Fuel.	Fissile material is no longer an approved shipping content per responses to RAI 5.1, RAI 5.2 and RAI 5.6.
Section 5.3.1.1	Editorial modification under Irradiated Hardware and Byproducts and Cobalt-60 Isotope Rods.	For consistency and match shielding model.
Section 5.3.1.3	Added "(except cavity radius which is nominal)" to the third sentence of Section 5.3.1.3.	Drawing 001N8425 Revision 2 includes a tolerance.
Table 5.3-1	Added Note d.	Drawing 001N8425 Revision 2 includes a tolerance.
Section 5.3.1.3	Editorial modification due to removal of neutron shielding model because it is not applicable to irradiated hardware and byproduct and Co-60 isotope rod.	Fissile material is no longer an approved shipping content per responses to RAI 5.1, RAI 5.2 and RAI 5.6.
Table 5.3-1	Changed from MCNP to MCNP6, delete MCNP Surface column, change Dimension column to Parameter column, change value columns to Dimension columns, change note from 1-3 to a-c, add description in Parameter column.	For consistency.
Figure 5.3-2	Removed neutron shielding model because it is not applicable to irradiated hardware and byproduct and Co-60 isotope rod.	Fissile material is no longer an approved shipping content per responses to RAI 5.1, RAI 5.2 and RAI 5.6.

Location	Description of Change	Reason for Change
Section 5.3.1.4	Editorial modification due to removal of neutron shielding model because it is not applicable to irradiated hardware and byproduct and Co-60 isotope rod.	Fissile material is no longer an approved shipping content per responses to RAI 5.1, RAI 5.2 and RAI 5.6.
Figure 5.3-3	Removed neutron shielding model because it is not applicable to irradiated hardware and byproduct and Co-60 isotope rod.	Fissile material is no longer an approved shipping content per responses to RAI 5.1, RAI 5.2 and RAI 5.6.
Section 5.3.1.5	Changed from MNCP to MCNP6 and delete tally description.	Tally description is not needed because it is consistent with 10 CFR 71.47 and 10 CFR 71.51.
Tables 5.3-2	Deleted Table 5.3-2.	Tally description is not needed because it is consistent with 10 CFR 71.47 and 10 CFR 71.51.
Tables 5.3-3	Deleted Table 5.3-3.	Tally description is not needed because it is consistent with 10 CFR 71.47 and 10 CFR 71.51.
Section 5.3.2	Removed description of neutron shielding model because it is not applicable to irradiated hardware and byproduct and Co-60 isotope rod.	Fissile material is no longer an approved shipping content per responses to RAI 5.1, RAI 5.2 and RAI 5.6.
Section 5.4.1.1	Editorial modification due to removal of neutron shielding model because it is not applicable to irradiated hardware and byproduct and Co-60 isotope rod.	Fissile material is no longer an approved shipping content per responses to RAI 5.1, RAI 5.2 and RAI 5.6.
Section 5.4.1.2	Editorial modification due to removal of neutron shielding model because it is not applicable to irradiated hardware and byproduct and Co-60 isotope rod.	Fissile material is no longer an approved shipping content per responses to RAI 5.1, RAI 5.2 and RAI 5.6.
Section 5.4.1.3	Deleted Section 5.4.1.3.	Fissile material is no longer an approved shipping content per responses to RAI 5.1, RAI 5.2 and RAI 5.6.
Section 5.4.3	Deleted description of neutron conversion factor.	The neutron conversion factor is not applicable to irradiated hardware and byproduct and Co-60 isotope rod.
Table 5.4-2	Deleted Table 5.4-2.	The neutron conversion factor is not applicable to irradiated hardware and byproduct and Co-60 isotope rod.

Location	Description of Change	Reason for Change
Section 5.4.4	Changed from three content types to two content types.	Fissile material is no longer an approved shipping content per responses to RAI 5.1, RAI 5.2 and RAI 5.6.
Section 5.4.4.1	Deleted previous Section 5.4.4.1.	Fissile material is no longer an approved shipping content per responses to RAI 5.1, RAI 5.2 and RAI 5.6.
Section 5.4.4.2 (now 5.4.4.1)	Changed from 3000 W to 1500 W.	Configuration 2 (3000W) is no longer an approved configuration per response to RAI 5.5.
Table 5.4-15 (now 5.4-4)	Updated activity limit in Table 5.4-15 (now 5.4-4) due to 1500W. thermal limit	Configuration 2 (3000W) is no longer an approved configuration per response to RAI 5.5.
Table 5.4-16 (now 5.4-5)	Updated dose rate in Table 5.4-16 (now 5.4-5) due to 1500W thermal limit.	Configuration 2 (3000W) is no longer an approved configuration per response to RAI 5.5.
Section 5.4.4.3 (now 5.4.4.2)	Changed from 3000 W to 1500 W.	Configuration 2 (3000W) is no longer an approved configuration per response to RAI 5.5.
Table 5.4-19 (now 5.4-8)	Updated dose rate in Table 5.4-19 (now 5.4-8) due to 1500W thermal limit.	Configuration 2 (3000W) is no longer an approved configuration per response to RAI 5.5.
Section 5.4.4.4 (now 5.4.4.3)	Removed irradiated fuel related text.	Fissile material is no longer an approved shipping content per responses to RAI 5.1, RAI 5.2 and RAI 5.6.
Section 5.5.1	Deleted Section 5.5.1.	Fissile material is no longer an approved shipping content per responses to RAI 5.1, RAI 5.2 and RAI 5.6.
Section 5.5.2 (now 5.5.1)	Added a sentence to the end of the first paragraph.	Updated per responses to RAI 5.3 and RAI 7.3.
Table 5.5-7 (now 5.5-2)	Changed note from 1 to a.	For consistency.
Section 5.5.3 (now 5.5.2)	Removed Configuration 2 from the sentence before Table 5.5-28 (now 5.5-23).	Configuration 2 (3000W) is no longer an approved configuration per response to RAI 5.5.
Table 5.5-28 (now 5.5-23)	Changed note from 1 to a.	For consistency.
Section 5.5.3 (now 5.5.2)	Deleted the last 5 paragraphs.	Paragraphs are not needed per response to RAI 5.4.

Location	Description of Change	Reason for Change
Table 5.5-29	Deleted Table 5.5-29.	Table is not needed per response to RAI 5.4.
Section 5.5.4 (now 5.5.3)	Removed Configuration 1 and Configuration 2 from the first sentence.	Configuration 2 (3000W) is no longer an approved configuration per response to RAI 5.5.
Table 5.5-30 (now 5.5-24)	Changed note from 1 and 2 to a and b; removed isotopes Sn-117 and Sn-119.	Consistent with Table 5.5-7 (now 5.5-2).
Section 5.5.5	Deleted Section 5.5.5.	Fissile material is no longer an approved shipping content per responses to RAI 5.1, RAI 5.2 and RAI 5.6.
Section 5.5.6 (now 5.5.4)	Removed the sentence (related to Configuration 2) before Table 5.5-40 (now 5.5-28).	Configuration 2 (3000W) is no longer an approved configuration per response to RAI 5.5.
Table 5.5-39 (now 5.5-27)	Updated the total activity.	Configuration 2 (3000W) is no longer an approved configuration per response to RAI 5.5.
Table 5.5-40 (now 5.5-28)	Changed the decay heat limit from 3000 W to 1500 W.	Configuration 2 (3000W) is no longer an approved configuration per response to RAI 5.5.
Table 5.5-41 (now 5.5-29)	Changed the decay heat limit from 3000 W to 1500 W.	Configuration 2 (3000W) is no longer an approved configuration per response to RAI 5.5.
Table 5.5-42 (now 5.5-30)	Changed the decay heat limit from 3000 W to 1500 W and update values.	Configuration 2 (3000W) is no longer an approved configuration per response to RAI 5.5.
Section 5.5.7 (now 5.5.5)	Removed irradiated fuel related text.	Fissile material is no longer an approved shipping content per responses to RAI 5.1, RAI 5.2 and RAI 5.6.
Table 5.5-43	Deleted Table 5.5-4.	Fissile material is no longer an approved shipping content per responses to RAI 5.1, RAI 5.2 and RAI 5.6.
References	Deleted References 5-3 and 5-10.	Fissile material is no longer an approved shipping content per responses to RAI 5.1, RAI 5.2 and RAI 5.6.
Chapter 6		
Chapter 6	Replaced Chapter 6 content with a paragraph.	Fissile material is no longer an approved shipping content per responses to RAI 6.1 and RAI 6.2.

Location	Description of Change	Reason for Change
Chapter 7		
Chapter 7 has been modified to reflect the global removal of the 3000W configuration and text associated with irradiated fuel rods and special nuclear material. In addition to the changes listed below to address the RAIs provided, Chapter 7 has been modified to incorporate operational experiences and current lessons learned.		
Section 7.1.1.3:b	Inserted "± 20".	In response to RAI 7.2.
Section 7.1.2.2	Deleted.	Removal of Irradiated Fuel Rods from the Cask scope and in response to RAI 7.5.
Section 7.1.2.2.c (Previously Section 7.1.2.3.c)	Deleted second sentence. Inserted "The HPI material basket may be used as shoring, but is not required."	Clarification in response to RAI 7.1.
Section 7.1.2.4	Deleted.	Removal of Special Nuclear Material from the Cask scope and in response to RAI 7.5.
Section 7.1.3.2.a	Inserted "500" deleted, "720±30".	Correction to the required torque bolt and in response to RAI 7.2.
Section 7.1.4.1.e	Inserted "±5".	Addition of tolerance in response to RAI 7.2.
Section 7.2.1.3.c	Inserted "±20".	Addition of tolerance in response to RAI 7.2.
Section 7.2.2.1	Removed reference to irradiated fuel.	Removal of Irradiated Fuel Rods from the Cask scope.
Section 7.2.2.2	Deleted "/ 500 grams U-235 Equivalent Mass of SNM".	Removal of Special Nuclear Material from the Cask scope and in response to RAI 7.5.
Section 7.2.2.2	Deleted "either" and "or 500 grams U-235 equivalent mass of SNM".	Removal of Special Nuclear Material from the Cask scope.
Section 7.2.2.3.b	Inserted "Install the spacer, if one came with the packaging" deleted, "If spacer was provided, confirm it is secured to the HPI top plug".	Clarification on spacer use and in response to RAI 7.2.
Section 7.3.2.b	Inserted "500" deleted, "720±30".	In response to RAI 7.2.
Section 7.5.1 (Previously Section 7.5.2)	Inserted second to last bullet "criticality" deleted, "activity."	In response to RAI 8.3.
Section 7.5.1 – 2.	Inserted "(alpha and beta emitters)"; inserted "A list of radionuclides for consideration to include in the loading plan is provided in, but not limited to, Table 5.5-24."	In response to RAI 7.3.

Location	Description of Change	Reason for Change
Section 7.5.2 – 1.	Changed to "Verify that the peak activity in any axial 1-inch increment in the HPI cavity is in accordance with Section 5.5.2."	In response to RAI 7.4.
Section 7.5.2 – 1.	All bullets deleted.	Clarification in response to RAI 7.4.
Section 7.5.4 – 1.	Deleted.	Removal of Irradiated Fuel Rods from the Cask scope.
Section 7.5.5	Deleted.	Removal of Special Nuclear Material from the Cask scope and in response to RAI 7.5.
Chapter 8		
Section 8	Removed Reference 8-1, which points to 10 CFR 71, which does not need a reference. Other references have been renumbered.	Administrative change.
Section 8.1.5.2	Eliminated reference to the configuration numbers, as well as the lid seal material for the 3000 W case, as the 1500 W decay heat case forms the basis for containment as stated in Section 4.1. Clarified the lid seal test conditions.	The lid seal material is based on the 1500 W decay heat case, as stated in Section 4.1.
Section 8.1.7	Added clarification at the end of the section denoting the decay heat basis.	Because the thermal testing is designed for 2000 W, it was necessary to clarify that the thermal basis for the cask is 3000 W, even though the allowable decay heat for shipping is 1500 W.
Section 8.2	Clarified the end of the second.	In response to RAI 8.1.
Section 8.2.1.2	Clarified the first sentence.	In response to RAI 8.1.
Section 8.2.2.2	Clarified the end of the second.	In response to RAI 8.1.
Section 8.2.3.1	Eliminated reference to Configuration 2.	There is no Configuration 1/Configuration 2 designation for contents as seen in Section 1.2.2.3.
Section 8.4	Along with the deletion of Reference 8-1, as stated previously, References 8-8, 8-9, 8-10, 8-12, and 8-13 have been deleted (and citations in the text removed). These are internal GEH specifications and reports that normally are not cited in a SAR.	Administrative change.

ACRONYMS

Term	Definition
3D	Three-Dimensional
Amb.	Ambient
ANSI	American National Standards Institute
APDL	ANSYS Parametric Design Language
ASM	American Society for Metals
ASME	American Society of Mechanical Engineers
ASNT	American Society for Nondestructive Testing
ASTM	American Society for Testing and Materials
Aux.	Auxiliary
B&PVC	Boiler and Pressure Vessel Code
CFR	Code of Federal Regulations
C.G.	Center of Gravity
CSI	Criticality Safety Index
DOF	Degree-of-Freedom
DR	Total Dose Rate
DU	Depleted Uranium
[[	]]
FEA	Finite Element Analysis
GE	General Electric
GEH	GE-Hitachi Nuclear Energy Americas LLC
HAC	Hypothetical Accident (Transport) Conditions
HEPA	High Efficiency Particulate Air
HPI	High Performance Insert
IAEA	International Atomic Energy Agency
ID	Inner Diameter
MCNP	Monte Carlo N-Particle
MS	Margin of Safety

Term	Definition
MSLD	Mass Spectrometer Leak Detector
NBS	National Bureau of Standards
NCT	Normal Conditions of Transport
NDE	Nondestructive Examination
Nom.	Nominal
NPT	National Pipe Taper (Thread)
NRC	Nuclear Regulatory Commission
OD	Outer Diameter
OR	Outer Radius
PNNL	Pacific Northwest National Lab
QAP-1	GEH Quality Assurance Program
S/N	Serial Number
SS	Stainless Steel
Std.	Standard
TCC	Thermal Contact Conductance
UNC	Unified Coarse
U.S.	United States

1 GENERAL INFORMATION

1.1 Introduction

The Model 2000 Radioactive Material Transport Package was developed at Vallecitos Nuclear Center. The primary use of the packaging is to provide containment, shielding, impact resistance, criticality safety, and thermal resistance for its contents during normal and hypothetical accident conditions. The packaging is designed to transport Type B quantities of radioactive materials. It complies with the Nuclear Regulatory Commission (NRC) regulations contained in the Code of Federal Regulations, Title 10, Part 71 (10 CFR 71). The package is to be shipped in all modes of transportation, except air. The Model 2000 Transport Package may only be shipped exclusive use, as discussed in Section 5.1.2. No Criticality Safety Index (CSI) is determined, as a criticality evaluation is not required as discussed in Chapter 6.

Calculations, engineering logic, and all related documents that demonstrate compliance with regulations are presented in subsequent sections of this report.

The GEH Quality Assurance Program (QAP-1) (Reference 1-1) controls design, purchase, fabrication, handling, shipping, storing, cleaning, assembly, inspection, testing, operation, maintenance, repair and modification of the packages. The NRC has approved QAP-1 under docket number 71-0171 upon demonstration that the QA plan meets the requirements of Subpart H of 10 CFR 71.

1.2 Package Description

The Model 2000 Transport Package, shown in Figure 1.2-1, is transported exclusive use, in the upright position. The approximate overall packaging dimensions are 131.5 inches in height and 72 inches in diameter. The approximate total weight of the package (packaging plus the contents) is 33,550 lb. Table 2.1-3 shows the breakdown of the component weights for the Model 2000 Transport Package.

The Model 2000 Transport Package and contents are described below:

Packaging

- Cask
- Overpack

Contents

- High performance insert (HPI)
- HPI material basket
- Solid radioactive materials

1.2.1. Packaging

1.2.1.1. Cask

The cask body (the containment vessel), shown in Figure 1.2-2, is constructed of two concentric, 1-inch thick stainless steel (SS) SS304 cylindrical shells (ASTM A240 / ASME SA 240). The shells are joined at the bottom end by a type SS304 forging (ASTM A182 / ASME SA 182). A SS304 forging connects the cask shell and cavity shell at the top end of the cask. This flange is part of the cask lid sealing joint and has an electropolished finish on the sealing surface. The annulus between the two shells is approximately 4 inches thick and filled with lead. The cask body height is approximately 71 inches and the outer diameter (OD) is approximately 38.5 inches. The cavity is approximately 26.5 inches in diameter and 54 inches deep.

The cask lid is made of SS304 and lead. It has a stepped design and is fully recessed into the cask top flange. The lid sealing surface is on the underside of the top flange and has an electropolish finish. The cask lid seal is composed of four rings of contoured [[ ]] material (two on the top and two on the bottom) bonded to a [[ ]] thick metal retainer with an OD of 34 inches. The area between the inner and outer seal is designed to permit flow for a seal test port to verify leak-tightness of the package by evaluating the performance of the inner seal. The cask lid [[ ]] and metal retainer material design is evaluated to support 1500 W decay heat. The cask lid seal is a [[ ]] retainer with four Parker Compound No. [[ ]] rings. The material specifications are included in Section 1.3.2.1. The cask lid is secured to the cask body by fifteen (15) 1¼-inch diameter socket head screws.

The cask has three penetrations. Only two of the three penetrations are within the cask containment boundary. They include: the drain and vent ports for the cask cavity. The drain port hole leads from the center of the cavity bottom out the side of the outer shell. The vent port line spirals through the cask lid near the cask centerline. The third penetration, that is not within the containment boundary, is the test port, which is used to test the adequacy of the seal joint after the cask body and lid are assembled. The test port path leads from the side of the top forging to the region between the inner and outer seals and is sealed in the same manner as the other penetrations.

All of the cask port seals are composed of ½ National Pipe Taper (NPT) thread socket head pipe plugs, followed by an exterior plug cover with O-ring to seal the port. The plug cover and O-ring provide a backup seal to the pipe plug, and they are not considered part of the containment boundary. The O-ring [[ ]] compound.

The cask body utilizes attachment plates for lifting devices that are detached during transport and rendered inoperable. There are three types of lifting devices use in the Model 2000 cask: (1) standard ears used for crane and fork truck handling; (2) auxiliary ears used for crane only handling; and (3) optional ears that function as a trunnion. Except for these devices, there are no other devices or features of the cask that could be used for lifting the package, once the cask is within the overpack.

1.2.1.2. Overpack

The cask is positioned inside a protective overpack, shown in Figure 1.2-3, for transport. The overpack is constructed of two 0.5-inch thick SS304 concentric cylindrical shells (ASTM A240/ASME SA 240), which are separated radially by eight equally spaced tubes along the length of the shells, and by two tube sections around the perimeter of the shells. A toroidal shell impact limiter made of SS304 is attached to each end of the overpack shells. The overpack opens just above the lower impact limiter for access to the cask. The top section of the overpack is joined to the base by fifteen (15) $1^{3}/_{8}$-inch diameter shoulder screws. Gussets on the top and bottom impact limiters provide tie-down points for the package.

Additional impact protection is provided by aluminum honeycomb impact absorbers permanently positioned on the inside of the overpack at the top and bottom ends of the cask.

The cask sits on a 0.5-inch thick, 42-inch diameter plate called the cask support plate. It features eight square cross-section prongs welded to the plate perimeter to ensure cask concentricity within the overpack. The cask support plate material of construction is SS304; however, there are two cask support plate options. One option is solid SS304, while the other option includes a tungsten insert.

1.2.2. Contents

1.2.2.1. High Performance Insert

The Model 2000 Transport Package is equipped with an HPI, shown in Figure 1.2-4, to increase the shielding capability of the package. The HPI is nominally [[ ]] The HPI body consists of [[ ]] SS concentric cylindrical shells. The annulus between the two shells is filled with [[ ]] thick depleted uranium. The HPI body is positioned in the cask cavity by [[ ]] to provide uniform support. The [[ ]] are joined together by [[ ]] arms that function as the primary lifting fixture. The HPI body assembly is completed with the addition of ASME [[ ]] at each end of the cylindrical sub-assembly.

Closure of the HPI is provided by top and [[ ]] The [[ ]] is a stepped design comprised of a [[ ]] thick depleted uranium cylinder encapsulated by a [[ ]] shell. Holes are machined in the [[ ]] on the HPI body. The [[ ]] The top plug is a stepped design comprised of a [[ ]] depleted uranium cylinder encapsulated by a [[ ]] shell. To facilitate lifting of the top plug, [[ ]] circular plate. The top plug is held in position by [[ ]] Attachment of the top and [[ ]] does not produce a pressure boundary. Grooves are cut into the surface of the plugs to allow moisture to escape during the vacuum drying process.

1.2.2.2. HPI Material Basket

The material basket is shown in Figure 1.2-5 with an example of supplemental dunnage. The material basket is constructed of [[ ]] pattern and are identified as Item 1 on Drawing 001N8424. See Figure 1.2-6 for material basket details. The outer [[ ]] of the material basket form a composite section with the addition of [[ ]] The center location of the material basket is a developed cell, which is created by the surrounding [[ ]] To allow for the proper insertion of supplemental dunnage and facilitate fabrication, [[ ]] are inserted at the top and bottom of the developed cell and are identified as Item 2 on Drawing 001N8424. Therefore, the exterior view of the material basket shows [[ ]] facilitate loading and positioning of the material basket within the HPI cavity. Parts List 001N8424G001 is provided in Section 1.3.

1.2.2.3. Radioactive Material Contents

The Model 2000 Transport Package is designed to transport Type B quantities of radioactive materials. This may include irradiated hardware and byproducts or Co-60 isotope rods. The following are requirements for all shipments:

a) The maximum quantity of material per package shall not exceed 5,450 lb, including all cask internals and contents.
b) All contents shipped shall be in solid form.
c) All configurations require the use of the HPI.
d) The decay heat for shipping all contents shall be limited to no more than 1500 W. However, a decay heat of 3000 W is conservatively used as the design basis for the Model 2000 Transport Package, where applicable. There are a few exceptions as noted within this SAR where 1500 W forms the basis; while a 1500 W decay heat is used in these sections, it is demonstrated that the 3000 W design basis is bounding.

The specific radioactive contents transported in the Model 2000 cask are:

1. Irradiated Hardware and Byproducts
    a. Irradiated hardware components composed of stainless steels, carbon steels, nickel alloys, and zirconium alloys.
    b. Irradiated byproducts such as control rods and/or blades composed of hafnium and boron carbide.
    c. Minimum decay time shall be at least 30 days prior to shipment.
    d. Refer to loading table provided in Section 7.5.2
2. Cobalt-60 Isotope Rods
    a. Must be shipped with the HPI material basket in the upright position and confined per 2.b and demonstrated to meet NCT.
    b. Content shall be in the form of pellets or cylindrical solid rods with the source(s) evenly distributed and encapsulated in normal or special form.
    c. Total activity in any axial 1-inch increment in the HPI cavity must be ≤ 17,000 Ci (see Section 5.5.2).

Shipment of combined contents is allowed.

1.2.3. Special Requirements for Plutonium

Fissile material is not an approved content of the Model 2000 Transport Package. Thus, any plutonium present in the Model 2000 Transport Package is negligible due to the insignificant quantities of crud build-up on the Section 1.2.2.3 approved content.

1.2.4. Operational Features

The Model 2000 Transport Package description in Section 1.2.1 shows that the packaging is not a complex system. There are no valves or items that require specialized knowledge for proper operation, and cooling is provided through natural convection and radiation. [[ ]] during installation, and only normal practices for seal handling (e.g., cleanliness) are required.

The Model 2000 Transport Package operation is described in Chapter 7. The loading operation is a dry or wet-loaded operation. If wet-loaded, the cask and cask internals contain features to allow easy drainage of water for underwater loading. To vacuum dry the cask, its cavity pressure is reduced below the vapor pressure of water and maintained at or below this pressure level for a period of time.

Content shoring may include components such as the rod [[ ]] holders shown in Figure 1.2-5. This example shoring is designed to fit into the HPI material basket (Drawing 001N8424), but other shoring components may be placed directly into the HPI cavity (Drawing 001N8423). The HPI material basket is loaded into the HPI cavity (Figure 1.2-4) if required for a specific content.

When the HPI top plug is installed (Drawing 001N8427), additional shoring may be added, as necessary, to ensure the [[ ]] between the bottom of the cask lid and the top of the HPI does not exceed 0.25 inches. However, no credit for shoring is given in the Normal Conditions of

Transport (NCT) and Hypothetical Accident Conditions (HAC) evaluations. The required evaluations are included in this application to demonstrate safe transport of the Model 2000 Transport Package for the included contents with specified required internals.

Once the package is loaded onto the transport vehicle, external temperature measurements are taken of the loaded overpack. If any temperature exceeds 185°F, a protective personnel barrier is installed around the package to block access as discussed in Section 3.3.1.1.3. The cask containment boundary is illustrated in Figure 4.1.3-1.

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Figure 1.2-1. Model 2000 Packaging with High Performance Insert

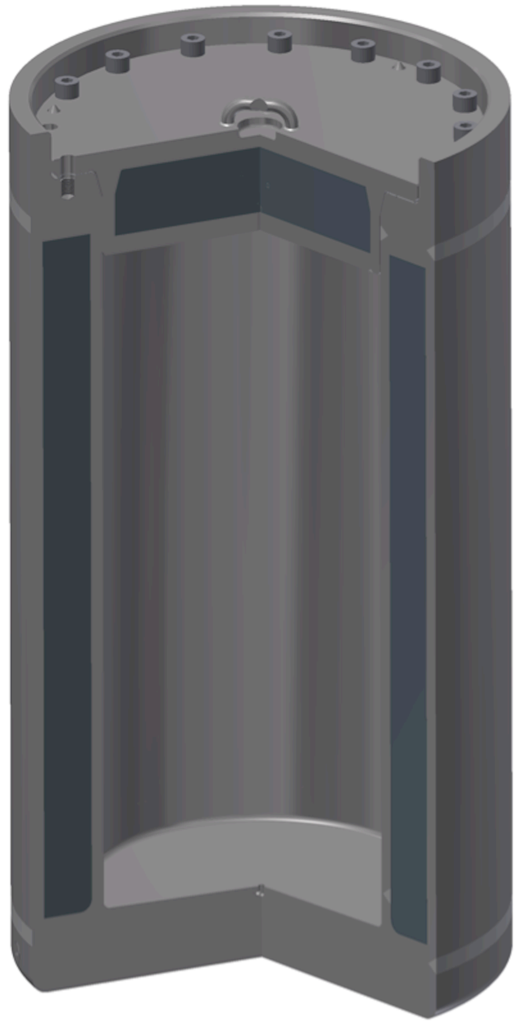

Figure 1.2-2. Model 2000 Cask

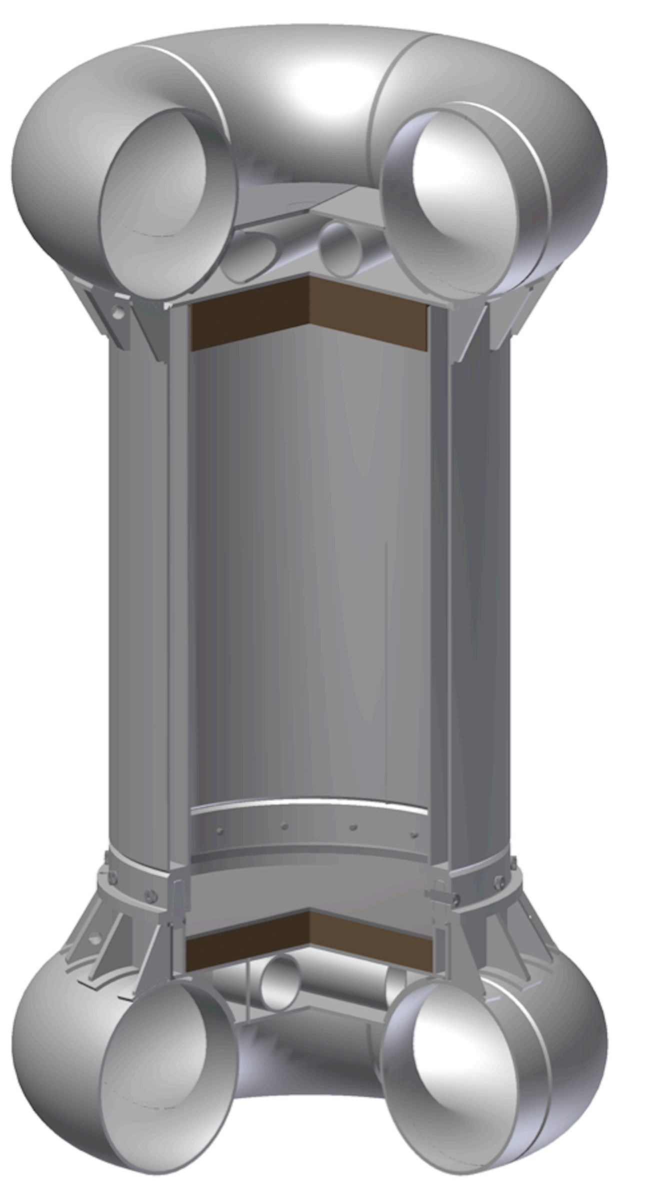

Figure 1.2-3. Model 2000 Overpack

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Figure 1.2-4. Model 2000 High Performance Insert with Material Basket

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Figure 1.2-5. Material Basket and Rod [[ ]] Holder

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Figure 1.2-6. Material Basket Details

1.3 Appendix

1.3.1. Drawings

This section contains the Model 2000 Transport Package licensing drawings and bill of materials. Table 1.3-1 provides a list of current licensing drawings, which follow, and current revision level.

