NUHOMS®-MP197 TRANSPORT PACKAGING

CHAPTER 2

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CHAPTER 2

STRUCTURAL EVALUATION

2.1 STRUCTURAL DESIGN

This chapter, including its appendices, presents the structural evaluation of the NUHOMS®-MP197 packaging. This evaluation consists of numerical analyses and impact limiter testing which demonstrate that the NUHOMS®-MP197 packaging satisfies applicable requirements for a Type B(U) packaging.

2.1.1 Discussion

The structural integrity of the packaging under normal conditions of transport and hypothetical accident conditions specified in 10CFR71 [1] is shown to meet the design criteria described in Section 2.1.2. The NUHOMS®-MP197 transport package consists of three major structural components: the cask body, the 61B transportable canister (shell assembly and basket assembly), and the impact limiters (front and rear). These components are described in Chapter 1 and are shown on drawings provided in Appendix 1.3.

- Cask Body

Drawing 1093-71-1 shows the overall transport configuration of the NUHOMS®-MP197 packaging. Drawing 1093-71-2 shows the general arrangement of the NUHOMS®-MP197 packaging. Drawing 1093-71-3 shows the part list. Drawing 1093-71-4 shows the cask body assembly. Drawings 1093-71-5 and 6 show the cask body details. Drawing 1093-71-7 presents the lid assembly. Drawings 1093-71-8 and 9 provide details of the impact limiter design. The regulatory plate is provided on drawing 1093-71-20. Drawing 1093-71-21 shows the NUHOMS®-MP197 packaging on the transport skid. ASME Code compliance and exemptions are provided in drawing 1093-71-22.

The shell or cask body cylinder assembly is an open ended (at the top) cylindrical unit with an integral closed bottom end. This assembly consists of concentric inner shell (SA-240 Gr. XM 19) and outer shell (SA-240 Gr. 316), welded to a massive closure flange (SA-240 Gr. XM 19) at the lid end and a flat stainless steel plate (SA-240 Gr. XM 19) at the bottom end. The closure lid material is SA-705 Type 693 H1100. The annulus between the shells is filled with lead shielding. The lead is poured into the annulus in a molten state using a carefully controlled procedure.

The two rear trunnions are cylindrical, SA-182 F304 stainless steel forgings. The rear pair of trunnions is designed for horizontal lifting of the cask and also provides the capability to rotate the cask. Two sets of front trunnions are designed. One set of trunnions has double shoulders and is used for lifting. The double shoulder front trunnions have a minimum factor of safety of three against yield stress or five against ultimate stress; whichever is most restrictive. The other set of front trunnions has a single shoulder and is also used for lifting. The single shoulder front trunnions have a minimum factor of safety of six against yield stress or ten against ultimate stress; whichever is most restrictive. Only one set of trunnions will be used depending on-site and transfer operation requirements. The two sets of front trunnions are made from SA-182 F304 stainless steel forgings and are designed to lift the loaded NUHOMS®-MP197 cask vertically and horizontally. Both the front and rear trunnions are bolted to the cask body with a flange connection, using 12-1 ¼" diameter bolts made of SA-540 Gr. B24 Cl. 1. The front trunnions are designed to meet the requirements of ANSI N14.6 [2]. The trunnions are shown in Drawing 1093-71-5.

The shield shell around the neutron shield consists of a cylindrical shell section, with closure plates at each end. The closure plates are welded to the outer surface of the outer shell of the cask body. The shield shell provides an enclosure for the resin-filled aluminum containers, and maintains the resin in the proper location with respect to the active length of the fuel assemblies in the cask cavity. The shield shell has no structural function. The shell is made of SA-240 Type 304 stainless steel.

- 61B Transportable Canister (Shell and Basket Assemblies)

The canister shell assembly and details are shown on drawings 1093-71-13 through 18. The shell assembly is a high integrity stainless steel (SA-240 Type 304) welded pressure vessel that provides containment of radioactive materials, encapsulates the fuel in an inert atmosphere (the canister is backfilled with Helium before being seal welded closed), and provides biological shielding (in axial direction).

The details of the NUHOMS®-61BT Basket are shown in drawings 1093-71-10 to 12. The NUHOMS®-61BT basket is a welded assembly of stainless steel boxes and is designed to accommodate 61 intact standard BWR fuel assemblies with or without fuel channels. The basket structure consists of an assembly of stainless steel tubes (fuel compartments) separated by poison plates and surrounded by larger stainless steel boxes and support rails.

The basket structure is open at each end. Therefore, longitudinal fuel assembly loads are applied directly on the canister/cask body and not on the fuel basket structure. The fuel assemblies are laterally supported in the stainless steel structural boxes, and the basket is laterally supported by the rails and the canister inner shell.

The basket is keyed to the canister at 180° in order to fix the basket's orientation with respect to the canister. Under normal conditions of transport, the canister rests on four transfer support rails, attached to the inside surface of the NUHOMS®-MP197 Cask.

As described above, the basket structure consists of an assembly of stainless steel tubes (fuel compartments) separated by poison plates (borated aluminum, an aluminum/B_4C metal matrix composite, or Boral®) and surrounded by larger stainless steel boxes (outer wraps) and support rails. The assembly includes:

1. Four (4) 2 by 2 large boxes (four compartment assembly), each box consists of 4 stainless steel fuel compartments (0.12 in. thick) separated by poison plates (0.31 in. thick) and wrapped in a 0.105 in. thick stainless sheet.

2. Five (5) 3 by 3 large boxes (nine compartment assembly), each box consists of 9 stainless steel fuel compartments (0.135 in. thick) separated by poison plates (0.31 in. thick) and wrapped in a 0.105 in. thick. stainless sheet.

3. Eight (8) type 1 stainless steel rails; the rails are fabricated from 0.19/0.25 in. thick, SA-240, type 304 stainless steel.

4. Four (4) type 2 stainless steel rails; the rails are also fabricated from 0.19/0.25 in. thick, SA-240, type 304 stainless steel.

The poison plates provide the heat conduction path from the fuel assemblies to the canister cavity wall, and also provide the necessary criticality control.

The nominal open dimension of each fuel compartment cell is 6.0 in. × 6.0 in., which provides clearance around the fuel assemblies. The overall basket length including the hold down ring (178.5 in.) is less than the canister cavity length of the canister (179.30 in.) to allow for thermal expansion, tolerances, and access to the top of the fuel assemblies.

Stainless steel rails are oriented parallel to the axis of the canister and attached to the periphery of the basket to establish and maintain basket orientation and to support the basket.

Stainless steel plate inserts (0.31in. thick × 3 in. wide × 3.5 in. long) are placed between the stainless steel fuel compartments and between the outer wrappers at the top and bottom of the basket assembly. These plate inserts are fillet welded to the stainless steel tubes and wrappers to prevent the poison plates from sliding in the axial direction.

The basket hold down ring is set between the top of the basket assembly and inside surface of the canister top shield plug assembly. The hold down ring is used to prevent the basket assembly from sliding freely in the axial direction during the normal transport conditions.

- NUHOMS®-MP197 Transport Package

The cask body and the transportable canister together with the two impact limiters, form the packaging designed to meet all of the applicable 10CFR71 requirements for a Type B(U) packaging.

The cask body wall thickness (excluding the shield shell, shield shell closure plates and neutron shield) enables the packaging to withstand the hypothetical puncture accident. The shell is designed to be both strong and ductile. The top and bottom impact limiters absorb the kinetic energy from the 1 ft. normal and 30 ft. hypothetical accident condition free drops.

Table 2-1 summarizes the specific evaluation methods that are used to demonstrate compliance with the regulations. Numerical analyses have been performed for the normal and accident conditions, as well as for the lifting and tie-down loads. In general, numerical analyses have been performed for the regulatory events. These analyses are summarized in the main body of this section, and described in detail in Appendices 2.10.1 through 2.10.8. Testing of the impact limiters is conducted to confirm the analytical assumptions and results. The test results are included in Appendix 2.10.9.

The detailed structural analysis of the NUHOMS®-MP197 packaging is included in the following appendices:

Appendix 2.10.1	NUHOMS®-MP197 Cask Body Structural Evaluation
Appendix 2.10.2	NUHOMS®-MP197 Cask Lid Bolt Analysis
Appendix 2.10.3	NUHOMS®-61BT DSC (Canister and Basket) Structural Evaluation
Appendix 2.10.4	NUHOMS®-MP197 Cask Lead Slump Analysis
Appendix 2.10.5	NUHOMS®-MP197 Cask Inner Containment Buckling Analysis
Appendix 2.10.6	Dynamic Amplification Factor Determination
Appendix 2.10.7	Evaluation of Fuel Assembly under Accident Impacts
Appendix 2.10.8	Structural Evaluation of the NUHOMS®-MP197 Package Impact Limiters
Appendix 2.10.9	NUHOMS®-MP197 Package Impact Limiter Testing

2.1.2 Design Criteria

The packaging consists of three major components:

- Cask Body
- Canister/Basket
- Impact Limiters

The structural design criteria for these components are described below.

2.1.2.1 Cask Body

2.1.2.1.1 Containment Vessel

The containment vessel consists of the inner shell with a flange out to the seal seating surface, the bottom closure, and the lid. The lid bolts and seals are also part of the containment vessel as are the drain and vent port plugs, bolts and seals. The containment vessel is designed to the maximum practical extent as an ASME Class I component in accordance with the rules of the ASME Boiler and Pressure Vessel Code, Section III, Subsection NB [3]. The Subsection NB rules for materials, design, fabrication and examination are applied to all of the above components to the maximum practical extent. In addition, the design meets the requirements of Subsection WB of the ASME Section III, Division 3 [4] and Regulatory Guides 7.6 [5] and 7.8 [6]. Exceptions to the ASME Code are discussed in Section 2.11 of this Chapter.

The acceptability of the containment vessel under the applied loads, is based on the following criteria:

- Title 10, Chapter 1, Code of Federal Regulations, Part 71.
- Regulatory Guide 7.6 Design Criteria
- ASME Code Design Stress Intensities
- Preclusion of Fatigue Failure
- Preclusion of Brittle Fracture

The stresses due to each load are categorized as to the type of stress induced, e.g. membrane, bending, etc., and the classification of stress, e.g. primary, secondary, etc. Stress limits for containment vessel components, other than bolts, for Normal (Level A) and Hypothetical Accident (Level D) Loading Conditions are given in Table 2-2. The stress limits used for Level D conditions, determined on an elastic basis, are based on the entire structure (containment shell and gamma shielding material) resisting the accident load. Local yielding is permitted at the point of contact where the load is applied.

The primary membrane stress and primary membrane plus bending stress are limited to S_m (S_m is the code allowable stress intensity) and 1.5 S_m, respectively, at any location in the cask for normal load conditions.

The hypothetical impact accidents are evaluated as short duration, Level D conditions. The stress criteria are taken from Section III, Appendix F of ASME Code [7]. For elastic quasi-static analysis, the primary membrane stress intensity (P_m) is limited to the smaller of the 2.4 S_m or 0.7 S_u, and membrane plus bending stress intensities ($P_m + P_b$) are limited to the smaller of the 3.6 S_m or S_u.

The allowable stress limits for the containment bolts are listed in Table 2-3. The allowable stress limits for the lid bolts are listed separately in Tables 2.10.2-3 and 2.10.2-4.

The allowable stress intensity value, S_m, as defined by the Code, is taken at the maximum temperature calculated for each service load condition.

2.1.2.1.2 Non-Containment Structure

Certain components such as the outer shell, the neutron shield shell and the trunnions are not part of the cask containment vessel but do have structural functions. These components referred to as non-containment structures are required to react to the containment environmental loads, and in some cases share the loads with the containment vessel. The stress limits for the outer shell structures are is same as given in Table 2-2 for the containment structure. The neutron shield shell is designed, fabricated and inspected in accordance with the ASME Code Subsection NF [3], to the maximum practical extent. Other structural and structural attachment welds are examined by the liquid penetrant method, in accordance with Section V, Article 6 of the ASME Code [8]. The liquid penetrant examination acceptance standards are in accordance with Section III, Subsection NF, Paragraphs NF-5350 [3].

Seal welds are examined visually, or by liquid penetrant method, in accordance with Section V of the ASME Code [8]. Electrodes, wire, and fluxes used for fabrication comply with the applicable requirements of the ASME Code, Section II, Part C [9].

The welding procedures, welders and weld operators are qualified in accordance with Section IX of the ASME Code [10].

The radial neutron shield, including the stainless steel enclosure, have not been designed to withstand all of the hypothetical accident loads. The shielding may degrade during the fire or due to the 40 inch drop onto the puncture bar. Therefore a bounding shielding analysis, assuming that the exterior neutron shielding is completely removed, has been performed. This analysis shows that the accident dose rates are not exceeded. These accident shielding analyses are described in Chapter 5.

2.1.2.2 Canister and Basket

2.1.2.2.1 Canister

The canister shell, the inner top cover plate, the inner bottom cover plate, the siphon vent block, and the siphon/vent port cover plate are designed, fabricated and inspected in accordance with the ASME Code Subsection NB to the maximum practical extent with the exception listed in Section 2-11 of this SAR. The basis for the allowable stresses is ASME Code Section III, Division I, Subsection NB Article NB-3200 for normal condition loads (Level A), and Appendix F for accident condition loads (Level D). Stress limits for Normal (Level A) and Hypothetical Accident (Level D) Loading Conditions are given in Table 2-2. When evaluating the results from the non-linear elastic-plastic analysis for the accident conditions, the general primary membrane stress intensity, P_m, shall not exceed 0.7 S_u and the maximum stress intensity at any location ($P_m + P_b$) shall not exceed 0.9 S_u.

2.1.2.2.2 Basket

The basket is designed, fabricated and inspected in accordance with the ASME Code Subsection NG [3], to the maximum practical extent. The following exceptions are taken:

The poison and aluminum plates are not used for structural analysis. Therefore, the materials are not required to be code materials. The quality assurance requirements of NQA-1 is imposed in lieu of NCA-3800. The basket will not be code stamped. Therefore the requirements of NCA are not imposed. Fabrication and inspection surveillance is performed by the design organization in lieu of an authorized nuclear inspector

The basket is designed to meet the heat transfer, nuclear criticality, and the structural requirements. The basket structure must provide sufficient rigidity to maintain a subcritical configuration under the applied loads. The 304 stainless steel members in the NUHOMS®-61BT basket are the primary structural components. The neutron poison plates are the primary heat conductors, and provide the necessary criticality control.

The stress analyses of the basket for normal and accident conditions do not take credit for the poison plates except for through-thickness-compression. However, the weight of the poison plates is included in the stress evaluations.

The stress limits for the basket are summarized in Table 2-4. The basis for the allowable stresses for the 304 stainless steel fuel compartment wraps and rails is Section III, Division I, Subsection NG of the ASME Code. The primary membrane stress and primary membrane plus bending stress are limited to S_m (S_m is the code allowable stress intensity) and 1.5 S_m, respectively, at any location in the basket for normal (Design and Level A) load conditions.

The hypothetical impact accidents are evaluated as short duration, Level D conditions. The stress criteria are taken from Section III, Appendix F of the ASME Code [7]. For elastic quasi-static analysis, the primary membrane stress intensity (P_m) is limited to the smaller of 2.4 S_m or 0.7 S_u, and membrane plus bending stress intensities ($P_m + P_b$) are limited to smaller of 3.6 S_m or S_u. When evaluating the results from the non-linear elastic-plastic analysis for the accident conditions, the general primary membrane stress intensity, P_m shall not exceed 0.7 S_u and the maximum stress intensity at any location ($P_m + P_b$) shall not exceed 0.9 S_u.

The fuel compartment walls under compressive loads are also evaluated against the ASME Code rules for component supports, to ensure that buckling will not occur. The acceptance criteria (allowable buckling loads) are taken from the ASME Code, Section III, Appendix F, paragraph F-1341.3, Collapse Load. The allowable buckling load is determined by plastic analysis collapse load according to the criteria given in Section III, Subsection NB, Paragraph NB-3213.25.

The basket hold down ring is set between the top of the basket assembly and inside surface of the lid assembly. The hold down ring is used to prevent the basket assembly from sliding freely in the axial direction during the normal/accident transport conditions. The basket hold down ring is designed, fabricated, and inspected in accordance with the ASME Code Subsection NF [3] to the maximum practical extent.

2.1.2.3 Impact Limiters (Front and Rear)

The NUHOMS®-MP197 packaging is provided with an impact limiter at each end of the cask body. The limiters are identical. The inside diameter of the limiter is determined by the diameter of the cask body. The length and outside diameter of the limiters are sized to limit the cask inertial loads during the 1 foot normal and 30 foot accident drop events, so that the containment vessel (and the non-containment structures) meets the design criteria.

The impact limiter stainless steel cylinders, gussets, and end plates, are designed to position and confine the balsa and redwood blocks so that the impact energy is properly absorbed. The stainless steel shell is also designed to support and protect the wood blocks under normal environmental conditions (moisture, pressure, temperature, etc.).

The impact limiter and attachments are designed to withstand the applied loads and to prevent separation of the limiters from the cask during an impact. The design criteria for the impact limiters and attachments are both unique and specific. They are specified in Appendix 2.10.9.

2.1.2.4 Trunnions

NUHOMS®-MP197 cask includes removable front and rear trunnions, as shown in drawing 1093-71-5, which are used for on-site lifting and transfer operations. The trunnions are removed prior to transportation and replaced with non-protruding plugs to provide the required crush clearance distance for the impact limiter. The trunnion plugs allow the largest possible stopping distance and minimize the package impact loads resulting from the postulated accident condition drop. The trunnion plugs also provide shielding in the trunnion regions during transportation.

The evaluation and design criteria for the lifting/tiedown trunnions are based on the requirements of 10CFR71.45. The details of the evaluation are presented in Section 2.5. Two sets of front trunnions are designed. One set of trunnion has double shoulders and is used for lifting. The double shoulder front trunnions have a minimum factor of safety of three against yield stress or five against ultimate stress; whichever is most restrictive. The other set of trunnions has a single shoulder and is also used for lifting. The single shoulder front trunnions have a minimum factor of safety of six against yield or ten against ultimate; whichever is most restrictive. Only one set of trunnions will be used depending on-site and transfer operation requirements. The design and fabrication of the lifting trunnions are in accordance with the requirements of ANSI N14.6.

2.1.2.5 Tie-Down Device

NUHOMS®-MP197 cask includes a bearing block, located at the mid-length, on the bottom of the cask, designed to react all longitudinal loads encountered during transportation. As shown in drawing 1093-71-21, the package is supported by saddles and tie-down straps. The saddles and tie-down straps are designed to support the vertical, lateral, and rotational loads encountered during transport, while the bearing block resists the cask longitudinal and transportation loads. The details of the tie-down evaluation are presented in Section 2.5.

2.2 WEIGHTS AND CENTER-OF-GRAVITY

The weight of the NUHOMS®-MP197 packaging is 132.55 tons. The weights of the major individual subassemblies are listed in following table. The center of gravity of the cask is located on the axial centerline approximately 102.85 inches from the base of the cask.

Cask Weight and Center Gravity

Component	Nominal Weight (lbs. x 1000)
Cask Body	63.19
Lid and Lid Bolts	5.61
Neutron Shield Aluminum Boxes	2.02
Resin	9.96
Gamma Shield (Lead)	59.74
Outer Shield Shell	2.47
Impact Limiter Attachment Blocks	0.85
Trunnion replacement Plug	1.96
Trunnion Block	2.33
Shear Key Bearing Block	0.71
Cask Weight w/o Impact Limiters and Attachments	**148.84**
Canister	22.47
Basket	22.92
Impact Limiters w/Attachment bolts and Thermal Shield	27.87
Total Package Weight (Empty)	**222.10**
Fuel Assemblies	43.0
Total Package Weight (Loaded)	**265.1**

Summary of weights used for structural analysis:

1. Front (Top) Trunnion Lifting (W/o Limiters) — 260.3 kips w/1.1 factor
2. Cask Body Stress Analysis — 266.3 kips.
3. Puncture Analysis — 265.1 kips

2.3 MECHANICAL PROPERTIES OF MATERIALS

2.3.1 Cask Material Properties

This section provides the mechanical properties of materials used in the structural evaluation of the NUHOMS®-MP197 cask. Table 2-5 lists the materials selected, the applicable components, and the minimum yield, ultimate, and design stress values specified by the ASME Code, Section II, Part D [9].

Table 2-6 summarizes the thermal analysis results from Chapter 3. These results support the selection of cask body, canister, and basket component design temperatures for structural analysis purposes.

2.3.2 Canister/Basket Material Properties

The material properties of the 304 stainless steel plates are taken from the ASME Code, Section II, Part D [9]. These properties are listed with specific references in Table 2-5.

2.3.3 Impact Limiter Material Properties

Mechanical properties of the energy absorbing wood and wood adhesive used in the impact limiters are both unique and specific. They are specified in Appendix 2.10.8 (Tables 2.10.8-1 and 2).

2.3.4 Fracture Toughness Requirements

A. NUHOMS®-MP197 cask

With the exception of the NUHOMS®-MP197 cask closure fasteners, all of the structural components are fabricated from ASME SA-240 Type/Grade 304, 316, or XM19 and SA-705 type 630 H1100 stainless steel. Stainless steel materials do not undergo a ductile to brittle transition in the temperature of interest (> –40°F) and therefore are not subject to brittle fracture.

The fracture toughness requirements of the lid bolts meet the criteria of ASME Code, Section III, Division 3, Subsection WB (Para. WB-2333) [4]. Charpy V-Notch testing is performed at –20°F. The acceptance criteria is that the material exhibit at least 25 mils lateral expansion (Table WB-2333-1).

B. Canister

The containment components of the canister are fabricated from Type 304 stainless steel. Stainless steel materials do not undergo a ductile to brittle transition in the temperature of interest (down to –40°F), and therefore are not subject to brittle fracture.

