

CCA-000094

# **SAFETY ANALYSIS REPORT**

For

## **MODEL 8-120B TYPE B SHIPPING PACKAGING**

REVISION 12

March, 2017

Submitted by:



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<b>REVISION CONTROL SHEET</b>		
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1-5, 7-1, 7-4, 7-5, and 8-6 through 8-9.	Consolidated Revision 7 November 2013	Submitted to NRC October, 2013 to support issuance of Certificate of Compliance Revision 20.  Revision marks indicate changes since Consolidated Revision 3.
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## **1.0 GENERAL INFORMATION**

### **1.1 INTRODUCTION**

This Safety Analysis Report describes a reusable shipping package designed to protect radioactive material from both normal conditions of transport and hypothetical accident conditions. The package is designated the Model 8-120B package.

### **1.2 PACKAGE DESCRIPTION**

#### **1.2.1 PACKAGING**

The package consists of a steel and lead cylindrical shipping cask with a pair of cylindrical foam-filled impact limiters installed on each end. The package configuration is shown in Figure 1-1. The internal cavity dimensions are  $61 \frac{13}{16}$  inches in diameter and  $74 \frac{7}{8}$  inches high. The cylindrical cask body is comprised of a  $1 \frac{1}{2}$  inch thick external steel shell and a  $\frac{3}{4}$  inch internal steel shell. The annular space between the shells is filled with 3.35 inch thick lead. The base of the cask consists of two  $3 \frac{1}{4}$  inch thick flat circular steel plates. The cask lid consists of two  $3 \frac{1}{4}$  inch thick flat circular steel plates. The lid is fastened to the cask body with twenty 2-8 UN bolts. There is a secondary lid in the middle of the primary lid. This secondary lid is attached to the primary lid with twelve 2-8 UN bolts. A thermal shield protects the secondary lid. The thermal-shield consists of two polished stainless-steel plates that are separated by a thin air gap with stand-offs which provide an additional air gap above the secondary lid. The thermal-shield assembly is attached to the secondary lid lifting lugs with hitch-pins.

The impact limiters are 102 inches in outside diameter and extend 22 inches beyond each end of the cask. There is a 50.0 inch diameter void at each end. Each impact limiter has an external shell, fabricated from ductile low carbon steel, which allows it to withstand large plastic deformations without fracturing. The volume inside the shell is filled with a crushable shock and thermal insulating polyurethane foam. The polyurethane is sprayed into the shell and allowed to expand until the void is completely filled. The foam bonds to the shell, which creates a unitized construction for the impact limiters. The impact limiters' skin is 12 gage steel, including the upper impact limiter's weather cover. The lower impact limiter has a  $\frac{1}{2}$ " thick steel cover plate.

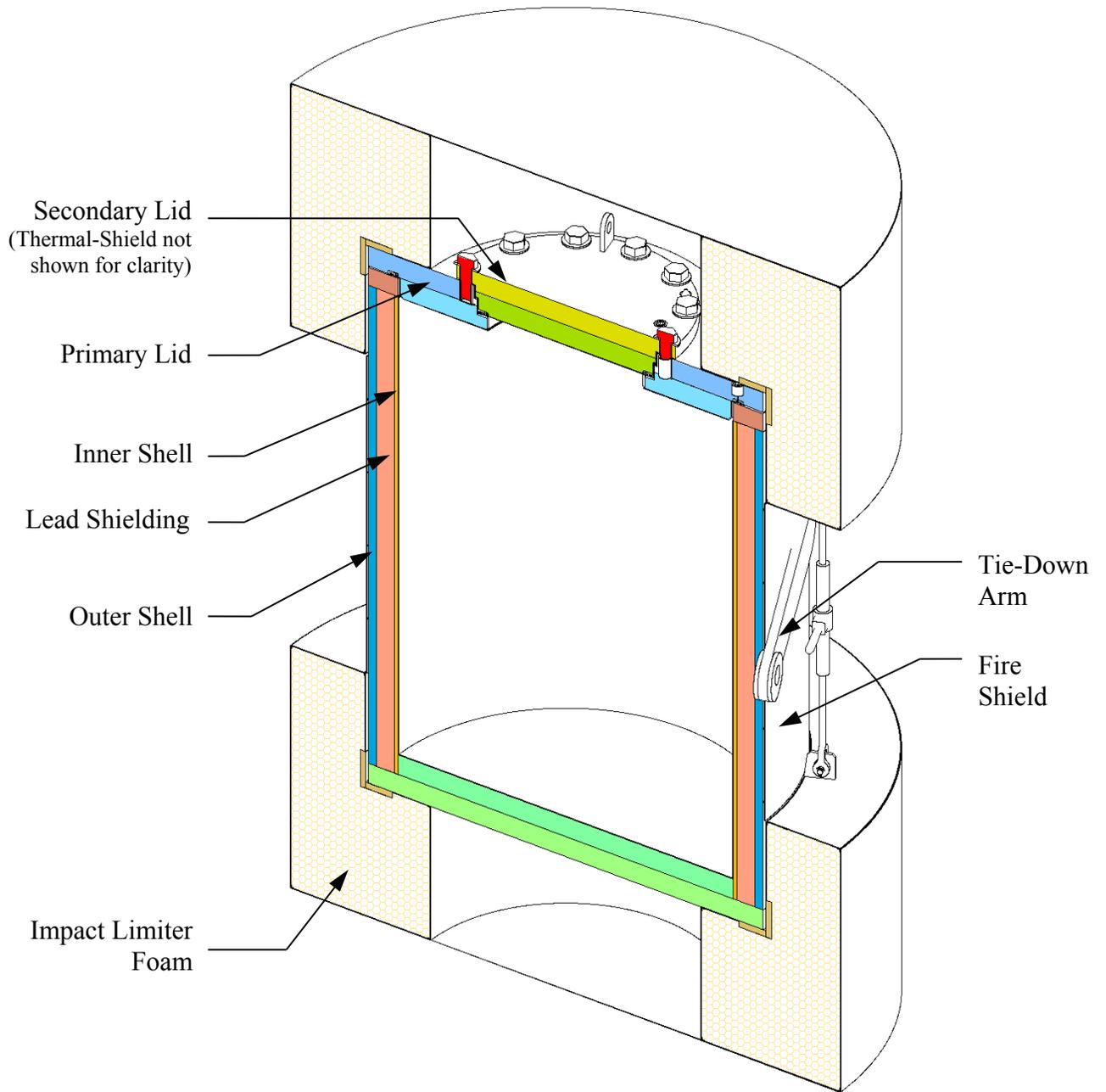


Figure 1-1 - Features of the 8-120B Cask

The properties of the foam are further described in Section 2.2. The top and bottom impact limiters are connected together by eight one-inch diameter ratchet binders. This serves to hold the impact limiters in place on the cask during shipment, while allowing easy removal of the impact limiters for loading and unloading operations.

A general arrangement drawing of the package is included in Appendix 1.3. It shows the package dimensions as well as all materials of construction.

#### 1.2.1.1 Containment Vessel

The containment vessel is formed by the carbon steel cask inner shell, primary lid, secondary lid, and associated welds, seals, and closure bolts as described in Section 4.1 and the drawings in Appendix 1.3. The containment system does not include any valves or pressure relief devices, or any features to ensure continuous venting.

#### 1.2.1.2 Neutron Absorbers

There are no materials used as neutron absorbers or moderators in the package.

#### 1.2.1.3 Package Weight

Nominal gross weight for the package is 74,000 lbs. including a maximum payload weight of 14,150 lbs.

#### 1.2.1.4 Receptacles

There are no receptacles on this package.

#### 1.2.1.5 Vent and Test Ports

Pressure test ports with manual venting features exist between the twin o-ring seals for both the primary and secondary lids. This facilitates leak testing the package in accordance with ANSI N14.5.

The vent port is provided with the same venting features for venting pressures within the containment cavity, which may be generated during transport, prior to lid removal. Each port is sealed with an elastomer gasket. Specification information for all seals and gaskets is contained in Chapter 4.