Table 1.3-1. Model 2000 Packaging Licensing Drawings

Drawing Number	Title	Revision
001N8422	GE 2000 HPI and Material Basket Licensing Drawing	3
001N8423	GE 2000 HPI Licensing Drawing	2
001N8424	GE 2000 HPI Material Basket Assembly Licensing Drawing	2
001N8425	GE 2000 HPI Body Licensing Drawing	2
001N8427	GE 2000 HPI Top Plug Assembly Licensing Drawing	2
001N8428	GE 2000 HPI [[ ]] Assembly Licensing Drawing	2
101E8718	Model 2000 Shipping Cask S/N 2001	17
105E9520	Model 2000 Shipping Cask all S/N's Except S/N 2001	9
129D4946	Model 2000 Transport Container Assembly	12
101E8719	Model 2000 Shipping Cask Overpack S/N 2001	14
105E9521	Model 2000 Shipping Cask Overpack all S/N's Except S/N 2001	7

PARTS LIST 001N8422G001

[[

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DWG 001N8422 DRAWING

Proprietary in its Entirety

[[

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PARTS LIST 001N8423G001

[[

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DWG 001N8423 DRAWING

Proprietary in its Entirety

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PARTS LIST 001N8424G001

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DWG 001N8424 DRAWING

Proprietary in its Entirety

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PARTS LIST 001N8425G001

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DWG 001N8425 DRAWING

Proprietary in its Entirety

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PARTS LIST 001N8427G001

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DWG 001N8427 DRAWING

Proprietary in its Entirety

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PARTS LIST 001N8428G001

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DWG 001N8428 DRAWING

Proprietary in its Entirety

[[

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PARTS LIST 101E8718

[[

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DWG 101E8718 DRAWING SH1

Proprietary in its Entirety

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DWG 101E8718 DRAWING SH2

Proprietary in its Entirety

[[

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PARTS LIST 101E9520

[[

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DWG 105E9520 DRAWING SH1

Proprietary in its Entirety

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DWG 105E9520 DRAWING SH2

Proprietary in its Entirety

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PARTS LIST 129D4946

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DWG 129D4946 DRAWING

Proprietary in its Entirety

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PARTS LIST 101E8719

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DWG 101E8719 DRAWING

Proprietary in its Entirety

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PARTS LIST 105E9521

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DWG 105E9521 DRAWING

Proprietary in its Entirety

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1.3.2. Material Specifications

1.3.2.1. Seal Specifications

The Parker [[ ]] material specification for Parker Compound [[ ]] for the cask lid seal and port "O" rings is provided below. (Reference 1-2)

[[

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1.4 References

1-1 GE-Hitachi Nuclear Energy, "Quality Assurance Program for Shipping Packages for Radioactive Material (Docket 71-0170)," QAP-1, Latest Revision.

1-2 Parker Hannifin Corporation, "Gask-O-Seal and Integral Seal Design Handbook," CSS 5124, 2010.

2 STRUCTURAL EVALUATION

This chapter presents the structural evaluation of the Model 2000 Transport Package, and demonstrates that the design meets all applicable structural criteria. All components that comprise the Model 2000 Transport Package are evaluated to the applicable regulatory requirements that includes the NCT and HAC, in accordance with 10 CFR 71 (Reference 2-1). Detailed description of each package component is provided in in Section 2.1.1.

The decay heat limit for shipping all contents shall be conservatively limited to 1500 W. However, a decay heat of 3000 W is conservatively used as the basis for the Model 2000 Transport Package structural evaluation (analysis) in this chapter. Analyses comply with the methodology and criteria presented in Section 2.1.2. The structural design of the Model 2000 Transport Package is based on the following critical characteristics:

- Ensure the maximum content weight does not exceed 5,450 pounds.
- Maintain structural integrity when subjected to the thermal conditions (3000 W maximum) associated with NCT and HAC in Chapter 3. This section demonstrates packaging integrity at extreme thermal conditions during NCT and HAC.
- Maintain containment integrity to remain leaktight during NCT and HAC as documented in Chapter 4. This section demonstrates cask containment integrity during NCT and HAC.
- Maintain integrity of lead and depleted uranium (DU) shielding boundaries during NCT and HAC to support Chapter 5. This section demonstrates that the shielding integrity is maintained during NCT and HAC to support the shielding analysis assumptions.

2.1 Description of Structural Design

2.1.1. Discussion

The Model 2000 Transport Package consists of a welded overpack structure containing a steel-encased, lead cask structure. The cask structure is a lead-filled SS304 weldment, cylindrical in shape, and measuring approximately 38.5 inches OD by 71 inches high. The inner cavity is 26.5 inches ID by 54 inches high. The lead shielding provided is approximately 4 inches of lead on the sides.

The cask body shell is made of 1 inch thick SS304 plate. At the bottom, the shells are welded to a 6-inch thick SS304 forging. At the upper section, the containment shell joins a 9-inch thick SS304 forging. This forging provides support and sealing surface to the cask seal. Also, it contains 15 equally spaced, internally threaded holes on a 32.25-inch diameter bolt circle. Fifteen 1¼-inch diameter ASTM A540 socket head screws attach the lid to the cask body during operation. The cask lid is SS304 encasing a lead cylinder. The lid has a lifting lug for handling.

There are three penetrations into the cask cavity. One serves as a drain for the cask cavity and another one as a vent. The drain hole goes from the center of the cavity bottom to the side of the outer surface. The vent line spirals through the cask lid around the center. These penetrations provide means to eliminate water from the cask cavity collected during underwater operations.

A ½ NPT socket head pipe plug followed by a 1¾ - 12 UN-2A cap closes both penetrations. The cap O-ring provides backup sealant to the pipe plug. The third penetration is used as a testing port for the cask seal joint. It is located in the upper forging on the side surface of the cask.

The cask lid seal and O-rings use Parker Compound No. [[ ]] material retainer. The cask lid seal retainer has a 34 inch OD and 28 inch ID. The cask lid seal and O-rings are designed for a 1500 W maximum content heat load.

The welded SS304 overpack structure is composed of two concentric cylinders, separated vertically by eight equally spaced [[ ]] sections. The external cylinder has a 48.5-inch OD. The internal cylindrical shell is 40.5-inch ID. A 24-inch [[ ]] diameter toroidal shell is attached at both ends of the external cylinder, and a circular plate is welded across the inner region of the torus. The internal cylinder is closed at each end by circular plates. All materials are 0.5 inches thick with the exception of the space [[ ]] and toroidal shells. The vertical [[ ]]

The toroidal shells may be fabricated using four 90° elbows (or two 180° returns). However, the Model 2000 toroidal shell wall thickness range is limited to 0.5 inches minimum to 0.76 inches maximum. The overpack structure separates near the bottom end to allow access to the lead cask. A collar 0.75 inches thick is attached in this area to provide bearing surface for the connecting bolts. A total of fifteen (15) 1-⅜ inches diameter ASTM A540 shoulder screws join both portions of the overpack structure. The toroidal shell of the overpack structure acts as an energy-absorbing device during the postulated drop conditions. In addition, the overpack structure provides thermal shielding for the lead cask in the event of a fire.

A total of 20 reinforcing ribs cradle the toroidal shell to the vertical cylinder. Four of the ribs provide tie-down points for the package during transport. These ribs also provide a means for lifting and removing the overpack top section using a spreader bar. The spreader bar is not part of the transport packaging.

There is a 6-inch thick aluminum honeycomb pad attached to the top inner surface of the overpack structure. A 4-inch thick aluminum honeycomb pad covered by a ½ inch thick circular plate provides a surface base for the lead cask structure. These honeycomb pads are included in the overpack structure design to assure a uniform loading distribution on the cask surface during the postulated free-drop events.

The Model 2000 Transport Package is equipped with a high performance insert (HPI) to increase the shielding capability of the package. The HPI is [[ ]] The cavity is approximately [[ ]] The HPI body consists [[ ]] inch stainless steel concentric cylindrical shells. The annulus between the [[ ]] shells is filled with [[ ]] thick depleted uranium. The HPI body is positioned in the cask cavity by five [[ ]] (Table 2.2-3) [[ ]] arranged axially to provide uniform support. The [[ ]] are joined together by four [[ ]] vertical lifting arms that function as the primary lifting fixture. The HPI body assembly is completed with the addition of ASME [[ ]] at each end of the cylindrical sub-assembly.

Top and [[ ]] joined to the ASME [[ ]] provide closure of the HPI. The [[ ]] and a [[ ]] thick depleted uranium cylinder encapsulated by a [[ ]] shell. Holes are machined in the [[ ]] on the HPI body. The [[ ]] is attached to the bottom [[ ]] with eight (8) $^{7}/_{8}$-inch socket head cap screws and four [[ ]] The top plug is a stepped design comprised of [[ ]] depleted uranium cylinder encapsulated by a [[ ]] shell. To facilitate lifting of the top plug, four hoist rings are recessed into the [[ ]] circular plate. The top plug is held in position by [[ ]] Attachment of the top and [[ ]] does not produce a pressure boundary. Grooves are cut into the surface of the plugs to allow moisture to escape during the vacuum drying process.

The material basket is a shoring device, which may be used for carrying various contents. The material basket is constructed of 18 full-length [[ ]], which form a [[ ]] pattern and are identified as Item 1 on drawing 001N8424. See for material basket details. The outer [[ ]] of the material basket form a composite section with the addition of stiffener plates welded to adjacent [[ ]] The center location of the basket is a developed cell, which is created by the surrounding [[ ]] To allow for the proper insertion of additional content shoring and facilitate fabrication, two partial length [[ ]] are inserted at the top and bottom of the developed cell and are identified as Item 2 on drawing 001N8424. Therefore, the exterior view of the basket shows [[ ]] Four circular [[ ]] evenly spaced in the axial direction facilitate loading and positioning of the material basket within the HPI cavity. In addition, dunnage (for example [[ ]] holders) may be used as a cask loading mechanism and to shore the contents during transport.

2.1.2. Design Criteria

This section defines the stress allowables for all the stresses resulting from the regulatory load combinations given in NRC Regulatory Guide 7.8 (Reference 2-2).

The cask is evaluated per ASME Service Levels A and D, normal and accident conditions, respectively. The analyses methods and stress criterion allowed by the ASME Code, Section III-Subsection NB is employed. Stress intensities caused by mechanical loads are combined before comparing to ASME code stress allowables, which are listed in Table 2.1-1.

Table 2.1-1. Structural Design Criteria for Model 2000 Cask

ASME Class 1 Design	Stress Limits
Normal conditions: Service Level A	$P_m \leq S$ $P_m + P_b \leq 1.5\ S_m$ $P_m + P_b + Q \leq 3\ S_m$ Bearing Stress $\leq S_y$ at temperature
Accident conditions: Service Level D	$P_m \leq 2.4\ S_m$ or $0.7\ S_u$ (whichever is less) $P_m + P_b \leq 3.6\ S_m$ or $1.0\ S_u$ (whichever is less)

Note: P_m = primary membrane stress intensity, P_b = primary bending stress intensity, S_m = design stress intensity, S_y = yield strength, S_u = ultimate strength, Q = secondary stress associated with thermal expansion.

The HPI is evaluated per ASME Service Levels A and D, normal and accident conditions, respectively. The analyses methods and stress criterion allowed by the ASME Code, Section III-Subsection NF is employed. Allowable stresses are based on section NF-3200. For normal conditions (Service Level A), design limits are defined in paragraph NF-3221.1. For accident conditions (Service Level D), design limits are defined in Appendix F of ASME Code, Section III (Reference 2-3). Note the evaluation of thermal stresses is not required per ASME Code III-NF (NF-3121.11). Stress intensities caused by mechanical loads are combined before comparing to ASME code stress allowables, which are listed in Table 2.1-2.

Table 2.1-2. Structural Design Criteria for HPI and Material Basket

ASME Class 1 Design	Stress Limits
Normal Conditions: Service Level A (NF-3221.1)	$P_m \leq S_m$ $P_m + P_b \leq 1.5\ S_m$
Bearing Loads: Service Level A (NF-3223.1)	S_y at temperature
Pure Shear: Service Level A (NF-3223.2)	$0.6S_m$
Bearing Loads: Service Level D (Appendix F, F-1332.3)	Except for pinned and bolted joints, bearing stresses need not be evaluated for loads for which Level D Service Limits are specified.
Pure Shear: Service Level D (Appendix F, F-1332.4)	$0.42S_u$
Accident Conditions: Service Level D (Appendix F, F-1332)	$P_m > 1.2\ S_y$ and $1.5\ S_m < 0.7\ S_u$ $P_m + P_b < 150\%$ of the limit for general primary stress intensity P_m

Note: Pm = primary membrane stress intensity, Pb = primary bending stress intensity, Sm = design stress intensity, Sy = yield strength, Su = ultimate strength.

2.1.3. Weights and Centers of Gravity

The weights and center of gravity of the Model 2000 Transport Package and detailed contents are presented in Table 2.1-3. Refer to Section 1.3.1 for component dimensions.

Table 2.1-3. Summary of Maximum Weights

DESCRIPTION	DRAWING NUMBER	WEIGHT (LB)	C.G. (IN)*
Total Packaging Weight	—	**28,100**	**63.9**
Cask Overpack	101E8719/ 105E9521	10,200	—
Cask Body	101E8718/ 105E9520	16,000	—
Closure Lid	101E8718/ 105E9520	1,900	—
Allowed Contents Weight	—	**5,450**	**62.3**
HPI Assembly	001N8423	[[	—
Material Basket	001N8424		—
Contents plus Shoring	—	]]	—
Total Package Weight	—	**33,550**	**63.6**

Notes: * Center of Gravity (C.G.) measured from component base.
** If material basket is not included in contents, contents plus shoring maximum weight is [[ ]] lb.

Table 2.1-4. Overpack Base Weight

Assembly ID	Component Description	Weight (lb)
2	[[	
4		
5		
6		
7		
8		
12		
13		
14		
15		
16		
19		
25		
26		
27		]]
	Total Overpack Base Weight =	3,633.15

2.1.4. Identification of Codes and Standards for Package Design

This section identifies the established codes and standards proposed for use in the Model 2000 Transport Package design, fabrication, assembly, testing, maintenance, and use.

The Model 2000 cask with HPI and material basket is allowed to ship a maximum of 1500 W of various radioactive contents. Per Regulatory Guide 7.11 (Reference 2-4), the package is considered Category I—Greater than 3,000 A_2 or greater than 30,000 Ci. From NUREG/CR-3854 (Reference 2-5), the fabrication code and standard is:

- The criteria for fabricating metal components of shipping containers used for transporting radioactive materials are based on the ASME Code Section III (Reference 2-3). ASME Code Section III is used for the design and fabrication of the HPI and material basket.

2.1.4.1. Category I Requirements

Acceptable criteria for the fabrication of metal components of shipping containers are contained in the ASME Code Section III, Subsection NB for containment components; Subsection NG for criticality components and Section VIII, Division I or Section III, Subsection NF for other safety components.

- The Model 2000 cask provides containment. Therefore, the cask shall be fabricated to Section III, Subsection NB.
- The HPI and material basket are relied upon for shielding, which falls under Component Safety Group "Other Safety". Therefore, the insert shall be fabricated to Section VIII, Division 1 or Section III, Subsection NF.

2.1.4.2. Component Classification According to Importance to Safety

The parts lists in Section 1.3.1 identify the Category A, B and C items for the Model 2000 cask, overpack, HPI, and material basket. The safety classification of all components is based on importance to safety criteria per NUREG/CR-6407 (Reference 2-6).

- For the Model 2000 cask, the components that comprise the cask inner shell, top forging, cask seals and lid are considered part of the containment boundary. Therefore, these items are Category A. Components such as the lead shielding, lifting and tie-down devices meet the definition of Category B items. See the parts lists in Section 1.3.1 for Drawing 101E8718 and 105E9520 for the Model 2000 cask assembly parts classification.
- See the parts list, Section 1.3.1, Drawing 001N8424, for the material basket assembly parts classification.
- The material basket is considered dunnage, and is not required to reduce impact loading on the containment boundary. However, it is required to maintain geometry during NCT to support the shielding analysis assumptions. Therefore, it is considered a Category B item. In addition, for fabrication, [[ ]] welds are Safety Category B. See the parts list in Section 1.3.1 for Drawing 001N8424 for the material basket assembly parts classification.

2.2 Materials

This section presents the mechanical properties of materials used to evaluate the performance of the Model 2000 cask, overpack, HPI, and material basket. Materials of construction for each component are found in Section 1.3.1, in the parts lists that accompany drawings.

2.2.1. Material Properties and Specifications

The material properties used in the structural analysis of the Model 2000 cask, HPI and material basket are presented in Tables 2.2-1 through 2.2-9. Material properties specific to the impact analysis are presented in Section 2.12.1.

Table 2.2-1. Structural Properties of Type 304 Stainless Steel

Temperature (°F)	**-20**	**70**	**200**	**300**	**400**	**500**	**600**	**700**	**800**	**900**	**1000**
Ultimate Tensile Strength S_u (ksi)	75.0	75.0	71.0	66.2	64.0	63.4	63.4	63.4	62.8	60.8	57.4
Yield Strength S_y (ksi)	30.0	30.0	25.0	22.4	20.7	19.4	18.4	17.6	16.9	16.2	15.5
Design Stress Intensity S_m (ksi)	20.0	20.0	20.0	20.0	18.6	17.5	16.6	15.8	15.2	—	—
Modulus of Elasticity (E+3, ksi)	28.8 [a]	28.3	27.5	27.0	26.4	25.9	25.3	24.8	24.1	23.5	22.8
Mean Coefficient of Thermal Expansion α (E-6, in/in/°F)	—	8.5	8.9	9.2	9.5	9.7	9.9	10.0	10.1	10.2	10.3
Poisson's Ratio	⟵ 0.31 ⟶										
Density **(lb/in³)**	⟵ 0.290 ⟶										

References:
Reference 2-7 Ultimate Tensile Strength: Table U, Page 493, Line 22.
Reference 2-7 Yield Strength: Table Y-1, Page 610 & 611, Line 26.
Reference 2-7 Design Stress Intensity: Table 2A, Page 306, Line 19.
Reference 2-7 Modulus of Elasticity: Table TM-1, Material Group G, Page 738.
Reference 2-7 Mean Coefficients of Thermal Expansion: Table TE-1, Group 3, Coefficient B, Page 711.
Reference 2-7 Poisson's Ratio: Table PRD, High Alloy Steels (300 series), Page 744.
Reference 2-7 Density: Table PRD, High Alloy Steels (300 series), Page 744.
Note:
[a] This value was interpolated.

Table 2.2-2. Structural Properties of ASME Type [[ ]]

[[											

]]

Note:
[a] Interpolated.

Table 2.2-3. Structural Properties of ASME Type [[ ]]

[[											

]]

Note:
[a] Interpolated.

Table 2.2-4. Structural Properties of Depleted Uranium Metal

Temperature (°F)	-20	70	200	300	400	500	600	700	800	900	1000
Yield Strength S_y (ksi)	—	47.2	43.8	40.2	36.3	33.3	30.5	23.9	15.3	9.3	5.8
Modulus of Elasticity (E+3, ksi)	—	23.6	—	—	—	—	—	—	—	—	—
Poisson's Ratio	⟵ 0.335 ⟶										
Density (lbm/in^3)	⟵ 0.674 – 0.689 ⟶										

References:
Reference 2-8 Yield Strength: Figure 1, Page 671.
Reference 2-8 Density: Page 670.
Reference 2-9 Modulus of Elasticity: Table 7, Page 19.
Reference 2-9 Poisson's Ratio: Table 7, Page 19.

Table 2.2-5. Structural Properties of Lead

Temperature (°F)	-40	-20	70	200	300	400	600
Modulus of Elasticity (E+3, ksi)	2.58	2.55 a	2.42	2.21	2.04	1.77	1.49
Yield Strength (psi)	795	763 [a]	620	500	400	—	—
Mean Coefficient of Thermal Expansion α (E-6, in/in/°F)	15.6 [a]	15.7 [a]	16.1 [a]	16.7 [a]	17.3 [a]	18.5 [b]	—
Poisson's Ratio	⟵ 0.4 ⟶						
Density (lb/in^3)	⟵ 0.4097 ⟶						

References:
Reference 2-10 Modulus of Elasticity: Figure B-8.
Reference 2-11 Yield Strength at (-40°F – 70°F).
Reference 2-12 Yield Strength: (200°F – 300°F): Figure 12.
Reference 2-10 Mean Coefficient of Thermal Expansion: Figure A-3.
Reference 2-13 Poisson's Ratio: Table 6.1.9, Page 6-10.
Reference 2-13 Density: Table 6.4.1, Page 6-47.

Notes:
[a] Interpolated
[b] Value for 440.33°F (500 K) used.

Table 2.2-6. Bolt – ASTM A-540 Grade B21 Class 3

Temperature (°F)	150	455
Ultimate Tensile Strength S_u (ksi)	145	
Yield Strength S_y (ksi)	127.9 [a]	117.2 [a]
Design Stress Intensity S_m (ksi)	42.6 [a]	39.1 [a]
Modulus of Elasticity (E+3, ksi)	29.2 [a]	27.7 [a]
Mean Coefficient of Thermal Expansion α (E-6, in/in/°F)	6.6	7.2
Poisson's Ratio	⟵ 0.30 ⟶	
Density (lb/in^3)	⟵ 0.280 ⟶	

References:
Reference 2-7 Tensile Strength: Table U, Page 473, Line 11
Reference 2-7 Yield Strength: Table Y-1, Page 562, Line 36
Reference 2-7 Design Stress Intensity: Table 4, Page 366, Line 20
Reference 2-7 Modulus of Elasticity: Table TM-1, Material Group C, Page 738
Reference 2-7 Mean Coefficient of Thermal Expansion: Table TE-1, Group 1, Coefficient B, Page 708
Reference 2-7 Poisson's Ratio: Table PRD, Low alloy steels: ½Cr to 1-¼Cr steels, Page 744
Reference 2-7 Density: Table PRD, Low alloy steels: ½Cr to 1-¼Cr steels, Page 744
Note:
[a] Interpolated

Table 2.2-7. Internal Thread – ASME SA-182 F304

Temperature (°F)	**150**	**455**
Ultimate Tensile Strength S_u (ksi)	73 [a]	63.7 [a]
Yield Strength S_y (ksi)	26.7	20 [a]
Design Stress Intensity S_m (ksi)	20.0	17.9 [a]
Modulus of Elasticity (E+3, ksi)	27.8 [a]	26.1 [a]
Mean Coefficient of Thermal Expansion α (E-6, in/in/°F)	8.8	9.7 [a]
Poisson's Ratio	⟵ 0.31 ⟶	
Density (lb/in^3)	⟵ 0.290 ⟶	

References:
Reference 2-7 Tensile Strength: Table U, Page 493, Line 16
Reference 2-7 Yield Strength: Table Y-1, Page 610, Line 11
Reference 2-7 Design Stress Intensity: Table 5A, Page 410, Line 25
Reference 2-7 Modulus of Elasticity: Table TM-1, Material Group G, Page 738
Reference 2-7 Mean Coefficient of Thermal Expansion: Table TE-1, Group 3, Coefficient B, Page 711
Reference 2-7 Poisson's Ratio: Table PRD, High Alloy Steels (300 series), Page 744
Reference 2-7 Density: Table PRD, High Alloy Steels (300 series), Page 744
Note:
[a] Interpolated

Table 2.2-8. ASTM A-193 B6 Bolt Properties

Minimum Ultimate Tensile Strength S_u (ksi)	110
Minimum Yield Strength S_y (ksi)	85
Design Stress Intensity S_m (ksi)	26.5 [ab]
Modulus of Elasticity (E+3, ksi)	28.1 [ab]
Mean Coefficient of Thermal Expansion α (E-6, in/in/°F)	6.2 [b]
Poisson's Ratio	0.31
Density (lb/in^3)	0.280

References:
Reference 2-7 Minimum Ultimate Tensile Strength: Table 3, Page 339, Line 17
Reference 2-7 Minimum Yield Strength: Table 3, Page 339, Line 17
Reference 2-7 Stress Intensity: Table 4, Page 366, Line 25
Reference 2-7 Modulus of Elasticity: Table TM-1, Material Group F, Page 738
Reference 2-7 Mean Coefficient of Thermal Expansion: Table TE-1; Coefficients for 12Cr, 12Cr-1Al, 13Cr, and 13Cr-4Ni Steels; Page 710.
Reference 2-7 Poisson's Ratio: Table PRD, High alloy steels (400 series), Page 744
Reference 2-7 Density: Table PRD, High alloy steels (400 series), Page 744
Notes:
[a] Interpolated
[b] Evaluated at 250°F

Table 2.2-9. ASTM A-540 Grade B22 Class 3 Bolt Properties

Minimum Ultimate Tensile Strength S_u (ksi)	145
Minimum Yield Strength S_y (ksi)	115.7
Design Stress Intensity S_m (ksi)	37.6 [a1]
Modulus of Elasticity (E+3, ksi)	27.4 [a1]
Mean Coefficient of Thermal Expansion α (E-6, in/in/°F)	7.3 [a]
Poisson's Ratio	0.30
Density (lb/in^3)	0.280

References:
Reference 2-7 Minimum Ultimate Tensile Strength: Table 3, Page 335, Line 25
Reference 2-7 Minimum Yield Strength: Table 3, Page 335, Line 25
Reference 2-7 Design Stress Intensity: Table 4, Page 366, Line 4
Reference 2-7 Modulus of Elasticity: Table TM-1, Group C, Page 738
Reference 2-7 Mean Coefficient of Thermal Expansion: Table TE-1, Group 1, Column B, Page 708
Reference 2-7 Density: Table PRD, Low alloy steels: ½-Cr to 1-¼Cr steels, Page 744
Notes:
[a] Evaluated at 500°F
[1] B21 Bolt properties used because data for B22 Bolts could not be found

2.2.2. Chemical, Galvanic, or Other Reactions

The Model 2000 cask is fabricated from SS304, SS316, and lead. The lead is completely encased in the SS. This construction excludes moisture at the stainless boundary, thus assuring no galvanic or deleterious reactions could occur. The cask contents contact the stainless cavity surface. The radioactive material contents are in solid form and typically are placed in supplemental shoring. GEH's experiences in operating other transport packages with similar arrangements show that chemical, galvanic or other reactions between the cask cavity surface and the radioactive material shoring, or between the shoring and their solid contents, do not occur.

The structural components of the HPI and material basket are fabricated from SS304, [[ ]] steels, which are chemically compatible. These materials are selected because of their strength, ductility, and high resistance to corrosion and brittle fracture over a broad temperature range and high levels of radiation. Therefore, no chemical or galvanic reaction is anticipated. The primary function of the HPI body, including top and [[ ]], is to encapsulate the depleted uranium shield. Depleted uranium is cast and machined to precise tolerance to form the required shield geometry. To prevent potential oxidation, assembly of the shield is performed in an inert atmosphere. Once encapsulated, oxidation and galvanic reactions with stainless steel does not occur.

The cask containment features have no indication of chemical or galvanic reactions between [[ ]] compounds and stainless interfaces of the cask. This has been confirmed in the qualification of the cask containment.