2.4 GENERAL STANDARDS FOR ALL PACKAGES

The NUHOMS®-MP197 transport package is designed to comply with the general standards for all packages specified by 10CFR71.43.

2.4.1 Minimum Package Size

The overall package dimensions of 281.25 inches long and 122 inches in diameter exceed the minimum dimension requirement of 10 cm (4 inches).

2.4.2 Tamper-proof Feature

The primary access path into the package is through the closure lid. The vent port, test port, drain port and bottom ram closure are smaller access paths. During transport the top (front) impact limiter entirely covers and prevents access to the cask closure lid and the test port & vent port penetrations. A security wire seal is installed in the upper impact limiter attachment bolt prior to each shipment. The presence of this seal demonstrates that unauthorized entry into the package has not occurred. The bottom impact limiter covers and prevents access to the drain port, test port and bottom ram cover closure.

2.4.3 Positive Closure

Positive fastening of all access openings through the containment vessel is accomplished by bolted closures which preclude unintentional opening. In addition, the presence of the impact limiters and security seal described in Section 2.4.2 provide further protection against unintentional opening.

2.4.4 Chemical and Galvanic Reactions

The materials of the NUHOMS®-MP197 cask have been reviewed to determine whether chemical, galvanic or other reactions among the materials, contents and environment might occur during any phase of loading, unloading, handling or transport.

- The materials from which NUHOMS®-MP197 transportation package is fabricated will not experience significant chemical, galvanic, or other reaction in air, helium, or water environment.

- During wet loading, the canister and the cask are submerged in BWR pool water or clean deionized water. The discussion that follows will demonstrate that no significant corrosion or hydrogen generation will occur in this environment for the wetted materials.

- During transportation, the exterior of the cask and impact limiters is exposed to ambient environmental conditions of temperature, rain, snow, etc. All of the exterior surfaces with the exception of bolts and fusible plugs are fabricated from stainless steel. Therefore, the cask exterior is protected from chemical, galvanic or other reactions during transportation.

- During transportation, the interior of the canister and the space between the canister and the cask is exposed to an inert helium environment. The canister is vacuum-dried; the space between the cask and the canister is vacuum-dried if loaded wet. Both the canister and cask are backfilled with helium. The inert environment precludes general or galvanic corrosion on the interior surfaces.

- Various materials are sealed under air at the fabricator, and remain sealed during all normal operations:
  a) radial neutron shielding materials and the aluminum resin boxes are sealed between stainless steel shells
  b) lead shielding is sealed between stainless steel shells
  c) wood is sealed inside the stainless steel impact limiter shell
  d) a carbon steel shield plug is sealed between the stainless steel inner and outer bottom covers of the canister

The free volume in these spaces is small. Consequently the amount of oxygen or moisture is too insufficient to cause significant corrosion or galvanic reactions between these materials. The neutron shielding material is inert after it has cured and does not affect the aluminum boxes.

Dissimilar materials in contact in the NUHOMS®-MP197, and the material environments are summarized in the following table.

Component	Dissimilar Materials in Contact	Wet Loading Environment	Transport Environment
Basket	304 stainless steel / aluminum 304 stainless steel / neutron poison (aluminum–based)	BWR pool water	vacuum dried, helium backfill
Canister	stainless steel / nickel-plated carbon steel top shield plug	BWR pool water	vacuum dried, helium backfill
Canister	304 stainless steel / bare carbon steel bottom shield plug	air, sealed at fabricator	air, sealed at fabricator
cask (interior)	304 stainless steel / lubricant (slide rails)	BWR pool water	vacuum dried, helium backfill
Cask	lead / stainless steel[1] aluminum / borated polyester aluminum / stainless steel[1]	air, sealed at fabricator	air, sealed at fabricator
Cask	alloy steel bolts / stainless steel[1]	air, lubricant	air, lubricant
Cask	fluorocarbon seals / stainless steel[1]	air, helium	air, helium, ambient weather
Cask	304 stainless steel / brass (trunnion bolt plug)	BWR water	not applicable
Cask	304 stainless steal / lead (security wire and seal)	not applicable	ambient weather
Cask	304 stainless steel / polypropylene (trunnion plug)	not applicable	air
Cask	stainless steel[1] / transport saddle[2]	not applicable	ambient weather
impact limiter (IL)	304 stainless steel / nylon (fusible plug) 304 stainless steel / fluorocarbon (fusible plug seal) 304 stainless steel / alloy steel (lift ring bolt)	not applicable	ambient weather
cask & IL	stainless steel[1] / aluminum (thermal shield)	not applicable	air
IL	wood / wood glue / 304 stainless steel	not applicable	air, sealed at fabricator

Notes:

1. Stainless steel may be 304, XM19, or 17-4 PH; contact between these three materials is not listed as dissimilar material contact in this table.
2. Transport saddle is not part of this SAR: points of contact between cask and saddle may be stainless steel, painted carbon steel, or elastomer sheet

2.4.4.1 Cask/Canister Interior

The NUHOMS®-MP197 cask and NUHOMS®-61BT DSC materials are shown in the Parts List on Drawing 1093-71-3. Both of the cask and canister vessels are made from stainless steel.

Within the canister cavity, there is a basket with support rails made from SA-240 Type 304 stainless steel. The basket structure consists of an assembly of stainless steel tubes (fuel compartments) separated by poison plates and surrounded by larger stainless steel boxes and support rails.

The neutron poison is not welded or bolted to the stainless steel, but is captured by the geometry of the boxes and stainless steel plates.

Potential sources of chemical or galvanic reactions are the interaction between the aluminum, aluminum-based neutron poison and stainless steel within the basket itself, and the interaction of the stainless steel rails with the stainless steel canister cavity wall and the pool water.

Typical water chemistry in a BWR Spent Fuel pool is as follows:

pH	5.6 - 7.1
Chloride	1 - 10 ppb
Conductivity	0.7 - 1.8 µmho
Silica	2.5 - 2.7 ppm
Pool Temperature	70 - 115°F

Behavior of Aluminum in Deionized Water

Aluminum is used for many applications in spent fuel pools. In order to understand the corrosion resistance of aluminum within the normal operating conditions of spent fuel storage pools, a discussion of each of the types of corrosion is addressed separately. None of these corrosion mechanisms are expected to occur in the short time period that the cask is submerged in the spent fuel pool.

General Corrosion

General corrosion is a uniform attack of the metal over the entire surfaces exposed to the corrosive media. The severity of general corrosion of aluminum depends upon the chemical nature and temperature of the electrolyte and can range from superficial etching and staining to dissolution of the metal. Figure 2-1 shows a potential -pH diagram for aluminum in high purity water at 77°F. The potential for aluminum coupled with stainless steel and the limits of pH for BWR pools are shown in the diagram to be well within the passivation domain. The passivated surface of aluminum (hydrated oxide of aluminum) affords protection against corrosion in the domain shown because the coating is insoluble, non-porous and adherent to the surface of the aluminum. The protective surface formed on the aluminum is known to be stable up to 275°F and in a pH range of 4.5 to 8.5 [13].

Galvanic Corrosion

Galvanic corrosion is a type of corrosion which could cause degradation of dissimilar metals exposed to a corrosive environment for a long period of time.

Galvanic corrosion is associated with the current of a galvanic cell consisting of two dissimilar conductors in an electrolyte. The two dissimilar conductors of interest in this discussion are aluminum and stainless steel in deionized water. There is little galvanic corrosion in deionized water since the water conductivity is very low. There is also less galvanic current flow between the aluminum-stainless steel couple than the potential difference on stainless steel which is known as polarization. It is because of this polarization characteristic that stainless steel is compatible with aluminum in all but severe marine, or high chloride, environmental conditions [14].

Pitting Corrosion

Pitting corrosion is the forming of small sharp cavities in a metal surface. The first step in the development of corrosion pits is a local destruction of the protective oxide film. Pitting will not occur on commercially pure aluminum when the water is kept sufficiently pure, even when the aluminum is in electrical contact with stainless steel. Pitting and other forms of localized corrosion occur under conditions like those that cause stress corrosion, and are subject to an induction time which is similarly affected by temperature and the concentration of oxygen and chlorides. As with stress corrosion, at the low temperatures and low chloride concentrations of a spent fuel pool, the induction time for initiation of localized corrosion will be greater than the time that the cask internal components are exposed to the aqueous environment.

Crevice Corrosion

Crevice corrosion is the corrosion of a metal that is caused by the concentration of dissolved salts, metal ions, oxygen or other gases in crevices or pockets remote from the principal fluid stream, with a resultant build-up of differential galvanic cells that ultimately cause pitting. Crevice corrosion could occur in the basket plates, around the stainless steel welds. However, due to the short time in the spent fuel pool, this type of corrosion is not expected to be significant.

Intergranular Corrosion

Intergranular corrosion is corrosion occurring preferentially at grain boundaries or closely adjacent regions without appreciable attack of the grains or crystals of the metal itself. Intergranular corrosion does not occur with commercially pure aluminum and other common work hardened aluminum alloys.

Behavior of Austenitic Stainless Steel in Deionized Water

The fuel compartments and the structural plates which support the fuel compartments are made from type 304 stainless steel. Stainless steel does not exhibit general corrosion when immersed in deionized water. Galvanic reactions with aluminum are discussed above.

Stress corrosion cracking in the 304 stainless steel welds is also not expected to occur, since the baskets are not highly stressed during normal operations. Of the corrosive agents that could initiate stress corrosion cracking in the 304 stainless steel basket welds, only the combination of chloride ions with dissolved oxygen could occur in spent fuel pool water. Although stress corrosion cracking can take place at very low chloride concentrations and temperatures such as those in spent fuel pools (less than 10 ppb and 160°F, respectively), the effect of low chloride concentration and low temperature is to greatly increase the induction time, that is, the period during which the corrodent is breaking down the passive oxide film on the stainless steel surface. Below 60°C (140°F), stress corrosion cracking of austenitic stainless steel does not occur at all. At 100 °C (212 °F), chloride concentration on the order of 15% is required to initiate stress corrosion cracking [16]. At 288 °C (550 °F), with tensile stress at 100% of yield in BWR water containing 100 ppm O_2, time to crack is about 40 days in sensitized 304 stainless steel [17]. Thus, the combination of low chlorides, low temperature and short time of exposure to the corrosive environment eliminates the possibility of stress corrosion cracking in the basket welds.

Behavior of Aluminum Based Neutron Poison in Deionized Water

The aluminum component of the borated aluminum is a ductile metal having a high resistance to corrosion. Its corrosion resistance is provided by the buildup of a protective oxide film on the metal surface when exposed to a corrosive environment. As stated above for aluminum, once a stable film develops, the corrosion process is arrested at the surface of the metal. The film remains stable over a pH range of 4.5 to 8.5.

Tests were performed by Eagle Picher [18] which concluded that borated aluminum exhibits a strong corrosion resistance at room temperature in deionized water. Satisfactory long-term usage in these environments is expected. At high temperature, the borated aluminum still exhibits high corrosion resistance in the pure water environment.

From tests on pure aluminum, it was found that borated aluminum was more resistant to uniform corrosion attack than pure aluminum.

An alternate neutron poison material is a boron carbide / aluminum composite, which is a matrix of full-density aluminum with a fine dispersion of boron carbide particles throughout. The corrosion behavior is similar to that of the base aluminum alloy.

The third neutron poison material is Boral®. The faces of the Boral sheet are 1100 aluminum, while the aluminum/boron carbide core is exposed at the edges of the sheet.

There are no chemical, galvanic or other reactions that could reduce the areal density of boron in any of the poison plate materials for the NUHOMS®-61BT.

Electroless Nickel Plated Carbon Steel

The carbon steel top shield plug of the DSC is plated with electroless nickel. This coating is identical to the coating used on the 52B DSC. It has been evaluated for potential galvanic reactions in Transnuclear West's response to NRC Bulletin 96-04 [28]. In BWR pools, the reported corrosion rates are insignificant and are expected to result in a negligible rate of reaction for the NUHOMS® BWR systems.

2.4.4.2 Cask Exterior

The exterior of the cask is made from stainless steel and will not cause significant chemical, galvanic or other reactions in air or water environments.

Potential galvanic couples are:

- The brass bolt covers and the stainless 304 trunnions during wet loading. The bolt covers are not important to safety components.

- The thermal shield and the stainless steel cask bottom and impact limiter. The aluminum is not directly exposed to the weather, road salt, etc., because it is covered by the impact limiter. The thermal shield is not an important to safety component.

- The low alloy steel bolts and stainless steel. The lid, test, drain cover, and ram cover bolts are not directly exposed to the weather, road salt, etc, because they are covered by the impact limiters. The impact limiter hoist ring replacement bolts and the trunnion plug bolts will be exposed,

In all these cases, minor sacrificial galvanic corrosion of these anodic (non-stainless) components will have no adverse affect on an important to safety function.

2.4.4.3 Lubricants and Cleaning Agents

A lubricant may be used to coat the threads and shoulders of the bolts and the slide rails and the contact areas of the trunnions during lifting operations. Lubricants are generally selected from the list of materials approved for contact with the pool water at the facility where wet loading occurs.

Cask and DSC components are cleaned to remove all temporary markings, expendable materials, etc., during fabrication, using approved procedures.

After loading, exterior surfaces of the cask will be decontaminated using procedures and decontamination agents approved at the loading facility.

The cleaning agents and lubricants have no significant effect on the cask materials.

2.4.4.4 Hydrogen Generation

The NUHOMS 61BT canister is wet loaded, either in the MP-197 transport cask, or in a transfer cask. In the latter case, the seal canister may, at a later date, be dry loaded into the MP-197 directly from the horizontal storage module. In either event, there is no mechanism for galvanic corrosion in the space between the canister and the MP-197, because both the inner shell of the MP-197 and the outer shell of the canister are stainless steel, and because the canister is sealed before the lid is placed on the MP-197. Therefore, the following discussion applies entirely to the potential for the generation of hydrogen inside the canister during wet loading.

During the initial passivation of the stainless steel and aluminum components, small amounts of hydrogen gas may be generated in the DSC. The passivation stage may occur prior to submersion of the transport cask into the spent fuel pool. Any amounts of hydrogen generated in the DSC will be insignificant and will not result in a flammable gas mixture within the DSC. In order for concentrations of hydrogen in the cask to reach flammability levels, most of the DSC would have to be filled with water for the hydrogen generation to occur, and the lid would have to be in place with both the vent and drain ports closed. This does not occur during DSC loading or unloading operations.

After loading fuel into the NUHOMS®-61BT DSC, the shield plug is placed in the DSC and the transport cask and DSC are raised to the pool surface. At this time the DSC is completely filled with water.

An estimate of the maximum hydrogen concentration can be made, ignoring the effects of radiolysis, recombination, and solution of hydrogen in water. Testing was conducted by Transnuclear [19] to determine the rate of hydrogen generation for aluminum metal matrix composite in intermittent contact with 304 stainless steel. The samples represent the neutron poison plates paired with the basket compartment tubes. The test specimens were submerged in deionized water for 12 hours at 70 °F to represent the period of initial submersion and fuel loading, followed by 12 hours at 150 °F to represent the period after the fuel is loaded, until the water is drained. The hydrogen generated during each period was removed from the water and the test vessel and measured.

The test results were:

	12 hour @ 70 °F		**12 hour @ 150 °F**	
	$cm^3hr^{-1}dm^{-2}$	**$ft^3hr^{-1}ft^{-2}$**	**$cm^3hr^{-1}dm^{-2}$**	**$ft^3hr^{-1}ft^{-2}$**
aluminum MMC/SS304	0.517	1.696E-4	0.489	1.604E-4

The total surface area of the aluminum/stainless steel interface at the neutron absorber/ compartment wall interface is 1462 ft^2. This surface area, combined with the test data at 150 °F above result in a hydrogen generation rate of

$$(1.6\times10^{-4}\ ft^3/ft^2hr)(1462\ ft^2) = 0.23\ ft^3/hr$$

in the 61BT DSC. During welding of the top inner plate, the DSC is partially filled with water. The minimum free volume of the DSC is 120 ft^3. (Operations require draining 1100 gallons, equal to 147 ft^3). The following assumptions are made to arrive at a conservative estimate of hydrogen concentration:

- All generated hydrogen is released instantly to the plenum between the water and the shield plug, that is, no dissolved hydrogen is pumped out with the water, and no released hydrogen escapes through the open vent port, and
- The welding and backfilling process takes 8 hours to complete.

Under these assumptions, the hydrogen concentration in the space between the water and the shield plug is a function of the time water is in the DSC prior to backfilling with helium. The hydrogen concentration is $(0.23\ ft^3\ H_2/hr)*(8\ hr) / (120\ ft^3) = 1.5\ \%$. Monitoring of the hydrogen concentration before and during welding operations will be performed to ensure that the hydrogen concentration does not exceed 2.4%. If the concentration exceeds 2.4%, welding operations will be suspended and the DSC will be purged with an inert gas. In an inert atmosphere, a flammable gas mixture will not be generated.

2.4.4.5 Seals

All closure seals are low temperature fluorocarbon conforming to AMS-R-83485[29]. This material is suitable for use from –40 to 400 °F. All o-ring temperatures reported in Chapter 3 are within this range for both normal and accident conditions.

All sealing surfaces are stainless steel 304 or XM-19.

To evaluate irradiation damage to the seals, note that the energy absorption of polymers and tissue is similar. Therefore, the gamma radiation energy absorbed by the seals may be approximated as the rad equivalent of the surface dose in rem. The absorbed neutron energy may be estimated as half the neutron dose rate to account for the tissue quality factor. From Chapter 5, the maximum dose rate at the surface of the MP-197 is 13 mrem/hour gamma, and 125 neutron. This is approximately equivalent to 0.076 rad/hr absorbed dose rate in polymers. If we increase that by a factor of 100 to account for the fact that the seals are somewhat below the surface, at the end of one year of continuous exposure, this would result in absorbed energy in the seals of about 7×10^4 rad, well below the threshold of polymer damage, generally about than 10^6 rad.

2.4.4.6 Neutron Shielding

The radial neutron shield is a proprietary reinforced polymer. Information on the composition and the radiation and temperature resistance of the material was provided to the NRC in the TN-68 SAR [30]. The fire retardant mineral fill makes it self-extinguishing. Furthermore, the material is contained in aluminum tubes inside a steel shell, so that it is retained in place and isolated from sources of ignition.

The trunnion plugs include polypropylene neutron shielding in a stainless 304 case. Polypropylene is slow burning to non-burning according to Table 24, Section 1 of the Handbook of Plastics and Elastomers[31].

2.4.4.7 Coatings

Corrosion-resistant coatings are optional on alloy steel bolts. The top shield plug is electroless nickel coated, as described above. There are no other coatings on the MP-197.

2.4.4.8 Effect of Chemical and Galvanic Reactions on the Performance of the Cask

There are no significant reactions that could reduce the overall integrity of the cask or its contents during transportation. The cask and fuel cladding thermal properties are provided in Chapter 3. The emissivity of the fuel compartment is 0.3, which is typical for non-polished stainless steel surfaces. If the stainless steel is oxidized, this value would increase, improving heat transfer. The fuel rod emissivity value used is 0.8, which is a typical value for oxidized Zircaloy. Therefore, the passivation reactions would not reduce the thermal properties of the component cask materials or the fuel cladding.

There are no reactions that would cause binding of the mechanical surfaces or the fuel to basket compartment boxes due to galvanic or chemical reactions.

There is no significant degradation of any important-to-safety components caused directly by the effects of the reactions or by the effects of the reactions combined with the effects of exposure of the materials to neutron or gamma radiation, high temperatures, or other possible conditions.

2.5 LIFTING AND TIE-DOWN STANDARDS

2.5.1 Lifting Devices

10CFR 71-45(a) requires that a minimum factor of safety of three against yield is required for all lifting attachments which are structural parts of the package. In addition, the package must be designed such that failure of any lifting device under excessive load would not impair the ability of the package to meet the requirements of 10CFR71. Section 2.5.1.1 provides the analysis of the trunnions which are the only components used to lift the cask. Two sets of trunnions will be provided for the NUHOMS®-MP197 transport package lifting. One set of trunnions has double shoulders (non single failure proof). The other set of trunnions has a single shoulder (single failure proof). Only one set of trunnions will be used depending on site and transfer operation requirements. Appendix 2.10.1 provides an analysis of the global stresses in the cask wall due to the effects of lifting loads on the trunnions. The global stress intensities from the ANSYS run at the stress reporting locations of the containment vessel and outer shell are presented in Table 2.10.1-9. The local stress intensities in the cask wall due to the 3G (double shoulder trunnion) and 6G (single shoulder trunnion) lifting load are calculated below and presented in Tables 2-11 and 2-14. The maximum combined stress intensity for 3G lifting is 18.36 ksi. The maximum combined stress intensity for 6G lifting is 22.99 ksi. These stresses are less than the yield stress of the outer shell material (24.65 ksi, SA-240 Gr. 316 at 250°F). Therefore the requirements of 10CFR 71-45(a) are met. The stress analyses of the front trunnion and trunnion flange bolts are provided in the following sections.

2.5.1.1 Trunnion Analysis

NUHOMS®-MP197 cask includes removable front and rear trunnions, as shown on drawing 1093-71-5, which are used for on-site lifting and transfer operations. The trunnions are removed prior to transportation and replaced with non-protruding plugs to provide the required crush distance for the impact limiter. This section provides the structural analysis of the NUHOMS®-MP197 cask trunnions.

A. Double Shoulder Front Trunnions (Non-Single Failure Proof)

Trunnion Stress Calculations

These two front trunnions are used for lifting the cask and are designed to the requirements of ANSI N14.6 [2]. They can support a loading equal to 3 times the weight of the cask without generating stresses in excess of the minimum yield strength of the material. They can also lift 5 times the weight of the cask without exceeding the ultimate tensile strength of the material. A dynamic load factor of 1.1 is used in evaluating the trunnion stresses.