#### 1.2.1.6 Lifting Devices

Lifting devices are a structural part of the package. From the General Arrangement Drawing shown in Appendix 1.3, it can be seen that two removable lifting ears are provided, which attach to the cylindrical cask body. Three lifting lugs are also provided for removal and handling of the lid. Similarly, three lugs are provided for removal and handling of the secondary lid. Refer to Section 2.5.1 for a detailed analysis of the structural integrity of the lifting devices.

#### 1.2.1.7 Tie-downs

From the General Arrangement Drawing, shown in Appendix 1.3, it can be seen that the tie-down arms are an integral part of the external cask shell. Consequently, tie-down arms are considered a structural part of the package. Refer to Section 2.5.2 for a detailed analysis of the structural integrity of the tie-down arms.

#### 1.2.1.8 Heat Dissipation

There are no special devices used for the transfer or dissipation of heat.

#### 1.2.1.9 Coolants

There are no coolants involved.

#### 1.2.1.10 Protrusions

There are no outer or inner protrusions except for the tie-down arms described above. Lifting lugs are removed prior to transport.

#### 1.2.1.11 Shielding

Cask walls provide a shield thickness of 3.35 inches of lead and 2¼ inches of steel. Cask ends provide a minimum of 6½ inches of steel. The contents will be limited such that the radiological shielding provided (4½ inches lead equivalent) will assure compliance with DOT and IAEA regulatory requirements.

#### 1.2.1.12 Configurations

There are three configurations of the 8-120B cask.

- Configurations 1 and 2 were fabricated per the previously approved drawing Rev. 13 and differ mainly in the inclusion (Configuration 1) or lack (Configuration 2) of the optional drain port. Configuration 1 now includes sealing the drain port with the insertion and welding of a rod in the drain port. Acceptance Testing of Configurations 1 and 2 are described in Section 8.1. Fabrication of Configurations 1 or 2 after April 1, 1999 are not permitted.
- Configuration 3 does not have a drain port and the base plate is fabricated differently than Configurations 1 and 2. Acceptance Testing of Configuration 3 is described in Section 8.2.
- Configurations 1, 2 and 3 have the same Operations and Maintenance requirements and are described in Sections 7.0 and 8.3 respectively

All configurations have the same structural, thermal, containment, shielding, and criticality evaluations.

## 1.2.2 CONTENTS OF PACKAGING

### 1.2.2.1 Type form of material:

- Byproduct, source, or special nuclear material, in the form of dewatered or grossly dewatered resins<sup>1</sup>, solids, including powdered or dispersible solids, or solidified material, contained within secondary container(s); or
- Radioactive material in the form of neutron activated metals or metal oxides in solid form contained within secondary container(s).

### 1.2.2.2 Maximum quantity of material per package:

Type B quantity of radioactive material not to exceed 3000A<sub>2</sub>, 200 thermal watts, and 14,430 pounds including weight of the contents, secondary container(s) and shoring. The contents may include fissile materials provided at least one of the paragraphs (a) through (f) of 10 CFR 71.15 is met. Materials producing more than 1 x 10<sup>5</sup> neutrons/sec in the total contents, other than fissile materials as allowed in the preceding sentence, are not authorized.

The activity of beta and gamma emitting radionuclides shall not exceed the limit determined per the procedure in Chapter 7 Attachment 1.

Powdered or dispersible solid radioactive materials must have a mass of at least 60 grams or a specific activity of 50 A<sub>2</sub>/g or less.

### 1.2.2.3 Loading Restrictions

Contents shall be packaged in secondary containers. Except for close fitting contents, shoring must be placed between the secondary containers or activated components and the cask cavity to prevent movement during accident conditions of transport.

Explosives, non-radioactive pyrophorics, and corrosives (pH less than 2 or greater than 12.5), are prohibited. Pyrophoric radionuclides may be present only in residual amounts less than 1 weight percent. Materials that may auto-ignite or change phase (i.e., change from solid to liquid or gas) at temperatures less than 350°F, not including water, shall not be included in the contents. In addition, as required by 10 CFR 71.43 (d), the contents shall not include any materials that may cause any significant chemical, galvanic, or other reaction.

Powdered solid radioactive material shall not include radioactive forms of combustible metal hydrides, combustible elemental metals, i.e., magnesium, titanium, sodium, potassium, lithium, zirconium, hafnium, calcium, zinc, plutonium, uranium, and thorium, or combustible non-metals, i.e., phosphorus.

For any package containing water and/or organic substances which could radiolytically generate combustible gases, a determination must be made that, over a period of time that is twice the

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<sup>1</sup> Grossly dewatered resin is an industry term applied to resins that have not been processed to reduce the water content further than that which can be obtained by pumping water out of the liner until the pump loses suction.

expected shipping time, the hydrogen generated must be limited to a molar quantity that would be no more than 5% by volume (or equivalent limits for other flammable gases) of the secondary container gas void if present at STP (i.e., no more than 0.063 g-moles/ft<sup>3</sup> at 14.7 psia and 70°F).

The determination of hydrogen generation will be made using the methods in NUREG/CR-6673, *Hydrogen Generation in TRU Waste Transportation Packages*. NUREG/CR-6673 has equations that allow prediction of the hydrogen concentration as a function of time for simple nested enclosures and for packages containing multiple contents packaged within multiple nested confinement layers. The inputs to these equations include the bounding effective G(H<sub>2</sub>)-value for the contents, the G(H<sub>2</sub>)-values for the packaging material(s), the void volume in the containment vessel and in the confinement layers (when applicable), the temperature when the package was sealed, the temperature of the package during transport, and the contents decay heat.

For any package delivered to a carrier for transport, the secondary container must be prepared for shipment in the same manner in which the determination for gas generation is made. Shipment period begins when the package is prepared (sealed) and must be completed within twice the expected shipping time.

For any package containing materials with radioactivity concentration not exceeding that for LSA and shipped within 10 days of preparation, or within 10 days of venting the secondary container, the gas generation determination above need not be made and the shipping time restriction does not apply.

### 1.2.3 SPECIAL REQUIREMENTS FOR PLUTONIUM

Any contents that contain more than 0.74 TBq (20 Ci) of plutonium must be in solid form.

### 1.2.4 OPERATIONAL FEATURES

Refer to the General Arrangement Drawing of the package in Appendix 1.3. There are no complex operational requirements associated with the package.

### 1.3 APPENDIX

#### 8-120B Shipping Cask Drawings

- C-110-E-0007, *8-120B Shipping Cask*, Revision 23
- DWG-CSK-12CV01-EG-0001, *8-120B Cask Secondary Lid Thermal-Shield Details*, Revision 4

Drawings withheld on the basis that they are  
Security-Related Information

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## 2.0 STRUCTURAL EVALUATION

This Section identifies, describes, discusses and analyzes the structural design of the 8-120B packaging components, and safety systems for compliance with performance requirements of 10 CFR 71 (Reference 2-1).

### 2.1 DESCRIPTION OF STRUCTURAL DESIGN

The package has been designed to provide a shielded containment vessel that can withstand the loading due to the Normal Conditions of Transport, as well as those associated with the Hypothetical Accident Conditions.

The 8-120B package is designed to protect the payload from the following conditions: Transport environment, 30-foot drop test, 40-inch puncture test, 1475°F thermal exposure, and transfer or dissipation of any internally generated heat. The design of the package satisfies these requirements.

Principal elements of the system consist of:

- Containment Boundary
- Lead Shielding
- Impact Limiters

These components are identified in the drawings of Appendix 1.3. The design and function of these components in meeting the requirements of 10 CFR 71 is discussed below.

Figure 2-1 shows the nomenclature of the components of the cask used throughout this SAR.

#### 2.1.1 DISCUSSION

##### Containment Boundary

The containment boundary of the package is made up of the cask body and the lid. They are fabricated of ASTM A516, Grade 70 steel. The cask body consists of two shells, which envelop a lead shield. The top end of the cask body consists of a bolting ring that provides sealing and bolting surfaces for the lid. The bottom end of the cask body consists of two baseplates. A removable primary lid is attached to the cask body with twenty (20) equally spaced 2”– 8UN bolts. A secondary lid is centered and attached to the primary lid with twelve (12) equally spaced 2”– 8UN bolts. The lid-to-cask body and lid-to-lid joints are each sealed by pairs of solid elastomeric O-rings. The cask containment boundary consists of the inner shell, the outer baseplate, the bolting ring, the inner O-ring, and the lids. This boundary is penetrated by the vent port. Thus, the parts of this port up to the seal are also considered to be on the containment boundary. Figure 2-2 shows the containment boundary of the package.