2.2.3. Effects of Radiation on Materials

Gamma radiation has no significant effect on metal and therefore, the radiation produced by the contents does not cause any measurable damage to the packaging metallic components (stainless steel, aluminum, depleted uranium, and lead). Seals are inspected prior to each use. The Parker O-ring Handbook (Reference 2-14) states that when experiencing radiation levels 1×10^6 rads the effects on all compounds are minor. The maximum absorbed dose rates that these [[ ]] seals could be exposed to through a year of continuous use, with the cask loaded and maximum cobalt-60 activity, are on the order of 10^2 to 10^4 rad. As the Model 2000 is not a storage cask, overall exposure time for the seals is significantly shorter than an entire year. With a 1-year replacement period on the [[ ]] seals and O-rings, there is no significant degradation of the seals due to irradiation.

2.3 Fabrication and Examination

2.3.1. Fabrication

Fabrication and examination of the Model 2000 Transport Package (i.e., overpack and cask) conform to the requirements of ASME Section, III, Subsection NB for Category A and B components. Components of the HPI assembly and material basket assembly that are Category B items are fabricated in accordance with ASME Section III, Subsection NF. Fabrication of package components follows the guidelines presented in NUREG/CR-3854, Fabrication Criteria for Shipping Containers (Reference 2-5). All package components are fabricated in accordance with an NRC approved quality assurance program.

2.3.2. Examination

Examination of the Model 2000 Transport Package (i.e., overpack and cask) conforms to the requirements of ASME Section, III, Subsection NB for Category A and B components. Components of the HPI assembly and material basket assembly that are Category B items are examined in accordance with ASME Section III, Subsection NF. All package components are examined in accordance with an NRC approved quality assurance program.

2.4 General Requirements for All Packages

This section addresses the requirements of 10 CFR 71.43, "General Standards for All Packages."

2.4.1. Minimum Package Size

The smallest overall dimension of the Model 2000 Transport Package is 131.5 inches. The cask overall dimensions are 71.0 inches high and 38.5 inches OD.

2.4.2. Tamper-Indicating Feature

A lock wire and seal of the type that must be broken is installed across the overpack joint section. This seal while intact, would be evidence that unauthorized persons have not opened the package.

2.4.3. Positive Closure

The Model 2000 Transport Package is an assembly of components for shipping radioactive material contents inside of a cask with a design pressure of 30 psia. The cask is sealed using a gasket and fifteen 1¼-inch socket head screws. In turn, the cask is contained by the overpack structure, which is bolted closed during transport by 15 shoulder bolts. With this double closure, overpack and cask, inadvertent opening of the cask cannot occur. The vent and drain ports on the cask each are plugged and sealed by pipe plugs and straight thread caps with O-rings.

The evaluation of the closure bolts is presented in Section 2.12.4. Review of the closure bolt evaluation at 3000 W shows that the bolt preload does not change as a result of the increase in thermal load. The closure bolt calculation shows that the controlling loads for the bolt preload are the internal pressure and the pin puncture loads. Further review of the temperatures presented in Chapter 3 show that because of the thermal modeling methodology, the heat load is concentrated

in the HPI and material basket. As a result, the temperature distribution in the closure bolt and flange are more uniform resulting in a smaller temperature delta and lower thermal stresses. To maintain positive closure during normal and hypothetical accident conditions, the closure bolts are torqued to 720±30 ft-lb.

2.5 Lifting and Tie-Down Standards for All Packages

The regulations require that lifting devices which are a structural part of the package shall be capable of supporting three times the weight of the loaded package without generating stress in any material of the package in excess of its yield stress. The following sections provide a summary of the lifting and tie-down evaluation, which is presented in Section 2.12.3.

2.5.1. Lifting Devices

The Model 2000 Transport Package lifting components are evaluated structurally in the following sections. The lifting and tie-down requirements are as specified in 10 CFR 71.45(a).

2.5.1.1. Lifting Ear Evaluation

As shown in Figure 2.5.1-1, there are two types of lifting ear designs employed during the handling of the Model 2000 cask, standard and auxiliary. The ears are removed from the cask during transport and are shipped separately. The ear design identified as Standard is used for crane and fork truck lifting, and only one pair is required for these operations. The Auxiliary ear is used in crane lifting only, and 2 pairs or 4 ears are required. The user may combine the different types of ears as necessary including, 2 Standard/2 Auxiliary, 4 Auxiliary or 2 Standard.

Both ear designs are attached to the cask outer shell by means of four ASTM A193-B6 1-8 UNC-2-1/2 bolts. For this evaluation, the following loading conditions are considered:

- Load rating of W = 23,630 pounds, which includes the dead weight of the cask, lifting ears and the cask maximum payload.
- The two pairs of auxiliary ears are to support 3W such that the lifting cable does not make an angle of more than +30° measured from the vertical.
- The pair of standard ears is to support 3W.

Three load cases are considered for this evaluation: Case I – vertical lift by crane; Case II – angular lift 30° from vertical by crane; and Case III – fork truck lift at two different points on the standard ears only. Figure 2.5.1-1 provides a free-body diagram for Cases I and II. Case III is similar to Case I and is not shown.

The magnitude and direction of loading in the ear analysis is shown in Figure 2.5.1-2. The analysis of each type of ear is presented in Section 2.12.3.

Material properties are based upon 250°F for the outer cask. The 249°F temperature is the maximum temperature under normal conditions for the cask outer surface (Section 3.3.1). Both standard and auxiliary ears and the cask outer shell are ASTM A240, Type 304 stainless steel. The attaching bolt material is ASTM A193-B6.

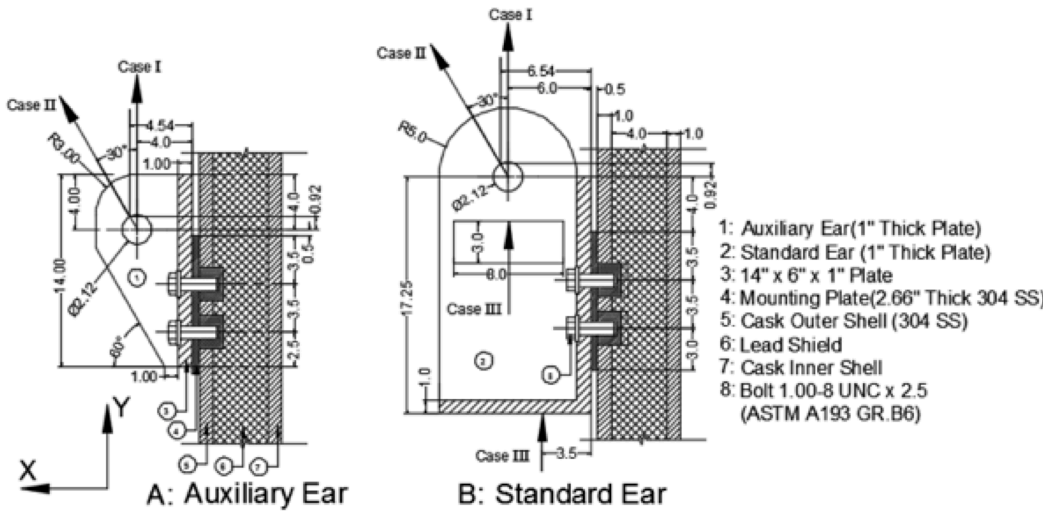

Figure 2.5.1-1. Lifting Ear Details

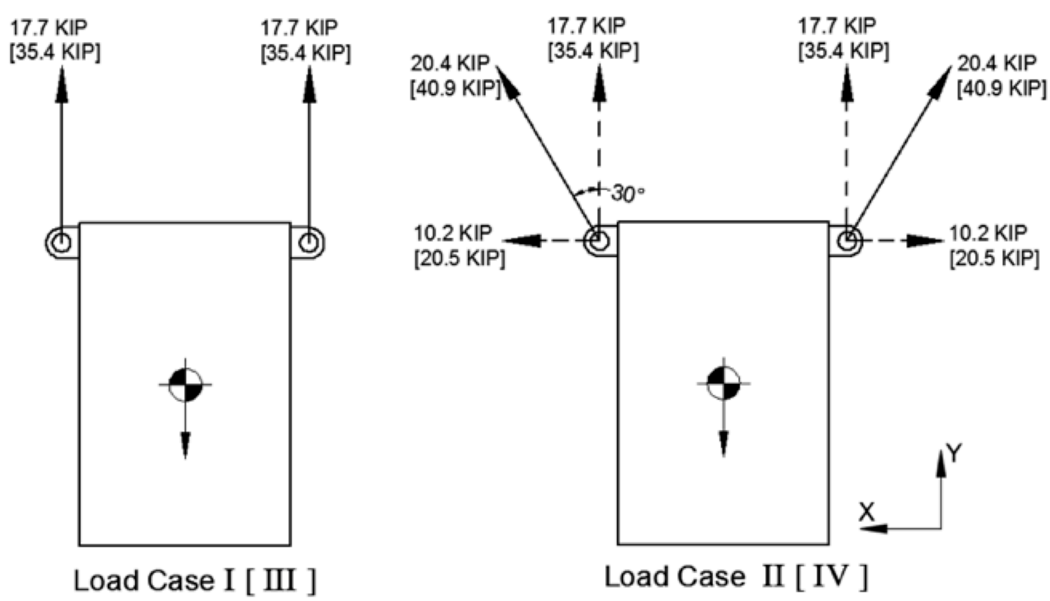

Figure 2.5.1-2. Magnitude and Direction of Loading in Ear Analysis

Table 2.5.1-1 provides a summary of the stress evaluation presented in Section 2.12.3. As the table shows, the margin of safety for all components and cases are positive. Therefore, the cask lifting device meets the requirements of 10 CFR 71.45.

Table 2.5.1-1. Summary of Cask Lifting Device Stresses

Condition	Allowable Yield (ksi)	Allowable Ultimate (ksi)	Case I			Case II			Case III		
			Stress (ksi)	*MS (y)	*MS (U)	Stress (ksi)	MS (y)	MS (U)	Stress (ksi)	MS (y)	MS (U)
Shear tearout of lifting hole - Auxiliary	14.00	26.18	6.02	1.33	3.35	---	---	---	---	---	---
Shear tearout of lifting hole - Standard	14.00	26.18	8.98	0.56	1.92	---	---	---	---	---	---
Tensile failure of lifting ear plate - Auxiliary	23.70	68.60	4.82	3.92	13.23	---	---	---	---	---	---
Tensile failure of lifting ear plate - Standard	23.70	68.60	17.70	0.34	2.88	---	---	---	---	---	---
Bearing of shackle pin on ear - Auxiliary	23.70	68.60	10.20	1.32	5.73	---	---	---	---	---	---
Bearing of shackle pin on ear - Standard	23.70	68.60	17.70	0.34	2.88	---	---	---	4.72	4.02	13.53
Tensile stress on weld joint - Auxiliary	23.70	68.60	6.50	2.65	9.55	---	---	---	---	---	---
Tensile stress on base metal - Auxiliary	23.70	68.60	9.19	1.58	6.46	9.20	1.58	6.46	---	---	---
Tensile stress on weld joint - Standard	23.70	68.60	8.16	1.90	7.41	---	---	---	---	---	---
Tensile stress on base metal - Standard	23.70	68.60	5.77	3.11	10.89	4.85	3.89	13.14	---	---	---
Tensile stress on mounting bolt-Standard	85.00	110.00	61.42	0.38	0.79	---	---	---	---	---	---
Shearing of bolt - Standard	51.00	---	14.60	2.49	---	---	---	---	---	---	---
Shearing of bolt threads-Standard	51.00	---	11.76	3.34	---	---	---	---	---	---	---
Shearing of tapered threads-Standard	14.00	26.18	9.18	0.53	1.85	---	---	---	---	---	---
Tensile stress on cask outer shell - Standard	23.70	68.60	10.95	1.16	5.26	---	---	---	---	---	---

*Note:
MS(y): Margin of safety based on yield strength.
MS(U): Margin of safety based on ultimate strength.

2.5.1.2. Cask Lifting Ear Mounting Bolt Fatigue Evaluation

The fatigue evaluation of the lifting ear mounting bolts per ASME Section III NB indicates that the bolts have an expected life of 11 years based on 12 usages per year. Bolts are inspected during the installation of the lifting ears. Damaged or defective bolts are replaced as needed.

2.5.1.3. Excessive Load Failure

The lifting devices must be designed such that their failure under excessive load would not impair the ability of the package to meet other requirements of 10 CFR 71.45(a). A review of the above margin of safety from Table 2.5.1-1 indicates that, under excessive loading, the ear attaching bolts will fail before the ear plates, ear welds or cask shell. Failure of the bolts assures that the ability of the package to meet any other regulatory requirements is not impaired.

2.5.1.4. Model 2000 Lid Lifting Lug Analysis

The lid is lifted by a single lifting lug that is composed of a 1-inch diameter stainless steel rod located at the center of the lid top. It is shown by analysis that this lifting device complies with requirements of 10 CFR 71.45(a). The lifting lug is able to support three times the weight of the lid without yielding.

The weakest part of the lifting lug is determined to have a factor of safety of 1.76 when analyzed for lifting three times the weight of the lid. Details of the analysis are documented in Section 2.12.3.

Because the lid lifting lug is covered by the cask overpack during transport the device is rendered inoperable. Therefore, no further evaluation is required.

2.5.2. Tie-Down Devices

The Model 2000 Transport Package tie-down components are evaluated structurally in the following sections. The lifting and tie-down requirements are as specified in 10 CFR 71.45(b).

2.5.2.1. Tie-Down Evaluation

The Model 2000 Transport Package is normally shipped by truck. Figure 2.5.2-1 shows the overall plan for tying the package to the vehicle. Eight wire ropes or chains tie the package to the vehicle: four connect to the upper [[ ]] tie-down ribs of the overpack, and the other four connect to the overpack base [[ ]] tie-down ribs. In addition, the base of the package is wedged to the truck bed to prevent sliding. Evaluation of the tie-down stresses is presented in Table 2.5.2-1. As the table shows all components exhibit a positive margin of safety.

Table 2.5.2-1. Tie-Down System Stress Analysis Results

Condition	Stress (ksi)	Allowable based on Yield (ksi)	MS	Allowable Based on Ultimate Strength (ksi)	MS
Shear tear-out of rib hole	20.99	0.6 × 45.2 = 27.12	0.29	96.8/(2 × 1.31) = 36.95	0.76
Bearing of shackle pin	42.46	45.2	0.06	96.8	1.28
Shear stress in weld joints	20.99	0.6 × 45.2 = 27.12	0.29	96.8/(2 × 1.31) = 36.95	0.76

2.5.2.2. Excessive Load Failure

Tie-down devices must be designed such that their failure under excessive load would not impair the ability of the package to meet other requirements of 10 CFR 71.45(b)(3). A review of the above margin of safety from Table 2.5.2-1 indicates that, under excessive loading, either the rib hole will tear out or the connecting weld will fail in shear. Failure of the rib or connecting weld does not impair the ability of the overpack or other package components from meeting other regulatory requirements.

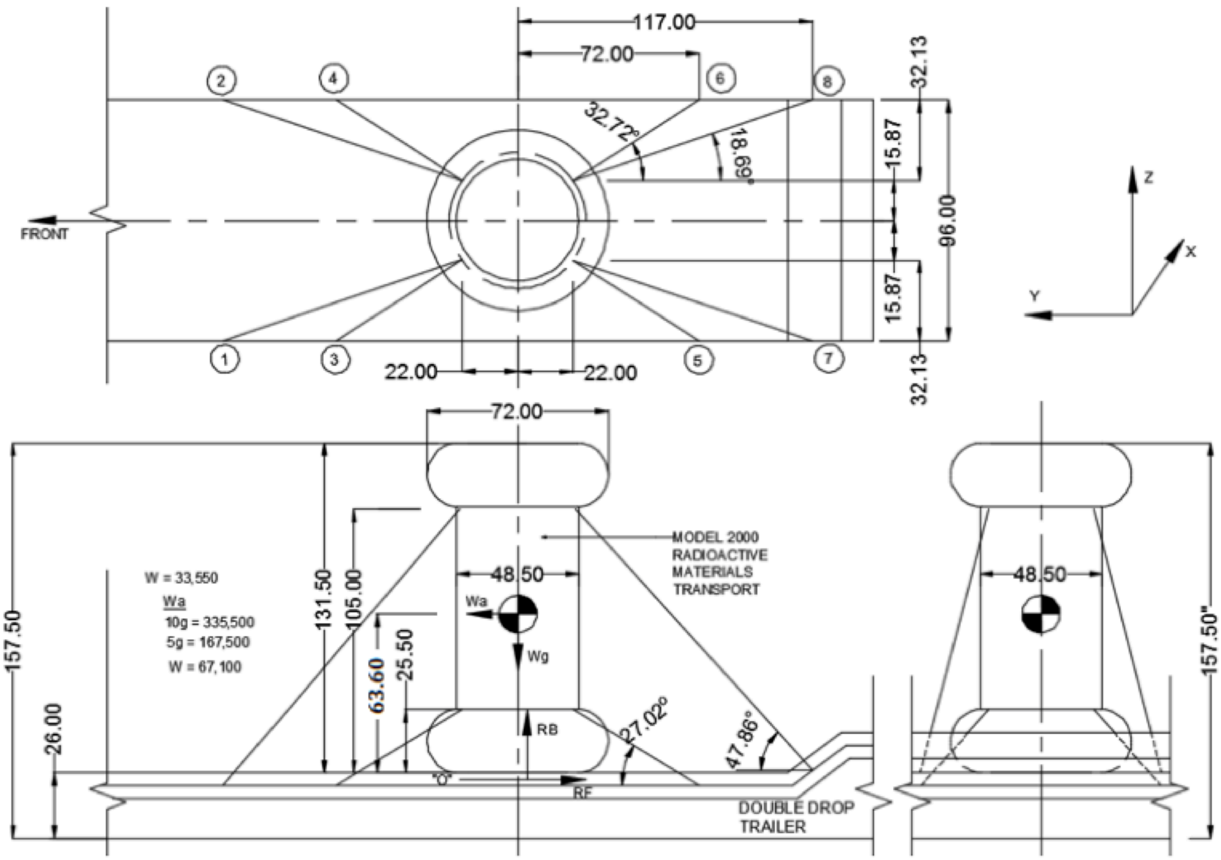

Figure 2.5.2-1. Tie-Down of Transport Package to Vehicle

2.6 Normal Conditions of Transport

This section provides the evaluation that shows the Model 2000 Transport Package, with HPI and material basket, meets the standards specified in 10 CFR 71.43 and 71.51, when subjected to the tests and conditions specified in 10 CFR 71.71 (Normal Conditions of Transport). The package is evaluated against each condition individually.

2.6.1. Heat

The thermal evaluation for the NCT heat conditions is presented in Section 3.3. The NCT heat condition consists of exposing the cask to direct sunlight and 100°F still air. For routine conditions, solar insolation is neglected. For NCT, solar insolation is applied to the package surface. For both cases, an initial temperature of 100°F and an internal power generation of 3000 W are used for the evaluation.

2.6.1.1. Summary of Pressures and Temperatures

Table 2.6.1-1 provides a summary of temperatures for the 3000 W thermal evaluation which thermally bounds 1500 W presented in Chapter 3 of this application. Additionally, internal gases in the cask and HPI are explicitly modeled in Chapter 3. Evaluation of the maximum pressure at the calculated average gas temperatures, presented in Section 3.1.4, shows that the 3000 W heat decay does not exceed the design pressure of 30 psia.

2.6.1.2. Differential Thermal Expansion

The differential thermal expansion of the Model 2000 cask is evaluated as part of the ASME Section III NB stress analysis included in Section 2.6.7 of this application to show compliance with the design criteria presented in Section 2.1.2. Review of the NCT heat conditions shows that a bounding thermal expansion model is possible by applying a 300°F temperature differential from the outside surface to the inside surface of the cask. To maximize thermal expansion, a temperature of 300°F is applied to the outer surface of the cask and 600°F to the inside surface of the cask. For the HPI and material basket thermal expansion and fit during worst-case thermal conditions assuming an initial temperature of 70°F.

<u>Radial Thermal Expansion</u>

Figure 2.6.1-1 through Figure 2.6.1-3 shows the HPI [[ ]], material basket, and HPI [[ ]] and cask inner shell diameters. Using the bounding temperature for each component, the change in diameter is calculated as:

$$d_{final} = d_0 (1 + \alpha\Delta T)$$

Where, the initial diameter, d_0, is multiplied by the product of the coefficient of thermal expansion, α, and change in temperature, ΔT, plus one. Table 2.6.1-2 shows the results of the evaluation. The minimum worst case difference in diameters is calculated to be [[ ]] between the HPI [[ ]], which results in no radial interference. Therefore, the HPI and material basket can be removed from the cask following shipment.

Axial Thermal Expansion

Axial thermal expansion occurs when the material basket is heated by the source material from ambient conditions to NCT steady-state temperatures. Axial thermal expansion also occurs as the HPI heat reaches steady state and the inner shell of the cask expands. Using the bounding temperature for each component, the change in length is calculated as:

$$L_{final} = L_0 (1 + \alpha\Delta T)$$

Where, the initial length, L_0, is multiplied by the product of the coefficient of thermal expansion, α, and change in temperature, ΔT. Table 2.6.1-3 shows the results of the evaluation. The minimum worst case difference in lengths is calculated to be 0.13 inches between the material basket and HPI inner cavity, which results in no axial interference.

2.6.1.3. Stress Calculations

Regulatory Guide 7.8 stress combination results are presented in Section 2.6.7. Individual thermal stresses are summarized in Table 2.6.1-4. For the HPI and material basket, the evaluation of thermal stresses is not required per ASME Code III-NF (NF-3121.11).

2.6.1.4. Comparison with Allowable Stresses

This section presents the stress combinations based upon the design criteria presented in Section 2.1.2 for NCT. The cask stresses resulting from NCT are presented in Table 2.6.1-5. Comparison of the calculated stresses to the allowable stresses presented in Section 2.1.2 demonstrates that the Model 2000 cask meets the performance requirements. In addition, the condition of the overpack during NCT is evaluated in Section 2.12.1, Cases 4, 5, and 6.

Evaluation of the HPI for end and side drop orientations calculated stresses in key components including the inner and out [[ ]] The results show that in all cases the calculated margin of safety is greater than +1. Therefore, the HPI meets the performance requirements specified in Section 2.1.2. The material basket was also evaluated for NCT drop conditions using classic methods. The results of the analysis show that the margin of safety is greater than +1. Therefore, the material basket meets the performance requirements specified in Section 2.1.2.

The NCT analysis results show that the overpack, cask, HPI and material basket meet all performance requirements, which include maintaining containment and geometry.

[[

]]

Figure 2.6.1-1. HPI [[ ]] **Details**

[[

]]

Figure 2.6.1-2. Material Basket Detail

[[

]]

Figure 2.6.1-3. HPI Inside Diameter

Table 2.6.1-1. Temperature Results, NCT (in Shade and with Insolation)

Component	100°F Ambient Temperature, in Shade			100°F Ambient Temperature, with Insolation		
	Max	Min	Avg	Max	Min	Avg
Material Basket	989	465	801	1,001	490	815
HPI	581	360	---	604	388	---
HPI Shielding (top)	517	506	513	539	529	535
HPI Shielding (sides)	581	435	544	601	460	565
HPI Shielding (bottom)	477	427	451	501	452	475
Cask (bottom, shells, top, lid)	430	309	---	455	338	---
Cask Shielding (lid)	424	408	414	449	433	440
Cask Shielding (sides)	405	341	385	431	370	412
Cask Lid Seal	406	383	---	432	409	---
Cask Drain Port (bottom)	342	309	---	370	338	---
Cask Test Port (top)	400	383	---	426	409	---
Cask Vent Port (lid)	416	410	---	442	435	---
Overpack Base	335	159	---	364	184	---
Overpack Cover	272	108	---	308	174	---
Overpack Toroidal Shell (top)	159	110	125	207	165	179
Overpack Toroidal Shell (bottom)	215	114	139	249	136	176
Overpack Honeycomb Impact Limiter (top)	220	205	215	263	249	258
Overpack Honeycomb Impact Limiter (bottom)	330	275	304	359	305	334
HPI Fill Gas	971	460	672	983	485	689
Cask Fill Gas	574	346	462	594	374	486
HPI and Cask Fill Gas, Combined	971	346	481	983	374	505

Note: Data taken from Table 3.3.1-1

Table 2.6.1-2. Radial Thermal Expansion Evaluation for HPI and Material Basket

[[						
						]]

Table 2.6.1-3. Axial Thermal Expansion Evaluation for HPI and Material Basket

[[						
						]]

Table 2.6.1-4. NCT Thermal Stress Results (psi)

Case	Section Number	Thermal Stress (psi)
NCT End Drop	1	15110
NCT End Drop	2	6404
NCT Side Drop	3	9649
NCT Side Drop	4	15110
NCT Side Drop	5	7039

Table 2.6.1-5. Model 2000 Cask NCT Stress Analysis Summary (psi)

Case	Stress Component	Stress Combination	Stress Intensity	Allowable	Margin of Safety
1	P_m	5411	20000	20000	2.7
	$P_m + P_b$	17510	20000	30000	0.7
	$P_m + P_b + Q$	40690	20000	60000	0.5
2	P_m	14500	20000	20000	0.4
	$P_m + P_b$	25000	20000	30000	0.2
	$P_m + P_b + Q$	42864	20000	60000	0.4
3	P_m	2906	19300	19300	5.6
	$P_m + P_b$	9699	19300	28950	2.0
	$P_m + P_b + Q$	19355	19300	57900	2.0
4	P_m	6023	19300	19300	2.2
	$P_m + P_b$	17910	19300	28950	0.6
	$P_m + P_b + Q$	41280	19300	57900	0.4
5	P_m	16090	19300	19300	0.2
	$P_m + P_b$	25950	19300	28950	0.1
	$P_m + P_b + Q$	44469	19300	57900	0.3

2.6.2. Cold

The Model 2000 Transport Package is analyzed for structural adequacy in accordance with the thermal evaluation of the Model 2000 Transport Package for the temperatures specified in 10 CFR 71.71(c)(2) is presented in Chapter 3. The thermal evaluation demonstrates that the Model 2000 Transport Package component temperatures are maintained within their safe operating ranges for all normal conditions of transport. The bounding methodology for evaluating the thermal stress in the Model 2000 Transport Package is presented in Section 2.6.1 and individual thermal stresses are summarized in Table 2.6.1-4. Thermal stresses are combined with mechanical stresses in Section 2.6.7 and compared to the appropriate ASME Code allowables.

2.6.3. Reduced External Pressure

The drop in atmospheric pressure to 24 kPa (3.5 psia) is specified in 10 CFR 71.71(c)(3). This additional differential pressure has a negligible effect on the Model 2000 cask because, in Section 2.6.7, the cask is analyzed for a normal transport conditions internal pressure of 15.3 psig (30 psia). Maximum internal pressure is included in combination with internal loads. Because the margins of safety are all positive, this satisfies the requirements of 10 CFR 71.71(c)(3) for reduced external pressure.

2.6.4. Increased External Pressure

An increased external pressure of 20 psia (5.3 psig external pressure), as specified in 10 CFR 71.71(c)(4), has a negligible effect on the Model 2000 cask because of the thick outer shell and end closures. Section 2.6.7 addresses many different loading cases, which exceed these prescribed external pressure requirements. Therefore, the requirements of 10 CFR 71.71(c)(4) are satisfied.

2.6.5. Vibration

The Model 2000 Transport Package is evaluated for effects of vibrations that are normally incident to transport, as specified in 10 CFR 71.71(c)(5). The effects of shock and vibration loads associated with this road on transportation on the Model 2000 are negligible as determined in this section. For this evaluation, rather than determining the frequency of vibration of the package to establish the maximum acceleration, the cask has been structurally analyzed using the accelerations associated with NCT. Table 2.6.7-1 provides a summary of the accelerations used to evaluate the cask. The accelerations are applied statically to the ANSYS model described in detail in Section 2.6.7 to produces the maximum stress intensity in the package components. The results of the cask body, HPI and material basket analyses show that the package is capable of experiencing continuous NCT accelerations without degrading the ability of the package to meet the other parts of the regulations. Additionally, the closure system is designed in accordance with NUREG/CR-6007, which determines the bolt preload based on the impact loads experienced during HAC, which bounds the loads experience during transport (Reference 2-15). Further, a fatigue analysis is performed in accordance with ASME Code, Section III, NB-3232.3, which concluded that after 190 transports, all bolts shall be replaced. Therefore, the requirements of 10 CFR 71.71(c)(5) are satisfied.