Figure 2-3 shows the basic dimensions of the front trunnions. A cask weight of 260,000 lbs. is used in this calculation. Following table shows the cross sectional area and moment of inertia at shoulder cross Section A-A, Section B-B, and Section C-C of the front trunnions. The loads applied to this section (for 3 W and 5 W loading) to evaluate the yield and ultimate limits are also listed.

<u>Front (Top) Trunnion Section Properties and Loads</u>
(Double Shoulder Trunnion)

Item	Section A-A	Section B-B	Section C-C
Cross Section Area, In^2	56.41	89.91	109.54
Area Moment of Inertia, In^4	429.52	924.2	954.93
Yield Condition* Shear Force, Lbs	429,000	429,000	429,000
Yield Condition* Bending Moment, In- Lbs	1,450,020	3,058,770	3,406,260
Ultimate Condition** Shear Force, Lbs.	715,000	715,000	715,000
Ultimate Condition** Bending Moment, In-Lbs	2,416,700	5,097,950	5,677,100

* Trunnion Loads to Support (3 × 1.1) times Cask Weight (260,000 lbs)
** Trunnion Loads to Support (5 × 1.1) times Cask Weight (260,000 lbs)

Following table presents a summary of the stresses at the same location to compare against the trunnion yield and ultimate strengths.

<u>Front (Top) Trunnion Stresses When Loaded</u>
<u>By 3 and 5 Times Cask Weight</u>
(Double Shoulder Trunnion)

Stress	Yield Limit (Ksi)	Yield Limit (Ksi)	Yield Limit (Ksi)
	SECTION A-A	SECTION B-B	SECTION C-C
Shear Stress	7.61	4.77	3.92
Bending Stress	16.61	19.54	21.06
Stress Intensity	22.52	21.67	22.47
Allowable Stress, S_y (SA-182 F304 at 250°F)	23.6	23.6	23.6
	Ultimate Limit (ksi)	**Ultimate Limit (ksi)**	**Ultimate Limit (ksi)**
Shear Stress	12.68	7.95	6.53
Bending Stress	27.68	32.57	35.10
Stress Intensity	37.53	36.12	37.45
Allowable Stress, S_u (SA-182 F304 at 250°F)	68.6	68.6	68.6

Stress at Trunnion/Cask Outer Shell Intersection

The local stresses induced in the outer shell cylinder by the trunnions are calculated using "Bijlaard's" method. The neutron shield and thin outer shell are not considered to strengthen either the trunnions or outer shell. The trunnion is approximated by an equivalent attachment so that the curves of the Reference WRC-107 [22] can be used to obtain the necessary coefficients. These resulting coefficients are inserted into blanks in the column entitled "Read Curves For," in a standard computation form, a sample of which is attached as Table 2-7. The stresses are calculated by performing the indicated multiplication in the column entitled "Compute Absolute Values of Stress and Enter Result". The resulting stress is inserted into the stress table at the eight stress locations, i.e., AU, AL, BU, BL, etc. Note that the sign convention for this table is defined in the figure by the load directions shown. The membrane plus bending stresses are calculated by completing Table 2-7. The maximum stress intensities in the outer shell calculated by this methodology are 18.36 ksi (3G load) and 30.61 ksi (5G load). These stresses are summarized in the following table to compare against the outer shell yield and ultimate strengths.

Trunnion Bolt Stresses

The front trunnion flange is attached to the outer shell by twelve 1.25-7UNC-2A bolts constructed from SA-540 Gr. B24 Cl. 1 material. The bolted flange is tightly fitted into the trunnion attachment block, which is welded to the cask outer shell. This trunnion block recess provides a bearing area between the outside perimeter of the trunnion flange and the block. The radial clearance between the bolt shank and trunnion flange bolt holes is large enough so that shear loads are carried by the trunnion flange-to-block recess interface and not the bolts. The bolts develop only the tensile load due to trunnion moment.

The bending moment at the flange interface due to 3G is equal to 3 (260,000)(1.1)(0.5)(11.19) = 4,800,510 in-lbs. From Reference 20, Case 3, (for bolt patterns symmetrical about the vertical axis and flange rotating about the bottom bolt) the maximum bolt force due to bending moment, M, is:

$$F_{max} = (4/(3RN))\, M$$

Where,

R = Bolt circle radius = 10.5 in.
N = No. of bolts = 12

$$F_{max} = 4(4,800,510)/(3\times10.5\times12) = 50,800 \text{ lbs.}$$

The bolt stress area = 0.969 in^2

Max. tensile stress = 50,800/0.969 = 52,425 psi = 52.43 ksi

Bolt allowable tensile stress = S_y (at 250°F) = 141.0 ksi > 52.43 ksi

For tensile load (5G), the maximum tensile stress = (5/3)(52.43) = 87.38 ksi

The bolt allowable tensile stress = S_u (at 250°F) = 165.0 ksi

Therefore the bolt stresses are acceptable for both 5G (ultimate) and 3G (yield) trunnion loads

Summary of the Double Shoulder Trunnion Stress Analysis

The maximum calculated stresses and their margin of safety are summarized in the following table. All the calculated stresses are less than the allowable stresses. Based on these calculations, the minimum margin of safety occurs at the trunnion shoulder. Therefore, an excessive load would damage the trunnion, but the cask would not lose its structural integrity, satisfying the requirements of the 10CFR71.45(a).

Stress Summary (Double Shoulder Trunnion)

3G Loading				
Component	**Stress Type**	**Maximum Calculated Stress (ksi)**	**Allowable Stress (ksi)**	**Margin of Safety**
Trunnion Shoulder	Stress Intensity	22.52	23.6	0.05
Trunnion Attachment Bolt	Tensile	52.43	141.0	1.69
Trunnion Flange	Stress Intensity	7.17	23.6	2.29
Cask – Block Intersection	Stress Intensity	18.36	24.65	0.34
5G Loading				
Component	**Stress Type**	**Maximum Calculated Stress (ksi)**	**Allowable Stress (ksi)**	**Margin of Safety**
Trunnion Shoulder	Stress Intensity	37.5	68.6	0.83
Trunnion Attachment Bolt	Tensile	87.38	165.0	0.89
Trunnion Flange	Stress Intensity	11.95	68.6	4.74
Cask – Block Intersection	Stress Intensity	30.61	73.95	1.42

B. Single Shoulder Front Trunnions (Single Failure Proof)

Trunnion Stress Calculations

These two optional front trunnions are used for lifting the cask and are designed to the requirements of ANSI N14.6 [2]. They can support a loading equal to 6 times the weight of the cask without generating stresses in excess of the minimum yield strength of the material. They can also lift 10 times the weight of the cask without exceeding the ultimate tensile strength of the material. A dynamic load factor of 1.1 is used in evaluating the trunnion stresses.

Figure 2-3 shows the basic dimensions of these front trunnions. A cask weight of 260,000 lbs. is used in this calculation. The following table shows the cross sectional area and moment of inertia at shoulder cross section A-A of the single shoulder front trunnions. The loads applied to this section (for 6 W and 10 W loading) to evaluate the yield and ultimate limits are also listed.

Front (Top) Trunnion Section Properties and Loads
(Single Shoulder Trunnion)

Item	Section A-A
Cross Section Area, In^2	93.64
Area Moment of Inertia, In^4	934.8
Yield Condition* Shear Force, Lbs	858,000
Yield Condition* Bending Moment, In- Lbs	2,145,000
Ultimate Condition** Shear Force, Lbs.	1,430,000
Ultimate Condition** Bending Moment, In-Lbs	3,575,000

* Trunnion Loads to Support (6 × 1.1) times Cask Weight (260,000 lbs)
** Trunnion Loads to Support (10 × 1.1) times Cask Weight (260,000 lbs)

Following table presents a summary of the stresses at the same location to compare against the trunnion yield and ultimate strengths.

Front (Top) Trunnion Stresses When Loaded
By 3 And 5 Times Cask Weight
(Double Shoulder Trunnion)

Stress Category	Yield Limit (Ksi) SECTION A-A
Shear Stress	9.16
Bending Stress	13.55
Stress Intensity	22.79
Allowable Stress, S_y	23.6 (SA-182 F304 at 250°F)
	Ultimate Limit (ksi) SECTION A-A
Shear Stress	15.27
Bending Stress	22.58
Stress Intensity	37.98
Allowable Stress, S_u	68.6 (SA-182 F304 at 250°F)

Stress at Trunnion/Cask Outer Shell Intersection

The local stresses induced in the outer shell cylinder by the trunnions are calculated using "Bijlaard's" method. The neutron shield and thin outer shell are not considered to strengthen either the trunnions or outer shell. The trunnion is approximated by an equivalent attachment so that the curves of the Reference WRC-107 [22] can be used to obtain the necessary coefficients. These resulting coefficients are inserted into blanks in the column entitled "Read Curves For," in a standard computation form, a sample of which is attached as Table 2-7. The stresses are calculated by performing the indicated multiplication in the column entitled "Compute Absolute Values of Stress and Enter Result". The resulting stress is inserted into the stress table at the eight stress locations, i.e., AU, AL, BU, BL, etc. Note that the sign convention for this table is defined in the figure by the load directions shown. The membrane plus bending stresses are calculated by completing Table 2-7. The maximum stress intensities in outer shell calculated by this methodology are 22.99 ksi (6G load) and 38.32 ksi (10G load). These stresses are summarized in the following table to compare against the outer shell yield and ultimate strengths.

Trunnion Bolt Stresses

The front trunnion flange is attached to the outer shell by twelve 1.25-7UNC-2A bolts constructed from SA-540 Gr. B24 Cl. 1 material. The bolted flange is tightly fitted into the trunnion attachment block, which is welded to the cask outer shell. This trunnion block recess provides a bearing area between the outside perimeter of the trunnion flange and the block. The radial clearance between the bolt shank and trunnion flange bolt holes is large enough so that shear loads are carried by the trunnion flange-to-block recess interface and not the bolts. The bolts develop only the tensile load due to a trunnion moment.

The bending moment at the flange interface due to 6G is equal to 6 (260,000)(1.1)(0.5)(5.75) = 4,933,500 in-lbs. From Reference 20, Case 3, (for bolt patterns symmetrical about the vertical axis and flange rotating about the bottom bolt) the maximum bolt force due to bending moment *M* is:

$$F_{max} = (4/(3RN))\, M$$

where

R = Bolt circle radius = 10.5 in.
N = No. of bolts = 12

$$F_{max} = 4(4{,}933{,}500)/(3 \times 10.5 \times 12) = 52{,}206 \text{ lbs.}$$

The bolt stress area = 0.969 in^2

Max. tensile stress = 52,206 /0.969 = 53,877 psi = 53.88 ksi < S_y (at 250°F) = 141.0 ksi

For tensile load (10G), the maximum tensile stress = (10/6)(53.88)
= 89.8 ksi < S_u (at 250°F) = 165.0 ksi

Therefore the bolt stresses are acceptable for both 10G (ultimate) and 6G (yield) trunnion loads

Summary of the Single Shoulder Trunnion Stress Analysis

The maximum calculated stresses and their margins of safety are summarized in the following table. All the calculated stresses are less than the allowable stresses. Based on these calculations, the minimum margin of safety occurs at the trunnion shoulder. Therefore, an excessive load would damage the trunnion, but the cask would not lose its structural integrity, satisfying the requirements of 10CFR71.45(a).

Stress Summary (Single Shoulder Trunnion)

6G Loading				
Component	**Stress Type**	**Maximum Calculated Stress (ksi)**	**Allowable Stress (ksi)**	**Margin of Safety**
Trunnion Shoulder	Stress Intensity	22.79	23.6	0.04
Trunnion Attachment Bolt	Tensile	53.88	141.0	1.62
Trunnion Flange	Stress Intensity	7.36	23.6	2.2
Cask – Block Intersection	Stress Intensity	22.99	24.65	0.07
10G Loading				
Component	**Stress Type**	**Maximum Calculated Stress (ksi)**	**Allowable Stress (ksi)**	**Margin of Safety**
Trunnion Shoulder	Stress Intensity	37.98	68.6	0.81
Trunnion Attachment Bolt	Tensile	89.80	165.0	0.84
Trunnion Flange	Stress Intensity	12.27	68.6	4.59
Cask – Block Intersection	Stress Intensity	38.32	73.95	0.93

C. Double Shoulder Rear Trunnion Stress Analysis

These two rear trunnions are used to lift the cask in the horizontal position and to rotate the cask from the horizontal orientation to he vertical orientation. The dimensions of the two rear trunnions are identical to the front double shoulder trunnions. During the horizontal lifting, the load is shared by four (4) trunnions instead of two trunnions. Therefore, the stresses in the front trunnions bound the stresses in the rear trunnions.

2.5.2 Tie-Down Devices

The structural components of the NUHOMS®-MP197 cask are designed to withstand transportation loads of 2G in the vertical direction, 5G in the transverse direction, and 10G in the longitudinal direction without generating stress in excess of the material's yield strength, per requirements of 10CFR71.45(b)(1).

The NUHOMS®-MP197 transportation package is secured during transport by the transportation skid. The cask shear key is designed to transfer the longitudinal cask transport loads to the skid. The vertical and transverse cask transport loads are supported by saddles and tie-down straps.

Section 2.10.1.4 provides an analysis of the global stresses in the cask wall due to the effect of a 2/5/10G tie-down load. The global stress intensities from the ANSYS run at the stress reporting locations of the containment vessel and outer shell are presented in Table 2.10.1-46. All the stresses are less than the yield stress of the cask outer shell material. The bearing stress, local weld stresses and stresses in the cask wall/shear key bearing block pad due to the 2/5/10G tie-down load are calculated below.

Discussion

The shear key bearing block is a part of the cask structure, and is designed to resist the 10g longitudinal transportation load. The bearing block is a welded structure that mates with the shear key, which is part of the transport skid. A 36" × 37.20" × 1.5" pad plate is used to spread the load over a large area of the cask outer shell. The bearing block and pad plate are manufactured from SA-240, Type XM-19 stainless steel. The shear key is made of ASTM A514.

Bearing Stress between Shear Key and Bearing Block

The bearing stress due to the 10g longitudinal transportation load is calculated assuming the load is applied uniformly to one face of bearing block.

$L_1 = 22.25 - 2[5\tan(12.5)] = 20.033$ in.
$L_2 = 20.033 + 2[4.25\tan(12.5)] = 21.917$ in.
$Y = [45.25^2 - (21.917/2)^2]^{0.5} - 41.0 = 2.903$ in
Area $A_1 = ½(20.033 + 21.917) \times 2.903 = 60.89$ in^2

Segment Area, $A_2 = ½\, R^2\, [2\alpha - \text{Sin}(2\alpha)]$
$\text{Sin}\alpha = L_2/\, 2(45.25) = 21.917/\, 2(45.25) = 0.242$ $\alpha = 14^\circ = 0.245$ rad.
$A_2 = ½\, 45.25^2\, [2 \times 0.245 - \text{Sin}(28)] = 21.017$ in^2
Bearing Area = 60.89 + 21.017 = 81.907 in^2

Load = 10 × 280,000 = 2,800,000 lb.

Bearing Stress = 2,800,000 / 81.907 = 34,185 psi ≈ 34.19 ksi

The allowable average bearing stress is limited to S_y. The yield strength of SA-240, Type XM-19 stainless steel, at 300° F, is 43.3 ksi. The yield strength of shear key material (A514) is much higher than that of XM-19. Therefore, the margin of safety is:

$$\text{M.S.} = \frac{43.3}{34.19} - 1.0 = 0.27$$

Weld between Pad and Outer Shell

The shear key pad is welded to the cask structure all around with 1" partial penetration groove weld and a 5/8" fillet weld. The shear stress in the base metal of cask outer shell (SA-240, Gr. 316) is calculated in the following way:

Shear area = $(36 \times 37.2) - (34 \times 35.2) + 2(36 + 37.2) \times 5/8$
$= 142.40 + 91.5 = 233.9 \text{ in}^2$

Shear Stress = 2,800,000/233.9 =11,970 psi = 11.97 ksi

The average primary shear stress across a section loaded in pure shear is limited to 0.6 S_y. For SA-316, the yield strength at 300° F is 23.4 ksi. Therefore, the allowable weld shear stress is 14.04 ksi.

The margin of safety in the base metal is:

$$\text{M.S.} = \frac{14.04}{11.97} - 1.0 = 0.17$$

The allowable for XM-19 is higher than the allowable for SA-316.

Weld Between Bearing Block and Pad Plate

The bearing block is welded to the 1.5" thick plate with a full penetration weld and a ½" outside cover fillet weld. The welds are loaded in bending, resulting from the offset 'e' of the 10g longitudinal load point, to the center of pad plate, which is calculated as follows:

$$M = P \times e = 2{,}800{,}000\ [4.25/2 - 1.5/2] = 3{,}850{,}000 \text{ in.lb.}$$

Section modulus of the weld is computed by treating the weld as line per unit thickness, t_{eff}

$$S_w = (bd + d^2/3)\ t_{eff}$$

$$t_{eff} = 1.5 + 0.707(0.5) = 1.8535 \text{ in.}$$

$$S_w = (26.3 \times 12.06 + 12.06^2/3)\ 1.8535 = 677.75 \text{ in}^3$$

Bending Stress = 3,850,000 / 677.75 = 5,680 psi = 5.68 ksi

The allowable maximum bending stress is limited to S_y. The yield strength of SA-240, Type XM-19 stainless steel, at 300° F, is 43.3 ksi. Therefore, the margin of safety is:

$$\text{M.S.} = \frac{43.3}{5.68} - 1.0 = 6.62$$

Stress at the Shear Key Bearing Block/Cask Outer Shell Intersection

The local stresses induced in the outer shell cylinder by the shear key bearing block are calculated using "Bijlaard's" method. The neutron shield and thin outer shell are not considered to strengthen either the bearing block or outer shell. The bearing block/welding pad is approximated by an equivalent attachment so that the curves of the Reference WRC-107 can be used to obtain the necessary coefficients. These resulting coefficients are inserted into blanks in the column entitled "Read Curves For," in a standard computation form, a sample of which is attached as Table 2-7. The stresses are calculated by performing the indicated multiplication in the column entitled "Compute Absolute Values of Stress and Enter Result". The resulting stress is inserted into the stress table at the eight stress locations, i.e., AU, AL, BU, BL, etc. Note that the sign convention for this table is defined on the figure by the load directions shown. The membrane plus bending stresses are calculated by completing Table 2-10. The maximum stress intensities in outer shell calculated by this methodology are 10.88 ksi (10G load) which is less than the outer shell (SA-240 Type 316) yield strength (23.4 ksi at 300°F). Therefore, the margin of safety is:

$$M.S. = \frac{23.4}{10.88} - 1.0 = 1.15$$

Conclusions

All the stresses calculated above are less than the allowable stresses. In the event of excessive loading during normal transport, the weld between the shear key pad plate and the cask outer shell would fail in shear (has lowest margin of safety), leaving the cask body intact without impairing the ability of package to meet the requirements of 10CFR71.45(b)(3).

2.6 NORMAL CONDITIONS OF TRANSPORT

Overview

This section describes the response of the NUHOMS®-MP197 package to the loading conditions specified by 10CFR71.71. The design criteria established for the NUHOMS®-MP197 for the normal conditions of transport are described in Section 2.1.2. These criteria are selected to ensure that the package performance standards specified by 10CFR71.43 and 71.51 are satisfied. Under normal conditions of transport there will be no loss or dispersal of radioactive contents, no significant increase in external radiation levels, and no substantial reduction in the effectiveness of the packaging. Under hypothetical accident conditions, the cask is protected so that there is no escape of radioactive material exceeding a total amount A_2 in one week, and no external dose rate exceeding one rem per hour at one meter from the external surface of the package.

Detailed structural analyses of various NUHOMS®-MP197 package components subjected to individual loads are provided in the Appendices to this chapter. The limiting results from these analyses are used in this section to quantify package performance in response to the normal condition of transport load combinations, specified in 10CFR71.71 and Regulatory Guide 7.8. Table 2-8 provides an overview of the performance evaluations reported in each load combination subsection. Each subsection provides the limiting structural analysis result for the affected cask component(s) in comparison to the established design criteria. This comparison permits the minimum margin of safety for a given component subjected to a given loading condition to be readily identified. In all cases, the acceptability of the NUHOMS®-MP197 packaging design with respect to established criteria, and consequently with respect to 10CFR71 performance standards is demonstrated.

The structural analysis of the cask body is presented in Appendix 2.10.1 and covers a wide range of individual loading conditions. The stress results from the various individual loads must be combined in order to represent the stress condition in the cask body under the specified condition evaluated in this section. An explanation of the reporting format used for the results, and the stress combination technique used in applying the results from Appendix 2.10.1 is provided here.

Reporting Method for Cask Body Stresses

Appendix 2.10.1 provides the detailed description of the structural analyses of the NUHOMS®-MP197 cask body. That appendix describes the detailed ANSYS model used to analyze various applied loads. Table 2-9 identifies the individual loads analyzed which are applicable to normal conditions of transport. Some of these individual loads are axisymmetric (e.g. pressure) and others are asymmetric (e.g. gravity). Due to the nonlinearities associated with contact elements, it is not possible to run the separate individual load cases and then combine the results by superposition. Rather, it's necessary to run each of the individual load cases or combined load cases independently and post process the results separately. Table 2-10 identifies the combined load cases for the normal condition of transport. A total of 26 separate loading conditions (individual and combined load cases) are executed.

A. Individual load conditions: Runs 1-12, see Table 2-9. The stress results are presented in Table 2.10.1-4 to 2.10.1-15. Some of the stress results from these runs will be used for fatigue analysis.

B. Load combinations for normal conditions of transport: Runs 13-26, see Table 2-10. The stress results are presented in Table 2.10.1-16 to 2.10.1-29.

Figure 2-4 shows the selected locations on the cask body numbered 1 through 35 where stress results for these analyses are reported. Detailed stresses are available at as many locations as there are nodes in the finite element model. However, for practical considerations, the reporting of stress results is limited to those locations shown on Figures 2-4. These locations were selected to be representative of the stress distribution in the cask body with special attention given to areas subject to high stresses. The maximum stress may occur at a different location for each individual load.