## Shielding

The space between the two shells, discussed above, is filled with lead. This lead shielding is subjected to a gamma scan inspection to assure lead integrity. The designed thickness assures that no biological hazard is presented by the package and all shielding requirements of 10 CFR 71 are met.

## Impact Limiters

The impact limiters are designed to protect the package from damage during the HAC drop test and to provide thermal protection during the hypothetical fire accident condition.

They are constructed of fully welded steel shells filled with foamed-in-place closed-cell rigid polyurethane foam. The impact limiter shells and internal foam cores deform and absorb energy during free drop impacts. Eight circumferentially located attachment points are provided to interconnect the two impact limiters. The steel plates that cover the central hollow regions of the upper and lower impact limiters are designed to remain intact and attached to the impact limiters during NCT. However, these cover plates have no significant effect on the energy-absorption characteristics of the impact limiters during the NCT and HAC free drop tests, and therefore they are not considered in the NCT and HAC free drop analyses.

Detailed discussions of all components and materials utilized in the 8-120B Package including stress, thermal, and pressure calculations are contained in the applicable sections of this SAR.

### 2.1.2 DESIGN CRITERIA

The package is designed to satisfy the requirements of 10 CFR 71.71 under the normal conditions of transport (NCT) and hypothetical accident conditions (HAC). Compliance with the “General Standards for All Packages” specified in 10 CFR 71.43 and the “Lifting and Tie-Down Standards” specified in 10 CFR 71.45 are discussed in Section 2.4 and 2.5 respectively. Table 2-1 summarizes the NCT and HAC loading and their combination with various initial conditions, used for the design assessment of the 8-120B package. Table 2-1 has been developed from the recommendations of Regulatory Guide 7.8 (Reference 2-2).

The allowable stresses in the package containment boundary (other than bolting) are based on the criteria of Regulatory Guide 7.6 (Reference 2-3).

The allowable stresses under normal conditions (RG 7.6, Regulatory Position 2) are:

$$\begin{aligned} \text{Primary membrane stresses} &< S_m \\ \text{Primary membrane + bending stresses} &< 1.5 S_m \end{aligned}$$

Where,  $S_m$  = design stress intensity

Based on ASME Code (Reference 2-4), Section II, Appendix 1, Article 1-100, the design stress intensity is defined to be:

$$S_m = \text{smaller of } (2/3 S_y \text{ or } S_u/3.5)$$

Where,  $S_y$  = material yield stress

$S_u$  = material ultimate strength

The allowable stresses under hypothetical accident conditions (RG 7.6, Regulatory Position 5), are:

Primary membrane stresses < smaller of (2.4  $S_m$  or 0.7  $S_u$ )

Primary membrane + bending stresses < smaller of (3.6  $S_m$  or  $S_u$ )

Regulatory Guide 7.6 does not provide guidance for the bolting allowable stress limits. The allowable stress in the bolting for the NCT loading is established to be similar to that for the non-bolting components. For the HAC conditions it is established based on the requirements of ASME B&PV Code, Section III, Appendix F, Article F-1335.

For HAC loading, average tensile stress in the bolts shall not exceed smaller of 0.7  $S_u$  or  $S_y$ . The direct tension plus bending, excluding stress concentration shall not exceed  $S_u$ . The average bolt shear stress shall not exceed the smaller of 0.42  $S_u$  or 0.6  $S_y$ . The combined tensile and shear stress to corresponding allowable stress ratio shall satisfy the following equation:

$$\left(\frac{f_t}{F_{tb}}\right)^2 + \left(\frac{f_v}{F_{vb}}\right)^2 \leq 1.0$$

Where,  $f_t$  = computed tensile stress

$f_v$  = computed shear stress

$F_{tb}$  = allowable tensile stress

$F_{vb}$  = allowable shear stress

Table 2-2 lists the allowable stresses for various stress components under NCT and HAC loading conditions. Allowable values for all the materials that are used for the construction of the structural components of the cask are listed in this table. It should be noted that the allowable stress values listed in this table are applicable to elastically calculated stresses only.

Table 2-3 lists the definition of the regulatory and/or the ASME code definition of stress components. This table also explains how these definitions have been incorporated into the 8-120B Cask analyses documented in this SAR.

The acceptance criterion for prevention of buckling is based on the criteria detailed in Section 2.7.1.7. Factors of safety of 2.0 for the normal conditions of transport and 1.34 for hypothetical accident conditions have been used in the buckling evaluation of the cask.

The primary structural components of the package are fabricated with ASTM A516, Grade 70 with supplemental nil ductility temperature (NDT) requirements. Fracture toughness requirements specified in Regulatory Guide 7.11 (Reference 2-6), "Fracture Toughness Criteria for Ferritic Steel Shipping Casks Containment Vessels with a Maximum Wall Thickness of Four Inches", (June 1991) and NUREG/CR-1815, "Recommendations for Protecting Against Failure by Brittle Fracture in Ferritic Steel Shipping Containers up to Four Inches Thick" (August 1981)

(Reference 2-18) are both complied with. Section 2.6.2 evaluates the critical components of the cask.

The design criteria, used for the evaluation of the impact limiters, is based on a proprietary methodology developed by EnergySolutions and is fully documented in EnergySolutions proprietary document ST-551 (Reference 2-5).

### 2.1.3 WEIGHT AND CENTER OF GRAVITY

The following is a nominal estimate of the weight of various components of the 8-120B package.

Cask Body.....	=	42,220 lb	
Lid.....	=	7,080 lb	
Payload.....	=	14,150 lb	
Impact Limiters (2).....	=	4,860 lb	(each)
Misc.....	=	830 lb	
Package.....	=	74,000 lb	

The C.G. of the package is located at approximately the same location as the geometric center of the package. The maximum possible axial shift of the package center of gravity due to eccentric payload configurations is small (i.e., approximately 6 inches, or 5% of the package length, if the payload is conservatively modeled as a solid steel cylinder at one end of the cask cavity), and therefore, will not significantly affect the package structural response.

### 2.1.4 IDENTIFICATION OF CODES AND STANDARDS FOR PACKAGE DESIGN

The 8-120B package is designed as a Type-B, Category II package per U.S. NRC Regulatory Guide 7.11 (Reference 2-6). Based on the recommendations of NUREG/CR-3854 (Reference 2-7), the fabrication, examination, and inspection of the containment boundary components of a Category II package should be per ASME B&PV Code Section III, Subsection ND.

## 2.2 MATERIALS

The material properties of the cask components used in the analysis of the 8-120B package are provided in Table 2-4. This table provides the temperature dependent yield stress, ultimate tensile strength, allowable membrane stress, Young’s modulus, and mean coefficient of thermal expansion for stainless steel, carbon steel and lead. The thermal properties of these materials that were used for the evaluation of temperature distribution in the cask are provided in Section 3.2.1.

### 2.2.1 MATERIAL PROPERTIES AND SPECIFICATIONS

All the components of the cask body are specified to be ASTM A516 Grade 70 steel, except for the seal rings that are specified to be ASTM A-240 Type 304L stainless steel. These materials are approved for the construction of the ASME Section III, Subsection ND vessels. The material properties for these materials have been obtained from the ASME Code.

The bolting used for connecting the primary lid to the cask body and the secondary lid to primary lid has been specified to be ASTM A-354 Gr. BD material. This material is approved for use in

the ASME Section III, Subsection ND vessels. The material properties for this material have been obtained from the ASME Code.

The poured in place lead shielding is specified to be ASTM B-29 lead. This material has been used in numerous radioactive shipping casks over the last 30 years. The material properties for lead are obtained from NUREG/CR-0481 (Reference 2-8).

Elastomeric seals are used in the primary lid, secondary lid, and in the cask vent port for containment. The allowable elastomer type(s) and temperature resistances are specified in the drawings in Appendix 1.3, and in Section 8.2.5.