2.6.6. Water Spray

Water causes negligible corrosion of the stainless shell of the Model 2000 Transport Package. The cask housed in the overpack and the contents are protected in the sealed cask cavity. A water spray as specified in 10 CFR 71.71(c)(6) has no adverse effect on the package. Therefore, the requirements of 10 CFR 71.71(c)(6) are satisfied.

2.6.7. Free Drop

The free drop scenario outlined by 10 CFR 71.71(c)(7) requires a demonstration of the structural adequacy of the Model 2000 cask for a 1-ft drop onto a flat, essentially unyielding horizontal surface in the orientation that inflicts the maximum damage to the cask. The Model 2000 Transport Package is shown to meet the free drop requirements through a combination of classic calculations, impact analyses, and static finite element. The evaluations include the qualification of the Model 2000 cask lid bolt design for the combined effects of free drop impact force, internal pressures, thermal stress, O-ring compression force, and bolt preload following the methodology of NUREG/CR-6007 (Reference 2-15) (Section 2.12.4). The combined effects of inertial loads, internal pressures, and thermal stress are considered for packaging components. The impact analysis of the package is presented in Section 2.12.1. Section 2.6.7.1 presents the evaluation of the cask body and Section 2.6.7.2 presents the structural evaluation of the HPI and material basket during free drop conditions. The cask body and HPI structural analyses are performed using the finite element program ANSYS (Reference 2-16) and the material basket is analyzed using classic methods.

2.6.7.1. Cask Body Stress Analysis

This section evaluates the structural performances of the Model 2000 cask body analyses and shows that the design meets the requirements of 10 CFR 71.71. Specifically, the evaluation addresses the loads associated with the NCT. The results of the analyses for various load cases are presented pictorially in stress intensity contour plots as well as in table form, with the corresponding safety factors in critical components of the cask body.

2.6.7.1.1. Model Description

Finite element analysis methods are used to perform the stress evaluation of the Model 2000 cask for normal free drop conditions. Each drop condition is analyzed using a three-dimensional finite element model using the computational modeling software ANSYS that were developed in accordance with the certification drawings. Figure 2.6.7-1 shows the major components of the cask represented in the model including the inner and outer shells, flange, top and bottom forgings, lid, and closure bolts.

As shown in Figure 2.6.7-1, the finite element model, which corresponds to half (180°) of the cask body, is generated by de-featuring the AutoDesk Inventor solid model and exporting the model to a .STEP file format. The .STEP file is imported directly into ANSYS where the finite element model is developed. The solid portion of the model is constructed using ANSYS solid (SOLID185) elements. Surface-to-surface contact elements are used to simulate the interaction between adjacent components. Specifically, contact between the cask shells and lead shielding is

modeled using CONTAC174/TARGE170 surface-to-surface contact elements with zero friction, which allows the lead to float between the inner and outer shells. Contact elements are also used to bond dissimilarly meshed components. Nodal displacements are used to simulate the interaction between the cask and overpack. Weak springs elements (COMBIN14) are inserted automatically during the solution to help stabilize the model. ANSYS assigns low spring stiffness so their presence will not adversely affect the accuracy of the solution.

Boundary conditions are applied to the model simulating the loading conditions the Model 2000 cask experiences during NCT. The categories of cask loading considered in the free drop event are closure lid bolt preload, internal pressure load, thermal load, inertial body load and displacement. ANSYS input files are used to apply boundary conditions and loads to the cask model.

Closure Lid Bolt Preload

The closure lid bolt preload for 750 ft-lb maximum torque is 48,000 lb (Section 2.12.4). To apply the bolt preload ANSYS pre-tension elements (PRETS179) are used to define the 3D pre-tension section within the meshed bolt. The PRETS179 element uses a single translation degree of freedom to define pretension direction. The pretension section is modeled by a set of pretension elements defined by the bolt shaft. Figure 2.6.7-2 shows the bolt pretension values and locations. As the figure shows, the bolt divided by the symmetry plane of the model is half of the other values presented.

Internal Pressure Loading

A pressure of 30 psia is used to envelope the maximum design pressure for all NCT impact loadings considered.

Inertial Loads

To evaluate the impact performance of the cask, an LS-DYNA analysis was performed (Section 2.12.1) to determine the maximum acceleration during hot/cold and heavy/light environmental conditions and varying impact limiter shell thicknesses. Table 2.6.7-1 provides a summary of the maximum accelerations that occur during cold/light conditions.

Table 2.6.7-1. LS-DYNA Results

DESCRIPTION	DROP ANGLE (DEGREE)	APPLICABLE BOUNDARY CONDITION						ACCELERATION (g)
		Temperature			Payload			
		*Amb.	Hot	Cold	*Nom.	Heavy	Light	
NCT, End Drop, Cold	90	—	—	✓	—	—	✓	15.5
NCT, Side Drop, Cold	0	—	—	✓	—	—	✓	55.1
NCT, C.G.-Over-Corner Drop, Cold	22	—	—	✓	—	—	✓	14.6

*Note: Amb. = Ambient; Nom. = Nominal.

Cask Contents Loading—End Drop

For the end drop analyses, the contents weight is assumed to be uniformly distributed on the cask top end, over an area determined by the inside diameter of the cask lid. Therefore, one half the contents weight of 5,450 lb is applied to the cask inner shell bottom plate as nodal forces. The contents load is multiplied by the appropriate g-load to accurately represent the 1-foot and 30-foot end drop.

Cask Contents Loading—Side Drop

For side drop conditions, the contact area between the contents and the cask cavity is approximately 120° (60° on each side of the drop centerline). The inertial load produced by the 5,450 lb contents weight is represented as nodal forces applied on the interior surface of the cask. The force is applied at the HPI [[ ]] and is varied in the circumferential direction as a cosine distribution. The maximum pressure occurs at the impact centerline; the load decreases to zero at locations that are approximately 60° either side of the impact centerline, as illustrated in Figure 2.6.7-3. The actual location is dependent on the actual nodal position. The following formula is used to determine the contents forces for the side drop analyses. This method uses a summation scheme to approximate the integration of the cosine-shaped pressure distribution:

$$F_{total} = \sum_{i=1}^{4} F_{max} \cos(\theta_i) \cos(\theta_i')$$

$$F_{total} = 5{,}450/2 \text{ lb} \times G$$

where

F_{max} = maximum pressure (at impact centerline)

θ_i = average angle of subtended arc of i^{th} element measured from centerline at point of impact, to obtain vertical component of pressure

i = i^{th} circumferential sector

θ'_i = normalized angle to peak at 0° and to be zero at 61.2°

G = impact acceleration

Figure 2.6.7-4 shows the applied nodal forces in the four regions for HAC based on the cosine distribution.

Nodal Displacement

With the absence of the overpack, nodal displacements are used to simulate the interaction between the overpack and cask body, which treats the cask body as a beam. For the side the nodes are constrained radially at the location where the cask body contacts the overpack. For the end drop, the nodal locations are visible in Figure 2.6.7-2 as a radial band at the top end of the cask. For the side drop, an additional smaller band of nodes located at the bottom end of the cask is used to represent the bottom impact limiter. Nodal displacements are also applied at the center plane of the cask to simulate symmetry. This is accomplished by fixing the out of plane displacement (Y) and the rotations about the other axes (X and Z).

Thermal

According to Regulatory Guide 7.8 (Reference 2-2), four credible thermal conditions must be considered.

Condition 1 – Hot Case 1:

a. Ambient temperature, 100°F
b. Initial temperature, 100°F
c. Heat transfer to ambient by natural convection, still air
d. Heat transfer to ambient by radiation
e. Solar insolation as a periodic heat flux applied as 12-hr on and 12-hr off
f. Internal heat load of 3000 W

Condition 2 – Hot Case 2:

a. Ambient temperature, 100°F
b. Initial temperature, 100°F
c. Heat transfer to ambient by natural convection, still air
d. Heat transfer to ambient by radiation
e. No solar insolation, in shade
f. Internal heat load of 3000 W

Condition 3 – Cold Case 1:

a. Ambient temperature, -40°F
b. Initial temperature, -40°F
c. Heat transfer to ambient by natural convection, still air
d. Heat transfer to ambient by radiation
e. No solar insolation, in shade
f. Internal heat load of 500 W (minimum payload case)

Condition 4 – Cold Case 2:

a. Ambient temperature, -20°F
b. Initial temperature, -20°F
c. Heat transfer to ambient by natural convection, still air
d. Heat transfer to ambient by radiation
e. No solar insolation
f. Internal heat load of 3000 W

Review of the four heat conditions shows that a bounding thermal expansion model is possible by applying a 300°F temperature differential from the outside surface to the inside surface of the cask. For the thermal stress evaluation, a temperature of 300°F is applied to the outer surface of the cask and 600°F to the inside surface of the cask. Using the higher temperatures maximizes the thermal expansion of the materials. The temperatures for the structural analysis are obtained from the results file and database file of the thermal analysis by writing the results to an ASCII file using the ANSYS BFINT command. Nodes for the structural model are transferred to the same coordinate system as used by the thermal run and the thermal results are interpolated for each thermal condition. The temperatures are applied as a boundary condition static structural model using the ANSYS BF command. Figure 2.6.7-5 shows the temperature distribution that is imported into the static structural model to solve for the thermal stresses. The resulting thermal stresses (Q) are combined with the inertial and pressure stresses (P_m+ P_b) to meet the stress requirements presented in Section 2.1.2.

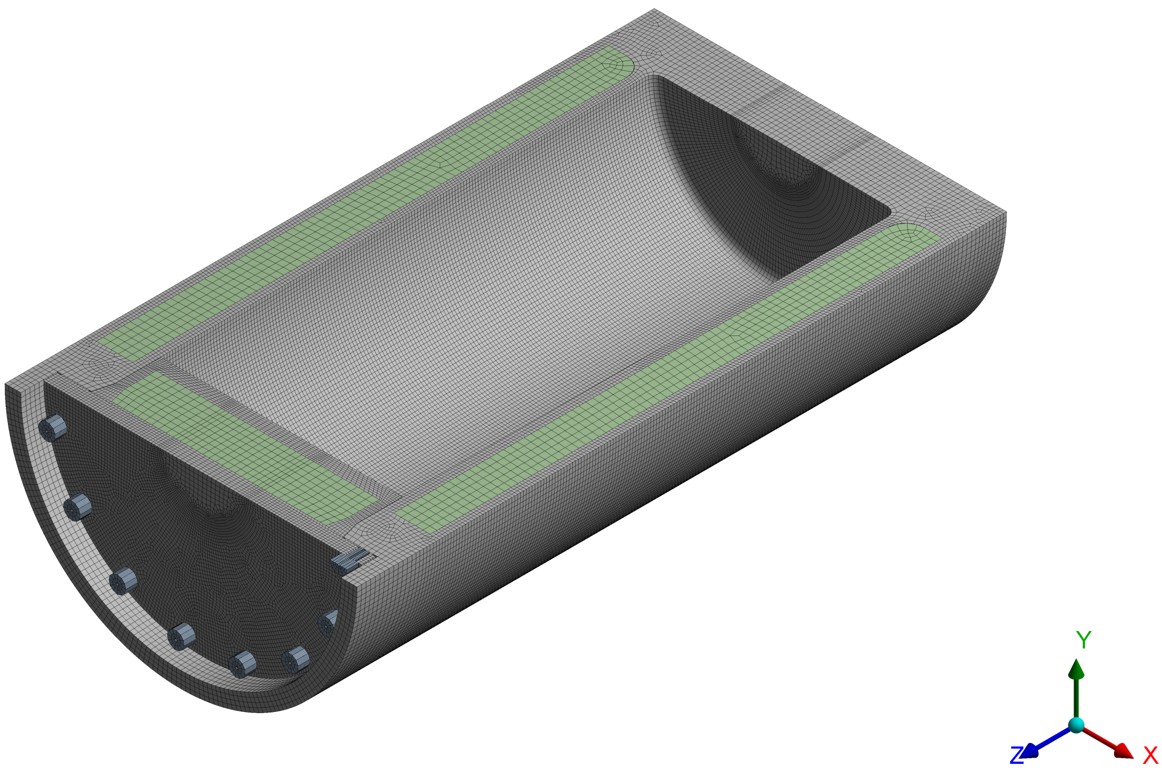

Figure 2.6.7-1. ANSYS Finite Element Model of the Cask Body

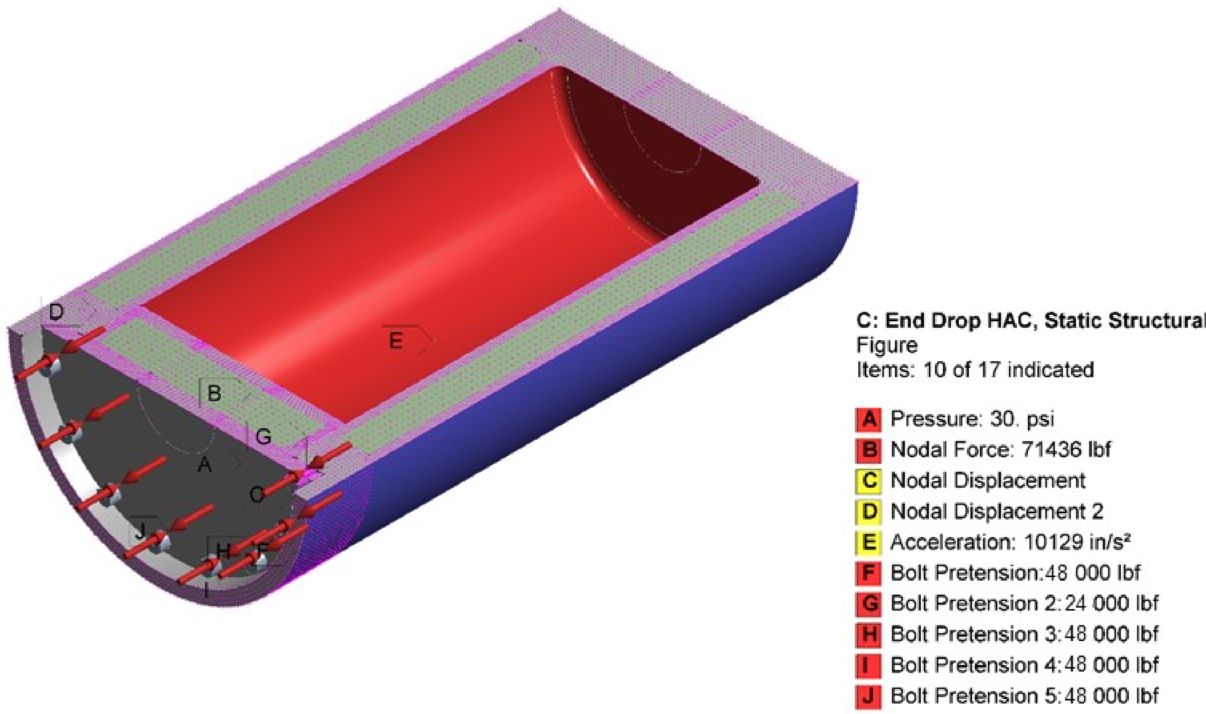

Figure 2.6.7-2. Applied Boundary Conditions for End Drop Model

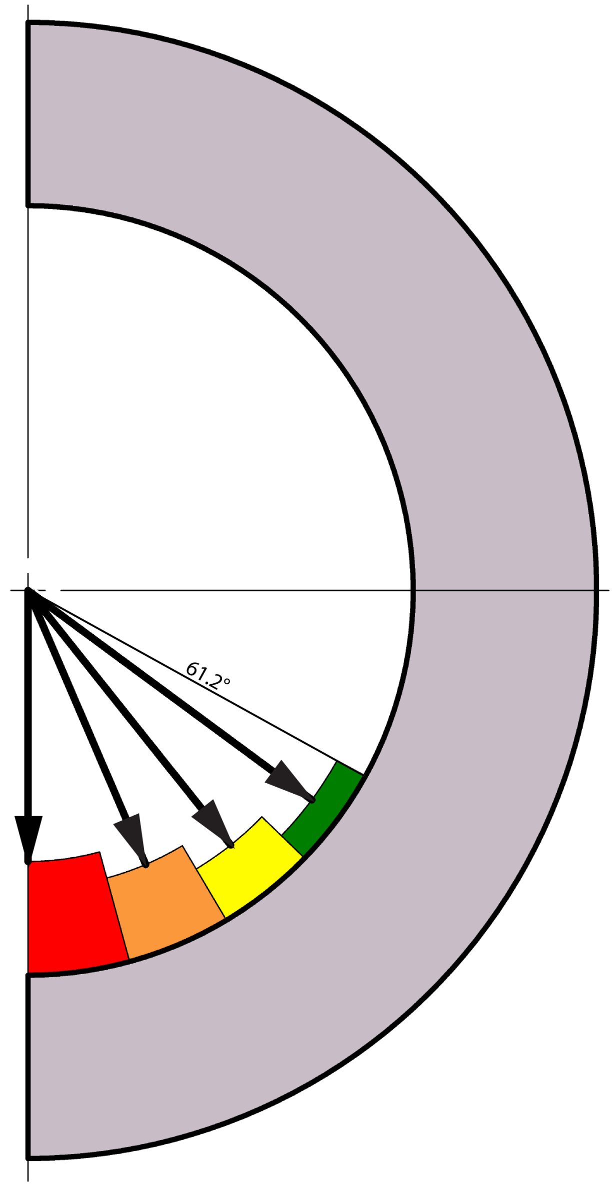

Figure 2.6.7-3. Cosine Distribution to Simulate Contents Loading During Side Drop

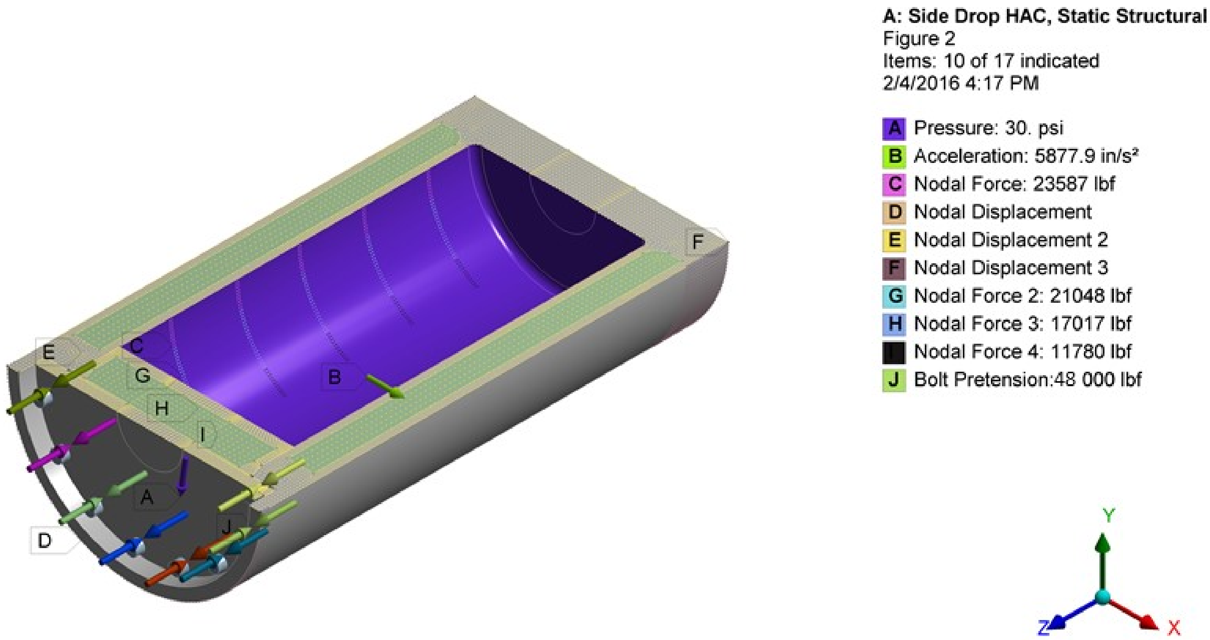

Figure 2.6.7-4. Applied Boundary Conditions for Side Drop Model

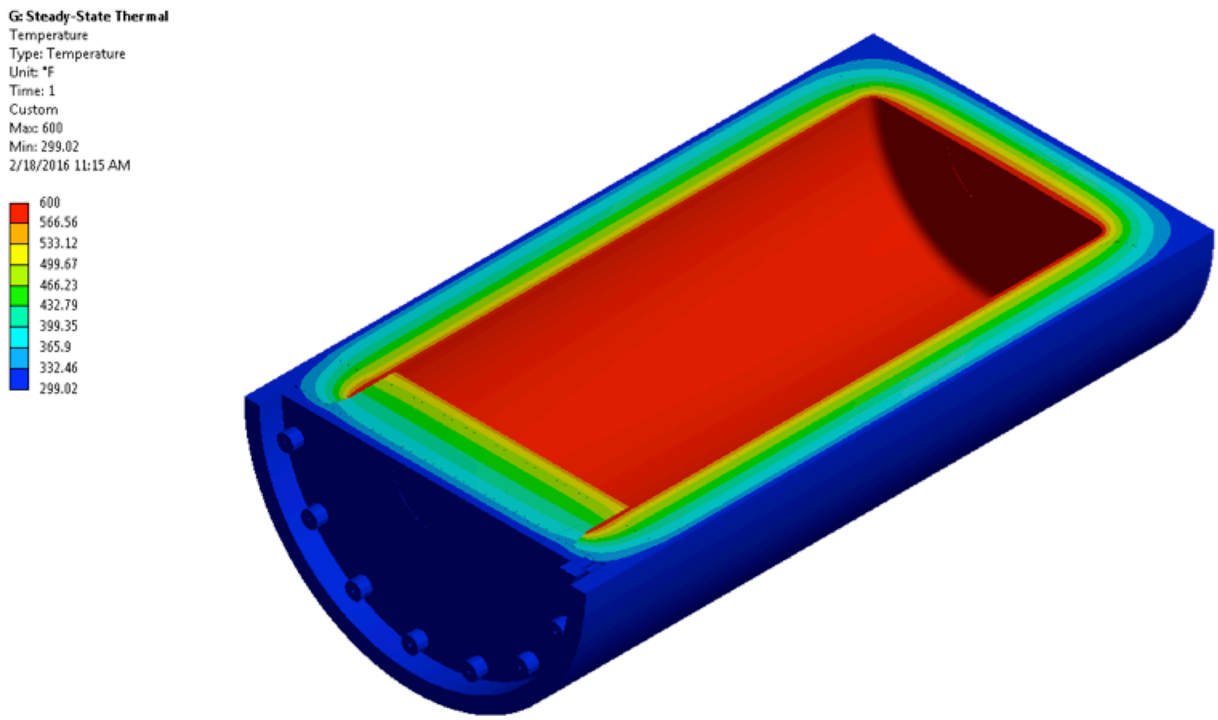

Figure 2.6.7-5. Temperature Profile for Thermal Stress Evaluation

2.6.7.1.2. NCT End Drop

In accordance with the requirements of 10 CFR 71.71, the Model 2000 cask is structurally evaluated for the normal condition of transport 1-foot end-drop. In this event, the cask (equipped with an impact limiter over each end) falls a distance of 1-foot onto a flat, unyielding, horizontal surface. The cask strikes the surface in a vertical position; consequently, an end impact on the bottom end or top end of the cask occurs. Because the cask bottom of fabricated from a solid stainless steel forging, the top drop orientation was chosen to maximum damage to the cask containment boundary. Closure bolts are evaluated separately (Section 2.12.4).

The most critically stressed component in the system is the cask flange region, which is due to bending of the flange from the inertial load imposed by the cask lid. The second region of interest is in the cask lid in the closure bolt contact region. To evaluate the stresses in these regions linearized stress are calculated across the thickness of the plate. For the top flange, Figure 2.6.7-6 shows the location of the maximum total stress intensity and Figure 2.6.7-7 indicates the path (Section 1) location where the stresses are calculated. Table 2.6.7-2 is a listing of the Section 1 stresses. Table 2.6.7-3 documents the primary membrane (P_m), primary membrane plus primary bending (P_m+P_b), primary membrane plus primary bending plus secondary stress (P_m+P_b+Q) in accordance with the criteria presented in Regulatory Guide 7.6 (Reference 2-17). Stresses are compared to the allowable at a bounding temperature of 300°F. The minimum margin of safety is found to be +2.7 for primary membrane, +0.7 for primary membrane plus bending and +0.5 for primary membrane plus bending plus secondary stress intensity.

Figure 2.6.7-8 shows the location of the maximum total stress intensity in the lid and Figure 2.6.7-9 indicates the path (Section 2). Table 2.6.7-4 presents a listing of the Section 2 stresses and Table 2.6.7-5 provides the stress combinations in accordance with the Regulatory Guide 7.6 criteria. The minimum margin of safety is found to be +0.4 for primary membrane, +0.2 for primary membrane plus bending and 0.4 for primary membrane plus bending plus secondary stress intensity. Because all of the margins of safety are positive, the Model 2000 cask meets the end drop requirement of 10 CFR 71.71(c)(7).