Several other items should be noted. In the NUHOMS®-MP197 cask body, thermal stresses occur due to the effects of differential thermal expansion between the inner shell, lead, and outer shell. These thermal stresses are conservatively treated as primary stresses. The combined stresses due to primary loads (like pressure) and differential expansion (such as heating from 70°F to hot thermal conditions) are also evaluated as primary stresses.

For the axisymmetric cases, the stress is constant around the circumference of the cask at each stress reporting location. The load cases, where there are significant differences in stress magnitudes at different orientations of the cask (usually contact side and side away from contact for an asymmetric impact load), are reported in separate columns.

For the increased external pressure load combination, it is assumed that the NUHOMS®-MP197 cask cavity is at 0 psia. Since the specified load combination condition is 20 psia, the net differential pressure acting on the cask body is 20 psi. However, for conservatism, a 25 psi external pressure is used for the load combinations.

2.6.1 Heat

Chapter Three describes the thermal analyses performed for the NUHOMS®-MP197 package subjected to hot environment conditions. These thermal analysis results are used to support various aspects of the structural evaluations as described in the following subsections.

2.6.1.1 Maximum Temperatures

Allowable Stresses for packaging components are a function of the component temperatures. They are based on actual maximum calculated temperatures or conservatively selected higher temperatures. Table 3-1 of Chapter Three summarizes significant temperatures calculated for the NUHOMS®-MP197 subjected to hot environment conditions. These temperatures are used to establish the allowable stress values for every normal and accident (except the thermal accident, which has higher temperatures) load combination evaluated in this Safety Analysis Report.

2.6.1.2 Maximum Pressure

The thermal analysis presented in Chapter Three also provides the average cavity gas temperature (276°F) under hot environment conditions. This value is used in Chapter Four (Containment) to determine the Maximum Normal Operating Pressure (MNOP). Calculation of MNOP includes cavity gas heating effects and the assumption that 1% of the fuel rods fail while in the loaded cask. The resulting calculated MNOP is 7.9 psig. For the purpose of the structural analysis of containment a value of 50 psig is conservatively assumed. Because of the thick walled construction of the NUHOMS®-MP197 containment vessel, this pressure loading provides a minimal contribution to calculated stress intensities. This pressure loading is analyzed using ANSYS as described in Appendix 2.10.1. The results using the 3D ANSYS model are reported in Tables 2.10.1-5 of Appendix 2.10.1.

2.6.1.3 Thermal Stresses

The thermal analysis of the NUHOMS®-MP197 Packaging, described in Chapter Three, is performed using a 3D ANSYS model. The temperature distribution from this analysis is used to perform an ANSYS structural thermal stress analysis of containment vessel with stress results reported at the standard locations shown in Figure 2-4. The stress results for this load case are reported in Table 2.10.1-7 of Appendix 2.10.1.

2.6.1.4 Containment Vessel Stresses - Hot Environment

Containment vessel stresses for the hot environment normal condition of transport are obtained from a combined load case (run # 13) as indicated in Table 2-10. For this condition it is assumed that the cask is in its normal transport configuration, mounted horizontally on the transport skid, and supported by the saddles and tie down straps. The combined loads included in the run are as follows:

- Bolt Preload
- Gravity (1G Down)
- 50 psig Internal pressure
- Thermal hot

The stress results for this load case are reported on Table 2.10.1-16 of Appendix 2.10.1.

2.6.2 Cold Environment

The Regulatory Guide 7.8 [6] cold environment load combination results in all cask components in thermal equilibrium at –40°F. As with hot environment, for this condition it is assumed that the cask is in its normal transport configuration, mounted horizontally on the transport skid, and supported by the saddles and tie down straps. The combined loads included in the run are as follows:

- Bolt Preload
- Gravity (1G Down)
- 25 psig External Pressure
- -40°F Thermal Uniform

The stress results for this load case are reported on Table 2.10.1-17 of Appendix 2.10.1.

2.6.3 Reduced External Pressure

Containment vessel stresses for the 3.5 psia ambient normal condition of transport are obtained from a combined load case (run # 16) as indicated in Table 2-10. The conservatively assumed MNOP of 7.9 psig results in a net pressure loading of 19.1psig (7.9 + 14.7 – 3.5) (cask stresses are conservatively calculated based on 50 psi pressure). For this condition it is assumed that the cask is in its normal transport configuration, mounted horizontally on the transport skid, and supported by the saddles and tie down straps. The combined loads included in the run are as follows:

- Bolt Preload
- Gravity (1G Down)
- 50 psig Internal pressure
- 100°FThermal hot

The stress results for this load case are reported on Table 2.10.1-19 of Appendix 2.10.1.

2.6.4 Increased External Pressure

Containment vessel stresses for the 20 psia ambient normal condition of transport are obtained from a combined load case (run # 15) as indicated in Table 2-10. This load combination is similar to the cold environment load combination with the exception of the pressure loading. The conservatively assumed minimum cask cavity pressure of 0 psia results in a net external pressure loading of 20 psi (25 psi is conservatively used). For this condition, the cask is in the horizontal orientation mounted on the transport skid, and supported by the saddles and tie down straps. The combined loads included in the run are as follows:

- Bolt Preload
- Gravity (1G Down)
- 25 psig External Pressure
- -20°F Thermal Cold

The stress results for this load case are reported on Table 2.10.1-18 of Appendix 2.10.1.

2.6.5 Transport Shock Loading

Transport By Rail

The transport rail shock loading used to evaluate the NUHOMS®-MP197 cask are based on NUREG 766510 [24] which specifies a maximum inertia loading of 4.7G in each of the three x-y-z coordinate directions:

Vertical	4.7G
Longitudinal	4.7G
Lateral	4.7G

The resultant transverse load is $(4.7^2 + 4.7^2)^{1/2} = 6.65$ G

The stresses due to the transport rail shock load case are obtained from a combined load case (run #s 19 and 20) as indicated in Table 2-10. Table 2.10.1-22 lists the combined stresses under hot thermal conditions where the load combination is performed for the maximum temperature thermal stresses. Lid bolt pre-load, internal pressure, and the thermal effects are included.

In addition, Table 2.10.1-23 lists the combined stresses under –20°F thermal conditions where the load combination is performed for the –20°F thermal stresses. Lid bolt pre-load, external pressure, and the thermal effects are also included.

Transport By Truck

The transport truck shock loading used to evaluate the NUHOMS®-MP197 cask are based on truck bed accelerations in ANSI N14.23 [23] which are :

Vertical	3.5G
Longitudinal	2.3G
Lateral	1.6G

The resultant transverse load is $(3.5^2 + 1.6^2)^{1/2} = 3.85$ G

The truck shock loadings are less than the rail car shock loadings, therefore, the rail car shock loadings are used for structural analysis of the cask body.

2.6.6 Transport Vibration Loading

Transport By Rail

The input loading conditions used to evaluate the NUHOMS®-MP197 cask for transport rail vibration are obtained from NUREG 766510. The peak inertia values used are:

Vertical	0.37G
Longitudinal	0.19G
Lateral	0.19G

The resultant transverse load is $(0.37^2 + 0.19^2)^{1/2} = 0.416$ G

The stresses due to the transport rail vibration load case are obtained from a combined load case (run # 17 And 18) as indicated in Table 2-10. Table 2.10.1-20 lists the combined stresses under hot thermal conditions where the load combination is performed for the maximum temperature thermal stresses. Lid bolt pre-load, internal pressure, and the thermal effects are included.

In addition, Table 2.10.1-21 lists the combined stresses under –20°F thermal conditions where the load combination is performed for the –20°F thermal stresses. Lid bolt pre-load, external pressure, and the thermal effects are included.

Transport By Truck

The input loading conditions used to evaluate the NUHOMS®-MP197 cask for truck transport vibration are also obtained from truck bed accelerations in ANSI N14.23 [23]. The peak inertia values used are:

Vertical	0.60G
Longitudinal	0.30G
Lateral	0.30G

The resultant transverse load is $(0.6^2 + 0.3^2)^{1/2} = 0.67$ G

Since vibration accelerations are higher on a truck than on a rail car, the truck vibration loads are considered bounding. The maximum stress intensity generated by truck vibration is computed by extrapolating from the maximum stress intensity obtained in the railcar vibration load case. The truck vibration load is roughly 160% of the railcar vibration load. The maximum stress intensity in the NUHOMS®-MP197 cask due to railcar vibration is 7.06 ksi (Table 2.10.1-11, location 5). Therefore the maximum stress intensity in the NUHOMS®-MP197 cask due to truck vibration would be roughly 11.3 ksi, this stress is used for containment fatigue analysis.

2.6.7 Water Spray

All exterior surfaces of the NUHOMS®-MP197 cask body are metal and therefore not subject to soaking or structural degradation from water absorption. The water spray condition is therefore of no consequence to the NUHOMS®-MP197 cask body.

2.6.8 Free Drop

Two drop orientations are considered credible for the one-foot free drop normal condition of transport. The structural response of the NUHOMS®-MP197 cask body is evaluated for a one-foot end drop of the package on the bottom end, one foot end drop of the package on the lid end, and a one-foot side drop. The assessment of cask body stresses follows the same logic as that established in the previous sections. For the three drop cases, the evaluations are performed for both the high temperature environment and at the -20°F minimum transport temperature.

The load combinations performed to evaluate these drop events are indicated in Table 2-10. In all cases, bolt pre-load effects and fabrication stress are included. For the hot environment condition, thermal stress load, 50 psi internal pressure, and impact load cases are combined. For the cold environment evaluation, -20°F thermal stress, 25 psi external pressure, and impact load cases are combined.

Table 2.10.1-24 lists the combined stress intensities for the lid end drop under hot environment conditions. Table 2.10.1-25 lists the combined stress for the lid end drop under cold environment conditions

Table 2.10.1-26 lists the combined stress intensities for the bottom end drop under hot environment conditions. Table 2.10.1-27 lists the combined stress for the bottom end drop under cold environment conditions.

Table 2.10.1-28 lists the combined stress intensities for the side drop under hot environment conditions. Table 2.10.1-29 lists the combined stress for the side drop under cold environment conditions.

2.6.9 Corner Drop

This test does not apply to the NUHOMS®-MP197 Package since the package weight is in excess of 100 kg (220 lbs.).

2.6.10 Compression

This test does not apply to the NUHOMS®-MP197 Package since the package weight is in excess of 5,000 kg (11,000 lbs.).

2.6.11 Penetration

Due to lack of sensitive external protuberances, the one meter (40 in.) drop of a 13 pound steel cylinder of 1-1/4 inch diameter, with a hemispherical head, is of negligible consequence to the NUHOMS®-MP197 Package.

2.6.12 Fabrication Stresses

The NUHOMS®-MP197 cask is subjected to stresses during the lead pouring process and subsequent cool down. These stresses relax over time and do not add significantly to the cask stresses due to normal operating conditions.

The primary concern during lead pouring and cool down is buckling of the containment vessel. A detail evaluation of this event is shown in Section 2.10.1.5.

From the results of that analyses, it is concluded that the cask fabrication stresses due to the molten lead pouring process and subsequent freezing to room temperature are small. The differential contraction induced stresses, during the –40° F normal condition, are negligible. Further, the fabrication stresses remaining in the cask components at the time the cask will be used for transportation will be insignificant.

2.6.13 Lid Bolt Analysis

The lid bolts are analyzed for both normal and accident condition loadings in Appendix 2.10.2. The analysis is based on NUREG/CR-6007 [25]. The bolts are analyzed for the following normal and accident loading conditions: operating pre-load, gasket seating load, internal pressure, temperature changes, impact loads, and puncture loads.

The bolt preload is calculated to withstand the worst case load combination and to maintain a clamping (compressive) force on the closure joint, under both normal and accident conditions. Based upon the load combination results (see Appendix 2.10.2, Section 2.10.2.3), it is shown that a positive (compressive) load is maintained on the clamped joint for all load combinations. Therefore, in both normal and accident load cases, the maximum non-prying tensile force of 110,000 lb. from preload + temperature load is used for bolt stress calculations.

A summary of the calculated stresses is listed in the Appendix 2.10.2, Section 2.10.2.5. The calculations result in a maximum average tensile stress of 86.0 ksi, which is below the allowable tensile stress of 95.6 ksi. The maximum average shear stress in the bolts is due to torsion during pre-loading. This stress is 19.3 ksi, which is well below the allowable shear stress of 57.4 ksi. The maximum combined stress intensity due to tension plus shear plus bending is 121.5 ksi., which is also less than the maximum allowable stress intensity of 129.1 ksi.

The lid bolt fatigue analysis is also presented in Appendix 2.10.2. This analysis shows that the bolts should be replaced after approximately 85 shipments. This is primarily due to the pre-load stresses.

2.6.14 Fatigue Analysis of the Containment Boundary

The purpose of the fatigue analysis is to show that the containment vessel stresses are within acceptable limits under normal transport conditions. This is done by determining the fatigue damage factor for each normal transport event at locations on the containment vessel with the highest stresses. The cumulative fatigue damage or usage factor for all of the events is conservatively determined by adding the fatigue usage factors for the individual events, assuming these maximum stress intensities occur at the same location.

The fatigue analysis is based on the procedure described in Regulatory Guide 7.6 and ASME Code Section III [7]. When determining the stress cycles, consideration is given to the superposition of individual loads which can occur together and produce a total stress intensity range greater than the stress intensity range of individual loads. Also, the maximum stress intensities for all individual loads are conservatively combined simultaneously. The following sequence of events was assumed for the fatigue evaluation. The fatigue evaluation is based on 1000 shipments.

1. Operating bolt preload
2. Test pressure
3. Road shock/vibration
4. Pressure and temperature fluctuations
5. 1 foot normal condition drop

Bolt Preload

Assuming that the bolt torque is applied twice every round trip, the number of preload cycle is two times the number trips 2 × 1,000, or 2,000 cyles.

The maximum stress intensity in the NUHOMS®-MP197 cask due to bolt preload is 4,310 psi (Table 2.10.1-4, location 5).

Test Pressure

The proof test is 1.25 × (maximum design pressure, 50 psi.) = 62.5 psi, and will only be performed once. The test pressure loads are calculated using the pressure loads computed in Appendix 2.10.1, Table 2.10.1-5. Table 2.10.1-5 lists the stresses based on 50 psi internal pressure. The maximum stress occurs in the containment vessel is 4,940 psi, and occurs at location 5. Therefore, the maximum stress due to 62.5 psi test pressure is 4,940 × 1.25 = 6,175 psi.

Shock

The NUHOMS®-MP197 cask may be shipped either by truck or by railcar. ANSI N14.23 specifies a peak shock loading of 1.8 *g* longitudinal, 1.1g lateral, 2g vertical up, and 1.5g vertical down, for truck transport, while NUREG 766510 [24] specifies a peak shock loading of 4.7 *g*s in all directions for rail car transport. Consequently, only the inertial loading caused by a railcar shock is considered, since it is bounding.

Assume 1000 round trip shipments, averaging 3,000 miles each way. NUREG 766510 reports that there are roughly 9 shock cycles per 100 miles of rail car transport. Therefore the total number of cycles is 3,000 (miles) × 2 (round trip) × 1,000 (shipments) × 0.09 (Shocks per mile) = 540,000 cycles.

The maximum stress intensity in the NUHOMS®-MP197 cask due to railcar shock is 12,710 psi. (Table 2.10.1-10, location 1).

Vibration

Since vibration accelerations are higher on a truck than on a rail car, the truck vibration loads are considered bounding. According to ANSI N14.23, the peak vibration load at the bed of a truck is 0.3*g* longitudinal, 0.3*g* transverse, and 0.6*g* vertical. The maximum stress intensity generated by truck vibration is computed by extrapolating from the maximum stress intensity obtained in the railcar vibration load case. The NUREG 766510 specifies a peak vibration loading of railcar is 0.19*g* longitudinal, 0.19*g* transverse, and 0.37*g* vertical. Therefore the truck vibration load is roughly 160% of the railcar vibration load. The maximum stress intensity in the NUHOMS®-MP197 cask due to railcar vibration is 7,060 psi. (Table 2.10.1-11). Therefore the maximum stress intensity in the NUHOMS®-MP197 cask due to truck vibration would be roughly 11,296 psi.

The transport vibration inertia loading assumed for the containment vessel stress analysis was obtained from NUREG 766510. Data from that reference indicates that the vibration loading occurs over a frequency range of 30-45 cps. Using the upper bound frequency of 45 cps and based on an average speed of 40 mph for the 2000 one-way trips, the total number of vibration cycles is:

$$n = 2{,}000 \text{ trips} \times (3{,}000 \text{ miles/40 mph}) \times 3{,}600 \text{ sec/hr.} \times 45\text{cps} = 24.4\times10^9$$

Pressure Fluctuations

Assuming the temperature cycle occurs once each one way shipment, the total number of temperature fluctuation cycles is 2,000.

The maximum stress intensity in the NUHOMS®-MP197 cask due to normal condition pressure loads is 4,940 psi. (Table 2.10.1-5, location 5)

Temperature Fluctuations

Assuming the temperature cycle occurs once each one way shipment, the total number of temperature fluctuation cycles is 2,000.

The maximum stress intensity in the NUHOMS®-MP197 cask due to normal condition thermal loads occurs in the 100° F ambient load case, and is 17,190 psi. (2.10.1-7, location 20).

1 Foot Normal Condition Drop

Conservatively assume that the cask is dropped once per shipment, resulting in 1,000 normal condition drops.

The maximum stress intensity in the NUHOMS®-MP197 cask due to normal condition inpact loads occurs in the 1 foot side drop load case, and is 24,160 psi. (Table 2.10.1-14, location 14).

NUHOMS®-MP197 cask Fatigue Evaluation – Usage Factor Calculation

The following damage factors are computed based on the stresses and cyclic histories described above, and the fatigue curves shown in Figures I-9.2.1 and I-9.2.2 of ASME Section III Appendices. Since the model used for stress analysis of the NUHOMS®-MP197 cask includes detailed meshing of corners and bolt holes, the fatigue strength reduction factor, K_F, which accounts for stress concentrations, is already accounted for in the stresses reported above. However, for conservatism, a strength reduction factor of 2 is used. The value of the alternating stress, S_a, is determined as follows:

If one cycle goes from 0 to S.I:

$$S_a = \text{S.I.} \times K_F \times K_E / 2$$

If one cycle goes from –S.I. to S.I:

$$S_a = \text{S.I.} \times K_F \times K_E$$

Where,

K_F = fatigue strength reduction factor, 2

K_E = correction factor for modulus of elasticity.

The NUHOMS®-MP197 cask containment boundary is constructed from SA-240, Type XM-19, and SA-693, Type 630. The modulus of elasticity of SA-240, Type XM-19 is 27.0×10^6 psi. @ 300° F, and the modulus of elasticity of SA-693, Type 630 is 27.2×10^6 psi. @ 300° F. Therefore, the modulus of elasticity of SA-240, Type XM-19 is conservatively used, since it yields the higher value of K_E. Consequently, $K_E = 28.3 \times 10^6 / 27.0 \times 10^6 = 1.0481$.

Event	Stress Intensity (psi.)	S.I. × K_F × K_E (psi.)	S_a (psi.)	Cycles		Damage Factor n/N
				n	N	
Bolt Preload	4,310	9,035	4,518	2,000	∞*	0.00
Pressure Test	6,175	12,944	6,472	1,000	∞*	0.00
Pressure Fluctuations	4,940	10,356	10,356	2,000	∞*	0.00
Temperature Fluctuations	17,190	36,034	36,034	2,000	2×10^5	0.01
Shock Load	12,710	26,644	26,644	540,000	2×10^6	0.27
Vibration Load	11,296	23,680	23,680	24.4×10^9	∞*	0.00
1 Foot Drop Impact Load	24,160	50,646	25,323	1,000	7×10^6	0.00
Σ						0.28

* The maximum stresses for these load cases occur in locations away from welds, and stresses in the weld locations are small. Therefore, Curve A in Figure I-9.2.2 is used.

The above table shows that the total damage factor is less than one. Therefore the fatigue effects on the NUHOMS®-MP197 containment vessel are acceptable.

A separate fatigue analysis of the lid bolts is presented in Appendix 2.10.2.

2.6.15 Summary of Normal Condition Cask Body Structural Analysis

The following table lists the highest stress intensities in the cask body and also identifies the load combination tables and locations where these maximum stresses occur. The stress limits based on the Section 2.1.2 structural design criteria are also listed in the table.

Comparison of the Maximum Stress Intensities with the Allowables
(Cask Body)

Component	Maximum Stress Intensity (ksi)	Stress Category (ksi)	Stress Result Table	Allowable Stress Intensity(1) (ksi)
Lid	18.31	$P_m + P_b$	2.10.1-22 Location 2	$P_m = 46.7$ $P_m + P_b = 70.05$
Upper Flange	27.99	$P_m + P_b$	2.10.1-29 Location 14	$P_m = 31.4$ $P_m + P_b = 47.1$
Inner Shell	17.94	$P_m + P_b$	2.10.1-22 Location 10	$P_m = 31.4$ $P_m + P_b = 47.1$
Outer Shell	18.43	$P_m + P_b$	2.10.1-29 Location 23	$P_m = 20.0$ $P_m + P_b = 30.0$
Bottom	26.07	$P_m + P_b$	2.10.1-28 Location 30	$P_m = 31.4$ $P_m + P_b = 47.1$

Note: 1. See Table 2-14 for cask body allowable stresses at different components.

From the analysis results presented in the above table, it can be shown that the normal loads will not result in any structural damage to the cask and that the containment function of the basket and fuel assembly will be maintained.