The impact limiters are filled with closed-cell rigid polyurethane foam. The required foam properties are specified in the drawings in Appendix 1.3, and in Section 8.2.5. The General Plastics Technical Manual (Reference 2-9) provides the stress-strain properties of various density foams. The safety evaluations use the 25 lb/ft<sup>3</sup> nominal density foam's stress-strain properties perpendicular-to-rise direction as the required property. However, in the analyses of the impact limiters both parallel-to-rise and perpendicular-to-rise direction properties have been used, as appropriate. These properties are shown in Figures 2-3 and 2-4.

## 2.2.2 CHEMICAL GALVANIC AND OTHER REACTIONS

The 8-120B cask is fabricated from carbon steel, stainless steel and lead and has impact limiters containing polyurethane foam. These materials will not cause chemical, galvanic, or other reactions in air or water environments. These materials are commonly used in radioactive material (RAM) packages for transport of radioactive wastes and have been so used for many years without incident. The materials of construction were specifically selected to ensure the integrity of the package will not be compromised by any chemical, galvanic or other reactions.

### 2.2.2.1 Materials of Construction

The 8-120B package is primarily constructed of ASTM A516 Grade 70 steel with the tie-down arms and lifting ears made from ASTM A514 or A517 steel. This material is painted and is corrosion-resistant to most environments. The weld material and processes have been selected in accordance with the ASME Boiler and Pressure Vessel Code to provide as good or better material properties than the base material. The polyurethane foam in the impact limiters is closed-cell foam that is very low in free halogens. The foam material is sealed inside a dry cavity in each impact limiter, to prevent exposure to the elements. Even if moisture were available for leaching trace chlorides from the foam, very little chloride would be available, since the material is closed-cell foam and water does not penetrate the material to allow significant leaching. The solid elastomeric O-ring seals contain no corrosive material that would adversely affect the packaging.

### 2.2.2.2 Materials of Construction and Payload Compatibility

The typical contents of the 8-120B will be similar to the primary materials of construction, i.e., carbon steel, contained in a secondary container typically made of carbon steel. Corrosive materials are prohibited from the payloads. The steel contents of the cask will not react with the cask materials of construction. Water will not react with the painted steel cask body.

### 2.2.3 EFFECTS OF RADIATION ON MATERIALS

The material from which the package is fabricated (carbon steel, stainless steel, lead, ethylene propylene or butyl rubber, and foam) along with the contents exhibit no measurable degradation of their mechanical properties under a radiation field produced by the contained radioactivity. Polyurethane can absorb more than  $10^8$  rads without damage (see Reference 2-9). Section 4.1 discusses radiation exposure to the containment seal materials. Over the lifetime of these components, the absorbed dose will not result in damage.

## 2.3 FABRICATION AND EXAMINATION

As discussed in Section 2.1.4, the 8-120B packaging is designed as a Category II container. To assure the fabrication and examination processes used for the package (e.g. material procurement and control, fitting, welding, lead pouring, foaming, examining, testing, personnel qualification, etc.) are appropriately controlled, EnergySolutions will apply its USNRC approved 10 CFR 71 Subpart H Quality Assurance Program, which implements a graded approach to quality based on a component's or material's importance to safety consistent with the guidance provided in NUREG/CR-6407 (Reference 2-22), NUREG/CR-3854 (Reference 2-7), NUREG/CR-3019 (Reference 2-10) and Industry practice.

### 2.3.1 FABRICATION

As specified in the above referenced documents, fabrication of the 8-120B containment components will be based on ASME B&PV Code, Section III, Subsection ND and that of the non-containment components will be based on ASME B&PV Code, Section III, Subsection NF.

### 2.3.2 EXAMINATION

As specified in the above referenced documents, examination of the 8-120B containment components will be based on ASME B&PV Code, Section III, Subsection ND-5000 and that of the non-containment components will be based on ASME B&PV Code, Section III, Subsection ND-5000 or NF-5000.

Section 8.0 provides additional information on examination and acceptance criteria for the packaging.

## 2.4 GENERAL REQUIREMENTS FOR ALL PACKAGES

10 CFR 71.43 establishes the general standards for packages. This section identifies these standards and provides the bases that demonstrate compliance.

### 2.4.1 MINIMUM PACKAGING SIZE

10 CFR 71.43(a) requires that:

“The smallest overall dimension of a package must not be less than 10 cm (4”).”

The smallest overall dimension of the package is the diameter of the cask (73.20"), which is larger than 4". Therefore, the minimum package size requirement is satisfied.

#### 2.4.2 TAMPER-INDICATING FEATURES

10 CFR 71.43(b) requires that:

"The outside of a package must incorporate a feature, such as a seal, which is not readily breakable, and which, while intact, would be evidence that the package has not been opened by unauthorized persons."

The 8-120B package incorporates a tamper resistant seal that is installed between the cask body and each of the two impact limiters after the package has been closed. Breach of these seals would indicate that the package has been tampered with by unauthorized persons.

#### 2.4.3 POSITIVE CLOSURES

10 CFR 71.43(c) requires that:

"Each package must include a containment system securely closed by a positive fastening device that cannot be opened unintentionally or by a pressure that may arise within the package,"

The 8-120B package uses 20 bolts that fasten the primary lid to the cask body and 12 bolts to attach the secondary lid to the primary lid. Additionally, the vent port is closed with the help of threaded attachment. These closure components are encompassed within the two impact limiters when the package is prepared for the shipment. They can not be opened unintentionally. Also, it has been shown that the MNOP produces very small bolt loads. These loads are much smaller than the bolt pre-tension and are not capable of loosening them.

### 2.5 LIFTING AND TIE-DOWN STANDARDS FOR ALL PACKAGES

10 CFR 71.45 specifies the requirements for the lifting and tie-down devices that are "structural parts of the package". The 8-120B package is designed to be lifted with two removable lifting ears that are attached to the side of the cask. The primary and secondary lids are each furnished with three lifting lugs by which the lids may be removed from the cask. The cask is also equipped with four tie-down arms that are used for the tie-down of the 8-120B cask during transportation.

#### 2.5.1 LIFTING DEVICES

According to 10 CFR 71.45(a), "any lifting device, that is a structural part of the package must be designed with a minimum safety factor of three against yield when used to lift the package in the intended manner and it must be designed so that failure of any lifting device under excessive load would not impair the ability of the package to meet other requirements of this subpart."

The 8-120B Cask is designed to be lifted with the help of a pair of lifting lugs. Depending on the crane characteristics, a dynamic load amplification may result due to such lifting. The dynamic load factor for a typical crane is between 1.0 and 1.1. For conservatism a dynamic load factor of 1.3 is

used for the evaluation of the lifting assembly. It should be noted that the users of this cask shall perform an evaluation based on their crane characteristics to obtain the dynamic load factor and ensure that it is less than 1.30 in order to use this cask.

### 2.5.1.1 Cask Lifting Ears

#### (1) Cask Lifting Ear Eye Tear-out Stresses

The cask lifting ears can be used only with the impact limiters removed. Therefore, the total lifted weight is:

$$74,000 - 2 \times 4,860 = 64,280 \text{ lbs}$$

With the dynamic amplification of 1.3 the load is:

$$W = 1.3 \times 64,280 = 83,564 \text{ lbs} \quad \text{say } 84,000 \text{ lbs}$$

For three times the weight of the cask, the vertical ear load is:

$$P_v = \frac{3W}{2 \text{ ears}} = \frac{3 \times 84,000}{2} = 126,000 \text{ lb/ear}$$

The critical tear-out area for the cask lifting ear is determined from Figure 2-6 as:

$$A_{\text{tear-out}} = 2 \times t \times d$$

Where:

t = section thickness = 1.0 in.

d = tear-out distance = 1.6 in.

$$A_{\text{tear-out}} = 3.20 \text{ in}^2$$

As previously determined, the vertical force applied to the cask lifting ear is 126,000 lbs. This results in a nominal tear-out stress of:

$$\tau = \frac{P}{A_{\text{tear-out}}} = \frac{126,000}{3.20} = 39,375 \text{ psi}$$

The allowable shear stress is  $0.6 \times \text{Allowable Normal Stress} = 0.6 \times S_y$