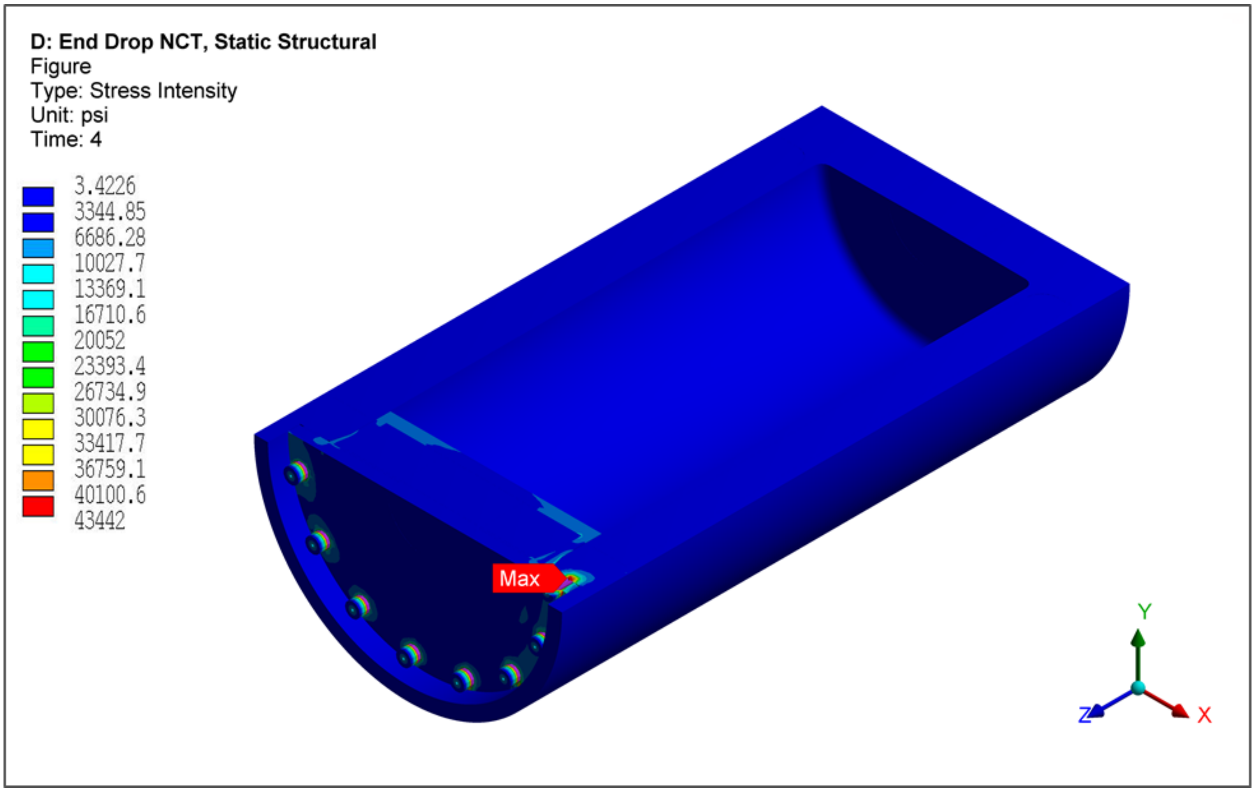

Figure 2.6.7-6. NCT End Drop Cask Body Stress Intensity (total stress psi)

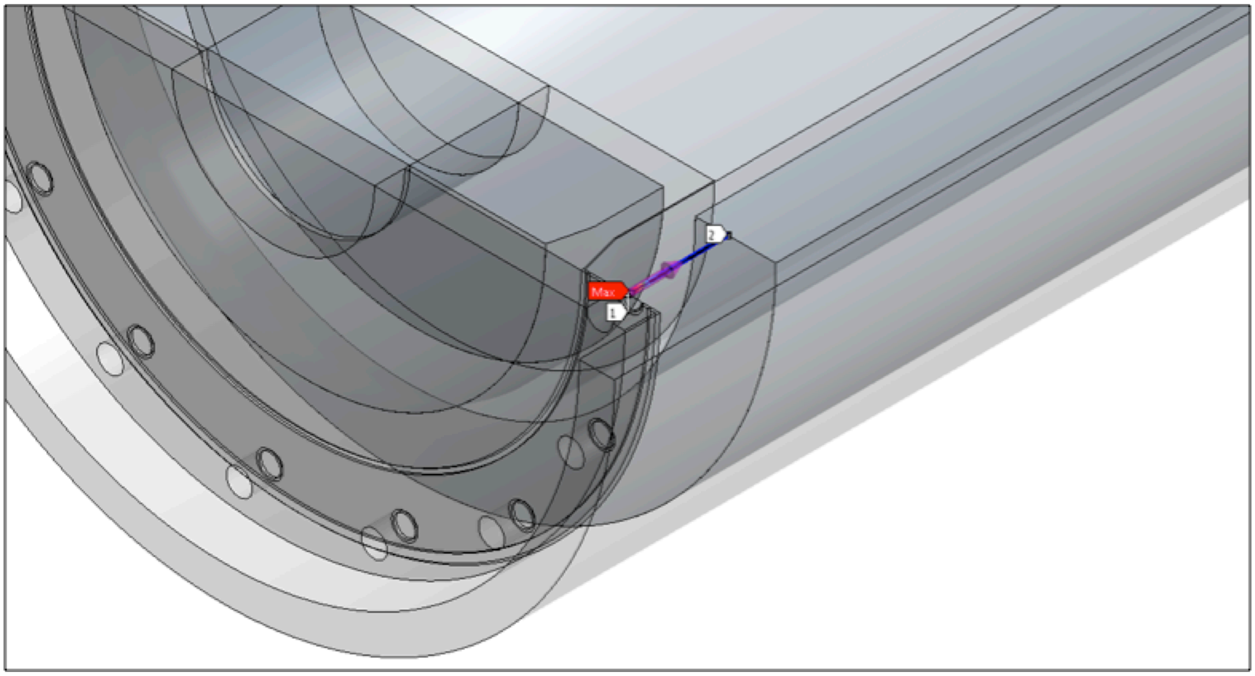

Figure 2.6.7-7. NCT End Drop Linearized Stress Location (Section 1)

Table 2.6.7-2. NCT End Drop Section 1 Stress Results (psi)

Stress State	Location	S1	S2	S3	SINT
MEMBRANE (P_m)	—	5846	902	435	5411
BENDING (P_b)	Inside	14100	2053	1685	12420
	Center	0	0	0	0
	Outside	-1685	-2053	-14100	12420
MEMBRANE + BENDING	Inside	19920	2688	2411	17510
	Center	5846	902	435	5411
	Outside	-748	-1599	-8309	7561
PEAK	Inside	23120	13060	9779	13340
	Center	-626	-827	-5431	4805
	Outside	7948	1290	966	6982
TOTAL	Inside	42540	15680	12760	29781
	Center	962	-224	-438	1401
	Outside	366	-369	-449	815

Table 2.6.7-3. NCT End Drop Section 1 Stress Results (psi)

Stress Component	Stress Combination	Stress Intensity	Allowable	Margin of Safety
P_m	5411	20000	20000	2.7
$P_m + P_b$	17510	20000	30000	0.7
$P_m + P_b + Q$	40690	20000	60000	0.5

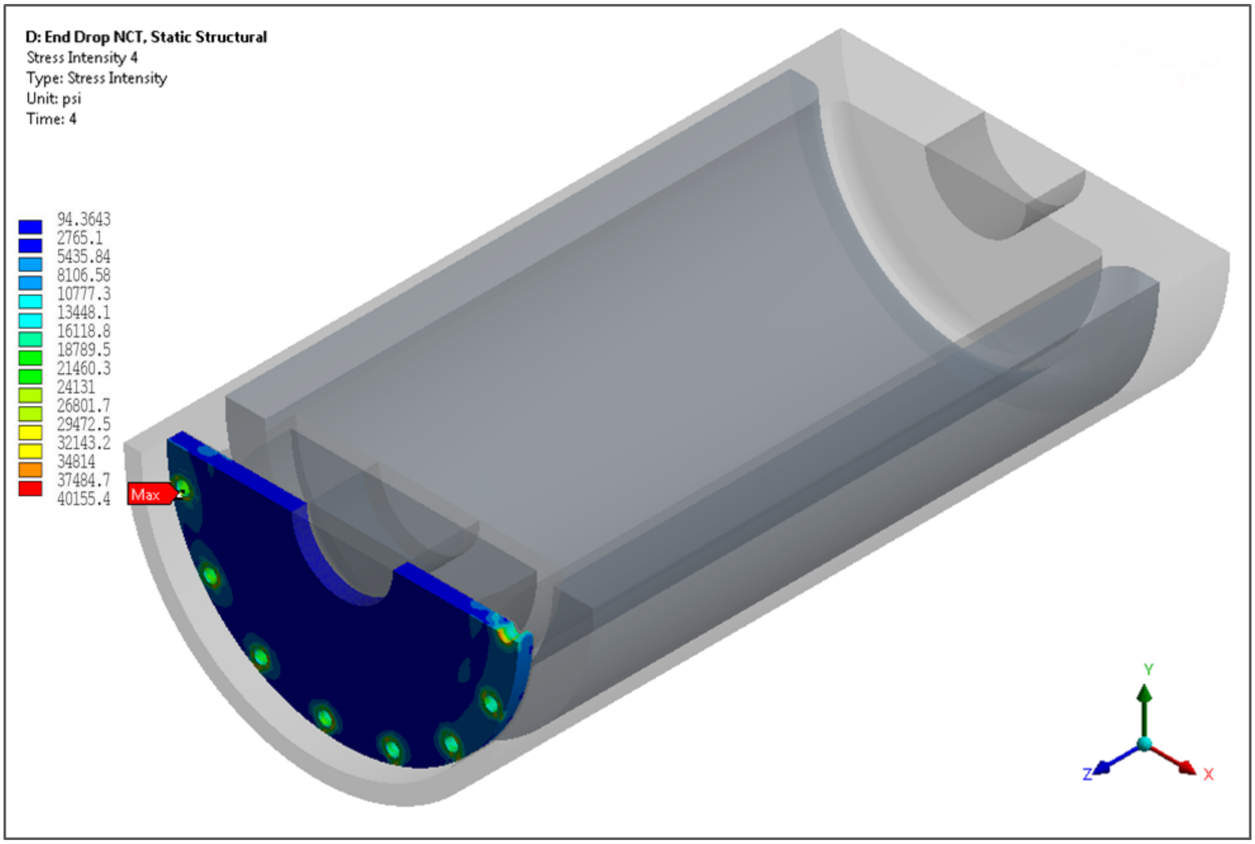

Figure 2.6.7-8. NCT End Drop Lid Stress Intensity (total stress psi)

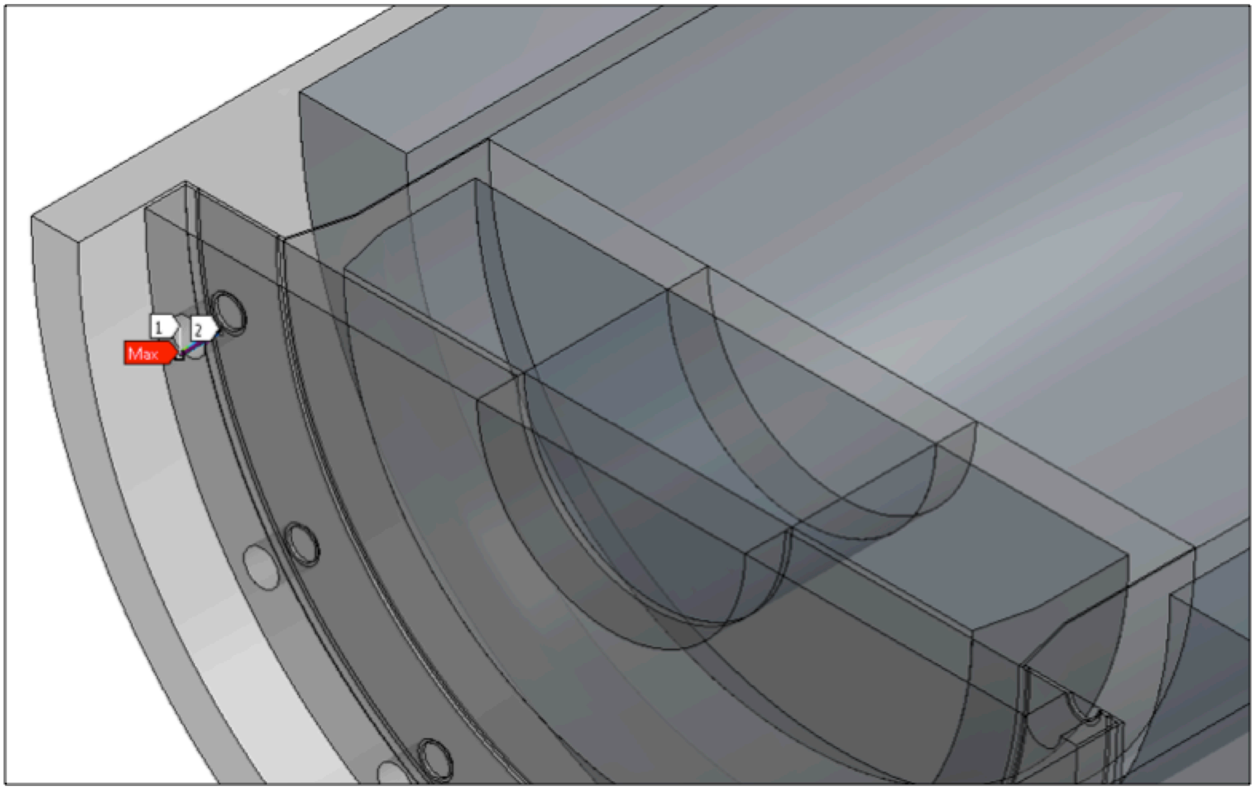

Figure 2.6.7-9. NCT End Drop Linearized Stress Location (Section 2)

Table 2.6.7-4. NCT End Drop Section 2 Stress Results (psi)

Stress State	Location	S1	S2	S3	SINT
MEMBRANE (P_m)	—	285	-189	-14210	14500
BENDING (P_b)	Inside	-2024	-5455	-13050	11030
	Center	0	0	0	0
	Outside	13050	5455	2024	11030
MEMBRANE + BENDING	Inside	-2239	-5170	-27240	25000
	Center	285	-189	-14210	14500
	Outside	5740	2036	-1360	7100
PEAK	Inside	-9130	-10750	-14340	5215
	Center	4992	2307	395	4597
	Outside	235	-3380	-6623	6858
TOTAL	Inside	-13380	-14350	-41140	27760
	Center	2592	294	-9308	11900
	Outside	2789	1800	-7942	10730

Table 2.6.7-5. NCT End Drop Section 2 Stress Results (psi)

Stress Component	Stress Combination	Stress Intensity	Allowable	Margin of Safety
P_m	14500	20000	20000	0.4
$P_m + P_b$	25000	20000	30000	0.2
$P_m + P_b + Q$	42864	20000	60000	0.4

2.6.7.1.3. NCT Side Drop

In accordance with the requirements of 10 CFR 71.71, the Model 2000 cask is structurally evaluated for the normal condition of transport 1-foot side-drop. In this event, the cask (equipped with an impact limiter over each end) falls a distance of 1-foot onto a flat, unyielding, horizontal surface. The cask strikes the surface in a horizontal position. Closure bolts are evaluated separately Section 2.12.4.

The most critically stressed component in the system is the cask inner shell at the interface with the bottom forging, the cask flange region, and the cask lid. To evaluate the stresses in these

regions linearized stress are calculated across the thickness of the plate. For the cask inner shell, Figure 2.6.7-10 shows the location of the maximum total stress intensity and Figure 2.6.7-11 indicates the path (Section 3) location where the stresses are calculated. Table 2.6.7-6 is a listing of the Section 3 stresses. Table 2.6.7-7 documents the primary membrane (P_m), primary membrane plus primary bending (P_m+P_b), primary membrane plus primary bending plus secondary stress (P_m+P_b+Q) in accordance with the criteria presented in Regulatory Guide 7.6. Stresses are compared to the allowable at a bounding temperature of 350°F. The minimum margin of safety is found to be +5.6 for primary membrane, +2.0 for primary membrane plus bending and +2.0 for primary membrane plus bending plus secondary stress intensity.

For the top flange, Figure 2.6.7-12 shows the location of the maximum total stress intensity and Figure 2.6.7-13 indicates the path (Section 4) location where the stresses are calculated. Table 2.6.7-8 is a listing of the Section 4 stresses. Table 2.6.7-9 documents the primary membrane (P_m), primary membrane plus primary bending (P_m+P_b), primary membrane plus primary bending plus secondary stress (P_m+P_b+Q) in accordance with the criteria presented in Regulatory Guide 7.6. The minimum margin of safety is found to be +2.2 for primary membrane, +0.6 for primary membrane plus bending and +0.4 for primary membrane plus bending plus secondary stress intensity.

Figure 2.6.7-14 shows the location of the maximum total stress intensity in the lid and Figure 2.6.7-15 indicates the path (Section 5). Table 2.6.7-10 presents a listing of the Section 5 stresses and Table 2.6.7-11 provides the stress combinations in accordance with the Regulatory Guide 7.6 criteria. The minimum margin of safety is found to be +0.2 for primary membrane, +0.1 for primary membrane plus bending and +0.3 for primary membrane plus bending plus secondary stress intensity. Because all of the margins of safety are positive, the Model 2000 cask meets the end drop requirement of 10 CFR 71.71.

For NCT bearing stresses are also considered in the region where the HPI contacts the cask inner shell. Bearing stress is the total applied load divided by the contact area. Because contact with the HPI is explicitly modeled by applying nodal force at the location of the HPI [[ ]], the bearing stress can be represented as the normal stress in ANSYS. Figure 2.6.7-16 presents the normal stress distribution. As predicted the compressive stress with the largest magnitude, -10,009 psi, occurs at the centerline of the cask. Comparing the absolute value of the compressive stress to the yield strength of the 304 stainless steel at 600°F, 18,400 psi, the margin of safety is +0.84. Therefore, the bearing stress meets the stress criteria presented in Section 2.1.2.

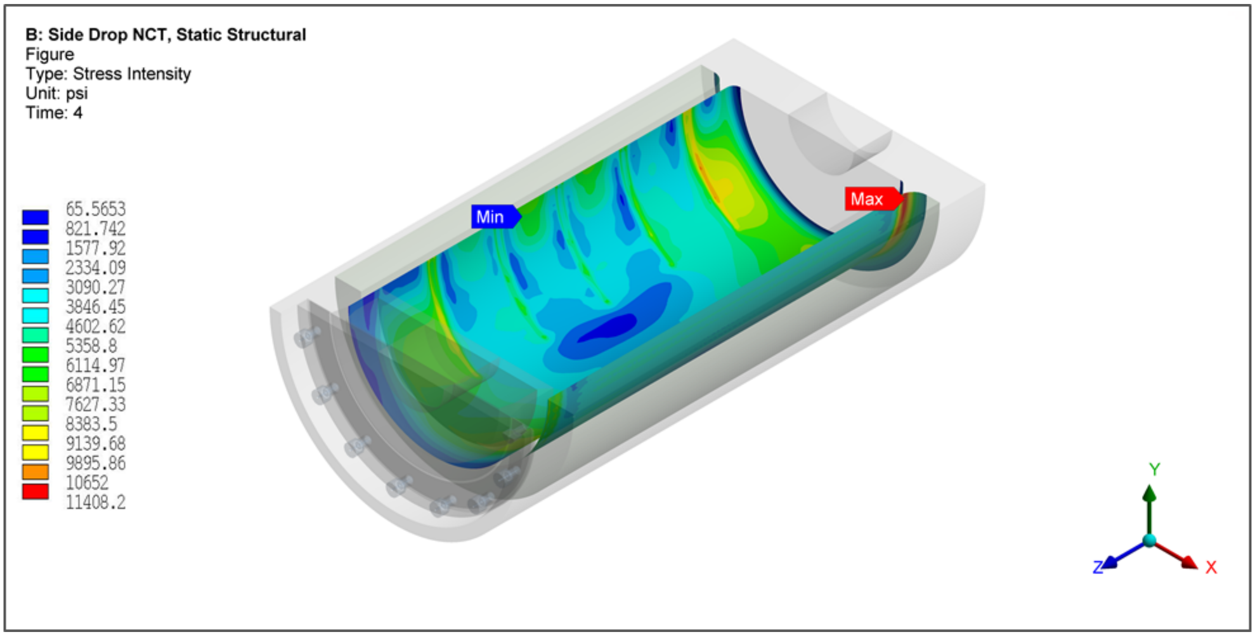

Figure 2.6.7-10. NCT Side Drop Cask Inner Shell Stress Intensity (total stress psi)

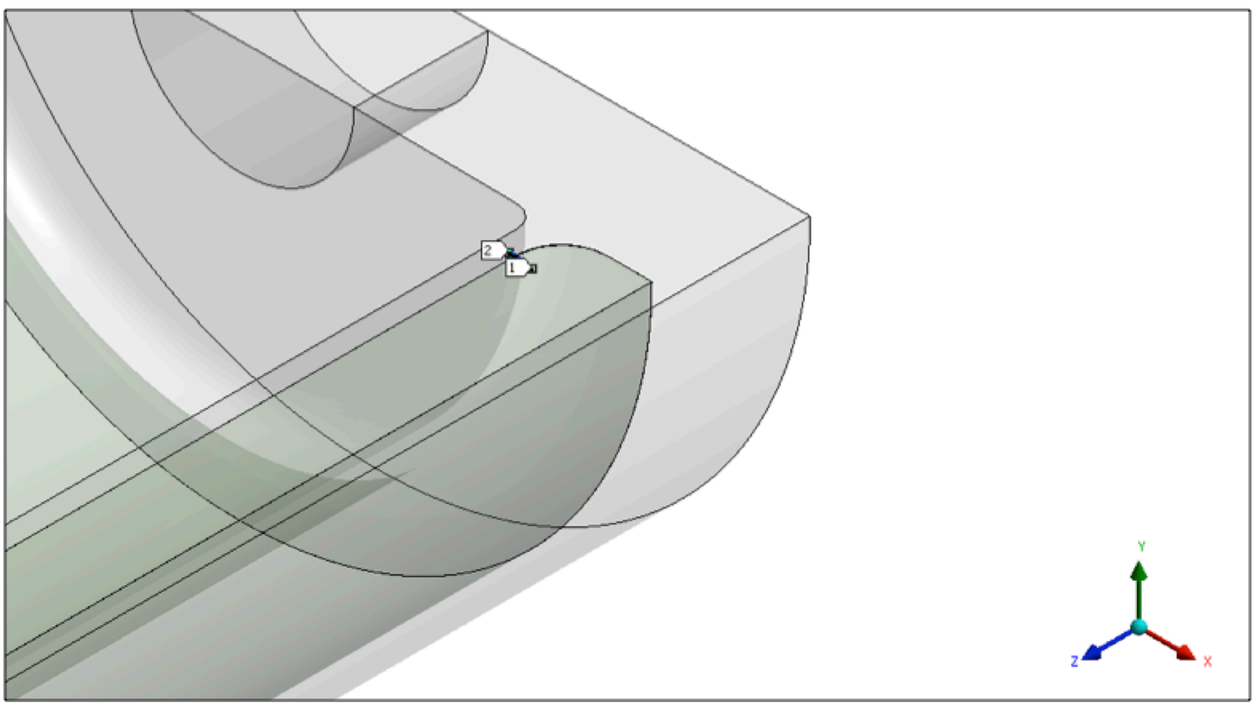

Figure 2.6.7-11. NCT Side Drop Linearized Stress Location (Section 3)

Table 2.6.7-6. NCT Side Drop Section 3 Stress Results (psi)

Stress State	Location	S1	S2	S3	SINT
MEMBRANE (P_m)	—	2685	1199	-221	2906
BENDING (P_b)	Inside	7757	2447	384	7373
	Center	0	0	0	0
	Outside	-384	-2447	-7757	7373
MEMBRANE + BENDING	Inside	10150	3660	447	9699
	Center	2685	1199	-221	2906
	Outside	-50	-1218	-5656	5606
PEAK	Inside	1466	320	-257	1723
	Center	118	-40	-328	446
	Outside	379	-33	-363	742
TOTAL	Inside	11600	3980	200	11401
	Center	2363	1155	-104	2468
	Outside	41	-1251	-5731	5772

Table 2.6.7-7. NCT Side Drop Section 3 Stress Results (psi)

Stress Component	Stress Combination	Stress Intensity	Allowable	Margin of Safety
P_m	2906	19300	19300	5.6
$P_m + P_b$	9699	19300	28950	2.0
$P_m + P_b + Q$	19355	19300	57900	2.0

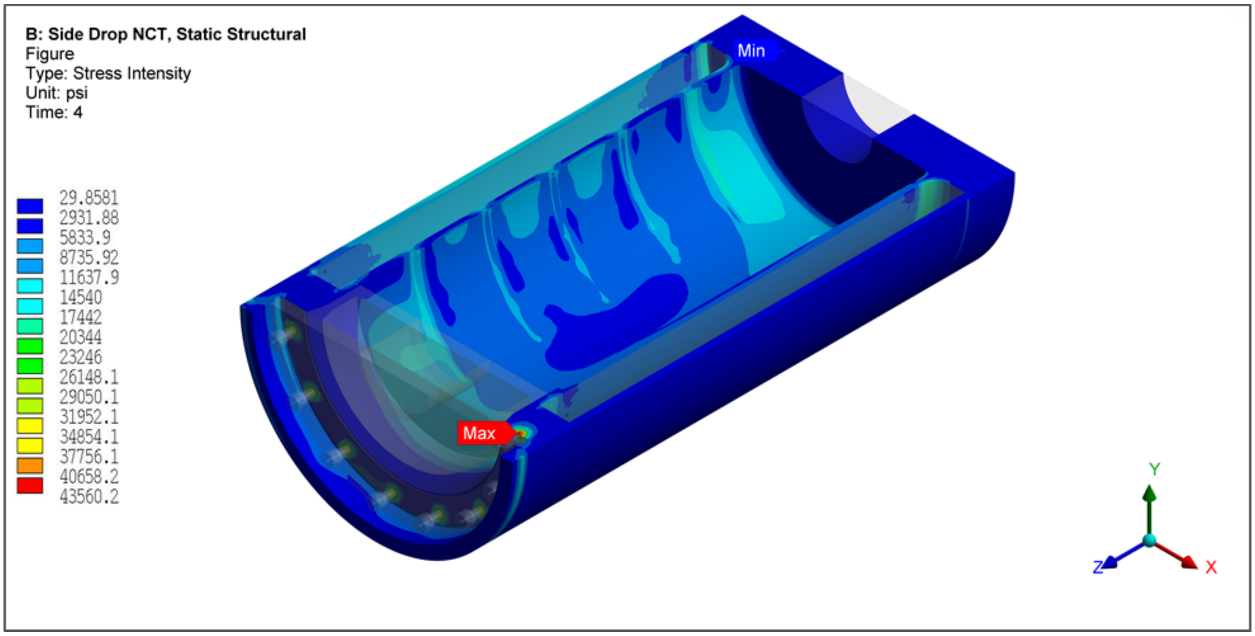

Figure 2.6.7-12. NCT Side Drop Cask Flange Stress Intensity (total stress psi)

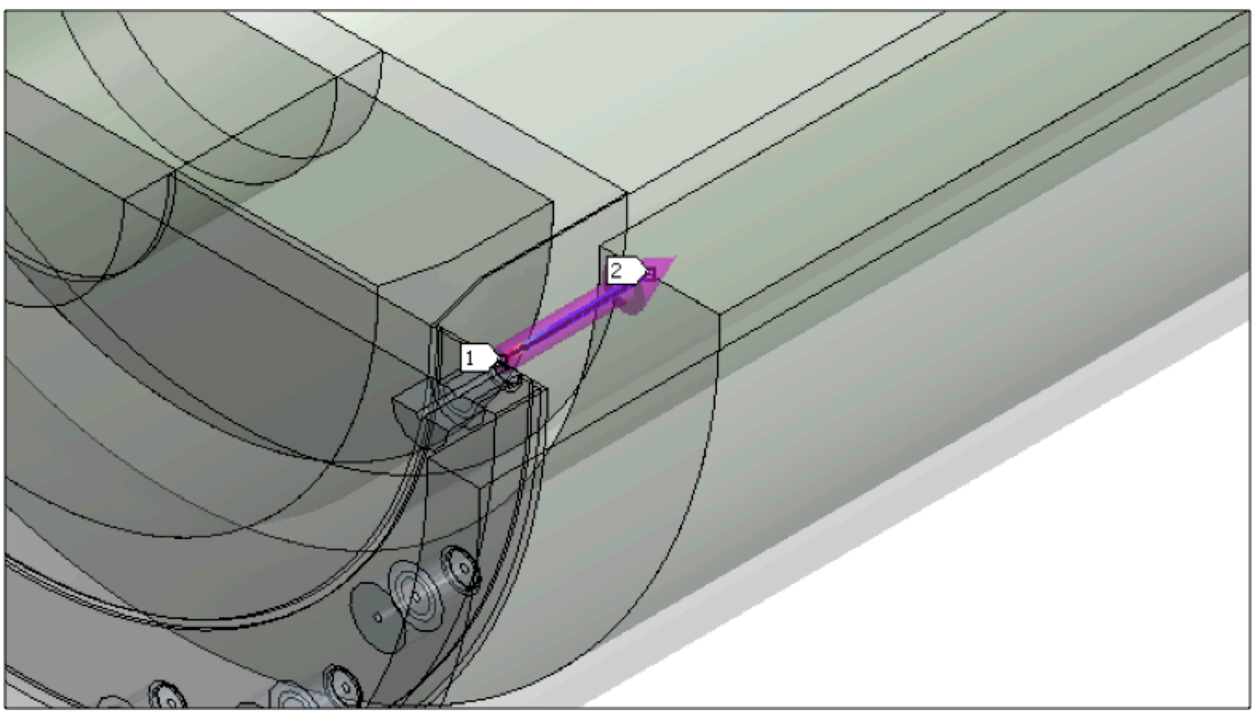

Figure 2.6.7-13. NCT Side Drop Linearized Stress Location (Section 4)

Table 2.6.7-8. NCT Side Drop Section 4 Stress Results (psi)

Stress State	Location	S1	S2	S3	SINT
MEMBRANE (P_m)	—	6412	939	389	6023
BENDING (P_b)	Inside	13800	2527	1895	11900
	Center	0	0	0	0
	Outside	-1895	-2527	-13800	11900
MEMBRANE + BENDING	Inside	20200	3478	2287	17910
	Center	6412	939	389	6023
	Outside	-1476	-1576	-7429	5952
PEAK	Inside	22380	12760	10030	12350
	Center	-681	-1027	-5044	4363
	Outside	7436	1432	1107	6329
TOTAL	Inside	42240	16060	12840	29400
	Center	1480	-190	-302	1782
	Outside	45	-120	-431	477

Table 2.6.7-9. NCT Side Drop Section 4 Stress Results (psi)

Stress Component	Stress Combination	Stress Intensity	Allowable	Margin of Safety
P_m	6023	19300	19300	2.2
$P_m + P_b$	17910	19300	28950	0.6
$P_m + P_b + Q$	41280	19300	57900	0.4