2.6.16 Structural Evaluation of the Basket/Canister under Normal Condition Loads

2.6.16.1 Basket Stress Analysis

The loading conditions considered in the evaluation of the fuel basket consist of inertial loads resulting from normal inertial loading (1foot drop), accident inertial loading (30 foot drop) and thermal loads. The inertial loads of significance for the basket analysis are those transverse to the cask and basket longitudinal axes, so that the loading from the fuel assemblies is applied normal to the basket plates and transferred to the cask wall by the basket.

To determine the structural adequacy of the basket plate in the NUHOMS®-61B BWR fuel assembly basket under a normal condition free drop, the basket is evaluated for a 30G end drop and a 30G side drop. The G loads and drop orientations used for the structural analysis of the basket are described in Appendix 2.10.8. The stress analysis of the basket due to inertial and thermal loads is described in detail in Appendix 2.10.3. The results of the analyses are summarized in the following table. Based on the results of these analyses, all the calculated stresses in the basket, rails, and hold down ring are within the allowable stress limits.

Therefore, the basket is structurally adequate and it will properly support and position the fuel assemblies under normal loading conditions.

Summary of Basket Normal Condition Stress Analysis

Drop Orientation	Component	Stress Category	Max. Stress Due to 1 foot drop (ksi)	Max. Thermal Stress (ksi)	Combined Stress (ksi)	Allowable Stress (ksi)
End Drop	Fuel Compartment & Outer Wrapper	P_m	2.7	-	2.7	16.40
		$P_m + P_b + Q$	2.7	12.95	15.65	49.20
	Plate Insert Weld	Shear	4.50	-	4.50	9.84
	Rail Stud	Shear	5.70	-	5.70	9.84
	Hold Down Ring	P_m	3.0	-	3.00	16.40
45° Side Drop	Basket	P_m	6.42	-	6.42	16.40
		$P_m + P_b$	22.72	-	22.72	24.60
		$P_m + P_b + Q$	29.85	12.95	42.80	49.20
	Rails	P_m	5.81	-	5.81	17.50
		$P_m + P_b$	19.19	-	19.19	26.25
		$P_m + P_b + Q$	22.22	1.76	23.98	52.50
60° Side Drop	Basket	P_m	8.14	-	8.14	16.40
		$P_m + P_b$	21.30	-	21.30	24.60
		$P_m + P_b + Q$	29.25	12.95	42.20	49.20
	Rails	P_m	9.49	-	9.49	17.50
		$P_m + P_b$	25.03	-	25.03	26.25
		$P_m + P_b + Q$	30.88	1.76	32.64	52.50
90° Side Drop	Basket	P_m	7.92	-	7.92	16.40
		$P_m + P_b$	13.75	-	13.75	24.60
		$P_m + P_b + Q$	13.75	8.80	22.55	49.20
	Rails	P_m	15.17	-	15.17	17.50
		$P_m + P_b$	26.11	-	26.11	26.25
		$P_m + P_b + Q$	26.11	1.76	27.87	52.50
180° Side Drop, Impact on support Rails	Basket	P_m	6.32	-	6.32	16.40
		$P_m + P_b$	11.98	-	11.98	24.60
		$P_m + P_b + Q$	11.98	8.80	20.78	49.20
	Rails	P_m	13.62	-	13.62	17.50
		$P_m + P_b$	18.24	-	18.24	26.25
		$P_m + P_b + Q$	18.24	1.76	20.00	52.50

2.6.16.2 Canister Stress Analysis

The loading conditions considered in the evaluation of the canister consist of inertial loads resulting from normal condition inertial loading (1foot drop), accident condition inertial loading (30 foot drop), 50 psig internal /external pressures and thermal loads. The inertial loads of significance for the canister analysis are those transverse to the cask and canister longitudinal axes, so that the loadings from the fuel assemblies and basket are transferred to the cask wall by the canister.

To determine the structural adequacy of the canister in the NUHOMS®-MP197 cask during a normal condition free drop, the canister is evaluated for 30G end drop and 30G side drop. The G loads and drop orientations used for structural analysis of the basket are described in Appendix 2.10.8. The stress analysis of the canister is described in detail in Appendix 2.10.3. The results of the analyses are summarized in the following table. Based on the results of these analyses, all the calculated stresses in the canister are within the allowable stresses.

Summary of Canister Normal Condition Stress Analysis

Load Combination		Stress Category	Maximum Stress (ksi.)	Allowable Membrane Stress Intensity (ksi.)
30*g* Front End Drop	External Pressure, Cold Environment	$P_m + P_b$	9.2	18.7*
	Internal Pressure, Hot Environment	$P_m + P_b$	9.0	18.7*
30*g* Rear End Drop	External Pressure, Cold Environment	$P_m + P_b$	11.6	18.7*
	Internal Pressure, Hot Environment	$P_m + P_b$	10.3	18.7*
45° Azimuth 30g Side Drop	External Pressure, Cold Environment	P_m	6.2	18.7
		$P_m + P_b$	15.1	28.1
	Internal Pressure, Hot Environment	P_m	11.4	18.7
		$P_m + P_b$	20.4	28.1
60° Azimuth 30g Side Drop	External Pressure, Cold Environment	P_m	6.4	18.7
		$P_m + P_b$	19.3	28.1
	Internal Pressure, Hot Environment	P_m	11.6	18.7
		$P_m + P_b$	24.6	28.1
90° Azimuth 30g Side Drop	External Pressure, Cold Environment	P_m	6.6	18.7
		$P_m + P_b$	12.4	28.1
	Internal Pressure, Hot Environment	P_m	11.8	18.7
		$P_m + P_b$	17.7	28.1
180° Azimuth 30g Side Drop	External Pressure, Cold Environment	P_m	7.2	18.7
		$P_m + P_b$	15.0	28.1
	Internal Pressure, Hot Environment	P_m	12.5	18.7
		$P_m + P_b$	20.2	28.1

*The stress intensities (membrane + bending) generated in the canister during the end drop events are conservatively compared with the membrane allowable stress, P_m for SA-240, Type 304.

2.7 HYPOTHETICAL ACCIDENT CONDITIONS

Overview

This section describes the response of the NUHOMS®-MP197 package to the accident loading conditions specified by 10CFR71.73. The design criteria established for the NUHOMS®-MP197 Packaging for the hypothetical accident conditions are described in Section 2.1.2. These criteria are selected to ensure that the packaging performance standards specified by 10CFR71.51 are satisfied.

The presentation of the hypothetical accident condition analyses and results is accomplished in the same manner as that used for the normal condition analysis. Table 2-11 provides an overview of the performance evaluations presented in this section. The detailed analyses of the various packaging components under different loading conditions are presented in the Appendices to this Chapter. The limiting results for the specified hypothetical accident loading conditions are taken from the Appendices and summarized here along with a comparison made to the established design criteria. In all cases, the acceptability of the NUHOMS®-MP197 packaging design with respect to hypothetical accident loads is demonstrated.

Drop Testing of the 1/3 scale impact limiters and test body was performed. The results of the testing in presented in Appendix 2.10.9. In addition, an analytical evaluation of the impact limiters is also presented in Appendix 2.10.8. The test and analytical results presented in Appendix 2.10.9 and 2.10.8 are used to determine the *g* loads used in the cask and basket structural evaluations.

Reporting Method for Containment Vessel Stresses

Appendix 2.10.1 provides the detailed description of the structural analyses of the NUHOMS®-MP197 cask body. That appendix describes the detailed ANSYS model used to analyze various applied loads. Due to the nonlinearities associated with contact elements, it is not possible to run the separate individual load cases and then combine the results by superposition. Rather, it's necessary to run each of the combined load cases independently and post process the results separately. Table 2-11 provides a matrix of the individual loads and how they are combined to determine the cask body stresses for the hypothetical accident conditions. The thermal stresses due to the hot and cold conditions are actually secondary stresses that could be evaluated using higher allowables than for primary stresses. They are conservatively added to the primary stresses, and the combined stresses are evaluated using the primary stress allowables.
A total of 16 separate loading conditions (combined load cases) are executed.

The load combinations for accident conditions of transport were performed in Runs 27 - 42, as shown in Table 2-11. The stress results are presented in Table 2.10.1- 30 to 2.10.1- 45.

Figure 2-4 shows the selected locations on the cask body numbered 1 through 35 where stress results for these analyses are reported. Detailed stresses are available at as many locations as there are nodes in the finite element model. However, for practical considerations, the reporting of stress results is limited to those locations shown on Figures 2-4. These locations were selected to be representative of the stress distribution in the cask body with special attention given to areas subject to high stresses. The maximum stress may occur at a different location for each individual load.

For the axisymmetric cases, the stress is constant around the circumference of the cask at each stress reporting location. The load cases, where there are significant differences in stress magnitudes at different orientations of the cask (usually contact side and side away from contact for a asymmetric impact loads), are reported in separate columns of the table.

2.7.1 30 Foot Free Drop

The response of the NUHOMS®-MP197 Packaging is evaluated for a free drop from a height of 30 feet onto an unyielding surface at various orientations. The inertial loading applied to the NUHOMS®-MP197 components is determined in the dynamic analysis presented in Appendix 2.10.8. The 30 foot drop is measured from the impact surface to the bottom of the impact limiter; the C.G. of the cask is much higher than 30 feet.

The stresses in the cask body are reported for the following drop orientations:

- End drop onto bottom end
- End drop onto lid end
- Side drop
- C. G. over corner drop on bottom end
- C. G. over corner drop on lid end
- 20° slap down impact on lid end
- 20° slap down impact on bottom end

2.7.1.1 End Drop

The dynamic impact analysis of the NUHOMS®-MP197 packaging shows that the maximum expected inertia loading from the 30-foot end drop is 50 g's. Because of the symmetry of the cask and impact limiters, these values are applicable for both the bottom end drop and lid end drop.

The structural analysis of the cask body for these loading conditions was conservatively performed using an inertial loading of 75g. The load combinations performed to evaluate these drop events are indicated in Table 2-11. In all cases, bolt pre-load stresses are included. For the hot environment condition, 100° F thermal stress, 50 psi internal pressure, and impact load cases are combined. For the cold environment evaluation, -20°F thermal stress, 25 psi external pressure, and impact load cases are combined.

Table 2.10.1-30 lists the combined stress intensities for the bottom end drop under hot environment conditions. Table 2.10.1-31 lists the combined stress for the bottom end drop under -20°F cold environment conditions.

Table 2.10.1-32 lists the combined stress intensities for the lid end drop under hot environment conditions. Table 2.10.1-33 lists the combined stress for the lid end drop under -20°F cold environment conditions.

2.7.1.2 Side Drop

The dynamic analysis of the 30-foot side drop provided a maximum expected inertial loading of 60 g (Appendix 2.10.8). The structural analysis of the cask body for this loading condition was conservatively performed using an inertial loading of 75g. The load combinations performed to evaluate these drop events are indicated in Table 2-11. In all cases, bolt pre-load stresses are included. For the hot environment condition, 100° F thermal stress, 50 psi internal pressure, and impact load cases are combined. For the cold environment evaluation, -20°F thermal stress, 25 psi external pressure, and impact load cases are combined.

Table 2.10.1-34 lists the combined stress intensities for the side drop (contact side and 90° away from contact side) under hot environment conditions.

Table 2.10.1-35 lists the combined stress intensities for the side drop (contact side and 90° away from contact side) under -20°F cold environment conditions.

2.7.1.3 C.G. Over Corner Drop

The response of the NUHOMS®-MP197 package to the 30-foot corner drops was analyzed for impact on the bottom and lid ends. The analyses were performed using the ANSYS model described in Appendix 2.10.1. The C.G. over corner drop occurs at a drop angle of approximately 60°. That is, the longitudinal axis of the containment vessel is at an angle of 60° from the impact surface. The dynamic analysis (Appendix 2.10.8) of the 60° drop orientation calculated maximum inertia loadings of 34g (axial) along the cask longitudinal axis and 12g transverse to the longitudinal axis. The ANSYS analysis of the C.G. over corner drop was conservatively performed using a higher axial inertia loading of 45g and higher transverse inertia loading of 16g.

The load combinations performed to evaluate these two drop events are indicated in Table 2-11. In all cases, bolt pre-load stresses are included. For the hot environment condition, 100° F thermal stress, 50 psi internal pressure, and impact load cases are combined. For the cold environment evaluation, -20°F thermal stress, 25 psi external pressure, and impact load cases are combined.

Table 2.10.1-36 lists the combined stress intensities for the C.G. over corner bottom end drop (contact side and 90° away from contact side) under hot environment conditions. Table 2.10.1-37 also list the combined stress intensities for the C.G. over corner bottom end drop (contact side and 90° away from contact side) under hot environment conditions.

Table 2.10.1-38 lists the combined stress intensities for the C.G. over corner lid end drop (contact side and 90° away from contact side) under -20°F cold environment conditions. Table

2.10.1-39 lists the combined stress intensities for the C.G. over corner lid end drop (contact side and 90° away from contact side) under -20°F cold environment conditions.

2.7.1.4 20° Slap Down Impact

The limiting oblique drop for the containment vessel occurs at a drop angle of 20°. Based on the dynamic impact analysis, this drop orientation is limiting because it results in the highest impact force and total inertial loads over the full length of the containment vessel. The 20° slap down impact has a maximum combined transverse inertia load of 133g (G_{normal} = 53, $G_{rotational}$ = 80) at the package end which first contacts the target (Appendix 2.10.8). The simultaneous inertia load at the opposite end is 28g, and the average value which corresponds to that at the center of gravity is 53 g. The stress analysis of the cask body was performed using the ANSYS model as described in Appendix 2.10.1. The maximum normal and rotational accelerations are conservatively increased to 66G and 198G, respectively for the ANSYS analysis.

The load combinations performed to evaluate this drop event are indicated in Table 2-11. In all cases, bolt pre-load stresses are included. For the hot environment condition, 100° F thermal stress, 50 psi internal pressure, and impact load cases are combined. For the cold environment evaluation, -20°F thermal stress, the 25 psi external pressure, and impact load cases are combined.

Table 2.10.1-40 lists the combined stress intensities for the 20° oblique impact on lid end (contact side and 90° away from impact side) under hot environment conditions. Table 2.10.1-41 lists the combined stress intensities for the 20° oblique impact on lid end (contact side and 90° away from impact side) under -20°F cold environment conditions.

Table 2.10.1-42 lists the combined stress intensities for the 20° oblique impact on bottom end (contact side and 90° away from impact side) under hot environment conditions. Table 2.10.1-43 lists the combined stress intensities for the 20° oblique impact on bottom end (contact side and 90° away from impact side) under -20°F cold environment conditions.

2.7.1.5 Lid Bolts

The lid bolts are analyzed for normal and accident condition loadings in Appendix 2.10.2. The analysis is based on NUREG/CR-6007 [25]. The bolts are analyzed for the following normal and accident conditions: operating pre-load, gasket seating load, internal pressure, temperature changes, impact loads, and puncture loads.

The bolt preload is calculated to withstand the worst case load combination and to maintain a clamping (compressive) force on the closure joint, both under normal and accident conditions. Based upon the load combination results (see Appendix 2.10.2, Section 2.10.2.3), it is shown that a positive (compressive) load is maintained on the clamped joint for all load combinations. Therefore, in both normal and accident load cases, the maximum non-prying tensile force of 110,000 lbs from preload + temperature load is used for bolt stress calculations.

A summary of the calculated stresses is listed in Appendix 2.10.2, Section 2.10.2.5. The maximum average tensile stress is 86.0 ksi, which is below the allowable tensile stress of 115.5 ksi. The average shear stress in the bolts is due to torsion during pre-loading. This stress is 19.3 ksi, which is well below the allowable shear stress of 69.3 ksi.

2.7.1.6 Impact Limiter Attachments

The impact limiters must remain attached to the cask body before, during, and after each hypothetical accident drop condition.

The limiting loading condition for the impact limiter attachments is the secondary impact (slap-down) associated with the 20° slap down 30-foot drop. This loading condition applies the greatest overturning moment on to the impact limiter and cask body interface. Although this loading condition is not limiting with respect to any other cask component, an evaluation of the attachments is performed to demonstrate that the effected impact limiter remains in place to insulate the cask during the subsequent hypothetical thermal accident.

The analysis and results, summarized here, are provided in detail in Section 2.10.8.6 of Appendix 2.10.8.

The analysis concludes that the impact limiter attachment design is sufficiently strong to ensure that the impact limiters remain attached to the cask body during and following all hypothetical accident conditions.

2.7.1.7 Cask Lead Slump analysis

In the event of a cask drop, permanent deformation of the lead gamma shield may result for certain impact orientations. The lead gamma shield is supported by friction between the lead and cask shells, in addition to bearing at end of the lead column. In order to determine the amount of permanent lead slump for the postulated end drop, an elastic-plastic analysis is required. The detailed lead slump analysis using a finite element model is described in detail in Appendix 2.10.4.

The following table summarizes the lead slump cavity length for all four load combinations analyzed. Nodal displacement distributions for the four load combinations are shown Figures 2.10.4-3 through 2.10.4-6.

Load Combination	Lead Slump Cavity Length
75*g* Lid End Drop, Hot Environment	0 in.
75*g* Lid End Drop, Cold Environment	0.235 in.
75*g* Bottom End Drop, Hot Environment	0 in.
75*g* Bottom End Drop, Cold Environment	0.107 in.

The table above shows that the maximum longitudinal cavity length, caused by lead slump, is 0.235 inches, and occurs during the accident condition lid end drop, in the cold environment. The table above, as well as the displacement plots (Figures 2.10.4-3 through 2.10.4-6) also show that in the hot environment, differential thermal expansion between the lead shield and the structural shells precludes cavity formation during both lid and end drops. An upper bound lead slump of 3.5 inches is conservatively assumed for the post drop shielding evaluation in Chapter 5.

2.7.2 Puncture

An evaluation of the puncture drop event includes the local effects in the containment vessel at the impact point as well as the overall inertia loading on the packaging components.

2.7.2.1 Puncture Drop Impact on the Outer Cylindrical Shell

The impact limiters will protect the ends of the cask body from a 40-inch drop, onto a 6-inch diameter bar. Consequently, the most severe damage to the cask body, resulting from the puncture drop will occur on the outer cylindrical shell, between the impact limiters. Since this portion of the package is not the containment vessel, release of the contents cannot occur.

For this load condition it is conservatively assumed that the cask outer shell surface impacts the puncture bar directly (eliminated the neutron shield and stainless steel shield shell). The puncture bar as specified in 10CFR71, is a solid, vertical, cylindrical, mild steel bar, 6 inches in diameter.

Required Thickness

The required thickness, t_{req}, to preclude puncture is calculated using the Nelms[4] equation for lead backed shells, which is given by

$$t_{req} = \left[\frac{W}{S_u}\right]^{0.71}$$

Where, W is the weight of the package (265,100 lb.), S_u is the ultimate strength of the outer shell material (73,680 psi @ 263° F)

$$t_{req} = \left[\frac{265{,}100}{73{,}680}\right]^{0.71} = 2.48 \text{ in.}$$

The thickness of the outer shell is 2.5 in., which is greater than the required thickness computed above. Therefore, the outer shell will preclude penetration of the bar during the postulated puncture event. This analysis is conservative since the cask outer shell is protected by a neutron shield (4.5625" thick.) and a 3/16" thick stainless steel shield shell, so that the puncture bar will not directly impact the outer shell.

Stress Analysis

The maximum force, F_p, acting on the outer shell due to impact on the puncture bar is:

$$F_p = \sigma_s A_b$$

Where σ_s is the yield strength of the bar, 45 ksi (typical yield strength of the mild steel, such as SA-36, is 36 ksi), and A_b is the cross sectional area of the 6 inch diameter bar, 28.27 in.^{2}.

Therefore,

$$F_p = 1.272 \times 10^6 \text{ lb.}$$

This force produces a cask deceleration and induces a bending moment at the midsection of the cask. If the cask is considered a beam uniformly loaded (downward) by its inertial load and supported by the puncture bar at the center, the deceleration, g, caused by the puncture drop is then the following.

$$g = \frac{F_p}{W_{package}} = \frac{1.272 \times 10^6}{265{,}100} = 4.8$$

Here, $W_{package}$ is the weight of the NUHOMS®-MP197 transport package. If the cask body is considered to be uniformly loaded and supported as described above, then the maximum moment, M, in the cask shell is:

$$M = \frac{F_p L}{8} = \frac{(1.272 \times 10^6)(208.0)}{8} = 3.307 \times 10^7 \text{ in. lb.}$$

Conservatively neglecting the inner shell, lead, neutron shield, and shield shell, the moment of inertia of the cask outer shell is:

$$I = \frac{\pi}{4}\left(r_o^4 - r_i^4\right) = \frac{\pi}{4}\left(41.00^4 - 38.50^4\right) = 4.938 \times 10^5 \text{in.}^4$$

The shell bending stress is then:

$$\sigma_b = \frac{M r_0}{I} = \frac{(3.307 \times 10^7)(41.00)}{4.938 \times 10^5} = 2{,}746 \text{ psi.}$$

Since the stress is nearly constant through the wall thickness, it should be treated as a membrane stress, P_m. The allowable stress for this accident condition is $2.4S_m$ (smaller of $0.7S_u$ or $2.4S_m$, Appendix F-1331.1) or 2.4(20,000) = 48,000 psi (S_m for SA-240 Type 316 = 20.0 ksi. @ 263° F), which is well above σ_b.

The deceleration of 4.8 gs is small compared to the g-loads that will occur during the 30-foot free drop. Therefore, the global stresses that result from the inertial forces are bounded by those of the 30-foot free drop event, and can be neglected in the load combinations. The bending stress of 2,746 psi at the center of the cask is also negligible compared to stresses due to other loads considered.

2.7.2.2 Puncture Drop Impacting the Lid End and Bottom Ram Port Cover

The impact limiters will protect the ends of the cask body from a 40-inch drop, onto a 6-inch diameter bar. However, for these load conditions it is conservatively assumed that the cask lid and bottom ram port cover outer surfaces impact the puncture bar directly. No credit is taken for the energy absorption provided by the impact limiter.