The tie-down arms and lifting ears are fabricated from ASTM A514 or ASTM A517 material with minimum yield stress of 90,000 psi. Therefore,

$$\tau_{\text{allowable}} = 0.6 \times 90,000 = 54,000 \text{ psi}$$

This corresponds to a factor of safety of:

$$F.S. = \frac{\tau_{\text{allowable}}}{\tau} = \frac{54,000}{39,375} = 1.37$$

(2) Lifting, Ear Mounting Plate Weld Stresses

The stresses in the welds attaching the lifting ear mounting plate to the cask outer shell are found by applying the bolt shear and tensile forces to the weld around the perimeter of the plate. The shear stress in the weld due to the shear force is given by,

$$\tau_1 = \frac{V}{A_w}$$

Where:

$$A_w = \text{effective weld area} \\
 = 2 \times (b + L) \times t \times 1.0 = 2 \times 19.5 \times 1.375 \times 1.0 = 53.625 \text{ in}^2 \\
 b = \text{plate width} = 7.5 \text{ in.} \\
 L = \text{plate length} = 12 \text{ in.} \\
 t = \text{weld leg dimension} = 1.375 \text{ in.} \\
 V = \text{shear force} = 126,000 \text{ lb} \\
 \tau_1 = 2,350 \text{ psi}$$

The shear stress in the weld due to the tensile force is given by:

$$\tau_2 = \frac{F}{A_w}$$

Where:

$$A_w = \text{weld area as defined above} = 53.625 \text{ in}^2 \\
 F = \text{tensile force} = 7,298 \text{ lb. [Calculated in Section 2.5.1.1(4)]} \\
 \tau_2 = 136 \text{ psi}$$

The maximum shear stress is given by:

$$\tau_{\text{max}} = \sqrt{\tau_1^2 + \tau_2^2} = 2,354 \text{ psi}$$

This corresponds to a factor of safety for the welds of:

$$F.S. = \frac{\tau_{\text{allowable}}}{\tau_{\text{max}}} = \frac{22,800}{2,354} = 9.69$$

(3) Outstanding Lifting Ear Plate Weld Stresses

The outstanding lifting ear plate is attached to the lower flush plate with a vertical double vee weld, as shown in Figure 2-6.

The shear stress in the weld due to the shear force is given by:

$$\tau_3 = \frac{V}{A_w}$$

Where:

$A_w$  = effective weld area =  $2 \times t \times L$   
 $t$  = Weld leg dimension = 0.5 in  
 $L$  = Plate length = 12.0 in  
 $V$  = shear force = 126,000 lb

$$\tau_3 = 10,500 \text{ psi}$$

The shear stress in the weld due to the tensile force is found from:

$$\tau_4 = \frac{F}{A_w}$$

Where:

$A_w$  = effective weld area as defined above  
 $F$  = tensile force = 7,298 lb. [Calculated in Section 2.5.1.1(4)]

$$\tau_4 = 608 \text{ psi}$$

The maximum shear stress is given by:

$$\tau_{\max} = \sqrt{\tau_3^2 + \tau_4^2} = 10,518 \text{ psi}$$

This corresponds to a factor of safety for the welds of:

$$F.S. = \frac{\tau_{\text{allowable}}}{\tau_{\max}} = \frac{22,800}{10,518} = 2.17$$

#### (4) Bolt Stresses

The equations of equilibrium for the lifting ear shown in Figure 2-5 are:

Summation of Forces:

$$\begin{aligned} \text{Horizontal:} & \quad F + P_H - R_T = 0 \\ \text{Vertical:} & \quad P_V - V = 0 \end{aligned}$$

Summation of Moments about point O:

$$25 \times F + 2.688 \times P_H - 5 \times P_V + 2 \times V = 0$$

Given:

$$P_v = 126,000 \text{ lbs}$$

$$P_H = \frac{P_v}{\tan 60} = 72,746 \text{ lbs}$$

Then:

$$V = 126,000 \text{ lb.}$$

$$F = (1/25)(5 \times P_v - 2.688 \times P_H - 2 \times V) \\ = 7,298 \text{ lb.}$$

$$R_T = 80,044 \text{ lb.}$$

Each lifting ear is attached to the cask, as shown in Figure 2-6, using four 1-1/4 – 7 UNC-2A, 2-3/4 inch long ASTM A354 Grade BD hex head bolts. The stress area for each bolt is 0.969 in<sup>2</sup>.

The shear force, V, will be carried by four bolts, so the shear stress in the bolts is:

$$\tau = \frac{126,000}{4 \times 0.969} = 32,508 \text{ psi}$$

The tensile force, F, will be carried by the four bolts. The resulting tensile stress will be:

$$\sigma_t = \frac{F}{4 \times 0.969} = 1,883 \text{ psi}$$

The maximum principal stresses in the bolt are found by:

$$\sigma_p = \frac{\sigma_t}{2} \pm \sqrt{\left(\frac{\sigma_t}{2}\right)^2 + \tau^2} = \frac{1,883}{2} \pm \sqrt{\left(\frac{1,883}{2}\right)^2 + (32,508)^2}$$

Thus:

$$\sigma_{p1} = 33,463 \text{ psi}$$

$$\sigma_{p2} = -31,580 \text{ psi}$$

The maximum shear stress is given by:

$$\tau_{\text{maximum}} = \frac{\sigma_{p1} - \sigma_{p2}}{2} = 32,522 \text{ psi}$$

The yield stress for ASTM A354, Grade BD material bolts is 130,000 psi. Therefore, the allowable shear stress is:

$$\tau_{allowable} = 0.6 \times \text{Allowable Normal Stress} = 0.6 \times S_y$$

The factor of safety for the bolts is:

$$F.S. = \frac{\tau_{allowable}}{\tau_{maximum}} = \frac{0.6 \times 130,000}{32,522} = \frac{78,000}{32,522} = 2.40$$

(5) Threads - Cask Metal

Because the cask material is weaker than the bolt material, failure will occur at the root of the cask material threads. From Reference 2-19, the equation for the length of thread engagement required to develop full strength of the threads is:

$$L_e = \frac{S_{st} \times 2 \times A_s}{S_{nt} \times \pi \times n \times D_{min} \left[ \left( \frac{1}{2 \times n} \right) + 0.57735 \times (D_{min} - E_{nmax}) \right]}$$

Where:

$$D_{min} = \text{Min. O.D. of bolt, in.} \\ = 1.2314 \text{ in.}$$

$$E_{nmax} = \text{Max. P.D. of cask threads, in.} \\ = 1.167 \text{ in.}$$

$$S_{st} = \text{Tensile Strength of bolt material, psi} \\ = 150,000 \text{ psi}$$

$$n = \text{Threads per inch} \\ = 7.0 \text{ threads/in.}$$

$$A_s = \text{Stress area of bolt threads, in}^2 \\ = 0.969 \text{ in}^2$$

$$S_{nt} = \text{Tensile strength of cask material, psi} \\ = 70,000 \text{ psi}$$

$L_e$  = Length of thread engagement required to develop full strength, in.

$$L_e = \frac{150,000 \times 2 \times 0.969}{\pi \times 70,000 \times 7 \times 1.2314 \times \left[ \left( \frac{1}{2 \times 7} \right) + 0.57735 \times (1.2314 - 1.167) \right]} = 1.41 \text{ in Deep}$$

The bolt engagement provided in the design is  $2.75 - 1 = 1.75$  inch, which is larger than 1.41 inch required.

(6) Cask Lifting Ear Stress Summary

The results of the cask lifting ear stress analyses are summarized below from Sections 2.5.1.1 (1) to 2.5.1.1 (5):

<u>Location</u>	<u>Max. Shear Stress Memb.+Bending (psi)</u>	<u>Factor of Safety</u>
Lifting ear tear-out	39,375	1.37
Lifting ear mounting plate (weld)	2,354	9.69
Outstanding lifting ear plate (weld)	10,518	2.17
Bolt	32,522	2.40

(7) Failure of the Cask Lifting Ears under Excessive Loads

From the stress summary presented above it is observed that the lifting ear design has the minimum margin of safety against the tear-out. Therefore, under excessive loading the failure of the lifting ear will occur by tear-out at the hole. This will not impair the ability of the package to meet other regulatory requirements.