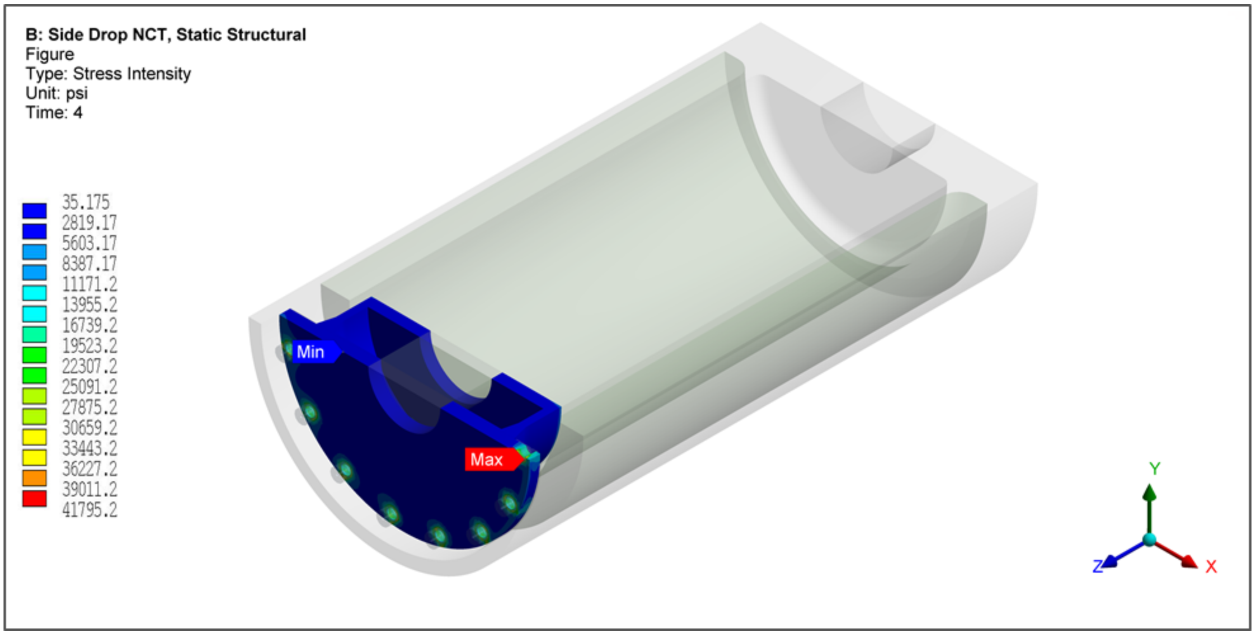

Figure 2.6.7-14. NCT Side Drop Cask Lid Stress Intensity (total stress psi)

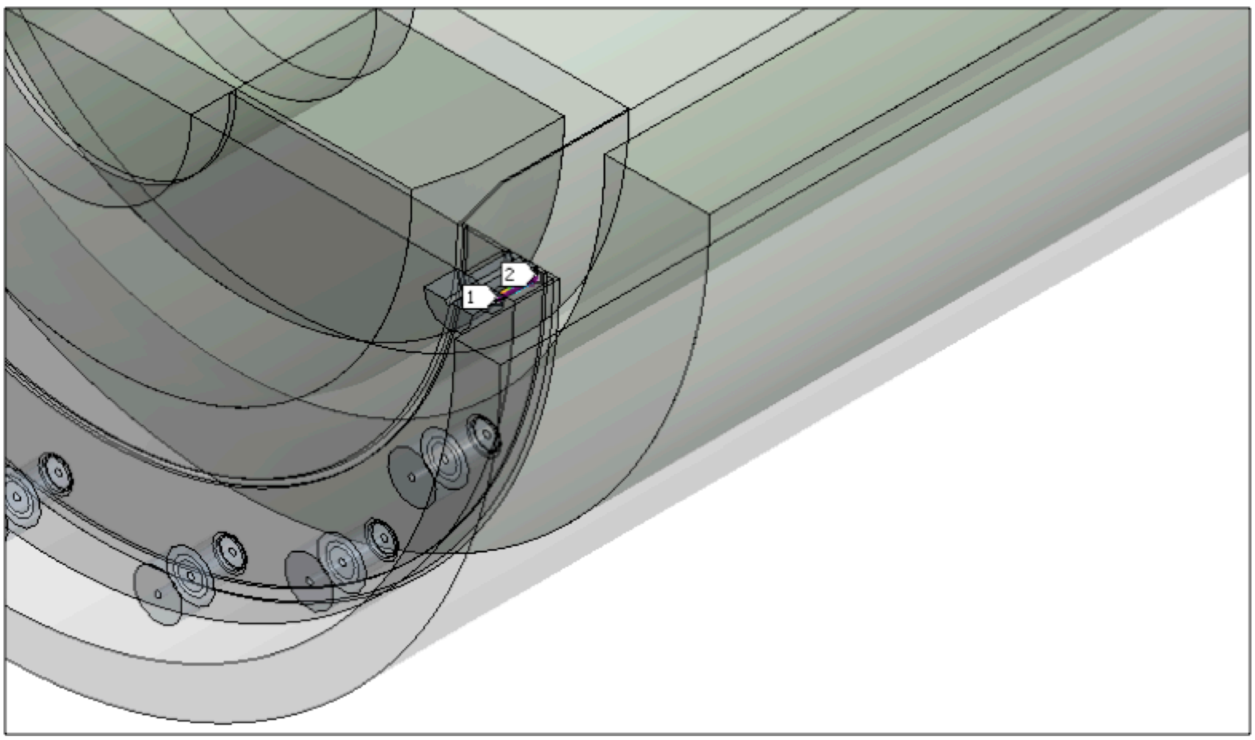

Figure 2.6.7-15. NCT Side Drop Linearized Stress Location (Section 5)

Table 2.6.7-10. NCT Side Drop Section 5 Stress Results (psi)

Stress State	Location	S1	S2	S3	SINT
MEMBRANE (P_m)	—	-684	-4079	-16770	16090
BENDING (P_b)	Inside	-343	-5757	-10400	10060
	Center	0	0	0	0
	Outside	10400	5757	343	10060
MEMBRANE + BENDING	Inside	-1106	-9877	-27050	25950
	Center	-684	-4079	-16770	16090
	Outside	1773	-30	-6771	8544
PEAK	Inside	117	-4066	-6171	6288
	Center	3818	2746	408	3410
	Outside	640	-4755	-5971	6611
TOTAL	Inside	-1541	-15960	-30660	29120
	Center	10	-1488	-13080	13090
	Outside	726	-3232	-12610	13330

Table 2.6.7-11. NCT Side Drop Section 5 Stress Results (psi)

Stress Component	Stress Combination	Stress Intensity	Allowable	Margin of Safety
P_m	16090	19300	19300	0.2
$P_m + P_b$	25950	19300	28950	0.1
$P_m + P_b + Q$	44469	19300	57900	0.3

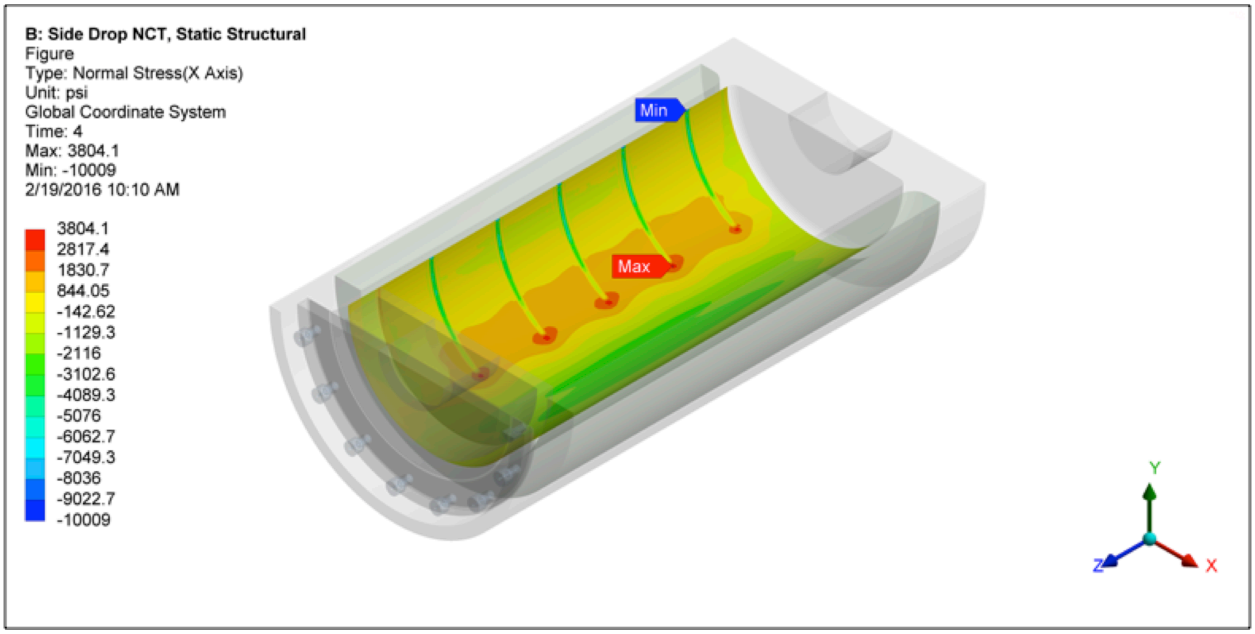

Figure 2.6.7-16. NCT Side Drop Normal Stress Distribution (psi)

2.6.7.1.4. NCT Corner Drop

The Model 2000 cask is composed of materials other than fiberboard or wood. Also, the weight of the Model 2000 cask exceeds 220 lb. According to 10 CFR 71.71(c)(8), the corner drop test is not applicable to the Model 2000 cask.

2.6.7.1.5. Penetration

According to 10 CFR 71.71(c)(10), a penetration test involving a 13-lb penetration cylinder dropped from a height of 40 inches is required for evaluation of packages during normal conditions of transport. However, Regulatory Guide 7.8 states "the penetration test of 10 CFR 71.71 is not considered by the NRC staff to have structural significance for large shipping casks (except for unprotected valves and rupture disks) and is not considered as a general requirement." A penetration evaluation is not performed because the Model 2000 cask has no unprotected valves or rupture disks that could be affected by normal conditions of transport.

2.6.7.1.6. Cask Overpack Bolt Evaluation

During normal use, the overpack bolt is subjected to two stresses. One is the stress due to preload and acts on the reduced cross sectional area between the threaded region and the shoulder. The other stress is due to the shear from lifting the package by the top part of the overpack. Fatigue life for each stress case is evaluated to determine the limiting value.

Preload Stress:

Because the bolt is loaded in shear, preloading is only required to prevent its loosening during transport. To further ensure that the bolt will not come loose during transport, an adhesive/sealant compound is applied to the bolt threads prior to installation. The required torque for the overpack bolts is 100±5 ft-lb dry per 101E8719 and 105E9521.

The cask overpack uses 15 equally spaced 7/8-9 UNC-2A, ASTM A540 Grade B22, Class 3 bolts:

Proof Strength = Minimum Yield Strength x 85% = 115700 (0.85) = 98345 psi (Table 2.2-9)

Temperature = 192°F (Figure 3.5.1-2(b), Average of 175.0°F and 209.8°F)

The maximum preload on the bolt is:

$P = 5T_{Max} / D_{Nom} = 7200$ lb

where:

$T_{Max} = 100 + 5 = 105$ ft-lb = 1260 in-lb

D_{Nom} = Nominal thread size = 7/8 in = 0.875 in

The area of the reduced cross section between the threads and the shoulder is

$A = 0.25\ \pi\ (0.726)^2 = 0.414\ in^2$The tensile stress in this region is:

$\sigma_T = P/A = 7200/0.414 = 17391$ psi << Proof Strength = 98345 psi

From ASME NB 3232.3 (Reference 2-18), the fatigue strength reduction factor is 4.0. The modulus of elasticity at 192°F is $29.04(10)^6$ psi (Reference 2-7, Table TM-1, Material Group C, Page 785). Because the fatigue curve (ASME Section III, Figure I-9.4, Page 12) is based on a modulus of elasticity of $30(10^6)$ psi, the stress range is given by:

$S_r = 17391\ (4.0)\ [\ 30(10)^6/29.04(10)^6] = 71864$ psi

The alternating component is one-half of the range:

$S_a = S_r/2 = 71864/2 = 35932$ psi

The number of cycles to fatigue failure is determined from Reference 2-18, Table I-9.0, Figure I-9.4: MNS ≤ $2.7S_m$. The number of cycles to failure is calculated using the procedure defined in Table I-9.0, general note (b):

Fatigue Limit = $5000\ (10{,}000/5{,}000)^{\ Log(45/35.9)/Log(45/34)} = 5000\ (2)^{\ 0.806}$ cycles

Fatigue Limit ≈ 8700 cycles

Assuming an average of 2 cycles/usage and 12 usages per year, the expected life of the bolts is:

Bolt life = 8700/[2(12)] = 362 years

Lifting Shear Stress:
The weight transferred through the bolts during lifting of the assembled package is equal to the combined weight of the cask, HPI, material basket, contents, and overpack base. This total combined weight is:

$W_T = (W_{cask\ body} + W_{cask\ lid}) + W_{HPI} + (W_{material\ basket} + W_{contents}) + W_{overpack\ base}$

$= (16000 + 1900) + 5{,}133 + (114 + 203) + 3633 = 26983$ lb

The above component weights are obtained from Table 2.1-3 and Table 2.1-4.

The area of the 15 bolts loaded in double shear is:

A_T = Total area of bolt shoulders = $(2)(15)(0.25)\pi(1.375)^2 = 44.55\ in^2$

The bolt shearing stress associated with a vertical lift of the package and contents is:

$\tau = W_T / A_T = 26983/44.55 = 606$ psi

Correcting for fatigue strength and modulus of elasticity gives a stress range of:

$\tau_r = 606\ (4.0)\ [30(10)^6/29.04(10)^6] = 2504$ psi

The alternating component is:

$\tau_a = \tau_r/2 = 2{,}504/2 = 1{,}252$ psi

The fatigue limit is > 10^6 cycles (ASME Section III, Figure I-9.4, Page 12)

2.6.7.2. HPI Stress Analysis

The purpose of this section is to document the Model 2000 HPI and material basket analyses that shows the design meets the requirements of 10 CFR 71. Specifically, the evaluation addresses the mechanical loads associated with the NCT.

The results of the analyses for various load cases are presented pictorially as stress intensity contour plots as well as in table form, with the corresponding margin of safety in each component of the cask body.

2.6.7.2.1. HPI Model Description

The HPI design was developed using Autodesk Inventor. To generate the ANSYS compatible solid model, the Inventor model of the HPI is divided in half (180°) along the center plane. The final solid model is exported as a .STEP file and is imported directly into ANSYS where the finite element model is meshed. The solid model of the HPI is shown in Figure 2.6.7-17.

The solid portion of the model is constructed using ANSYS solid (SOLID185) elements. Surface-to-surface contact elements are used to simulate the interaction between adjacent components. Specifically, contact between the HPI shells and depleted uranium shielding is modeled using CONTAC174/TARGE170 surface-to-surface contact elements with zero friction, which allows the DU to float between the inner and outer shells. Contact elements are also used to bond dissimilarly meshed components. Spring elements (COMBIN14) are inserted automatically during the solution to help stabilize the model. ANSYS assigns low spring stiffness so their presence will not adversely affect the accuracy of the solution. Welds are modeled using ANSYS contact elements.

2.6.7.2.2. HPI Side Drop Model

The HPI side drop model evaluates the stresses in the [[ ]] and HPI assembly to ensure the HPI maintains structural integrity during NCT. Using the base model, refinements are made in the [[ ]] mesh to ensure accurate results. Figure 2.6.7-18 shows the finite element model of the HPI.

To simulate contact with the cask, the interaction between the HPI and cask inner shell is modeled using CONTAC52 gap elements, which acts as a compression only element. The size of the CONTAC52 gaps is determined from nominal dimensions between the impact limiter and cask body. Figure 2.6.7-19 shows the distribution of the contact elements used to simulate contact between the HPI and cask inner shell.

2.6.7.2.3. HPI End Drop Model

Of primary concern during a top or bottom end impact event is the inertial loading of the depleted uranium filled plug. For this case, a top impact is assumed because the HPI [[ ]] of depleted uranium. To evaluate the [[ ]] subassembly is treated as a separate component. Figure 2.6.7-20 shows the solid model of the [[ ]] is bolted to the HPI as a means of lifting the HPI from the cask without the need to remove the material basket. However, no credit is taken for the bolt. Therefore, only the lid assembly is evaluated using a highly-refined mesh to accurately predict stresses at the weld seam. Figure 2.6.7-21 shows the finite element model of the [[ ]]

[[

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Figure 2.6.7-17. HPI Solid Model

[[

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Figure 2.6.7-18. HPI Side Drop Finite Element Model

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Figure 2.6.7-19. Contact Elements Between HPI and Cask Inner Shell

[[

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Figure 2.6.7-20. Solid Model of HPI [[ ]]

[[

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Figure 2.6.7-21. Finite Element Model of HPI [[ ]]

2.6.7.2.4. Boundary Conditions

Boundary conditions are applied to the model simulating the loading conditions the HPI will experience during NCT. The five categories of cask loading considered in the free drop event are pressure loaded to simulate side drop contents, discrete mass to simulate end drop, thermal conditions, inertial body load and displacement. ANSYS input files are used to apply boundary conditions and loads to the cask model.

Inertial Load

To evaluate the impact performance of the HPI, an LS-DYNA analysis was performed (Section 2.12.1) to determine the maximum acceleration during hot/cold and heavy/light environmental conditions and varying impact limiter shell thicknesses. Table 2.6.7-12 provides a summary of the maximum accelerations that occur during cold conditions. With the exception of corner drop case, the accelerations listed in Table 2.6.7-12 are applied to the HPI model using the ANSYS ACEL command equivalent to NCT accelerations corresponding to the 0.3-meter drop case. Equivalent static forces, in accordance with D'Alembert's principle, represent the applied accelerations.

Pressure Loading Contents - Side Drop

Two cases are presented to evaluate the performance of the HPI during the side drop. Case 1 is a concentrated pressure distribution at the four [[ ]] Case 2 is a uniform pressure distribution ("area load"). The contact area between the material basket and the HPI inner shell is approximately 180° (90° on each side of the drop centerline). The inertial load produced by the 317-lb. content weight is represented as an equivalent static pressure applied on the interior surface of the cask. The pressure is uniformly distributed along the cavity length and is varied in the circumferential direction as a cosine distribution. The maximum pressure occurs at the impact centerline; the pressure decreases to zero at locations that are 90° from either side of the impact centerline. The pressure loading simulating the Case 1 (line load) is illustrated in Figure 2.6.7-22 and Figure 2.6.7-23 shows the pressure loading for Case 2 (area load). The following formula is used to determine the contents pressures for the side drop analyses, which vary around the circumference. This method uses a summation scheme to approximate the integration of the cosine-shaped pressure distribution:

$$F_{total} = \sum_{i=1}^{180} P_{max} A_i \cos(\theta_i) \cos(\theta'_i)$$

$$F_{total} = 317/2 \text{ kg} \times G$$

where

- P_{max} = maximum pressure (at impact centerline)
- θ_i = average angle of subtended arc of i^{th} element measured from centerline at point of impact, to obtain vertical component of pressure
- i = i^{th} circumferential sector
- θ'_i = normalized angle to peak at 0° and to be zero at 90°
- A_i = i^{th} circumferential area over which the pressure is applied
- G = side acceleration

Gap elements are defined at both ends of the cask to simulate the pressure applied by the cask inner shell during side drop conditions (see Figure 2.6.7-19). This is accomplished by defining the gap stiffness as a cosine function from a maximum value 1×10^6 lb/in at the centerline to 87,156 lb/in at 85° from the centerline of impact, and a value 50,000 lb/in from 90° to 180°.

Table 2.6.7-12. LS-DYNA NCT Impact Results Summary

DESCRIPTION	DROP ANGLE (DEGREE)	APPLICABLE BOUNDARY CONDITION						ACCELERATION (g)
		Temperature			Payload			
		Amb.	Hot	Cold	Nom.	Heavy	Light	
NCT, Cold, End Drop	90	—	—	X	—	—	X	15.5
NCT, Cold, Side Drop	0	—	—	X	—	—	X	55.1
NCT, Cold, Corner Drop	68 (=90-22)	—	—	X	—	—	X	14.6

[[

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Figure 2.6.7-22. Cosine Pressure Distribution Simulating Material Basket [[
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Figure 2.6.7-23. Cosine Pressure Distribution Assuming Uniform Contact

2.6.7.2.5. HPI NCT Side Drop Results

To evaluate the stresses in the HPI body, with a concentrated pressure load at the material basket [[ ]] linearized section stresses are evaluated at the intersection of plates, weld joints and anywhere a stress riser is observed. Stresses are evaluated using the ANSYS Parametric Design Language (APDL) macro language to cycle through each location of interest. To provide a thorough understanding of the stress profile, 684 individual sections are evaluated at axial and radial increments. At each section location, the primary membrane (P_m) and primary membrane plus primary bending (P_m+P_b) are calculated and compared to the stress criteria in accordance with the criteria presented in ASME Section III-NF (Reference 2-3). Figure 2.6.7-24 provides a visual representation of the section stress locations. Because of the total number of sections and close proximity, the section numbers are not legible. Separately, an additional seven sections are evaluated in the worst-case [[ ]] Figure 2.6.7-25 provides a visual representation of the section stress locations for the [[ ]]

2.6.7.2.6. NCT Case 1 Stress Results

The top 30 stress results for the Case 1 NCT HPI body results are presented in Table 2.6.7-13. Figure 2.6.7-26 and Table 2.6.7-14 present the Case 1 NCT [[ ]] stress results. As shown in the tables, the margins of safety when compared to the stress intensity for each category are greater than one.

Bearing loads, per ASME III-NF-3223.1 for Service Level A (NCT) events, are compared to the yield stress at temperature. From the ANSYS output, the maximum bearing stress that results from the total force applied by the material basket [[ ]] to the HPI inner shell is 1690.2 psi. Assuming a maximum temperature of 1000°F the yield stress is 17,000 psi. Therefore, the margin of safety is 9.1.

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Figure 2.6.7-24. Linearized Section Locations for the HPI Body Evaluation

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Figure 2.6.7-25. Linearized Section Locations for the [[ ]] **Evaluation**

Table 2.6.7-13. NCT Case 1 HPI Body Top 30 Results

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Table Key:

- M = Membrane stress intensity (psi)
- M+B = Membrane + Bending stress intensity (psi)
- In = stress at the inside surface of the element (psi)
- Cen = stress at the center of the element (psi)
- Out = stress at the outer surface of the element (psi)
- Max = maximum of in, cen, and out, which is compared to the allowable stress (psi)
- Allowable = Allowable stress at temperature (psi)
- MS = Margin of safety

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Figure 2.6.7-26. Case 1, NCT, Stress Intensity Result (psi)

Table 2.6.7-14. NCT [[ ]] Case 1 Results

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2.6.7.2.7. NCT Case 2 Stress Results

The top 30 stress results for the Case 2 NCT HPI body results are presented in Table 2.6.7-15. Figure 2.6.7-27 and Table 2.6.7-16 present the Case 2 NCT [[ ]] stress results. Review of the stress results shows that there is sufficient positive margin of safety of all cases.

Bearing loads per ASME III-NF-3223.1 for Service Level A (NCT) events are compared to the yield stress at temperature. From the ANSYS output the maximum bearing stress that results from the total force applied by the material basket to the HPI inner shell is 60.0 psi. Assuming a maximum temperature of 1000°F the yield stress is 17,000 psi. Therefore, the margin of safety is +Large.

Table 2.6.7-15. NCT Case 2 HPI Body Top 30 Results

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Table Key:

- M = Membrane stress intensity (psi)
- M+B = Membrane + Bending stress intensity (psi)
- In = stress at the inside surface of the element (psi)
- Cen = stress at the center of the element (psi)
- Out = stress at the outer surface of the element (psi)
- Max = maximum of in, cen, and out, which is compared to the allowable stress (psi)
- Allowable = Allowable stress at temperature (psi)
- MS = Margin of safety

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Figure 2.6.7-27. Case 2, NCT, Stress Intensity Result (psi)

Table 2.6 7-16. NCT [[ ]] Case 2 Results

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2.6.7.2.8. HPI NCT End Drop Results

Stress results for the NCT end drop discussed previously are documented in Table 2.6.7-17. The table presents the primary membrane (P_m) and primary membrane plus primary bending (P_m+P_b) in accordance with the criteria presented in ASME Section III-NF (Reference 2-3).

As shown in the table, the margins of safety when compared to the stress intensity for each category are positive. The most critically stressed component in the system is the [[

]] The minimum margin of safety is found to be large. The locations of the critical sections corresponding to the maximum stress location and axial displacement are shown in Figure 2.6.7-28.

Table 2.6.7-17. NCT End Drop Stress Summary

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Figure 2.6.7-28. HPI NCT End Drop Results – Peak Stress Intensity (psi) and Displacement (inches)

2.6.7.3. Material Basket Evaluation

This section evaluates the material basket for NCT. Factors of safety for the basket are calculated based on the criteria for Service Level 'A' limits from ASME Section III-NF (NF-3221).

End Drop Case

During the end drop the material basket is loaded by inertia loads acting on the end of the [[ ]] Depending on the orientation of the outer cask when dropped, the basket contents will either load the material basket or the lid of the high performance insert (HPI). There is a washer welded to the bottom of the basket [[ ]] that holds the rod holders. Nothing prevents the rod holders from exiting the top of the material basket. If the outer cask is dropped while in the upright position, the material basket will be loaded by the contents. The worst-case condition of upright end drop is evaluated. The inertial loading will load the [[ ]] bundle in compression. There is no bending or shear stress present. For this evaluation, all 18 full length [[ ]] are loaded.

Stresses at bottom of [[ ]]:

$$\sigma_{\text{membrane}} = \frac{P}{A} = 837 \text{ psi compression}$$

$$\sigma_{\text{bending}} = 0 \text{ psi}$$

$$\tau_{\text{shear}} = 0 \text{ psi}$$

where $P = W \times G = 4913.5$ lbs — inertial load on 18 [[ ]] bundle

$W =$ [[ ]] lbs — basket plus contents weight

$G = 15.5$ G — NCT end drop acceleration

$A =$ [[ ]] in^2 — Cross section area of [[ ]], Table 2.6.7-18)

$S_y = 16900$ psi — Yield Strength, 316 stainless steel, 800°F (Table 2.2-1)

Minimum Margin of Safety:

The minimum margin of safety for the NCT end drop case is:

$$MS = \frac{S_y}{\sigma_m} - 1 = \frac{16900}{837} - 1 = +19.2$$

Side Drop Case

During the side drop the steel [[ ]] provides a close fit with the high performance insert inner shell, which distributes the inertial load as three beam segments along the length of the basket assembly. The basket is assembled using short [[ ]] at each end of the basket starting at the center location. To provide strength to the basket assembly, [[ ]] are added between the [[ ]] at the outside of the assembly forming a [[ ]] shape. For this evaluation it is assumed that only the outer [[ ]] carry the load. Additionally, no credit is taken for the [[ ]], which is significantly stiffer than the individual [[ ]] The basket is analyzed using classical hand calculations for a 55.1 g side drop inertia load and a bounding weight of [[ ]] pounds. Assuming one-third of the inertial load is carried by one of the equivalent beam segments, the bending stress in the basket is:

$$\sigma_b = \frac{Mc}{I_{cc}} = 688.4 \text{ psi}$$

where

P	=	$W \times G$ = [[ ]]	
W	=	[[ ]] lb	Bounding basket weight
G	=	55.1 g	NCT side drop acceleration
M	=	$\frac{Wa \times l^2}{12}$ = 7,224.4 lb-in	Bending moment
l	=	[[ ]]	Length of beam section
Wa	=	391.02 lb/in	Uniformly distributed load
c	=	3.73 in	Neutral axis to outer fiber
I_{cc}	=	39.09 in^4	Moment of inertia (12 [[ ]])

The moment of inertia calculation is shown in Table 2.6.7-18.