The stresses in the cask lid and bottom ram cover closure are evaluated using an 2D ANSYS finite element analysis of the containment vessel as described in Appendix 2.10.1 (Section 2.10.1.2). The elastic analysis was performed by applying static forces corresponding to a 6*g* inertial loading (actual g load is 4.8 as calculated in Section 2.7.2.1). The reaction force due to the puncture bar is applied to the center of the lid or bottom ram port cover in order to maximize the resulting bending stresses. Figures 2-5 and 2-6 illustrate the loading conditions. The results of the two puncture analysis cases are reported in the same manner as that used for the previously described containment vessel ANSYS analyses. Tables 2-12 and 2-13 list the stress intensities for the 40 inch puncture on the lid and ram port cover respectively. All the calculated stresses are less than the code allowables.

To investigate the seal status during the impact event, the contact elements at the seal location are examined. All contact elements located near the lid and bottom ram port cover seals remained closed for both puncture drop load cases. It is concluded that during the 40 inch puncture events, positive (compressive) loads are maintained at the lid closure and ram port cover seals.

2.7.2.3 Puncture Drop Impacting Other Penetration Covers

An evaluation of the local effects of a puncture impact on the remaining penetration ports was also performed. Following table summarizes the key parameters in this evaluation.

Penetration	Containment Boundary	Max. Diameter of Penentration
Vent Port (Lid)	Yes	3 in.
Test Port (Lid)	No	3 in.
Test Port (Bottom Ram Cover Closure)	No	3 in.
Drain Port (Bottom Plate)	Yes	3 in.

All the penetrations are protected by the impact limiters. The maximum diameter of the penetrations is 3 inches which is less than the 6 inch diameter puncture bar. Therefore the shear area available to resist the puncture bar loading includes the wall thickness of the outer shell at these locations. Since the penetrations are covered by the impact limiters, and the penetration diameters are smaller than the puncture bar diameter, the penetrations are sufficiently protected against a potential puncture impact.

2.7.3 Thermal

2.7.3.1 Summary of Pressures and Temperatures

The analysis of the thermal accident is presented in Chapter Three. The maximum internal pressure during the thermal accident is calculated in Section 4.3. The calculated pressure is 1.64 atm, or 9.4 psig. However, the structural analysis is performed conservatively assuming a 50 psi internal pressure for the pressure stress calculations.

An ANSYS transient thermal analysis of the cask for the 30 minute thermal accident is reported in Chapter 3. The initial condition is steady state, at an ambient temperature of 100°F and maximum decay heat. The initial steady state condition is followed by a 0.5 hour severe thermal transient which is then followed by a cool-down period. The temperatures from the thermal analysis are reported in Chapter 3.

The temperature through the cross section of the cask, at the time of the maximum thermal gradient, is used for input to the cask model for thermal stress analysis.

2.7.3.2 Thermal Stresses due to Fire Accident

The load combination performed to evaluate the fire accident event is indicated in Table 2-11. In this case, bolt preload effect and 50 psig internal pressure are also included. Table 2.10.1-45 of Appendix 2.10.1 lists the combined stress intensities for the fire accident condition.

2.7.4 Water Immersion

2.7.4.1 Immersion - Fissile Material (Water Head of 3 feet, 1.3 psi External Pressure)

The criticality evaluation presented in Chapter 6.0 considers the effect of water in-leakage. Thus, the requirements of 10CFR71.73(c)(5) are met. The cask body stresses for this immersion condition (1.3 psi external pressure) is bounded by the immersion condition for all packages (water pressure of 290 psi) described in Section 2.7.4.3 below.

2.7.4.2 Immersion - All Packages (Water Head of 50 feet, 21.7 psi External Pressure)

The immersion loading condition results in an external pressure applied to the cask body corresponding to a 50 foot head of water. Assuming a 0 psia cask cavity pressure, this results in a maximum external pressure loading of 36.4 psi (21.7 + 14.7). The cask body stresses for this immersion condition (36.4 psi external pressure) is enveloped by the immersion condition for all packages (water pressure of 290 psi) described in Section 2.7.4.3 below.

2.7.4.3 Immersion - All Packages (Water Pressure of 290 psi)

Stress Analysis

10CFR 71.61 requires that the package be subjected to an external water pressure of 290 psi for a period of not less than one hour without collapse, buckling, or inleakage of water. The load combination performed to evaluate this event is indicated in Table 2-11. In this case, bolt preload and –20°F thermal stress effects are also included.

Table 2.10.1-44 of Appendix 2.10.1 lists the combined stress intensities for this accident event.

Buckling Analysis of the Inner Containment Vessel

Additional analysis is also performed to evaluate the inner cylindrical shell stability when subject to the 290 psi external pressure. Code Case N-284 [27] is used for calculating the buckling stress due to this load case.

The following table summarizes the code case N-284 buckling stress calculations.

Summary of Code Case N-284 Buckling Stress Calculations

Code Case N-284 Reference Paragraphs	Stress Calculations
Maximum Stress Intensity Based on 290 psi External Pressure + Thermal Cold	17.81 ksi
Factor of Safety (Para. 1400)	1.34
	23.87 ksi
Capacity Reduction Factor (Para. 1500)	0.8
Elastic Amplified Stress	29.83 ksi
Plastic Reduction Factor (Para. 1600)	1
Plastic Amplified Stress	29.83 ksi
Theoretical Buckling Stress (Para. 1712)	31.5 ksi
Analysis Result	29.83 ksi < 31.5 ksi

It is concluded that the containment vessel is adequate to withstand a 290 psi external pressure caused by immersion. The buckling pressure of the containment vessel is higher than 290 psi external pressure and thus there is no potential of buckling of the containment vessel structure.

Therefore, the NUHOMS®-MP197 cask satisfies all of the immersion requirements for a package that is used for shipment of radioactive materials.

2.7.5 Buckling Evaluation of the Containment Vessel due to Accident End Drop Loads

Additional analysis is also performed to evaluate the inner cylindrical shell stability when subject to the 75g end drop impact loads. The impact loads are combined with thermal loads corresponding to a 100° F ambient environment and a -20° F ambient environment. The analysis is based on the methodology provided in ASME Code Case N-284-1and the Collapse Load Analysis described in ASME B&PV Code Appendix F.

During a hypothetical accident condition end drop, permanent deformation of the lead gamma shield may occur. The lead gamma shield is supported by friction between the lead and cask shells, in addition to bearing at the end of the lead column. During fabrication, a small gap may develop between the lead gamma shield and the cask structural shells due to differential thermal expansion of the dissimilar materials during cooling after the lead pour. The gap between the lead and cask shells reduces the stresses in the cask shells during the postulated end drop, while maximizing the amount of permanent deformation in the lead column (i.e. lead slump). Therefore, for the purpose of analysis, the lead is conservatively assumed to be initially in contact with both the cask inner and structural shells.

A nonlinear finite element analysis is performed in order to evaluate the buckling capacity of the inner shell of the NUHOMS®-MP197 cask. A 2-dimensional axisymmetric ANSYS [21] finite element model is constructed for this purpose. The results of the finite element analysis provide both stresses and displacements generated during the end drop event. The resulting stress distribution is compared with the allowable buckling stresses in both the hoop and the axial directions as dictated by ASME Code CASE N-284-1. The resulting deformation is used to perform a collapse load analysis described in ASME B&PV Code Appendix F. The detail analysis is provided in Appendix 2.10.5.

The following table summarizes the maximum allowable collapse load and the maximum calculated and allowable hoop and axial stresses generated in the inner shell for all four load combinations analyzed.

Load Combination	Collapse Load	Stress Category	Maximum Stress (psi.)	Allowable Buckling Stress (psi.)
75*g* Lid End Drop, Hot Environment	>100 *gs*	Axial Stress	24,756	32,148
		Hoop Stress	10,677	18,796
75*g* Lid End Drop, Cold Environment	> 100 *gs*	Axial Stress	17,808	32,148
		Hoop Stress	5,386	18,796
75*g* Bottom End Drop, Hot Environment	>100 *gs*	Axial Stress	26,603	32,148
		Hoop Stress	12,594	18,796
75*g* Bottom End Drop, Cold Environment	>100 *gs*	Axial Stress	22,645	32,148
		Hoop Stress	15,934	18,796

2.7.6 Summary of Accident Condition cask body Structural Analysis

The following table lists the highest stress intensities in the cask body and also identifies the load combination tables and locations where these maximum stresses occur. Also listed in the tables are the stress limits based on the Section 2.1.2 structural design criteria.

Comparison of the Maximum Stress Intensities with the Allowables
(Cask Body)

Component	Maximum Stress Intensity (ksi)	Stress Category (ksi)	Stress Result Table	Allowable Stress Intensity[(1)] (ksi)
Lid	107.8	$P_m = 9.36$ $P_m + P_b = 107.0$	2.10.1-38 Location 2	$P_m = 98.0$ $P_m + P_b = 140.0$
Upper Flange	71.84	$P_m = 54.95$ $P_m + P_b = 71.84$	2.10.1-40 Location 6	$P_m = 65.94$ $P_m + P_b = 94.2$
Inner Shell	30.23	$P_m + P_b = 30.23$	2.10.1-34 Location 20	$P_m = 65.94$ $P_m + P_b = 94.2$
Outer Shell	37.9	$P_m + P_b = 37.9$	2.10.1-43 Location 23	$P_m = 48.0$ $P_m + P_b = 72.0$
Bottom	63.19	$P_m + P_b = 63.19$	2.10.1-34 Location 30	$P_m = 65.94$ $P_m + P_b = 94.2$

Note: 1. See Table 2-14 for cask body allowable stresses at different components.

From the analysis results presented in the above table, it can be shown that the accident loads will not result in any structural damage to the cask and that the containment function of the basket and fuel assembly will be maintained.

2.7.7 Structural Evaluation of the Basket/Canister Under Accident Loads

2.7.7.1 Basket Stress analysis

To determine the structural adequacy of the basket plates in the NUHOMS®-61BT DSC fuel basket under the accident condition free drop, 75*g* end and side drop load cases are conservatively performed. The *g* loads and drop orientations used for the structural analysis of the basket are described in Appendix 2.10.8. The stress and buckling analysis of the basket due to inertial loading is described in detail in Appendix 2.10.3. The results of the stress analyses are summarized in the following table. Based on the results of these analyses, all the calculated stresses in the basket, rails, and hold down ring are within the allowable stress limits.

The basket is structurally adequate and will properly support and position the fuel assemblies under accident loading conditions.

Summary of Basket Accident Condition Stress Analysis

Drop Orientation	Component	Stress Category	Max. Stress Due to 1 foot drop (ksi)	Max. Thermal Stress (ksi)	Combined Stress (ksi)	Allowable Stress (ksi)
End Drop	Fuel Compartment & Outer Wrapper	P_m	6.75	-	6.75	44.38
		P_m+P_b+Q	6.75	12.95	19.70	57.06
	Plate Insert Weld	Shear	11.25	-	11.25	26.63
	Rail Stud	Shear	14.25	-	14.25	26.63
	Hold Down Ring	P_m	7.5	-	7.5	44.38
45° Side Drop	Basket	P_m	14.54	-	14.54	44.38
		P_m+P_b	27.12	-	27.12	57.06
		P_m+P_b+Q	27.12	12.95	40.07	57.06
	Rails	P_m	16.52	-	16.52	44.38
		P_m+P_b	25.27	-	25.27	57.06
		P_m+P_b+Q	25.27	1.76	27.03	57.06
60° Side Drop	Basket	P_m	14.43	-	14.43	44.38
		P_m+P_b	27.30	-	27.3	57.06
		P_m+P_b+Q	27.30	12.95	40.25	57.06
	Rails	P_m	20.85	-	20.85	44.38
		P_m+P_b	28.72	-	28.72	57.06
		P_m+P_b+Q	28.72	1.76	30.48	57.06
90° Side Drop	Basket	P_m	18.02	-	18.02	44.38
		P_m+P_b	22.78	-	22.78	57.06
		P_m+P_b+Q	22.78	12.95	35.73	57.06
	Rails	P_m	29.03	-	29.03	44.38
		P_m+P_b	32.79	-	32.79	57.06
		P_m+P_b+Q	32.79	1.76	34.55	57.06
180° Side Drop, Impact on support rails	Basket	P_m	17.18	-	17.18	44.38
		P_m+P_b	22.54	-	22.54	57.06
		P_m+P_b+Q	22.54	12.95	35.49	57.06
	Rails	P_m	19.01	-	19.01	44.38
		P_m+P_b	28.16	-	28.16	57.06
		P_m+P_b+Q	28.16	1.76	29.92	57.06

2.7.7.2 Canister Stress Analysis

The loading conditions considered in the evaluation of the canister consist of inertial loads resulting from a 30 foot accident conditions drop, 50 psig internal /external pressures and thermal loads. The inertial loads of significance for the canister analysis are those transverse to the cask and canister longitudinal axes, so that the loads from the fuel assemblies and basket are transferred to the cask wall by the canister.

To determine the structural adequacy of the NUHOMS®-61BT DSC in the NUHOMS®-MP197 cask under an accident condition free drop, the canister is evaluated for 75*g* end drop and 75*g* side drop. The g loads and drop orientations used for the structural analysis of the basket are described in Appendix 2.10.8. The stress and buckling analysis of the canister is described in detail in Appendix 2.10.3. The results of the analysis are summarized in the following table. Based on the results of the analysis, all of the calculated stresses in the canister are within the allowable stresses.

Summary of Canister Accident Condition Stress Analysis

Load Combination		Stress Category	Maximum Stress (ksi.)	Allowable Membrane Stress Intensity (ksi.)
75*g* Front End Drop	Hot Environment, Internal Pressure	$P_m + P_b$	13.6	44.8*
	Cold Environment, External Pressure	$P_m + P_b$	16.8	44.8*
75*g* Rear End Drop	Hot Environment, Internal Pressure	$P_m + P_b$	17.8	44.8*
	Cold Environment, External Pressure	$P_m + P_b$	17.0	44.8*
45° Azimuth 75*g* Side Drop	External Pressure, Cold Environment	P_m	7.2	44.8
		$P_m + P_b$	24.8	57.6
	Internal Pressure, Hot Environment	P_m	12.4	44.8
		$P_m + P_b$	30.0	57.6
60° Azimuth 75*g* Side Drop	External Pressure, Cold Environment	P_m	7.6	44.8
		$P_m + P_b$	24.7	57.6
	Internal Pressure, Hot Environment	P_m	12.9	44.8
		$P_m + P_b$	30.0	57.6
90° Azimuth 75*g* Side Drop	External Pressure, Cold Environment	P_m	8.3	44.8
		$P_m + P_b$	22.0	57.6
	Internal Pressure, Hot Environment	P_m	13.6	44.8
		$P_m + P_b$	27.2	57.6
180° Azimuth 75*g* Side Drop	External Pressure, Cold Environment	P_m	8.7	44.8
		$P_m + P_b$	24.9	57.6
	Internal Pressure, Hot Environment	P_m	13.9	44.8
		$P_m + P_b$	30.1	57.6

*The stress intensities (membrane + bending) generated in the canister during the end drop events are conservatively compared with the membrane allowable stress, P_m for SA-240, Type 304.

2.8 SPECIAL FORM/FUEL RODS

2.8.1 Special Form

This section does not apply to the NUHOMS®-MP197 Packaging.

2.8.2 Fuel Rods

As discussed in Chapter 4, containment of the radioactive material is provided by the cask containment boundary. Analyses of the cask boundary for all normal conditions of transport and hypothetical conditions defined by the Part 71 Regulations demonstrate that the cask remains leak tight.

In addition, Appendix 2.10.7 of the SAR assesses the response of a typical BWR fuel assembly during 30 foot hypothetical end drop and 30 foot hypothetical side drop. Results from these analyses indicate that the lowest buckling load for GE fuel assemblies is about 95*g*, which is well above the 80*g* end drop and the maximum stress due to the side drop load is much less than the yield stress of the irradiated zicaloy tube. Therefore, the integrity of the fuel rods will not be breached during the normal and hypothetical accident loads.

2.9 REFERENCES

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3. American Society of Mechanical Engineers, ASME Boiler and Pressure Vessel Code, Section III, 1998 including 1999 addenda.

4. American Society of Mechanical Engineers, ASME Boiler and Pressure Vessel Code, Section III, Division 3, Subsection WB, 1998 including 1999 addenda.

5. USNRC Regulatory Guide 7.6, "Design Criteria for the Structural Analysis of Shipping Cask Containment Vessel", Rev. 1, March 1978.

6. USNRC Regulatory Guide 7.8, "Load Combinations for the Structural Analysis of Shipping Cask", Rev. 1, March 1989.

7. American Society of Mechanical Engineers, ASME Boiler and Pressure Vessel Code, Section III, Appendices, 1998 including 1999 addenda.

8. American Society of Mechanical Engineers, ASME Boiler and Pressure Vessel Code, Section V, 1998 including 1999 addenda.

9. American Society of Mechanical Engineers, ASME Boiler and Pressure Vessel Code, Section II, Part C and Part D, 1998 including 1999 addenda.

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11. NUREG/CR-3854,"Fabrication Criteria for Shipping Container".

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21. ANSYS Engineering Analysis System, Users Manual for ANSYS Rev. 5.6, Swanson Analysis Systems, Inc., Houston, PA, 1995.

22. WRC Bulletin 107, March 1979 Revision "Local Stresses in Spherical and Cylindrical Shells Due to External Loadings."

23. ANSI N14.23, "Draft American National Standard Design Basis for Resistance to Shock and Vibration of Radioactive Material Packages Greater Than One Ton in Truck Transport", May, 1980.

24. NUREG 766510, "Shock and Vibration Environments for Large Shipping Containers on Rail Cars and Trucks", June, 1977.

25. NUREG/CR-6007 "Stress Analysis of Closure Bolts for Shipping Casks", By Mok, Fischer, and Hsu, Lawrence Livermore National Laboratory, 1992.

26. NUREG/CR-4554, "SCANS A Microcomputer Based Analysis System for shipping Cask Design review", April, 1989.

27. ASME Section III, Code Case No. N-284, "Metal Containment Shell Buckling Design Methods", 1998.

28. Transnuclear West letter 31-B9604-97-003 dated Dec 19, 1997 from Dave Dawson to Tim McGinty, NRC

29. AMS-R-83485, "Rubber, Fluorocarbon, Improved Performance at Low Termperatures"

30. Final Safety Analysis Report, rev 0, TN-68 Dry Storage Cask, Appendix 9A

31. Harper, Charles A., ed., "Handbook of Plastics and Elastomers," McGraw-Hill, 1975

2.10 APPENDICES

The detailed structural analyses of the NUHOMS®-MP197 packaging are included in the following appendices:

Appendix 2.10.1	NUHOMS®-MP197 Cask Body Structural Evaluation
Appendix 2.10.2	NUHOMS®-MP197 Cask Lid Bolt Analysis
Appendix 2.10.3	NUHOMS®-61BT DSC (Canister and Basket) Structural Evaluation
Appendix 2.10.4	NUHOMS®-MP197 Cask Lead Slump Analysis
Appendix 2.10.5	NUHOMS®-MP197 Cask Inner Containment Buckling Analysis
Appendix 2.10.6	Dynamic Amplification Factor Determination
Appendix 2.10.7	Evaluation of Fuel Assembly under Accident Impacts
Appendix 2.10.8	Structural Evaluation of the NUHOMS®-MP197 Package Impact Limiters
Appendix 2.10.9	NUHOMS®-MP197 Package Impact Limiter Testing

2.11 ASME Code Exceptions

The cask containment boundary and the canister shell, the inner top plate, the inner bottom cover plate, the siphon vent block, and the siphon/vent port cover plate of the DSC are designed, fabricated and inspected in accordance with the ASME Code Subsections NB to the maximum practical extent. The basket is designed, fabricated and inspected in accordance with ASME Code Subsection NG to the maximum practical extent. Other cask components (such as the shield shell and neutron shielding) and canister components (such as outer bottom cover, top and bottom shield plugs) are not governed by the ASME Code.

ASME Code Exceptions for the NUHOMS®-MP197 Cask Containment Boundary

Reference ASME Code Section/Article	Code Requirement	Exception, Justification & Compensatory Measures
NCA	All	Not compliant with NCA
NB-1100	Requirements for Code Stamping of Components	The NUHOMS®-MP197 cask containment boundary is designed & fabricated in accordance with the ASME Code, Section III, Subsection NB to the maximum extent practical. However, Code Stamping is not required. As Code Stamping is not required, the fabricator is not required to hold an ASME "N" or "NPT" stamp, or to be ASME Certified.
NB-1131	The design specification shall define the boundary of a component to which other components are attached.	A code design specification is not prepared for the NUHOMS®-MP197 cask. A TN design criteria is prepared in accordance with TN's QA program.
NB-2130 NB-4121	Material must be supplied by ASME approved material suppliers Material Certification by Certificate Holder	Material is certified to meet all ASME Code criteria but is not eligible for certification or Code Stamping if a non-ASME fabricator is used. As the fabricator is not required to be ASME certified, material certification to NB-2130 is not possible. Material tractability & certification are maintained in accordance with TN's NRC approved QA program.
NB-7000	Overpressure Protection	No overpressure protection is provided for the NUHOMS®-MP197 cask. The function of the NUHOMS®-MP197 cask is to contain radioactive materials under normal, off-normal, and hypothetical accident conditions postulated to occur during transportation. The NUHOMS®-MP197 cask is designed to withstand the maximum internal pressure considering 100% fuel rod failure at maximum accident temperature. The NUHOMS®-MP197 cask is pressure tested in accordance with the requirements of 10CFR71 and TN's approved QA program.
NB-8000	Requirements for nameplates, stamping & reports per NCA-8000	The NUHOMS®-MP197 cask nameplates provide the information required by 10CFR71 and 49CFR173 as appropriate. Code stamping is not required for the NUHOMS®-MP197 cask. QA Data packages are prepared in accordance with the requirements of 10CFR71 and TN's approved QA program.