2.5.1.2 Primary and Secondary Lid Lifting Lugs

The primary and secondary lid lifting lugs have the same design and are illustrated in Figures 2-7 and 2-8. They are sized such that the combined weight of the primary and secondary lids may be lifted from either the secondary lift lugs or the primary lift lugs. These lugs are made of ASTM A516 Gr70 material.

(1) Weight Analysis

Weights of the primary and secondary lids are as follows:

Primary lid (including bolts)	5,180 lbs
Secondary lid	2,140 lbs
Total lid weight	7,320 lbs.

The effective weight to be lifted by each lug,  $P_v$  with the dynamic load factor of 1.3, is therefore determined as:

$$P_v = \frac{3 \times 1.3 \times 7,320}{3 \text{ lugs}} = 9,516 \text{ lbs.}$$

Considering a 45° lift angle, the total load per lug (see Figure 2-8) is determined as:

$$P = \frac{P_v}{\cos 45} = \frac{9,516}{0.707} = 13,460 \text{ lbs}$$

This results in a shear force of:

$$P_H = P \cos 45 = 13,560 \times 0.707 = 9,516 \text{ lbs}$$

## (2) Lifting Lug Tear-out Stress Analysis

The critical section for lifting lug tear-out was determined to be as shown in Figure 2-9. Numerically, this area is:

$$A_{shear} = 2 \times L \times t$$

Where:

L = length of tear-out section = 1.1875 in.

t = Section thickness = 0.75 in.

$$A_{shear} = 1.78 \text{ in}^2$$

As previously determined in Section 2.5.1.2 (1), the total cable force is 13,460 lbs. This results in a shear stress due to tear-out of:

$$\tau = \frac{P}{A_{shear}} = \frac{13,460}{1.78} = 7,562 \text{ psi}$$

These lugs are fabricated from ASTM A516 Grade 70 material with minimum yield stress of 38,000 psi. Therefore the allowable shear stress is:

$$\tau_{allowable} = 0.6S_y = 0.6 \times 38,000 = 22,800 \text{ psi}$$

This translates into a factor of safety of:

$$F.S. = \frac{\tau_{allowable}}{\tau} = \frac{22,800}{7,562} = 3.02$$

## (3) Base Stresses

The tensile stress at the bottom of the lifting lug as shown on Figure 2-8 is:

$$\sigma_{tensile} = \frac{P_v}{A_b}$$

Where:

$$\begin{aligned}A_b &= \text{base area} = w \times t \text{ in}^2 \\w &= \text{lug width} = 4 \text{ in.} \\t &= \text{lug thickness} = 0.75 \text{ in.} \\P_v &= \text{vertical reaction} = 9,516 \text{ lbs.}\end{aligned}$$

$$\sigma_{tensile} = \frac{9,516}{3} = 3,172 \text{ psi}$$

The bending stress, maximum at the bottom outer edge of each lug, is:

$$\sigma_{bending} = \frac{M \times c}{I}$$

Where:

$$\begin{aligned}M &= \text{bending moment} = 3 \times P_H = 3 \times 9,516 = 28,548 \text{ in-lbs} \\c &= \text{distance to neutral axis} = 2 \text{ in.} \\I &= \text{moment of inertia} = \frac{b \times h^3}{12} \\b &= \text{lug thickness} = 0.75 \text{ in.} \\h &= \text{lug height} = 4 \text{ in.}\end{aligned}$$

$$\sigma_{bending} = \frac{(28,548 \times 2)}{\frac{0.75 \times 4^3}{12}} = 14,274 \text{ psi}$$

At the outer edge of the lift ear, the bending stress will add to the tensile stress to produce a total tensile stress of:

$$\sigma_{total} = \sigma_{bending} + \sigma_{tensile} = 14,274 + 3,172 = 17,446 \text{ psi}$$

The shear stress at the bottom of the lift ear is:

$$\tau = \frac{P_H}{A_{bs}}$$

Where:

$$\begin{aligned}P_H &= \text{shear force} = 9,516 \text{ lb.} \\A_{bs} &= \text{base area} = 3 \text{ in}^2 \\ \tau &= 3,172 \text{ psi}\end{aligned}$$

The effects of the shear and total tensile stresses are combined to form the principal stresses for the lifting ears as follows:

$$\sigma_{p1}, \sigma_{p2} = \frac{\sigma_{total}}{2} \pm \left[ \left( \frac{\sigma_{total}}{2} \right)^2 + (\tau)^2 \right]^{1/2}$$

Thus,

$$\begin{aligned} \sigma_{p1} &= 18,005 \text{ psi} \\ \sigma_{p2} &= -559 \text{ psi} \end{aligned}$$

The maximum shear stress will be:

$$\tau_{maximum} = \frac{\sigma_{p1} - \sigma_{p2}}{2} = 9,282 \text{ psi}$$

Using an allowable shear = 0.6 × S<sub>y</sub> and a yield stress of 38,000 psi, therefore the allowable shear stress is:

$$\tau_{allowable} = 0.6 \times 38,000 = 22,800 \text{ psi}$$

The factor of safety will be:

$$F.S. = \frac{\tau_{allowable}}{\tau_{maximum}} = \frac{22,800}{9,282} = 2.46$$

#### (4) Lifting Lug Stress Analysis at Pin Hole

The maximum tensile stress in the lifting lug occurs in the section of least cross-sectional area, as shown in Figure 2-10. Numerically, this area is found to be:

$$A = (W - D) \times t$$

Where:

$$\begin{aligned} W &= \text{width of lifting lug at hole centerline} = 4.0 \text{ in.} \\ D &= \text{diameter of hole} = 1.63 \text{ in.} \\ t &= \text{plate thickness} = 0.75 \text{ in.} \\ A &= 1.78 \text{ in}^2 \end{aligned}$$

From Section 2.5.1.2(1), the shear and tensile forces were determined as:

$$P_H = P_V = 9,516 \text{ lbs.}$$

This translates into a nominal shear and tensile stress of:

$$\tau = \sigma_t = \frac{P_H}{A} = \frac{P_v}{A} = \frac{9,516}{1.78} = 5,346 \text{ psi}$$

Combining the effects of the shear and tensile stresses to form the principal stresses yields:

$$\sigma_{p1}, \sigma_{p2} = \frac{\sigma_t}{2} \pm \left[ \left( \frac{\sigma_t}{2} \right)^2 + \tau^2 \right]^{1/2} = \frac{5,346}{2} \pm \left[ \left( \frac{5,346}{2} \right)^2 + 5,346^2 \right]^{1/2}$$

Thus,

$$\sigma_{p1} = 8,650 \text{ psi}$$

$$\sigma_{p2} = -3,304 \text{ psi}$$

The maximum shear stress is found to be:

$$\tau_{\text{maximum}} = \frac{\sigma_{p1} - \sigma_{p2}}{2} = 5,977 \text{ psi}$$

These lugs are fabricated from ASTM A516 Grade 70 material with minimum yield stress of 38,000 psi. Therefore the allowable shear stress is:

$$\tau_{\text{allowable}} = 0.6S_y = 0.6 \times 38,000 = 22,800 \text{ psi}$$

This translates into a factor of safety of:

$$F.S. = \frac{\tau_{\text{allowable}}}{\tau_{\text{maximum}}} = \frac{22,800}{5,977} = 3.81$$

#### (5) Primary and Secondary Lid Lifting Lug Stress Summary

The results of the lifting lug stress analyses are summarized as follows:

<u>Location</u>	<u>Max. Shear Stress</u>	
	<u>Memb. + Bending (psi)</u>	<u>Factor of Safety</u>
Lug tear-out	7,562	3.02
Base	9,282	2.46
At pin hole	5,977	3.81

## 2.5.2 TIE-DOWN DEVICES

The cask is equipped with four tie-down arms that are used for the tie-down of the 8-120B cask during transportation (Figure 2-11). The transportation of the packages in the United States is controlled under the provisions of 49 CFR 393 (Reference 2-12). Loadings are specified by 49 CFR 393.102 for minimum performance criteria for cargo securement devices and systems. However, 10 CFR 71.45(b) requires that:

“If there is a system of tie-down devices that is a structural part of the package, the system must be capable of withstanding, without generating stress in any material of the package in excess of its yield strength, a static force applied to the center of gravity of the package having a vertical component 2 times the weight of the package with its contents, a horizontal component along the direction in which the vehicle travels of 10 times weight of the package with contents, and a horizontal component in the transverse direction of 5 times the weight of the package with its contents.”