Table 2.6.7-18. Moment of Inertia Calculation

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The pure shear stress, ASME III NF-3223.2, which develops across the composite [[ ]] section during the side drop is:

$$\tau = \frac{P}{2A} \approx 744.8 \text{ psi} < 0.6S_m = 0.6 \times 15{,}900 = 9{,}540 \text{ psi}$$

where

P	=	5822.2 lb	
A	=	3.91 in^2	Cross-sectional area (12 [[ ]])
d_o	=	[[ ]]	Outside diameter of [[ ]]
d_i	=	[[ ]]	Inside diameter of [[ ]]

The stress intensity in the basket that results from the combination of the bending and shear stresses is

$$\sigma = \sqrt{\sigma_b^2 + 4\tau^2} = 1641.0 \text{ psi}$$

The margin of safety is

$$MS = \frac{1.5S_m}{\sigma} - 1 = \frac{23850}{1641.0} - 1 = +Large$$

[[ ]] hold the basket together using [[ ]] (ASME III-NF, Class 1). The [[ ]] and welds are equivalent in thickness and strength to the adjoining [[ ]]. Therefore, the previous analysis bounds the stresses generated in the welds.

2.6.8. Corner Drop

The Model 2000 cask is composed of materials other than fiberboard or wood. Also, the weight of the Model 2000 cask exceeds 220 lb. According to 10 CFR 71.71(c)(8), the corner drop test is not applicable to the Model 2000 cask. Additionally, as can be seen in Table 2.6.7-12, the end drop and side drop NCT accelerations bound the corner drop. Therefore, a stress analysis of the corner drop scenario is not required.

2.6.9. Compression

This test does not apply to the Model 2000 Transport Package, because the package weight is in excess of 11,000 lb (5,000 kg).

2.6.10. Penetration

According to 10 CFR 71.71(c)(10), a penetration test involving a 13-lb penetration cylinder dropped from a height of 40 inches is required for evaluation of packages during NCT. However, Regulatory Guide 7.8 states "the penetration test of 10 CFR 71.71 is not considered by the NRC staff to have structural significance for large shipping casks (except for unprotected valves and rupture disks) and is not considered as a general requirement." A penetration evaluation is not performed because the Model 2000 cask has no unprotected valves or rupture disks that could be affected by normal conditions of transport.

2.7 Hypothetical Accident Conditions

The Model 2000 Transport Package has been demonstrated to meet the performance requirements specified in Subpart E of 10 CFR 71, when subjected to hypothetical accident conditions as specified in 10 CFR 71.73. According to the Regulatory Guide 7.6 (Reference 2-17), for the hypothetical accident conditions the stress intensities resulting from primary membrane and primary bending stresses are to be investigated. The stress intensities from the thermal stresses are presented in this section.

2.7.1. Free Drop

The free drop scenario outlined by 10 CFR 71.73(c)(1) requires a demonstration of the structural adequacy of the Model 2000 cask for a 30-ft drop onto a flat, essentially unyielding horizontal surface in the orientation that inflicts the maximum damage to the cask. The Model 2000 Transport Package is shown to meet the free drop requirements through a combination of classic calculations,

impact analyses, and static finite element. The evaluations include the qualification of the Model 2000 cask lid bolt design for the combined effects of free drop impact force, internal pressures, thermal stress, O-ring compression force, and bolt preload following the methodology of NUREG/CR-6007 (Reference 2-15) (Section 2.12.4). The combined effects of inertial loads, and internal pressures are considered for packaging components. The impact analysis of the package is presented in Section 2.12.1. Section 2.7.1.1 presents the evaluation of the cask body and Section 2.7.1.2 presents the structural evaluation of the HPI and material basket during free drop conditions. The cask body and HPI structural analyses are performed using the finite element program ANSYS (Reference 2-16) and the material basket is analyzed using classic methods. Table 2.7.1-1 provides a summary of the HAC accelerations predicted by the LS-DYNA analysis presented in Section 2.12.1. A lead slump analysis is provided in Section 2.12.2.

Table 2.7.1-1. LS-DYNA Results

DESCRIPTION	DROP ANGLE (DEGREE)	APPLICABLE BOUNDARY CONDITION						ACCELERATION (g)
		Temperature			Payload			
		Amb.	Hot	Cold	Nom.	Heavy	Light	
HAC, End Drop, Hot	90	—	✓	—	—	✓	—	157.5
HAC, Side Drop, Cold	0	—	—	✓	—	—	✓	161.9
HAC, Corner Drop, Cold	68 (90-22)	—	—	✓	—	—	✓	80.3
HAC, Slap Down	5	✓	—	—	✓	—	—	114.4
HAC, Slap Down	10	✓	—	—	✓	—	—	118.0

2.7.1.1. Cask Body Stress Analysis

This section evaluates the structural results of the Model 2000 cask body analyses and shows that the design meets the requirements of 10 CFR 71.71. Specifically, the evaluation addresses the loads associated with the HAC. The results of the analyses for various load cases are presented pictorially in stress intensity contour plots as well as in table form, with the corresponding safety factors in critical components of the cask body.

2.7.1.1.1. End Drop

In accordance with the requirements of 10 CFR 71.73(c)(1), the Model 2000 Transport Package is structurally evaluated for the 30-foot end-drop condition. In this hypothetical accident, the cask including the payload and the impact limiters falls 30 feet onto a flat, unyielding, horizontal surface. The cask strikes the surface in a vertical upright position. For the Model 2000 cask, the bottom end drop is bounding. In the bottom down position, the prying load on the closure bolts is maximized. Closure bolts are evaluated separately in Section 2.12.4.

The most critically stressed component in the system is the cask flange region, which is due to bending of the flange from the inertial load imposed by the cask lid. The second region of interest is in the cask lid in the closure bolt contact region. To evaluate the stresses in these regions

linearized stress are calculated across the thickness of the plate. For the top flange, Figure 2.7.1-1 shows the location of the maximum total stress intensity and Figure 2.7.1-2 indicates the path (Section 6) location where the stresses are calculated. Table 2.7.1-2 is a listing of the Section 6 stresses. Table 2.7.1-3 documents the primary membrane (P_m) and primary membrane plus primary bending (P_m+P_b) in accordance with the criteria presented in Regulatory Guide 7.6. Stresses are compared to the allowable at a bounding temperature of 300°F. The minimum margin of safety is found to be +3.7 for primary membrane, and +1.8 for primary membrane plus bending.

Figure 2.7.1-3 shows the location of the maximum total stress intensity in the lid and Figure 2.7.1-4 indicates the path (Section 7). Table 2.7.1-4 presents a listing of the Section 2 stresses and Table 2.7.1-5 provides the stress combinations in accordance with the Regulatory Guide 7.6 criteria. The minimum margin of safety is found to be +1.4 for primary membrane and +0.8 for primary membrane plus bending. Because all of the margins of safety are positive, the Model 2000 cask meets the end drop requirement of 10 CFR 71.73.

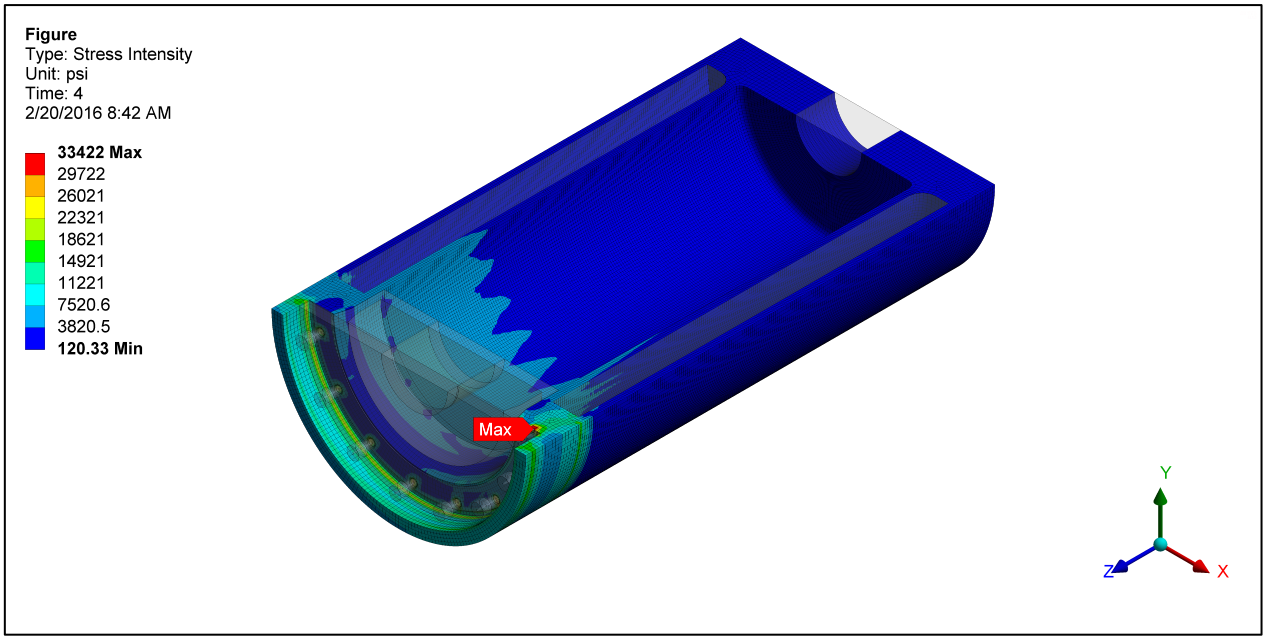

Figure 2.7.1-1. HAC End Drop Cask Body Stress Intensity (total stress psi)

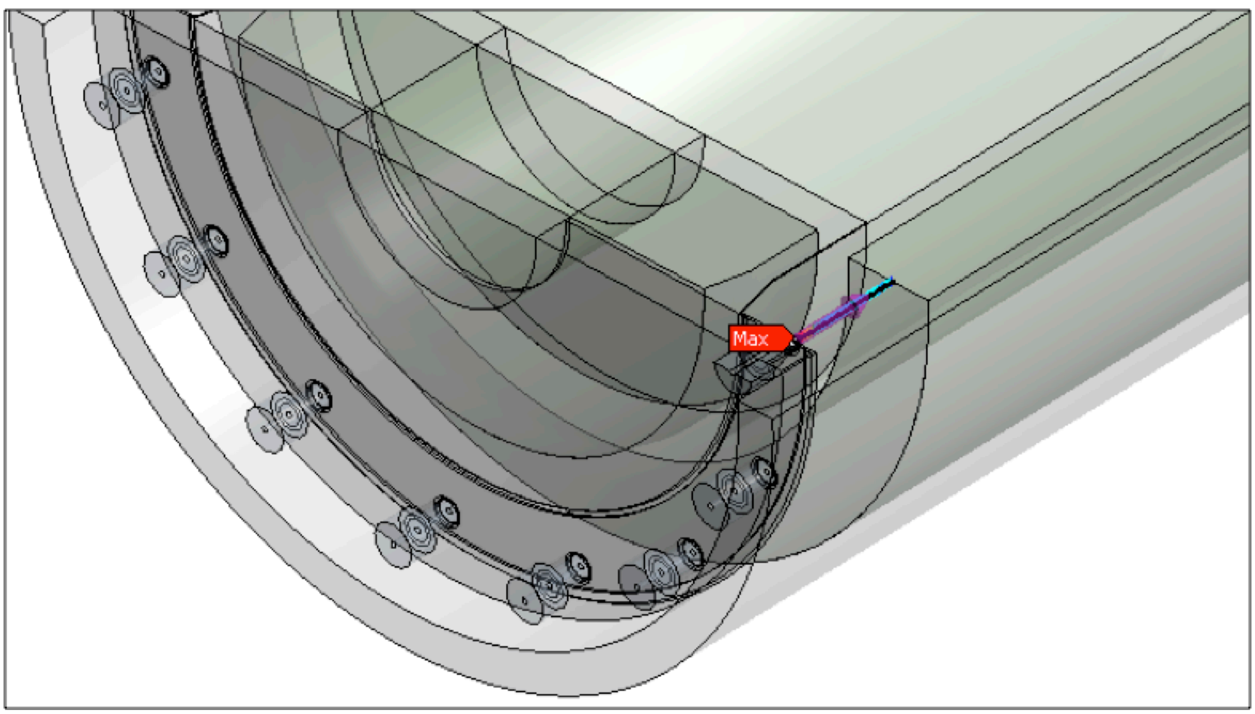

Figure 2.7.1-2. HAC End Drop Linearized Stress Location (Section 6)

Table 2.7.1-2. HAC End Drop Section 6 Stress Results (psi)

Stress State	Location	S1	S2	S3	SINT
MEMBRANE (P_m)	—	6581	-895	-3558	10140
BENDING (P_b)	Inside	14700	1514	-5075	19770
	Center	0	0	0	0
	Outside	5075	-1514	-14700	19770
MEMBRANE + BENDING	Inside	19290	500	-6531	25830
	Center	6581	-895	-3558	10140
	Outside	5773	-2708	-12070	17840
PEAK	Inside	23680	14560	11820	11860
	Center	-301	-939	-5909	5608
	Outside	7995	1326	524	7471
TOTAL	Inside	41600	13550	8174	33422
	Center	4518	-1942	-7597	12120
	Outside	6665	-1547	-4280	10940

Table 2.7.1-3. HAC End Drop Section 6 Stress Results (psi)

Stress Component	Stress Combination	Stress Intensity	Allowable	Margin of Safety
P_m	10140	20000	48000	3.7
$P_m + P_b$	25830	20000	72000	1.8

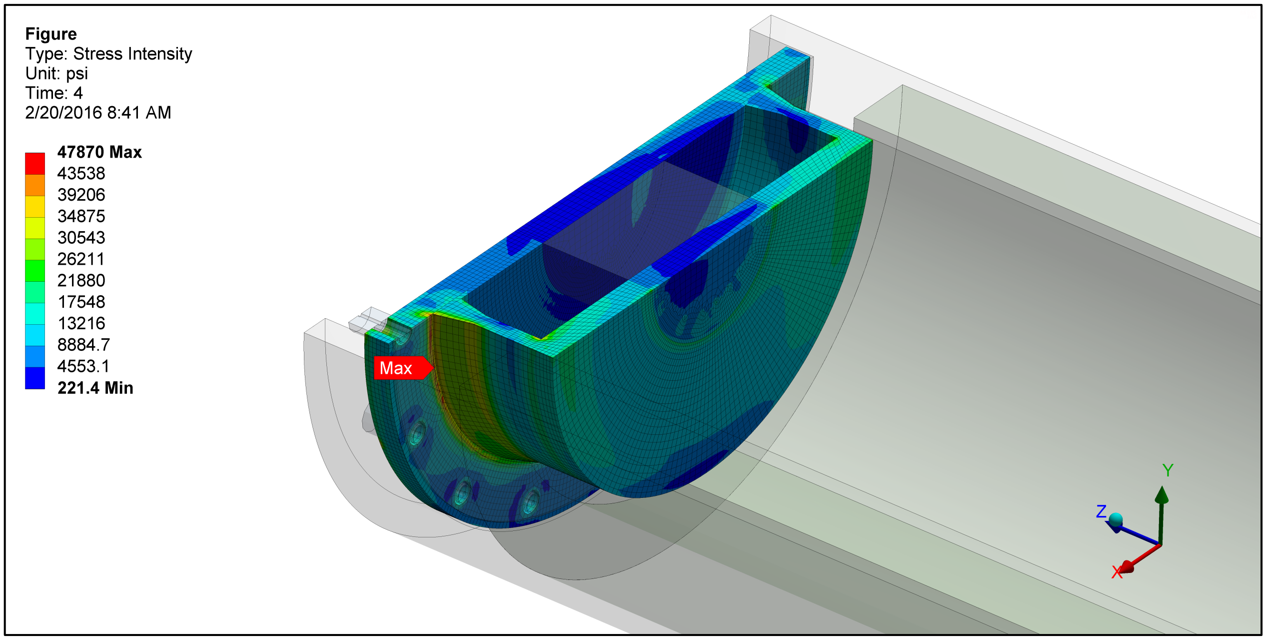

Figure 2.7.1-3. HAC End Drop Lid Stress Intensity (total stress psi)

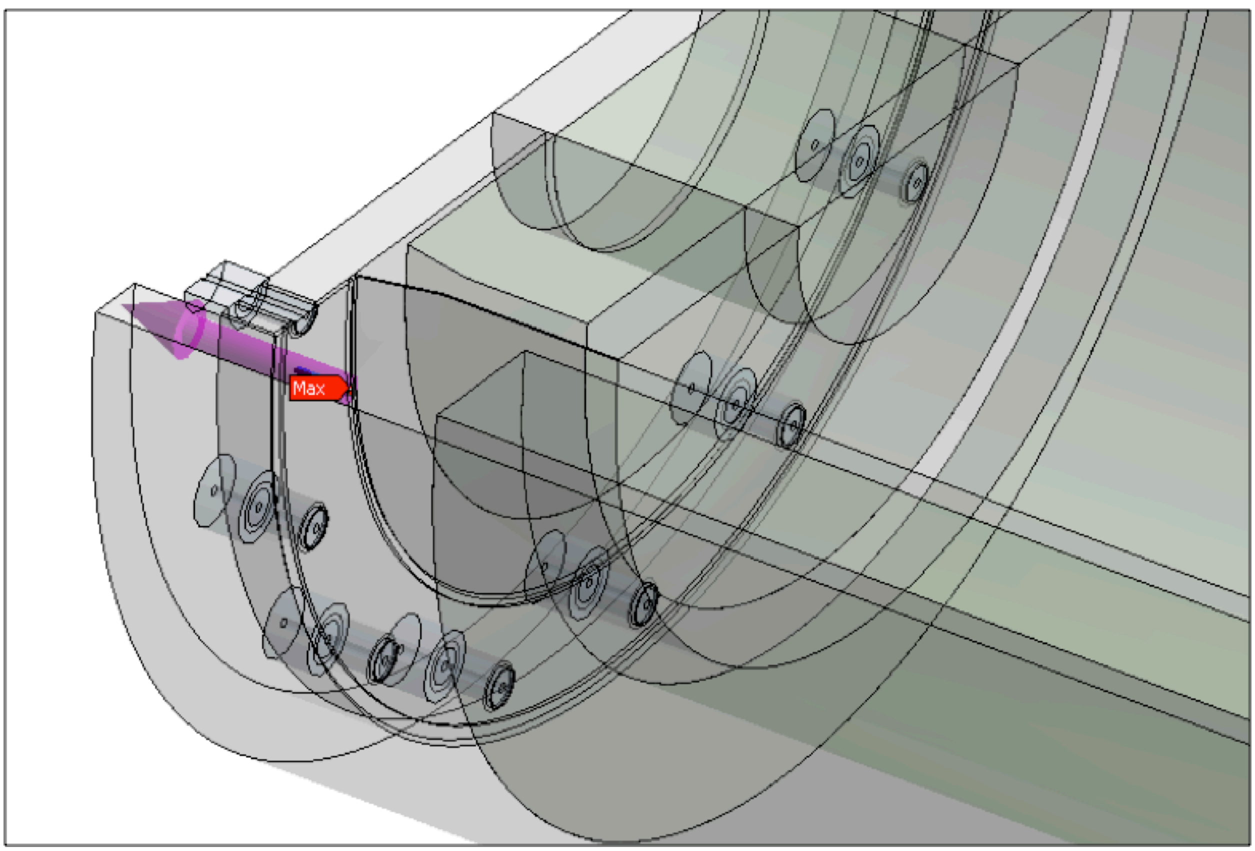

Figure 2.7.1-4. HAC End Drop Linearized Stress Location (Section 7)

Table 2.7.1-4. HAC End Drop Section 7 Stress Results (psi)

Stress State	Location	S1	S2	S3	SINT
MEMBRANE (P_m)	—	4664	-9598	-15170	19830
BENDING (P_b)	Inside	6095	-5767	-15640	21730
	Center	0	0	0	0
	Outside	15640	5767	-6095	21730
MEMBRANE + BENDING	Inside	10350	-15400	-30370	40720
	Center	4664	-9598	-15170	19830
	Outside	3790	-4026	-4558	8348
PEAK	Inside	6105	805	-4285	10390
	Center	1161	-449	-3088	4249
	Outside	3340	607	-925	4265
TOTAL	Inside	14800	-14510	-33070	47870
	Center	3087	-10080	-15480	18570
	Outside	3323	-1612	-3483	6806

Table 2.7.1-5. HAC End Drop Section 7 Stress Results (psi)

Stress Component	Stress Combination	Stress Intensity	Allowable	Margin of Safety
P_m	19830	20000	48000	1.4
$P_m + P_b$	40720	20000	72000	0.8

2.7.1.1.2. Side Drop

In accordance with the requirements of 10 CFR 71.73(c)(1), the Model 2000 cask is structurally evaluated for the hypothetical accident 30-foot side drop condition. In this event, the cask including the payload and impact limiters falls 30 feet onto a flat, unyielding, horizontal surface. The package strikes the surface in a horizontal position resulting in a side impact. The types of loading involved in a side drop accident are closure lid bolt preload, internal pressure, and inertial body load. Closure bolts are evaluated separately in Section 2.12.4.

The most critically stressed component in the system is the cask inner shell at the interface with the bottom forging, the cask flange region, and the cask lid. To evaluate the stresses in these regions linearized stress are calculated across the thickness of the plate. For the cask inner shell, Figure 2.7.1-5 shows the location of the maximum total stress intensity and Figure 2.7.1-6 indicates the path (Section 8) location where the stresses are calculated. Table 2.7.1-6 is a listing of the Section 8 stresses. Table 2.7.1-7 documents the primary membrane (P_m) and primary membrane plus primary bending (P_m+P_b) in accordance with the criteria presented in Regulatory Guide 7.6. Stresses are compared to the allowable at a bounding temperature of 350°F. The minimum margin of safety is found to be +4.5 for primary membrane and +1.5 for primary membrane plus.

Figure 2.7.1-7 shows the location of the maximum total stress intensity in the lid and Figure 2.7.1-8 indicates the path (Section 9). Table 2.7.1-8 presents a listing of the Section 9 stresses and Table 2.7.1-9 provides the stress combinations in accordance with the Regulatory Guide 7.6 criteria. The minimum margin of safety is found to be +1.6 for primary membrane and +1.2 for primary membrane plus bending. Because all of the margins of safety are positive, the Model 2000 cask meets the end drop requirement of 10 CFR 71.71.

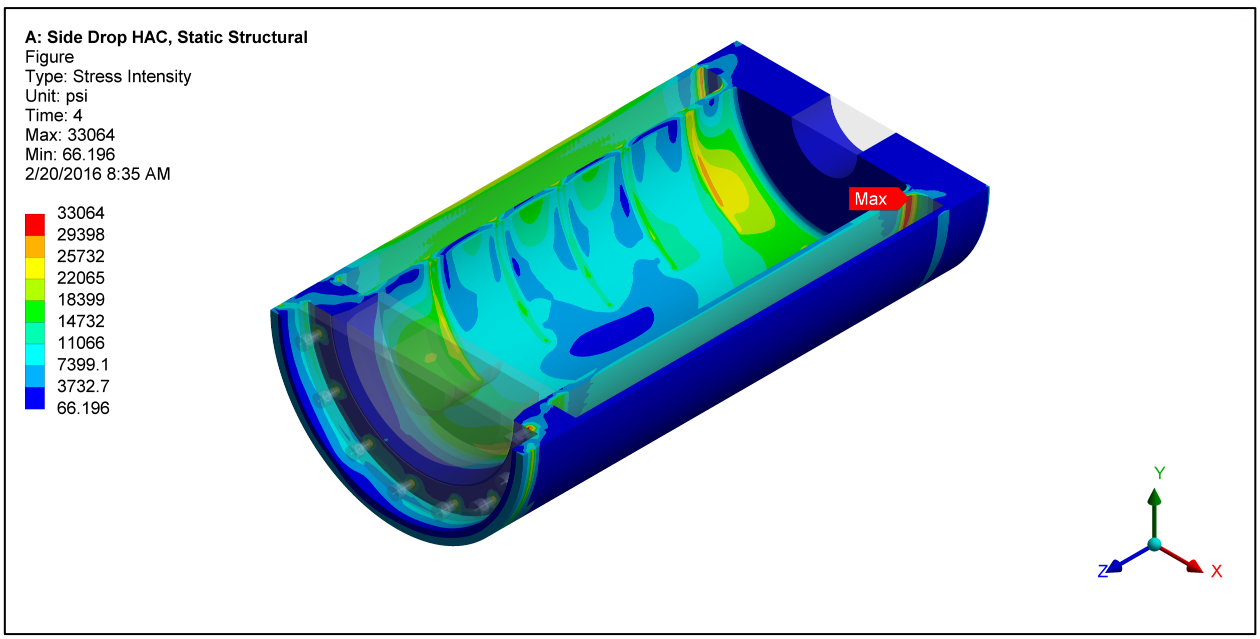

Figure 2.7.1-5. HAC Side Drop Cask Body Stress Intensity (total stress psi)

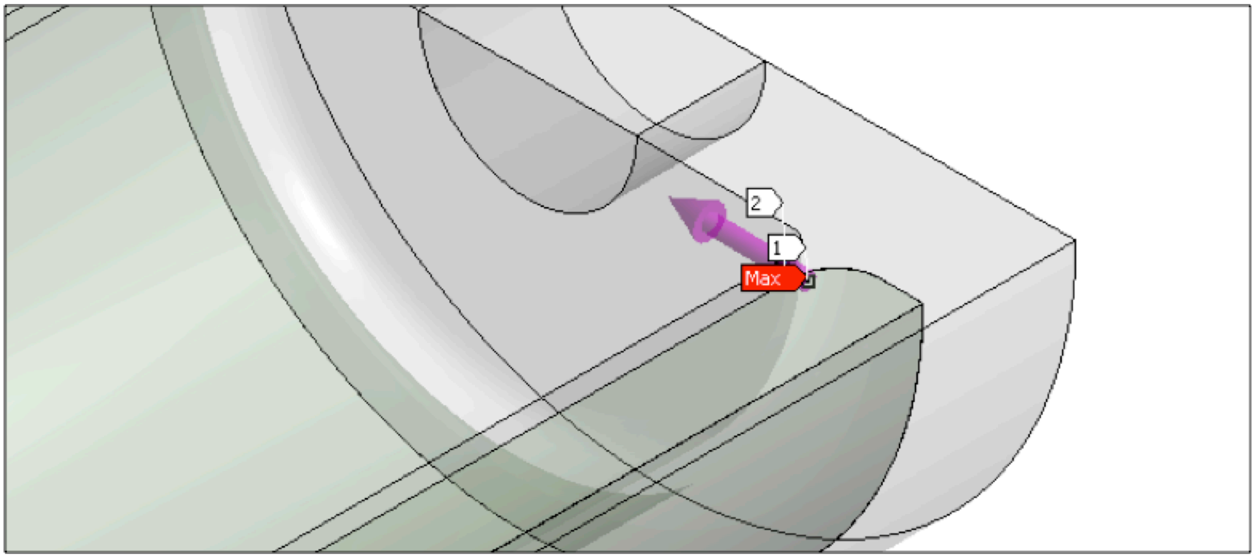

Figure 2.7.1-6. HAC Side Drop Linearized Stress Location (Section 8)

Table 2.7.1-6. HAC Side Drop Section 8 Stress Results (psi)

Stress State	Location	S1	S2	S3	SINT
MEMBRANE (P_m)	—	7919	3810	-536	8455
BENDING (P_b)	Inside	22400	7025	1106	21300
	Center	0	0	0	0
	Outside	-1106	-7025	-22400	21300
MEMBRANE + BENDING	Inside	29540	10850	1339	28200
	Center	7919	3810	-536	8455
	Outside	-98	-3191	-16050	15950
PEAK	Inside	4194	930	-743	4937
	Center	335	-133	-962	1297
	Outside	1120	-76	-1042	2162
TOTAL	Inside	33700	11780	633	33060
	Center	6962	3673	-204	7167
	Outside	175	-3267	-16250	16420

Table 2.7.1-7. HAC Side Drop Section 8 Stress Results (psi)

Stress Component	Stress Combination	Stress Intensity	Allowable	Margin of Safety
P_m	8455	19300	46320	4.5
$P_m + P_b$	28200	19300	69480	1.5