ASME Code Exceptions for the NUHOMS®-61BT Canister

Reference ASME Code Section/Article	Code Requirement	Exception, Justification & Compensatory Measures
NCA	All	Not compliant with NCA
NB-1100	Requirements for Code Stamping of Components	The canister shell, the inner top cover plate, the inner bottom cover plate, the siphon vent block, and the siphon/vent port cover plate of the DSC are designed & fabricated in accordance with the ASME Code, Section III, Subsection NB to the maximum extent practical. However, Code Stamping is not required. As Code Stamping is not required, the fabricator is not required to hold an ASME "N" or "NPT" stamp, or to be ASME Certified.
NB-2130 NB-4121	Material must be supplied by ASME approved material suppliers Material Certification by Certificate Holder	Material is certified to meet all ASME Code criteria but is not eligible for certification or Code Stamping if a non-ASME fabricator is used. As the fabricator is not required to be ASME certified, material certification to NB-2130 is not possible. Material traceability & certification are maintained in accordance with TN's NRC approved QA program.
NB-4243 and NB-5230	Category C weld joints in vessels and similar weld joints in other components shall be full penetration joints. This welds shall be examined by UT or RT and either PT or MT	The joint between the top outer and inner cover plates and shell are design and fabricated per ASME Code Case N-595-1. The welds are partial penetration welds and the root and final layer are PT examined.
NB-5231	Full penetration corner weld joints require the fusion zone and the parent metal beneath the attachment surface to be UT after welding.	The inner bottom cover plate weld joint is full penetration per Fig. NB-4243-1. The required UT inspection is performed on a best effort basis. The joint is examined by RT and either PT or MT methods.
NB-6100 and 6200	All completed pressure retaining systems shall be pressure tested	The vent and siphon block is also not pressure tested due to the manufacturing sequence. The siphon block weld is helium leak tested when fuel is loaded and then covered with the outer top closure plate.
NB-7000	Overpressure Protection	No overpressure protection is provided for the NUHOMS®-61BT DSC. The function of the NUHOMS®-61BT DSC is to contain radioactive materials under normal, off-normal, and hypothetical accident conditions postulated to occur during transportation. The NUHOMS®-61BT DSC is designed to withstand the maximum internal pressure considering 100% fuel rod failure at maximum accident temperature. The NUHOMS®-61BT DSC is pressure tested in accordance with the requirements of 10CFR71 and TN's approved QA program.
NB-8000	Requirements for nameplates, stamping & reports per NCA-8000	The NUHOMS®-61BT DSC nameplates provide the information required by 10CFR71, 49CFR173, and 10CFR72 as appropriate. Code stamping is not required for the NUHOMS®-61BT DSC. QA Data packages are prepared in accordance with the requirements of 10CFR71, 10CFR72, and TN's approved QA program.

ASME Code Exceptions for the NUHOMS®-61BT DSC Fuel Basket

Reference ASME Code Section/Article	Code Requirement	Exception, Justification & Compensatory Measures
NG-1100	Requirement for Code Stamping of Components	The NUHOMS®-61BT DSC baskets are designed & fabricated in accordance with the ASME Code, Section III, Subsection NG to the maximum extent practical as described in the SAR, but Code Stamping is not required. As Code Stamping is not required, the fabricator is not required to hold an ASME N or NPT stamp or be ASME Certified.
NG-2000	Use of ASME Material	Material is certified to meet all ASME Code criteria but is not eligible for certification or Code Stamping if a non-ASME fabricator is used. As the fabricator is not required to be ASME certified, material certification to NG-2130 is not possible. Material traceability & certification are maintained in accordance with TN's NRC approved QA program. The poison material and aluminum plates are not used for structural analysis, but to provide criticality control and heat transfer. They are not ASME Code Class I materials.
NCA	All	Not compliant with NCA as no code stamp is used.

Table 2-1

Evaluation Method Employed to Demonstrate Compliance With Specific Regulatory Requirements

10CFR71		Numerical Analysis	Material Test	Model Tests
Normal Condition	Heat	X		
	Cold	X		
	Reduced External Pressure	X		
	Increased External Pressure	X		
	Shock and Vibration	X		
	One Foot Free drop	X		
Accident Condition	30 foot Free Drop-Cask and Basket	X		
	30 foot Free Drop- Impact Limiters	X	X	X
	Puncture	X		
	Thermal Event	X		
	Water Immersion	X		
others	Lifting	X		
	Tie-Down	X		

Table 2-2
Containment Vessel Stress Limits

CLASSIFICATION	STRESS INTENSITY LIMIT
Normal (Level A) Conditions[1]	
P_m	S_m
P_l	1.5 S_m
(P_m or P_l) + P_b	1.5 S_m
Shear Stress	0.6 S_m
Bearing Stress	S_y
(P_m or P_l) + P_b + Q	3 S_m
(P_m or P_l) + P_b + Q + F	S_a
Hypothetical Accident (Level D)[2]	
P_m	Smaller of 2.4 S_m or 0.7 S_u
P_l	Smaller of 3.6 S_m or S_u
(P_m or P_l) + P_b	Smaller of 3.6 S_m or S_u
Shear Stress	0.42 S_u

Notes:

1. Classifications and Stress Intensity Limits are as defined in ASME B&PV Code, Section III, Subsection NB.

2. Stress intensity limits are in accordance with ASME B&PV Code, Section III, Appendix F.

Table 2-3
Containment Bolt Stress Limits (1)(5)

CLASSIFICATION	STRESS INTENSITY LIMIT
Normal (Level A) Conditions (2)	
Average Tensile Stress	$2\ S_m$
Maximum Combined Stress	$3\ S_m$
Bearing Stress	S_y
Hypothetical Accident (Level D)(3)	
Average Tensile Stress	Smaller of S_y or $0.7\ S_u$
Average Shear Stress	Smaller of $0.4\ S_u$ or $0.6\ S_y$
Maximum Combined Stress	S_u
Combined Shear & Tension	$R_t^2 + R_s^2 < 1$(4)

Notes:

1. The stress analysis of the lid bolt is performed in accordance with NUREG/CR-6007 [25] described in Appendix 2.10.2. The stress limits for the lid bolt are listed separately in Tables 2.10.2-3 and 4.

2. Classification and stress limits are as defined in ASME B&PV Code, Section III, Subsection NB.

3. Stress limits are in accordance with ASME B&PV Code, Section III, Appendix F.

4. R_t : Ratio of average tensile stress to allowable average tensile stress
   R_s : Ratio of average shear stress to allowable average shear stress

5. All stresses include the effect of tensile and torsional loads due to bolt preloading.

Table 2-4
Basket Stress Limits

CLASSIFICATION	STRESS INTENSITY LIMIT
Normal (Level A) Conditions (1)	
P_m	S_m
P_l	1.5 S_m
$(P_m + P_l) + P_b$	1.5 S_m
$(P_m + P_l) + P_b + Q$	3 S_m
$(P_m + P_l) + P_b + Q + F$	S_a
Shear Stress	0.6 S_m
Hypothetical Accident (Level D) (2)	
P_m	Smaller of 2.4 S_m or 0.7 S_u
P_l	Smaller of 3.6 S_m or S_u
$(P_m + P_l) + P_b$	Smaller of 3.6 S_m or S_u
Shear Stress	0.42 S_u

Notes:

1. Classifications and stress intensity limits are as defined in ASME B&PV Code, Section III, Subsection NG.

2. Limits are in accordance with ASME B&PV Code, Section III, Appendix F.

Table 2-5

MECHANICAL MATERIAL PROPERTIES

(Data From ASME Code, section II, Part D, 1998 w/1999 Addenda)

Material	Class	Temp (F°)	S_y (ksi)	S_u (ksi)	S_m (ksi)	E (10^6 psi)	α_m 10^{-6}
SA-540, Gr. B24, Cl. 1 (2 Ni-3/4Cr-1/3Mo)	Sec III, Class 1 (Bolt)	70	150.0	165.0	50.0	27.8	6.4
		200	143.4	165.0	47.8	27.1	6.7
		300	138.6	165.0	46.2	26.7	6.9
		400	134.4	165.0	44.8	26.1	7.1
		500	130.2	165.0	43.4	25.7	7.3
		600	124.2	165.0	41.4	25.2	7.4
		Ref. pg	510(1)	See Note 2	422	606.1	580
SA-240 Gr. 316	Sec III, Class 1	70	30.9	75.0	20.0	28.3	8.5
		200	25.9	75.0	20.0	27.6	8.9
		300	23.4	72.9	20.0	27.0	9.2
		400	21.4	71.9	19.3	26.5	9.5
		500	20.0	71.8	18.0	25.8	9.7
		600	18.9	71.8	17.0	25.3	9.8
		Ref. pg	508	450	316	606.1	583
SA-240, Gr. 304 (18Cr-8 Ni)	Sec III, Class I	70	30	75.0	20.0	28.3	8.5
		200	25.0	71.0	20.0	27.6	8.9
		300	22.4	66.2	20.0	27.0	9.2
		400	20.7	64.0	18.7	26.5	9.5
		500	19.4	63.4	17.5	25.8	9.7
		600	18.4	63.4	16.4	25.3	9.8
		650	18.0	63.4	16.2	25.1	9.9
		Ref. pg	520	453.4	330	606.1	583
SA-240, Gr. XM-19 (22Cr-13 Ni-5Mn)	Sec III, Class I	70	55.0	100.0	33.3	28.3	8.2
		200	47.1	99.4	33.2	27.6	8.5
		300	43.3	94.2	31.4	27.0	8.8
		400	40.7	91.1	30.2	26.5	8.9
		500	38.8	89.1	29.7	25.8	9.1
		600	37.4	87.7	29.2	25.3	9.2
		Ref. pg	540	453.14	350	606.1	583
SA-693 Type 630 H1100 (17Cr-4 Ni-4Cu) or SA-705 Type 630 H1100	Sec III Class 1	70	115	140	46.7	28.5	5.89
		200	106.3	140	46.7	27.8	5.90
		300	101.8	140	46.7	27.2	5.90
		400	98.3	136.1	45.5	26.6	5.91
		500	95.2	133.4	44.4	26.1	5.91
		600	92.7	131.4	43.8	25.5	5.93
		650	91.5	130.1	43.5	25.2	5.93
		Ref. pg	492	442	300	606.1	590(1)

Table 2-5 (continued)
Mechanical Properties of ASTM B-29 Chemical Lead

ASTM B-29 Chemical Lead	Temp (°F)	Poisson's Ratio	Density (lbs/in^3)	*E* (10^6 psi)	α_m (10^{-6})
	70	0.45	0.41	2.49	16.07
	100			2.35	16.21
	200			2.28	16.70
	250			2.13	16.95
	300			2.06	17.34
		See Note 3 Pg. 84	See Note 3 Pg. 84	See Note 4 Pg. 66	See Note 4 Pg. 56

Dynamic Stress-Strain Lead Properties[5]

Strain (in/in)	Stress at Temperature (ksi)		
	100°F	230°F	300°F [6]
0.000485	1.14	1.06	1.00
0.03	2.2	2.0	1.70
0.10	3.3	2.8	2.38
0.30	4.9	3.2	2.72
0.50	5.6	3.6	3.06

Notes:

1. Data at elevated temperatures is not available in 1998 ASME Code with 1999 Addenda. Data is taken from 1995 ASME Code with 1997 Addenda.

2. Data at elevated temperatures is not available in 1998 ASME Code with 1999 Addenda. Data is taken from a material with a similar chemical composition (SA-479-316, 16Cr 12Ni 2Mo).

3. Cask Design Guide, ORNL-NSIC-68, February, 1970.

4. NUREG/CR-0481, An Assessment of Stress-Strain Data Suitable for Finite-Element Elastic-Plastic Analysis of Shipping Containers.

5. U.S. Energy Research and Development Administration, "A Survey of Strain Rate Effects for some Common structural Materials Used in Radioactive Material Packaging and transportation System," Battelle Columbus Laboratories, August, 1976.

6. By ratio: 0.85 × stress at 230°F.

Table 2-6
Reference Temperatures For
Stress Analysis Acceptance Criteria[1]

Component	Max. Calculated Temperature, °F	Selected Design[2] Temperature, °F
Outer Shell	275	300
Gamma Shield (Lead)	299	300
Inner Shell	302	300
Lid Bolts	199	300
Basket Rail	482	500
Basket	578	600
Canister	388	400
Front Trunnion	225	250
Front Trunnion Bolts	225	250
Rear Trunnion	230	250

Notes:

1. For normal loading conditions
2. Temperatures specified are used to determine allowable stresses. They are not a maximum use temperature for the material.

Table 2-7
Bijlaard Computation Sheet

1. APPLIED LOADS[*]

RADIAL LOAD	P = ________	LB.
CIRC. MOMENT	M_c = ________	IN-LB.
LONG. MOMENT	M_L = ________	IN-LB.
TORSION MOMENT	M_T = ________	IN-LB.
SHEAR LOAD	V_c = ________	LB.
SHEAR LOAD	V_L = ________	LB.

[*] NOTE: ENTER ALL FORCE VALUES IN ACCORDANCE WITH SIGN CONVENTION

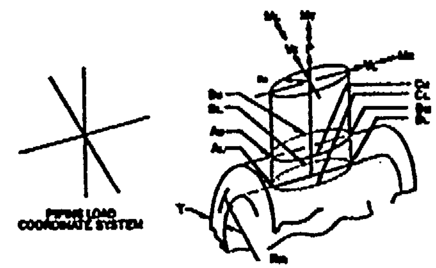
2. GEOMETRY

VESSEL THICKNESS	T = ________	IN.
ATTACHMENT RADIUS	r_o = ________	IN.
VESSEL RADIUS	R_m = ________	IN.

3. GEOMETRIC PARAMETERS

$\gamma = \frac{R_m}{T}$ = ________

$\beta = (0.875)\frac{r_o}{R_m}$ = ________



FROM FIG.	READ CURVES FOR	COMPUTE ABSOLUTE VALUES OF STRESS AND ENTER RESULT	STRESSES – IF LOAD IS OPPOSITE THAT SHOWN, REVERSE SIGNS SHOWN A_u	A_L	B_u	B_L	C_u	C_L	D_u	D_L
3C AND 4C	$\frac{N_\phi}{P/R_m}$ =	$\left(\frac{N_\phi}{P/R_m}\right)\cdot\frac{P}{R_m T}$ =	+	+	+	+	+	+	+	+
1C AND 2C-1	$\frac{M_\phi}{P}$ =	$\left(\frac{M_\phi}{P}\right)\cdot\frac{6P}{T^2}$ =	+	−	+	−	+	−	+	−
3A	$\frac{N_\phi}{M_c/(R_m^2\beta)}$ =	$\left(\frac{N_\phi}{M_c/(R_m^2\beta)}\right)\cdot\frac{M_c}{R_m^2\beta T}$ =					−	−	+	+
1A	$\frac{M_\phi}{M_c/(R_m\beta)}$ =	$\left(\frac{M_\phi}{M_c/(R_m\beta)}\right)\cdot\frac{6M_c}{R_m\beta T^2}$ =					−	+	+	−
3B	$\frac{N_\phi}{M_L/(R_m^2\beta)}$ =	$\left(\frac{N_\phi}{M_L/(R_m^2\beta)}\right)\cdot\frac{M_L}{R_m^2\beta T}$ =	−	−	+	+				
1B OR 1B-1	$\frac{M_\phi}{M_L/(R_m\beta)}$ =	$\left(\frac{M_\phi}{M_L/(R_m\beta)}\right)\cdot\frac{6M_L}{R_m\beta T^2}$ =	−	+	+	−				
ADD ALGEBRAICALLY FOR SUMMATION OF ϕ STRESSES σ_ϕ =										
3C AND 4C	$\frac{N_x}{P/R_m}$ =	$\left(\frac{N_x}{P/R_m}\right)\cdot\frac{P}{R_m T}$ =	+	+	+	+	+	+	+	+
1C-1 AND 2C	$\frac{M_x}{P}$ =	$\left(\frac{M_x}{P}\right)\cdot\frac{6P}{T^2}$ =	+	−	+	−	+	−	+	−
4A	$\frac{N_x}{M_c/(R_m^2\beta)}$ =	$\left(\frac{N_x}{M_c/(R_m^2\beta)}\right)\cdot\frac{M_c}{R_m^2\beta T}$ =					−	−	+	+
2A	$\frac{M_x}{M_c/(R_m\beta)}$ =	$\left(\frac{M_x}{M_c/(R_m\beta)}\right)\cdot\frac{6M_c}{R_m\beta T^2}$ =					−	+	+	−
4B	$\frac{N_x}{M_L/(R_m^2\beta)}$ =	$\left(\frac{N_x}{M_L/(R_m^2\beta)}\right)\cdot\frac{M_L}{R_m^2\beta T}$ =	−	−	+	+				
2B OR 2B-1	$\frac{M_x}{M_L/(R_m\beta)}$ =	$\left(\frac{M_x}{M_L/(R_m\beta)}\right)\cdot\frac{6M_L}{R_m\beta T^2}$ =	−	+	+	−				
ADD ALGEBRAICALLY FOR SUMMATION OF x STRESSES σ_x =										
SHEAR STRESS DUE TO TORSION M_T		$\tau_{\phi x} = \tau_{x\phi} = \frac{M_T}{2\pi r_o^2 T}$	+	+	+	+	+	+	+	+
SHEAR STRESS DUE TO LOAD V_c		$\tau_{x\phi} = \frac{V_c}{\pi r_o T}$	+	+	−	−				
SHEAR STRESS DUE TO LOAD V_L		$\tau_{\phi x} = \frac{V_L}{\pi r_o T}$					+	+	−	−
ADD ALGEBRAICALLY FOR SUMMATION OF SHEAR STRESSES τ =										

	LONGITUDINAL σ_x		CIRCUMFERENTIAL σ_ϕ	
PRESSURE STRESS	$\frac{PR-0.4PT}{2ET}$ =	= ________	$\frac{PR+0.6PT}{ET}$ =	= ________
LONGITUDINAL BENDING STRESS		= ________		
TOTAL MEMBRANE STRESS		= ________ < ________		= ________ < ________
TOTAL SURFACE STRESS		= ________ < ________		= ________ < ________

NOZZLE NO. ________

PIPING LOAD CODE ________

ANALYSIS POINT ________

COMPUTATION SHEET FOR LOCAL STRESSES IN CYLINDRICAL SHELLS

Table 2-8
NUHOMS®-MP197 Package Performance Evaluation Overview
(Normal Conditions of Transport)

Loading Condition	SAR Section	Scope of Evaluation
Heat 71.71(c)(1)	2.6.1.1	Maximum component temperatures for material allowables
	2.6.1.2	Cask cavity maximum pressure, 50 psi
	2.6.1.3	Cask body thermal gradients
	2.6.1.4	Cask body stresses due to hot environment load combinations
Cold 71.71(c)(2)	2.6.2	Cask body stresses due to cold environment load combinations
Reduced External pressure 71.71(c)(3)	2.6.3	Cask body stresses due to 50 psi internal pressure load combinations
Increase External Pressure 71.71(c)(4)	2.6.4	Cask body stresses due to 25 psi external pressure load combinations
Shock Loads 71.71(c)(5)	2.6.5	Cask body stresses due to truck shock loads
		Cask body stresses due to rail shock loads
Vibration Loads 71.71(c)(5)	2.6.6	Cask body stresses due to truck vibration loads
		Cask body stresses due to rail vibration loads
Water Spray 71.71(c)(6)	2.6.7	Negligible for NUHOMS®-MP197 cask
Free Drop 71.71(c)(7)	2.6.8	Cask body stresses due to 1 foot bottom end drop
		Cask body stresses due to 1 foot lid end drop
		Cask body stresses due to 1 foot side drop
Corner Drop 71.71(c)(8)	2.6.9	Not applicable
Compression 71.71(c)(9)	2.6.10	Not applicable
Penetration 71.71(c)(10)	2.6.11	Not applicable
Fabrication Stress	2.6.12	Discuss the cask stresses during the lead pouring process and subsequent cool down
Lid Bolt Analysis	2.6.13	Bolt stresses due to preload, pressure loads, temperature, impact and puncture loads
Fatigue Analysis of Containment Vessel	2.6.14	Fatigue evaluation of containment vessel due to lifting, pressure, temperature, shock/vibration, and 1 foot drop loads
Summary of Normal Condition Cask Analysis	2.6.15	Lists the highest stress intensities in the containment vessel and gamma shield and compares results with the allowables
Basket/canister Evaluation	2.6.16	Structural analysis of the basket/canister due to 1 foot end drop and 1 foot side drop loads

Table 2-9
Individual Load Conditions[1]

Run No.	Applicable Individual Loads	Load Used in Run	Stress Result Tables
1	Bolt preload	-	2.10.1-4
2	Internal pressure	50 psig	2.10.1-5
3	External pressure	25 psig	2.10.1-6
4	Thermal stresses at hot environment	-	2.10.1-7
5	Thermal stresses at –20° F cold environment	-	2.10.1-8
6	3G lifting	3G	2.10.1-9
7	Rail Car Shock loads	4.7G – all directions	2.10.1-10
8	Rail car vibration loads	0.37G – vertical 0.19G –lateral 0.19G – longitudinal	2.10.1-11
9	1 foot end drop on lid end	30 G	2.10.1-12
10	1 foot end drop on bottom end	30 G	2.10.1-13
11	1 foot side drop	30 G	2.10.1-14
12	1G gravity loading	1 G	2.10.1-15

Note:

1. Bolt Preload is included in all individual load cases.

Table 2-10

Summary of Load Combinations for Normal Condition of Transport

Run No.	Load Combination	Applicable Individual Loads Applied in the ANSYS Model									
		Bolt Pre-load	Gravity 1g	Int. Pres.	Ext. Pres.	Thermal Hot	Thermal Cold	Thermal -40°F Uniform	Rail Car Vib.	Rail Car shock	Stress Result Table
13	Hot Environment (100° F amb.)	x	x	x		x					2.10.1-16
14	Cold Environment (-40° F amb.)	x	x		x			x			2.10.1-17
15	Increased External Pressure	x	x		x		x				2.10.1-18
16	Min. External Pressure	x	x	x		x					2.10.1-19
17	Rail Car Vibration	x		x		x			x		2.10.1-20
18		x			x		x		x		2.10.1-21
19	Rail Car Shock	x		x		x				x	2.10.1-22
20		x			x		x			x	2.10.1-23