Since the 10 CFR 71 loading on the tie-down system is much more severe than the 49 CFR 393 loading, it is used for the evaluation of the 8-120B package for the transportation conditions.

### Description of the Tie-Down Device

The package has been provided with two 1-1/2” thick steel plates (tie-down arms) which are welded to the external shell of the cask body. The steel plates are used for tying the package down. They project outward from the cask in four directions so as to allow specially designed rigging components to be connected to the ends of the tie-down arms. Four shear blocks prevent movement of the base of the package.

The geometric configuration of the tie-down system was selected such that:

- (1) The resultant tie-down arm tensile loads are tangent to the cask surface in order to minimize the effects of out-of-plane stresses in the cask shell. (See Figure 2-12 for determination of the tie-down geometry).
- (2) The shear block loads are transferred to the cask surface via compression in the lower overpack.

### Tie-Down Forces

The analytical model for determining the loads required preventing rotation and translation of the package due to the applied loads is shown in Figure 2-13. The shear block forces at the bottom of the package are represented by the orthogonal components of a single force vector,  $S$ , making an angle of  $\theta$  with the global  $y$ -axis.

The six equations of equilibrium for the free body diagrams of Figure 2-13 yield the following for the six unknowns:

$$\sum F_x = 0$$

$$\frac{-59}{102.34} \times T_1 + \frac{59}{102.34} \times T_2 + \frac{59}{102.34} \times T_3 - S \times \sin\theta = 5(74) = 370$$

$$\sum F_y = 0$$

$$\frac{72.3}{102.34} \times T_1 + \frac{72.3}{102.34} \times T_2 - \frac{72.3}{102.34} \times T_3 + S \times \cos\theta = 10(74) = 740$$

$$\sum F_z = 0$$

$$\frac{42}{102.34} \times T_1 + \frac{42}{102.34} \times T_2 + \frac{42}{102.34} \times T_3 - V = 2(74) = 148$$

$$\sum M_x = 0$$

$$\left[ \frac{42}{102.34} \times 23.73 + \frac{72.3}{102.34} \times 79 \right] \times T_1 + \left[ \frac{42}{102.34} \times 23.73 + \frac{72.3}{102.34} \times 79 \right] \times T_2 - \left[ \frac{42}{102.34} \times 23.73 + \frac{72.3}{102.34} \times 79 \right] \times T_3 + 24 \times S \times \cos\theta = 10 \times 74 \times 62.5 = 46,250$$

$$\sum M_y = 0$$

$$\left[ \frac{42}{102.34} \times 29.04 - \frac{59}{102.34} \times 79 \right] \times T_1 + \left[ \frac{59}{102.34} \times 79 - \frac{42}{102.34} \times 29.04 \right] \times T_2 + \left[ \frac{59}{102.34} \times 79 - \frac{42}{102.34} \times 29.04 \right] \times T_3 - 24 \times S \times \sin\theta = 5 \times 74 \times 62.5 = 23,125$$

$$\sum M_z = 0$$

$$\left[ \frac{(59^2 + 72.3^2)^{0.5}}{102.34} \times 37.5 \right] \times T_1 - \left[ \frac{(59^2 + 72.3^2)^{0.5}}{102.34} \times 37.5 \right] \times T_2 + \left[ \frac{(59^2 + 72.3^2)^{0.5}}{102.34} \times 37.5 \right] \times T_3 = 0$$

In matrix notation the equations appear as:

$$\begin{bmatrix} -0.577 & 0.577 & 0.577 & -1 & 0 & 0 \\ 0.706 & 0.706 & -0.706 & 0 & 1 & 0 \\ 0.410 & 0.410 & 0.410 & 0 & 0 & -1 \\ 65.550 & 65.550 & -65.550 & 0 & 24 & 0 \\ -33.626 & 33.626 & 33.626 & -24 & 0 & 0 \\ 34.194 & -34.194 & 34.194 & 0 & 0 & 0 \end{bmatrix} \times \begin{bmatrix} T_1 \\ T_2 \\ T_3 \\ S\sin\theta \\ S\cos\theta \\ V \end{bmatrix} = \begin{bmatrix} 370 \\ 740 \\ 148 \\ 46,250 \\ 23,125 \\ 0 \end{bmatrix}$$

Simultaneous solution of the six equations yields the following:

$$\begin{aligned} T_1 &= 293 \text{ kips} \\ T_2 &= 653 \text{ kips} \\ T_3 &= 360 \text{ kips} \\ S\sin\theta &= 46 \text{ kips} \\ S\cos\theta &= 326 \text{ kips} \\ V &= 388 \text{ kips} \end{aligned}$$

### Tie-Down Arm

The tie-down arm is detailed as shown in Figure 2-14. The maximum tie-down arm load of 653 kips = 653,000 lbs. was determined in Section 2.5.2 above.

Stresses for the tie-down arm and its connection to the exterior cask shell are determined as follows:

Tension on Net Section at Hole

$$A_{\text{net}} = (6.5 - 2.875) \times 2.75 = 9.97 \text{ in}^2$$

$$\sigma_t = \frac{653,000}{9.97} = 65,497 \text{ psi}$$

$$\sigma_{\text{allow}} = \sigma_y = 90,000 \text{ psi}$$

Therefore:

$$F.S. = \frac{\sigma_{\text{allow}}}{\sigma_t} = \frac{90,000}{65,497} = 1.37$$

Contact Bearing at Lifting Hole

$$A_{\text{brg}} = 2.75 \times 2.75 = 7.56 \text{ in}^2$$

$$\sigma = \frac{653,000}{7.56} = 86,376 \text{ psi}$$

$$\sigma_{allow} = 1.35 \times 90,000 = 121,500 \text{ psi} \quad (\text{See ST-635, Reference 2-25})$$

Therefore:

$$F.S. = \frac{\sigma_{allow}}{\sigma} = \frac{121,500}{86,376} = 1.41$$

Arm Tension

$$A_{arm} = 1.5 \times 6.5 = 9.75 \text{ in}^2$$

$$\sigma_t = \frac{653,000}{9.75} = 66,974 \text{ psi}$$

$$\sigma_{allow} = \sigma_y = 90,000 \text{ psi}$$

Therefore:

$$F.S. = \frac{\sigma_{allow}}{\sigma} = \frac{90,000}{66,974} = 1.34$$

Edge Tear out

$$A = (3.25 + 0.75 - 0.5 \times 2.875) \times 2.75 \times 2 = 14.09 \text{ in}^2$$

$$\tau = \frac{653,000}{14.09} = 46,345 \text{ psi}$$

$$\tau_{allow} = 54,000 \text{ psi}$$

Therefore:

$$F.S. = \frac{\tau_{allow}}{\tau} = \frac{54,000}{46,345} = 1.17$$

### Weld Stresses

Welds connecting each tie-down arm to the cask outside shell are evaluated in EnergySolutions Document ST-635 (Reference 2-25).

## Outer Shell Stresses

To evaluate the cask outer shell, conservatively assuming the maximum tensile load of 653 kips is applied at each tie-down arm (symmetrical loading) and therefore a one-quarter finite element model of the 8-120B cask can be utilized. The model of the outer shell and one tie-down arm is made of all solid elements as detailed in *EnergySolutions* Document ST-635 (Reference 2-25). The cask outside shell is made of 20-node solid element (ANSYS SOLID186) and that of the tie-down arm is made of 10-node solid element (ANSYS SOLID187). Each tie-down arm is welded onto the cask outer shell with groove and fillet welds, as shown in *EnergySolutions* Document ST-635 (Reference 2-25). The groove welds are included in the FEM and the fillet welds are conservatively ignored. Since the objective of the modeling is to obtain stresses at the tie-down arm and the cask outer-shell interface, the doubler-plates near the tie-down arm holes have been neglected. The stresses in the vicinity of the hole have been evaluated in Section 2.5.2 above. (Tie-Down Arm section above).

The interface between the unwelded portion of the tie-down arm and the outer shell of the cask has been modeled by pairs of 3-dimensional 8-node contact (CONTA 174) and 3-dimensional target segments (TARGE 170) elements. The tie-down arm load is applied at the hole-surface as a distributed load.