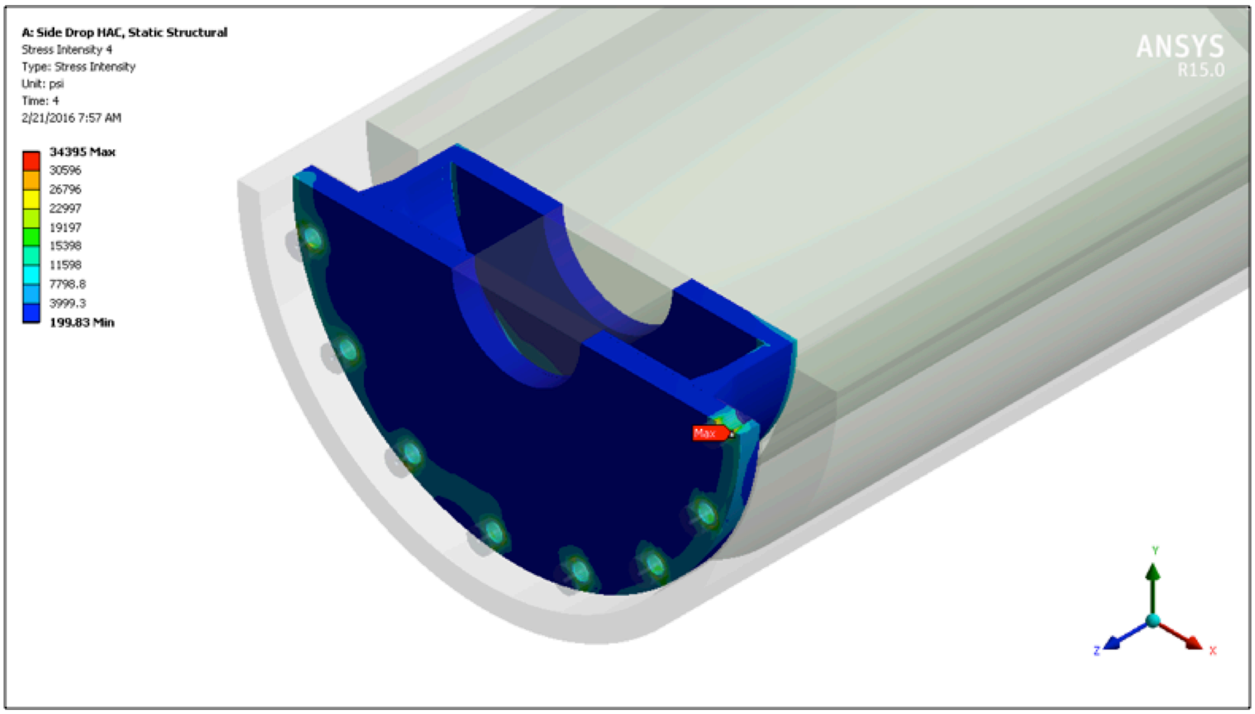

Figure 2.7.1-7. HAC Side Drop Lid Stress Intensity (total stress psi)

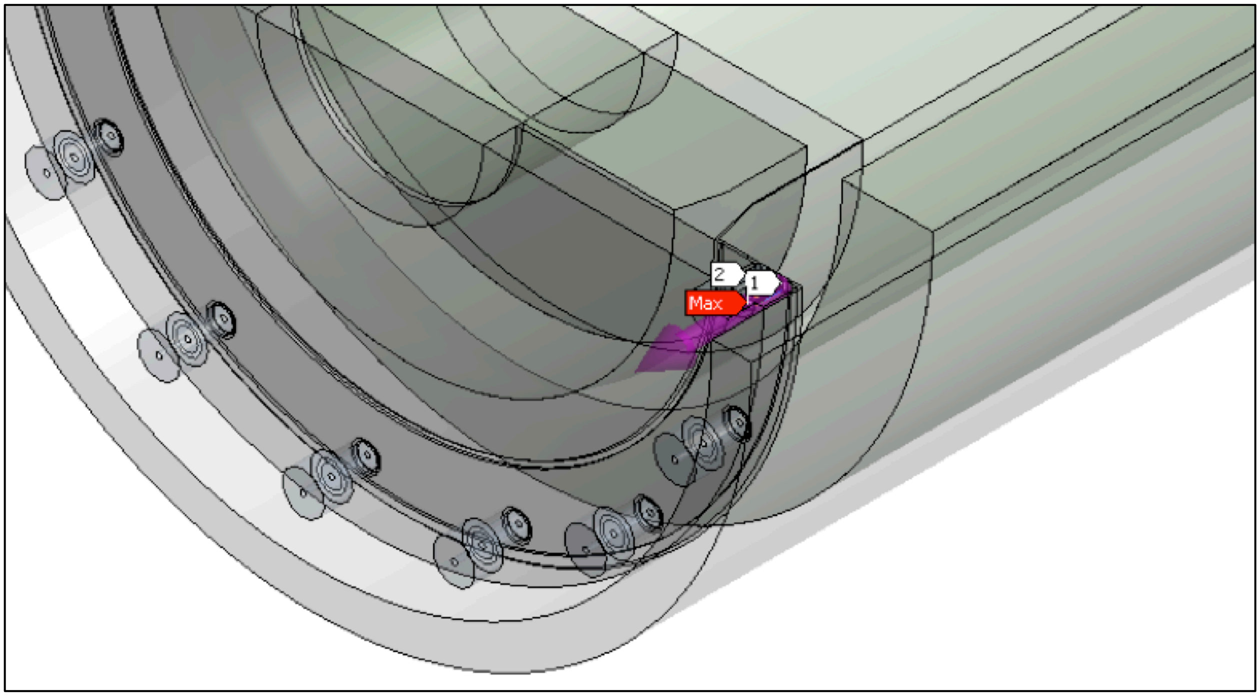

Figure 2.7.1-8. HAC Side Drop Linearized Stress Location (Section 9)

Table 2.7.1-8. HAC Side Drop Section 9 Stress Results (psi)

Stress State	Location	S1	S2	S3	SINT
MEMBRANE (P_m)	—	191	-4176	-17400	17590
BENDING (P_b)	Inside	13120	4683	-811	13930
	Center	0	0	0	0
	Outside	811	-4683	-13120	13930
MEMBRANE + BENDING	Inside	1165	-624	-4936	6102
	Center	191	-4176	-17400	17590
	Outside	993	-9012	-30360	31350
PEAK	Inside	945	-4458	-6602	7547
	Center	4003	2423	215	3787
	Outside	1120	-3506	-6124	7244
TOTAL	Inside	379	-4426	-10460	10840
	Center	1337	-1978	-14100	15440
	Outside	1005	-14500	-33390	34400

Table 2.7.1-9. HAC Side Drop Section 9 Stress Results (psi)

Stress Component	Stress Combination	Stress Intensity	Allowable	Margin of Safety
P_m	17590	19300	46320	1.6
$P_m + P_b$	31350	19300	69480	1.2

2.7.1.1.3. Corner Drop

In accordance with the requirements of 10 CFR 71.73(c)(1), the Model 2000 cask is structurally evaluated for the hypothetical accident 30-foot corner drop condition. The impact analysis presented in Section 2.12.1 and the summary of accelerations provided in Table 2.7.1-1 shows that the end and side drop accelerations bound the C.G. over corner drop acceleration. Therefore, the corner drop requirement is satisfied.

2.7.1.1.4. Oblique Drops

In accordance with the requirements of 10 CFR 71.73(c)(1), the Model 2000 cask is structurally evaluated for the hypothetical accident 30-foot oblique drop condition. The impact analysis presented in Section 2.12.1 and the summary of accelerations provided in Table 2.7.1-1 shows that the end and side drop accelerations bound the slap-down/oblique angle drops. Therefore, the oblique drop requirement is satisfied.

2.7.1.2. HPI Stress Analysis

The purpose of this section is to document the Model 2000 HPI and material basket analyses that shows the design meets the requirements of 10 CFR 71. Specifically, the evaluation addresses the mechanical loads associated with the HAC.

The results of the analyses for various load cases are presented pictorially as stress intensity contour plots as well as in table form, with the corresponding margin of safety in each component of the cask body.

2.7.1.2.1. End Drop

The HPI is evaluated using the ANSYS finite element model presented in Section 2.6.7. Stress results for the HAC end drop discussed previously are documented in Table 2.7.1-10. The table presents the primary membrane (P_m) and primary membrane plus primary bending (P_m+P_b) in accordance with the criteria presented in ASME Section III, Appendix F (Reference 2-18).

As shown in Table 2.7.1-10, the margins of safety when compared to the stress intensity for each category are positive. The most critically stressed component in the system is the interface between the [[ ]] that surrounds and supports the depleted uranium shield. The minimum margin of safety is +8.0 for primary membrane stress intensity. The locations of the critical sections correspond to the maximum stress location and axial displacement is shown in Figure 2.7.1-9.

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Figure 2.7.1-9. HPI HAC End Drop Results – Peak Stress Intensity (psi) and Displacement (in)

Table 2.7.1-10. HAC End Drop Stress Summary

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2.7.1.2.2. Side Drop

The HPI is evaluated using the ANSYS finite element model presented in Section 2.6.7. Table 2.7.1-1 provides a summary of the HAC accelerations predicted by the LS-DYNA analysis presented in Section 2.12.1. As with the NCT evaluation, two cases are presented to evaluate the performance of the HPI during the side drop. Case 1 is concentrated pressure distribution at the four [[ ]] locations ("line load"). Case 2 is a uniform pressure distribution ("area load").

Stress results for Case 1 are presented in Tables 2.7.1-11 and 2.7.1-12. Stress results for Case 2 are presented in Table 2.7.1-13 and 2.7.1-14. Figures 2.7.1-10 and 2.7.1-11 illustrate the stresses in the [[ ]] for Case 1 and Case 2, respectively. The tables present the primary membrane (P_m) and primary membrane plus primary bending (P_m+P_b) in accordance with the criteria presented in ASME Section III, Appendix F (Reference 2-18).

As Tables 2.7.1-11 through 2.1.7-14 show, the margins of safety for the [[ ]] when compared to the stress intensity for each category are positive. The minimum margin of safety in the HPI body is found to be +0.8 for primary membrane plus bending stress intensity for both Cases 1 and 2.

Table 2.7.1-11. HAC Case 1 HPI Body Top 30 Results

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Figure 2.7.1-10. Case 1, HAC, Stress Intensity Result (psi)

Table 2.7.1-12. HAC [[ ]] Case 1 Results

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Table 2.7.1-13. HAC Case 2 HPI Body Top 30 Results

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Figure 2.7.1-11. Case 2, HAC, Stress Intensity Result (psi)

Table 2.7.1-14. HAC [[ ]] Case 2 Results

[[										
										]]

2.7.1.2.3. Corner Drop

Results of the LS-DYNA analysis presented in Section 2.12.1 shows that the side drop accelerations bound the corner drop.

2.7.1.2.4. Oblique Drops

Results of the LS-DYNA analysis presented in Section 2.12.1 shows that the side drop accelerations bound the oblique drop angles.

2.7.1.2.5. Cask Overpack Bolt Evaluation

Bolt Torque

Per Model 2000 cask overpack drawings 1018719 and 105E9521 (Table 1.3.-1), the overpack bolt torque is 100±5 lb-ft dry. The following overpack evaluation assumes a maximum torque of 105 lb-ft.

Bolt Evaluation Procedure

This analysis is based on the procedure outlined in NEDE-31581, Subsection 2.10.7, which was developed to account for the overpack fastener failure during the quarter-scale model side drop test. Once the procedure was satisfactorily developed to explain the fastener failure, it was used to redesign the fastening system. This section presents the steps and results of this analysis as applied to the Model 2000 with the HPI.

Bolt Stresses – HAC Side Drop

The Model 2000 transport package overpack is fastened together with 15 equally spaced ASTM A-540 Grade B22, Class 3 or equivalent 7/8-9 UNC socket head shoulder bolts. The adequacy of these fasteners is determined by comparing the service loads (from the HAC) to the allowable loads, using the criteria given in the ASME Code, Section III, Division 1, Appendix F.

Bolts: 7/8-9 UNC-2A, ASTM A540 Grade B22, Class 3, 15 equally spaced

Tensile area of threaded portion = 0.462 in^2

Proof Strength = Minimum Yield Strength x 85% = 115700 (0.85) = 98345 psi

Loading: The highest stresses for the overpack fasteners occur during the HAC side drop accident condition. The maximum load is calculated for an impact acceleration of 161.9 g's.

For the side drop case, the load is applied to the overpack junction as shown in Figure 2.7.1-12. The overpack is modeled as a simple beam with the force of the cask and contents as a distributed load and the neutral axis at the side of the overpack opposite the side of impact.

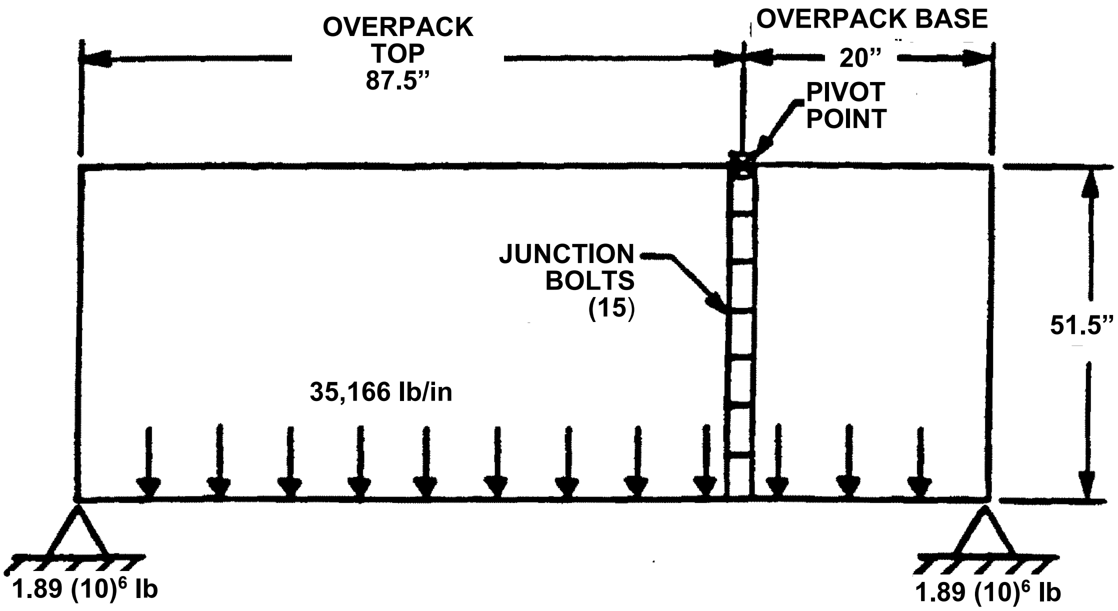

Figure 2.7.1-12. Overpack Loading, HAC Side Drop

The distributed load equals the weight of the cask (cask body and closure lid) and contents (HPI assembly + material basket + content) times the acceleration, divided by the length between toroidal reaction points:

Distributed Load = WG/L = 35,166 lb/in

Where:

W = (16,000 + 1,900) + [[ ]] = 23,350 lb

G = 161.9 g HAC Side Drop Cold

L = Overpack vertical length – toroid diameter

= 131.50 – 24 = 107.5 in

The total load to be reacted is:

$F_T = WG = 3.780(10)^6$ lb

The force at each reaction point is:

$F_R = 0.5F_T = 1.890(10)^6$ lb

Figure 2.7.1-13 shows a free body diagram of the overpack top. The distributed load from the cask is applied as a point load so that the moments can be calculated and the bolt loads determined.

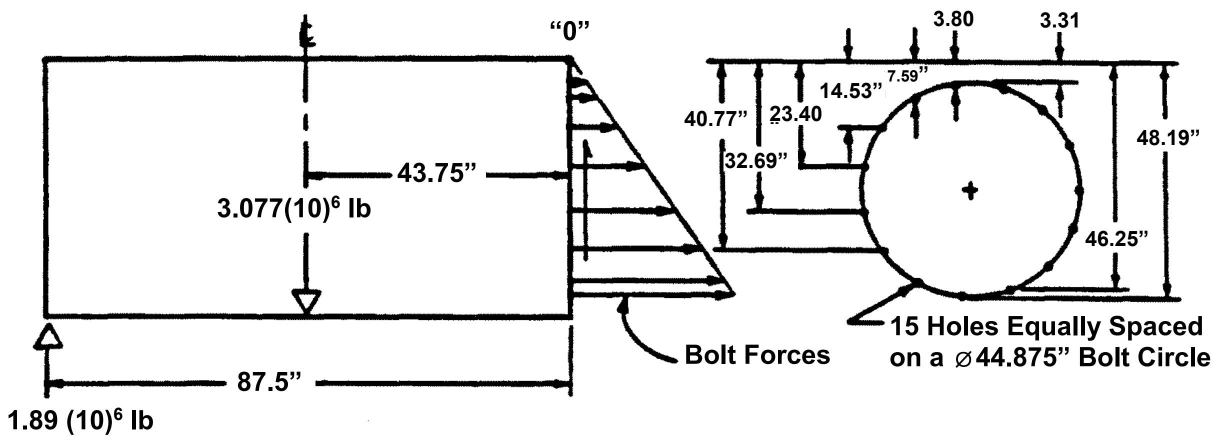

Figure 2.7.1-13. Free Body Diagram of Overpack Top

Summing the moments about the pivot point "0" yields the following equation:

$$\Sigma M_0 = 0 = -1.89(10)^6 (87.5) + 3.077(10)^6 (43.75) + k (48.19)^2 +$$
$$2k (46.25)^2 + 2k (40.77)^2 + 2k (32.69)^2 + 2k (23.40)^2 +$$
$$2k (14.53)^2 + 2k (7.59)^2 + 2k (3.80)^2$$

Solving for k yields:

$$k = 3.0756(10)^7 / [48.19^2 + 2(46.25^2 + 40.77^2 + 32.69^2 + 23.40^2 + 14.53^2 + 7.59^2 + 3.80^2)]$$

$$k = 2{,}241 \text{ lb/in}$$

The maximum shear force on a bolt occurs at the point farthest from the pivot point, so the maximum bolt load is:

$$F_{S\,Max} = (2{,}241)\ 48.19 = 10{,}7994 \text{ lb}$$

Because the bolts are loaded in double shear on the shoulder (see Figure 2.7.1-14), the maximum shear stress in the bolt material is:

$$\tau_{Max} = F_{S\,Max} / (2A_S) = 36{,}362 \text{ psi}$$

where:

A_S = Area of bolt shoulder = $0.25\pi D_S^2 = 1.485$ in^2

D_S = Diameter of bolt shoulder = 1.375 in

The allowable shear stress in the bolt for HAC conditions is $0.42S_U$.

where:

S_U = Ultimate strength for the bolts = 14,5000 psi

$\tau_{All} = 0.42S_U = 60900 \text{ psi} > \tau_{Max} = 36{,}362 \text{ psi}$

$MS = (.42S_U / \tau_{Max}) - 1 = 0.67$

The results indicate that the cask overpack bolts are sufficient for HAC side drop loading.

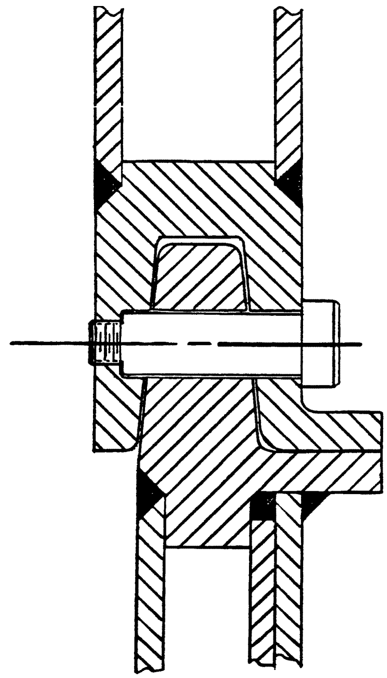

Figure 2.7.1-14. Overpack Junction

2.7.1.3. Material Basket Evaluation

This section evaluates the material basket for HAC. Factors of safety for the basket are calculated based on the criteria for Service Level 'D' limits from ASME Section III, Appendix F (F-1332).

<u>HAC End Drop</u>

The worst-case condition of upright end drop is evaluated. The inertial loading will load the [[ ]] in compression. There is no bending or shear stress present. For this evaluation, all 18 [[ ]] are loaded. The compression stress on the bottom of the [[ ]] is:

$$\sigma_{membrane} = \frac{P}{A} = 8{,}505.5 \text{ psi compression}$$

$$\sigma_{bending} = 0 \text{ psi}$$

$$\tau_{shear} = 0 \text{ psi}$$

where P = W x G = [[ ]] lbs — Inertial load on 18 [[ ]] sections

W = [[ ]] lbs — Basket plus contents weight

G = 157.5 G — HAC end drop acceleration (Table 2.7.1-1)

A = [[ ]] Cross section area of [[ ]] x 1.5)

Per Table 2.1-2, except for pinned and bolted joints, the bearing stress margin of safety need not be evaluated for which Level D service limits are specified.

The basket elastic stability is evaluated at HAC end drop conditions. The basket [[ ]] are modeled as a column with pinned ends. The bottom third of the 18 [[ ]] bundle is located between the HPI bottom and the material package center of gravity and is therefore evaluated using the Euler equation for buckling of a column with pinned ends:

$$P_{cr} = \frac{\pi^2 EI_{cc}}{L^2} = 5.553 \text{ x } 10^7 \text{ lbs}$$

where $E = 24.1\text{x}10^6$ psi — Modulus of 316 stainless steel, 800°F (Table 2.2-2)

L = [[ ]] — Length of lower 3rd of basket between [[ ]] (Drawing 001N1824)

$I_{cc} = 51.76 \text{ in}^4$ — Moment of inertia (18 [[ ]])

For the HAC end drop elastic stability evaluation, the moment of inertia for the 18 [[ ]] is determined from Table 2.6.7-18, as follows:

[[		
		]]

Comparing the critical load to the load applied to the 18-[[ ]] basket during the HAC end drop, the factor of safety is:

$$FS = \frac{P_{cr}}{P} = \frac{5.553x10^7}{49927.5} = +1112.2$$

HAC Side Drop

Assuming one-third of the inertial load is carried by one of the segments, the bending stress in the basket is:

$$\sigma_b = \frac{Mc}{I_{cc}} = 2022.7 \text{ psi}$$

where	P	=	$W \times G$ = [[ ]] lb	Load on [[ ]] section
	W	=	[[ ]] lb	Bounding basket weight
	G	=	161.9 g	HAC side drop acceleration
	M	=	$\frac{Wa \times l^2}{12}$ = 21227.5 lb-in	Bending moment
	l	=	[[ ]] in	Length of beam section
	Wa	=	1148.92 lb/in	Uniformly distributed load
	c	=	3.73 in	Neutral axis to outer fiber
	I_{cc}	=	39.09 in^4	Moment of inertia [[ ]]

The moment of inertia calculation is shown in Table 2.7.1-15.

Table 2.7.1-15. Moment of Inertia Calculation

[[

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The pure shear stress, ASME Appendix F (F-1332.4), which develops across the section during the side drop is

$$\tau = \frac{P}{2A} \approx 2188.5 \text{ psi} < 0.42S_u = 0.42 \times 70800 = 29736 \text{ psi}$$

where

P	=	17107.4 lb	
A	=	3.91 in^2	Cross-sectional area (12 [[ ]])
d_o	=	[[ ]] in	Outside diameter of [[ ]]
d_i	=	[[ ]] in	Inside diameter of [[ ]]

The stress intensity in the basket that results from the combination of the bending and shear stresses is

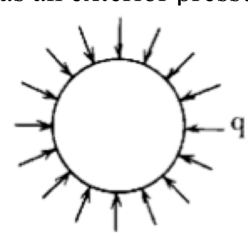
$$\sigma = \sqrt{\sigma_b^2 + 4\tau^2} = 4821.8 \text{ psi}$$

The margin of safety is per ASME Appendix F (F-1332) is

$$MS = \frac{1.5 \times (1.5S_m)}{\sigma} - 1 = \frac{35775}{4821.8} - 1 = +6.4$$

[[ ]] hold the basket together using [[ ]] (ASME III-NF, Class 1). The [[ ]] are equivalent in thickness and strength to the adjoining [[ ]]. Therefore, the previous analysis bounds the stresses generated in the [[ ]].

Because the [[ ]] form a composite section with the addition of [[ ]] is distributed along the face of the disk. Therefore, [[ ]] wall permanent deformation is unlikely to occur. However, assuming the basket [[ ]] are unsupported and uniformly loaded, a lateral external pressure load may be applied along the length of the [[ ]] Treating the [[ ]] as a thin shell, the elastic stability can be evaluated during HAC side drop event. From Roark's, Table 15.2, Case 19 (Reference 2-19), the elastic stability of a single basket [[ ]] is evaluated by applying the total payload weight times the side drop acceleration that is then applied as an exterior pressure load, q. The critical external pressure, q', is:



$$q' = \frac{1}{4}\frac{E}{1-\nu^2}\frac{t^3}{r^3} = 3180 \text{ psi}$$

E	=	24.1×10^6 psi	Modulus at 800°F
ν	=	0.3	Poisson's ratio
t	=	[[ ]] in	Wall thickness
r	=	[[ ]] in	[[ ]] outside radius

Applying the total contents weight during the HAC side drop to a single [[ ]], the external pressure is:

$$q = \frac{P}{A} = 208.5 \text{ psi}$$

G	=	161.9 g	Side drop acceleration
W	=	[[ ]] lb	Bounding loaded basket weight
P	=	$W \times G$ = 51322.3 lb	Total load
l	=	[[ ]] in	Basket length
A	=	$2\pi rl$ = 246.1 in²	Surface area of single [[ ]]

Comparing the critical external pressure to the external pressure applied to a single [[ ]] during the HAC side drop event, the factor of safety is:

$$FS = \frac{q'}{q} = 15.2$$

Therefore, unsupported basket [[ ]] sections will not collapse during HAC side drop conditions and the Subsection NF, Level A stress acceptance criteria still applies.

2.7.1.4. Summary of Results

Structural analyses are performed for the Model 2000 cask, HPI and material basket for hypothetical accident conditions free drop conditions. To evaluate the Model 2000 Transport Package, ANSYS finite element models and classic calculations are used to analyze the governing drop cases. All structural members have a positive margin of safety under worst case loading conditions. It is concluded that the Model 2000 Transport Package is structurally adequate for the HAC free drop conditions. Therefore, the requirements of 10 CFR 71.73(c)(1) have been satisfied.

2.7.2. Crush

In accordance with the requirements of 10 CFR 71.73(c)(2), the Model 2000 Transport Package is to be subjected to a dynamic crush test by evaluating the package on essentially unyielding horizontal surface so as to suffer maximum damage by the drop of an 1,100 pound mass from 30 feet onto the package. The mass must consist of a solid mild steel plate 40 inches × 40 inches and must fall in a horizontal attitude. The crush test is required only when the specimen has a mass not greater than 1,100 pounds, and overall density not greater than 1000 kg/m^3 (62.4 lb/ft^3) based on external dimension. The crush condition is not applicable because the Model 2000 Transport Package weighs more than 500 kg (1,100 lb.) and overall density is greater than 62.4 lb/ft^3.

2.7.3. Puncture

This section addresses the second event in the accident design sequence outlined in 10 CFR 71.73(c)(3), the 40-inch drop of the Model 2000 Transport Package onto a mild steel cylindrical punch. The evaluation of this condition is conducted for the package structure and the containment vessel. The demonstration of the puncture capability of the package is presented in Section 2.12.1 to predict the accumulated damage in support of the thermal analysis. The

maximum strain in the outer shell of the cask is 31% and limited to the puncture area. Therefore, no gross deformations of the cask are predicted.

2.7.4. Thermal

The fire condition is analyzed in Section 3.4. In this section, maximum values of temperatures and pressures are provided.

2.7.4.1. Summary of Pressures and Temperatures

Table 2.7.1-16 provides summary temperatures for the Model 2000 Transport Package for HAC. During HAC, the average temperature of the cask fill gas (including the gas within the HPI) peaks at 585°F 11 hours after the end of the 30-minute fire. Using the ideal gas law, the cask internal pressure from gas expansion is 29.0 psia, which is less than the design pressure of 30 psia.

Table 2.7.1-16. Summary Temperatures for HAC

Item	Peak Temperature (°F)
Material basket	1,045
HPI shielding (side)	670
HPI shielding (top)	599
HPI shielding (bottom)	618
Cask lid seal	508
Cask shielding (side)	570
Cask shielding (top)	529
Cask shell, puncture location	782
Cask shell, opposite side to puncture location	512
Overpack outer shell, puncture location	1,103
Overpack outer shell, opposite side to puncture location	1,337
Cask drain port (bottom)	612
Cask test port (top)	608
Cask vent port (lid)	520
HPI fill gas (average)	740
Cask fill gas (average)	571
HPI and cask fill gas, combined (average)	585

(Note: Data taken from Table 3.4.3-1)