Run No.	Load Combination	Applicable Individual Loads Applied in the ANSYS Model								
		Bolt Pre-load	Internal Pres. (50 psi)	External Pres. (25 psi)	Thermal Hot	Thermal Cold	Lid End Drop	Bottom End Drop	Side drop	Stress Result Table
21	1 Ft End Drop on Lid End	x	x		x		x			2.10.1-24
22		x		x		x	x			2.10.1-25
23	1 Ft End Drop on Bottom End	x	x		x			x		2.10.1-26
24		x		x		x		x		2.10.1-27
25	1 Ft Side Drop	x	x		x				x	2.10.1-28
26		x		x		x			x	2.10.1-29

Table 2-11

Summary of Load Combinations for Accident Condition of Transport

Run No.	Load Combination	Applicable Individual Loads Applied in the ANSYS Model								
		Bolt Pre-Load	Int. Pres. (50 psi)	Ext. Pres. (25 psi)	Thermal Hot	Thermal Cold	Lid End Drop	Bot. End Drop	Side Drop	Stress Result Table
27	30 Ft. End Drop on Bottom End	x	x		x			x		2.10.1-30
28		x		x		x		x		2.10.1-31
29	30 Ft. End Drop on Lid End	x	x		x		x			2.10.1-32
30		x		x		x	x			2.10.1-33
31	30 Ft. Side Drop	x	x		x				x	2.10.1-34
32		x		x		x			x	2.10.1-35

Run No.	Load Combination	Applicable Individual Loads Applied in the ANSYS Model								
		Bolt Pre-Load	Int. Pres. (50 psi)	Ext. Pres. (25 psi)	Thermal Hot	Thermal Cold	Corner Drop Lid End	Corner Drop Bot End	Oblique Drop Lid End	Stress Result Table
33	30 Ft. CG Over Corner Drop on Bottom End	x	x		x			x		2.10.1-36
34		x		x		x		x		2.10.1-37
35	30 Ft. CG Over Corner Drop on Lid End	x	x		x		x			2.10.1-38
36		x		x		x	x			2.10.1-39
37	30 Ft. 20° Oblique Impact on Lid End	x	x		x				x	2.10.1-40
38		x		x		x			x	2.10.1-41

Table 2-11(continued)

Summary of Load Combinations for Accident Condition of Transport (continued)

Run No.	Load Combination	Applicable Individual Loads Applied in the ANSYS Model							
		Bolt Pre-load	Int. Pres. (50 psi)	Ext. Pres. (25 psi)	Thermal Hot	Thermal Cold	Oblique Drop Lid End	Oblique Drop Bottom End	Stress Result Table
39	30 Ft. 20° Oblique Impact on Bottom End	x	x		x			x	2.10.1-42
40		x		x		x		x	2.10.1-43

Run No.	Load Combination	Applicable Individual Loads Applied in the ANSYS Model								
		Bolt Pre-load	Int. Pres. (50 psi)	Ext. Pres. (25 psi)	Thermal Hot	Thermal Cold	Immersion Ext. Pres. (290 psi)	Fire	Oblique Drop Bottom End	Stress Result Table
41	Immersion (290 psi)	x				x	x			2.10.1-44
42	Fire Accident	x	x					x		2.10.1-45

Table 2-12
40 in. Puncture on Lid End

Component	location	Max Stress Intensity $P_m + P_b$ (ksi)	Allowable Membrane Stress Intensity (ksi)
Lid	1	94.37	98.00
	2	82.08	98.00
	3	15.32	98.00
	4	19.54	98.00
Upper Cask Wall	5	2.71	65.94
	6	0.72	65.94
	7	17.84	65.94
	8	16.89	65.94
	9	9.58	65.94
	10	4.85	65.94
	11	2.42	65.94
	12	3.01	65.94
	13	5.12	65.94
	14	6.12	65.94
	15	8.62	65.94
Upper Trunnion	16	8.71	65.94
	17	8.01	65.94
	18	6.93	48.00
	19	8.41	48.00
Mid Cask Wall	20	16.70	65.94
	21	14.38	65.94
	22	9.81	48.00
	23	13.82	48.00
Lower Trunnion	24	10.81	65.94
	25	9.43	65.94
	26	7.58	48.00
	27	10.05	48.00
Lower Cask wall	28	6.61	65.94
	29	7.44	65.94
	30	7.03	65.94
	31	3.00	65.94
Base	32	2.68	65.94
	33	2.94	65.94
	34	3.12	65.94
	35	3.53	65.94

Table 2-13

40 in. Puncture on Bottom Ram Port Cover

Component	location	Max Stress Intensity $P_m + P_b$ (ksi)	Allowable Membrane Stress Intensity (ksi)
Lid	1	3.37	98.00
	2	3.76	98.00
	3	2.59	98.00
	4	3.40	98.00
Upper Cask Wall	5	5.64	65.94
	6	3.57	65.94
	7	5.61	65.94
	8	6.40	65.94
	9	16.00	65.94
	10	5.83	65.94
	11	4.72	65.94
	12	8.43	65.94
	13	7.82	65.94
	14	3.74	65.94
	15	3.27	65.94
Upper Trunnion	16	8.17	65.94
	17	7.40	65.94
	18	6.75	48.00
	19	8.29	48.00
Mid Cask Wall	20	16.67	65.94
	21	14.35	65.94
	22	9.77	48.00
	23	13.78	48.00
Lower Trunnion	24	11.45	65.94
	25	9.98	65.94
	26	7.72	48.00
	27	10.18	48.00
Lower Cask wall	28	10.38	65.94
	29	4.68	65.94
	30	6.83	65.94
	31	10.19	65.94
Base	32	15.07	65.94
	33	10.58	65.94
	34	38.67	65.94
	35	55.59**	65.94

** High stress is observed radially inward of location 35 (≈ 2.75 in., see Figure 2-4). The stress across that section is linearized, the max. P_m is 50.12 ksi (< 65.94 ksi, membrane allowable) and $P_m + P_b$ is 90.39 ksi (< 94.2 ksi, membrane + bending allowable).

Table 2-14
NUHOMS®-MP197 Cask Body Allowable Stress
(See Figure 2-4 for Stress Report Locations)

Normal Conditions
(Based on Temperature at 300°F)

Component	**Material**	**Allowable Stress (ksi)**	
		P_m (S_m)	$P_m + P_b$ (1.5 S_m)
Lid	SA-693, Type 630	46.7	70.05
Flange, Bottom Cover & Ram Plate, Inner Shell, Bearing Block &Tie Bar & Pad Plate	SA-240 Gr. XM-19	31.4	47.1
Outer Shell	SA-240 Type 316	20.0	30.0

Accident Conditions
(Based on Temperature at 300°F)

Component	**Material**	**Allowable Stress (ksi)**	
		P_m (Smaller of 2.4 S_m or 0.7 S_u)	$P_m + P_b$ Smaller of 3.6 S_m or S_u)
Lid	SA-693, Type 630	98	140
Flange, Bottom Cover & Ram Plate, Inner Shell, Bearing Block &Tie Bar & Pad Plate	SA-240 Gr. XM-19	65.94	94.2
Outer Shell	SA-240 Gr. 316	48.0	72.0

Figure 2-1
Effect of pH on Corrosion of Iron in Aerated Soft Water, Room Temperature

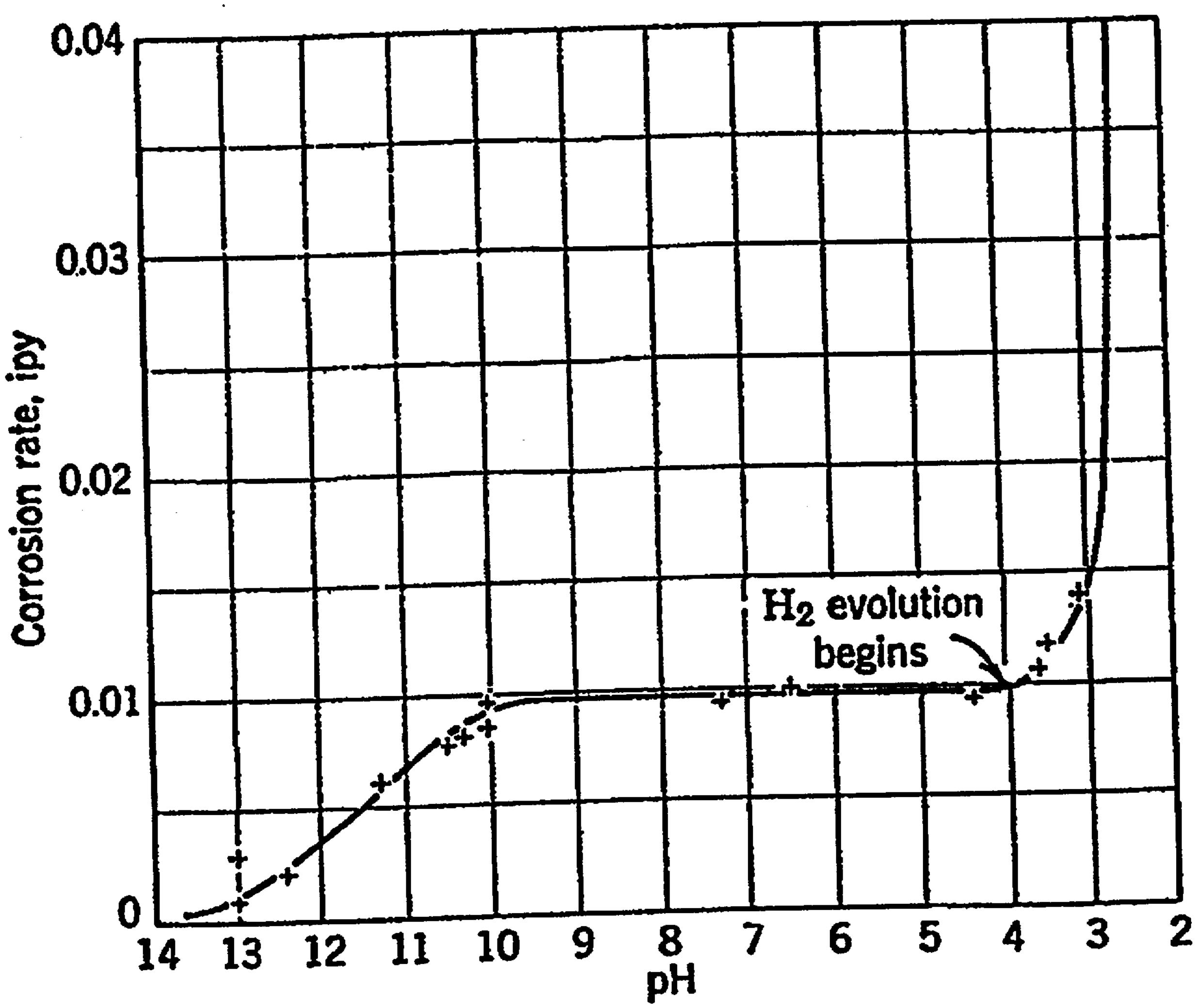
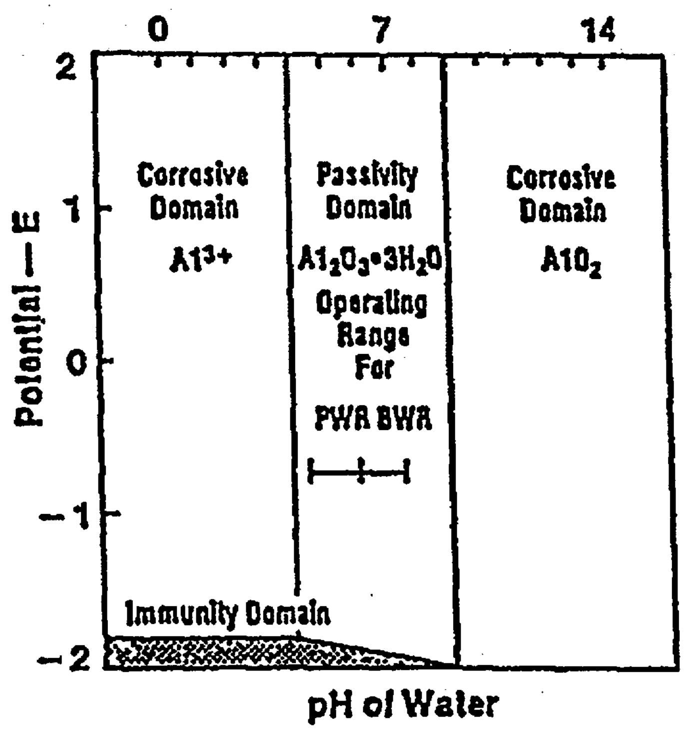


Figure 2-2
Potential versus pH Diagram for Aluminum-Water System

At 25°C (77°F):



At 60°C (140°F):

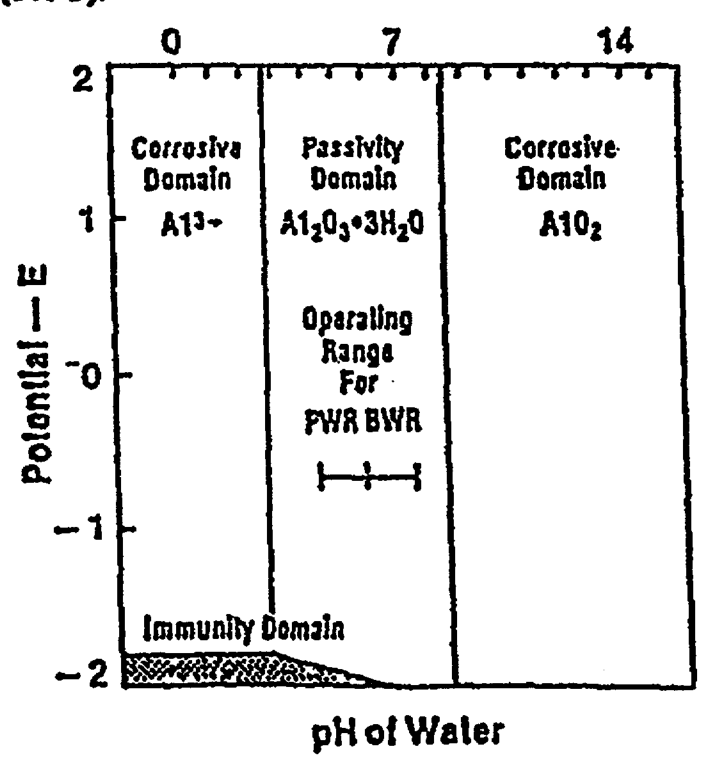


Figure 2-3
Trunnion Geometry

FIGURE WITHHELD AS SENSITIVE UNCLASSIFIED INFORMATION

DOUBLE SHOUL]DER FRONT TRUNNION

FIGURE WITHHELD AS SENSITIVE UNCLASSIFIED INFORMATION

SINGLE SHOULDER FRONT TRUNNION

Figure 2-4
Standard Stress Report Locations

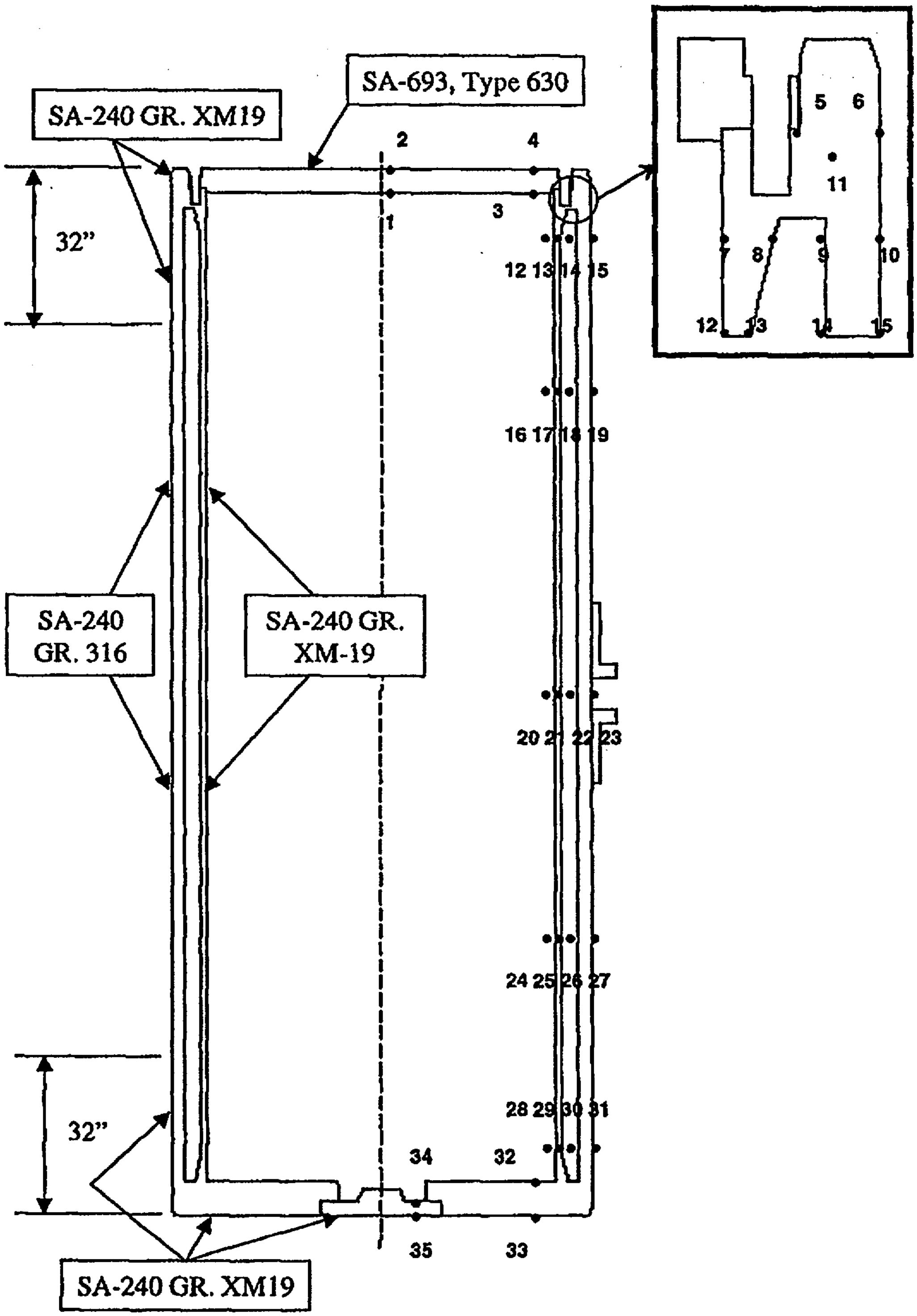


Figure 2-5
40 Inch Puncture on Lid End Loading

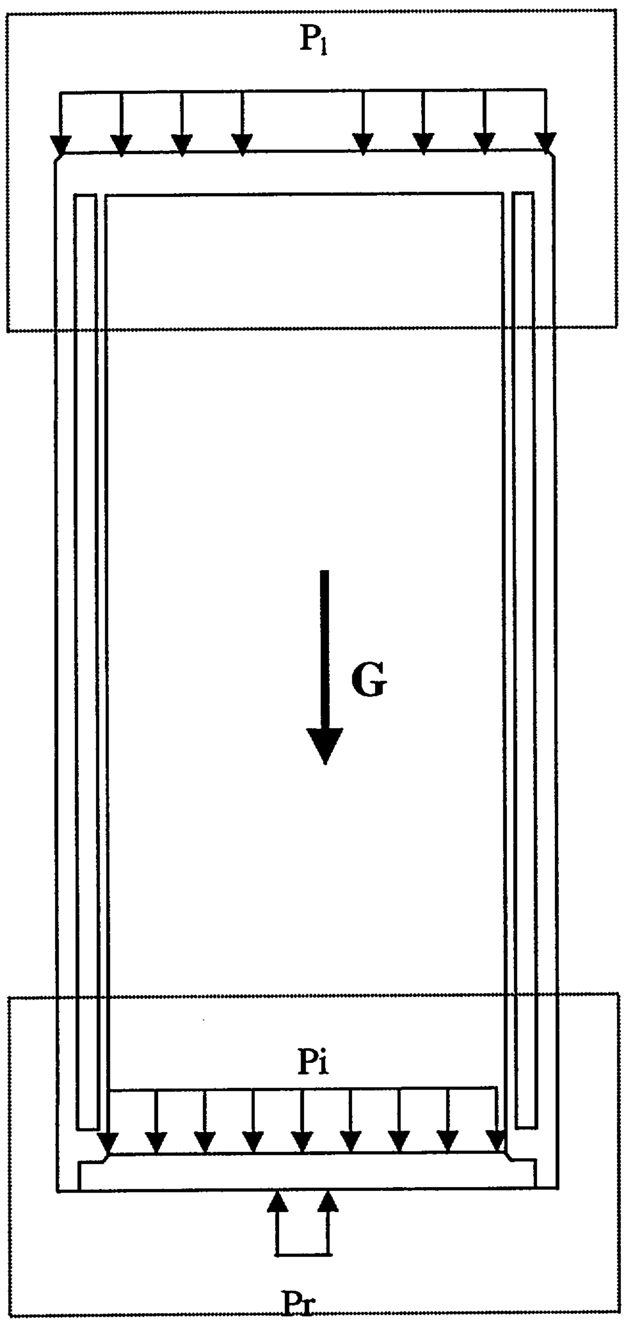


Figure 2-6
40 Inch Puncture on Bottom Ram Cover Loading