Figure 2-15 shows the finite element model of the outer shell and the tie-down arm. Figure 2-16 gives the maximum principal stress (tensile) for the outer shell. The maximum principal stress (tensile) of 36,653 psi obtained from the analysis is less than the yield stress of the material (38,000 psi) and is considered acceptable.

Figure 2-17 provides the maximum stress intensities in the entire finite element model. It shows that under the applied loading of 653,000 lbs, the maximum stresses are developed in the tie-down arm near the hole and in the welds. These stresses are much higher than those in the cask outer shell. Therefore, it is concluded that the failure of the tie-down arm under excessive loading will not impair the cask from meeting other requirements of the regulations.

Any other part of the package that could be used for the tie-down (e.g. impact limiter lifting lugs) will be rendered inoperable during the transportation of the package.

## **2.6 NORMAL CONDITIONS OF TRANSPORT**

This Section demonstrates that the package is structurally adequate to meet the performance requirements of Subpart E of 10 CFR 71 when subjected to NCT as defined in 10 CFR 71.71. Compliance with these requirements is demonstrated by analyses in lieu of testing as allowed by 10 CFR 71.41(a) and Regulatory Guide 7.6 (Reference 2-3).

The structural analyses of the 8-120B Cask under NCT events have been performed through the use of finite element models. ANSYS finite element analysis code (Reference 2-11) has been employed to perform the analyses. The cask assembly has at least one plane of symmetry, so a one-half model of the cask has been utilized for the analyses.

The model of the cask is made using 3-dimensional 8-node structural solid elements (ANSYS SOLID185) to represent the major components of the cask, the bolting ring, the lid, and the bolts.

The shell components of the cask - the inner and outer shells, and the baseplates have been represented in the finite element model by SOLSH190 elements.

The fire shield does not provide any structural strength to the cask. Therefore, it is not included in the model.

The poured lead in the body is not bonded to the steel. It is free to slide over the steel surface. Therefore, the interface between the lead and the steel is modeled by pairs of 3-d 8 node contact element (CONTA174) and 3-d target (TARGE170) elements. These elements allow the lead to slide over the steel at the same time prevent it from penetrating the steel surface. The interface between the two plates that form the lid is also modeled by the contact-target pairs. The transition from a coarser mesh to a finer mesh, as well as bondage between various parts of the model, is also modeled using these elements.

Figure 2-18 shows the finite element model used in the analyses of various load cases. The model has node-to-node and element-to-element correspondence with the thermal finite element model used for the thermal analysis of the package, described in Section 3.3. The nodal temperatures during various NCT events are obtained from the analyses in Section 3.

The details of the finite element model, including the assumptions, modeling details, boundary conditions, and input and output data are included in the *EnergySolutions* document ST-626 (Reference 2-13).

## 2.6.1 HEAT

The thermal evaluation of the 8-120B package is described in Section 3.3. Results from the thermal analyses are used in performing the evaluation in this section.

### 2.6.1.1 Summary of Pressure and Temperatures

Based on the requirements of 10 CFR 71.71(c)(1), the thermal finite element model described in Section 3.3 computes the nodal temperature of the cask body. Figure 2-19 (reproduced from Figure 3-4) shows the temperature distribution in the structural components of the package. The maximum temperatures in various components of the package are summarized as follows (Reference Table 3-1 and Figure 2-19):

Fire Shield	=	160.6°F
Outer Shell	=	161.3°F
Inner Shell	=	161.5°F
Lead	=	161.4°F
Seal	=	161.7°F
Lid/Baseplate	=	162.6°F

The maximum temperature of the cask cavity is under normal conditions is 162.6° which is conservatively assumed to be the average cask cavity temperature. The gas mixture in the cavity is conservatively assumed to be 200° F. This temperature has been used for calculating the Maximum Normal Operating Pressure (MNOP) in Section 3.3.2. The MNOP of 35.0 psig is used for the evaluation of the hot and cold environment load conditions.

### 2.6.1.2 Differential Thermal Expansion

The structural finite element model used for the analyses of the 8-120B package under various loading conditions, described in Section 2.6, uses temperature dependent material properties of the cask components. The differential thermal expansion of various components of the cask is included in the stress calculation of the package.

Differential thermal expansion between the grossly dewatered resin contents and the secondary container is evaluated to determine the total free volume (i.e., ullage and/or interstitial void space) that is required to permit free thermal expansion of the contents within the secondary container. For the NCT heat condition, the maximum temperature of the contents is conservatively assumed to be 200°F, which is the bounding temperature for the maximum decay heat load of 200 watts. Note that resin contents, which are dose limited, have a much lower decay heat load (e.g., less than 10 watts.)

Grossly dewatered resin consists of a mixture of resin media and water. The water content may be less than 20% of the secondary container volume or it may fill the entire interstitial void volume (i.e., water up to the top of the resin bed). Under NCT hot conditions, water expands more than the resin material. Therefore, the thermal expansion of grossly dewatered resin contents under NCT hot conditions is conservatively calculated assuming the contents are 100% water. The volume of water at 200°F is 3.6% greater than the volume of water at room temperature. The secondary container used for grossly dewatered resin contents is either made of carbon steel or a High Density Polyethylene (HDPE). The volumetric coefficient of thermal expansion of carbon steel is approximately one order of magnitude lower than that of HDPE. Therefore, the lower bound volumetric expansion of the secondary container internal volume, based on a carbon steel HIC, is approximately 0.3% under NCT heat conditions. The minimum free volume required to permit free thermal expansion of the grossly dewatered resin contents within the secondary container under NCT heat conditions is:

$$V_{\text{FREE}} = 1 - [(1 + 0.003)/(1 + 0.036)] = 0.032 \text{ (3.2\%)}$$

This is bounded by the differential thermal expansion under NCT cold conditions, as discussed in Section 2.6.2.

### 2.6.1.3 Stress Calculations

The stresses in the package under the hot environment loading conditions have been performed in *EnergySolutions* Document ST-626 (Reference 2-13). The loading combination is listed in Table 2-1. Table 2-5 presents the maximum stresses in various components of the package. Figure 2-20 shows the plot of stress intensity contour in the cask body.

### 2.6.1.4 Comparison with Allowable Stresses

The stresses in the package under the hot environment loading conditions are compared with their allowable values in Table 2-5. The allowable values in various components of the package are listed in Table 2-2. It is noticed from the comparison with the allowable values that all the components of the package experience stresses well below their allowable values. Of all components, a minimum factor of safety of 1.22 occurs in the bolting ring.

## 2.6.2 COLD

The thermal evaluation of the 8-120B package under cold conditions is described in Section 3.3. Results from the thermal analyses are used in performing the evaluation in this section.

Based on the requirements of 10 CFR 71.71(c)(2), the thermal finite element model described in Section 3.3 computes the nodal temperature of the cask body. Figure 2-21 (reproduced from Figure 3-5) shows the temperature distribution in the structural components of the package.

The structural finite element model used for the analyses of the 8-120B package under various loading conditions, described in Section 2.6, uses temperature dependent material properties of the cask components. The lead shrinkage, caused due to the differential thermal expansion of the lead and cask shells, is included in the stress calculation of the package.

The stresses in the package under the cold environment loading conditions have been performed in EnergySolutions Document ST-626 (Reference 2-13). The loading combination is listed in Table 2-1. Table 2-6 presents the maximum stresses in various component of the package. Figure 2-22 shows the plot of stress intensity contour in the cask body.

The stresses in the package under the cold environment loading conditions are compared with their allowable values in Table 2-6. It is noticed from the comparison with the allowable values that all the components of the package experience stresses well below their allowable values. Of all components, a minimum factor of safety of 3.94 occurs in the inner shell.

For the evaluation of the cold environment the ambient temperature of -40°F has been specified by the regulation. However, for the initial conditions for the other load combinations the ambient temperature of -20°F has been specified in 10 CFR 71.73(b). In the load combinations described in Regulatory Guide 7.8 (Reference 2-2), this condition is associated with the minimum decay heat load. It is not intuitively obvious that the minimum decay heat load in the cold conditions will result in a conservative estimate of thermal stresses in the package. Therefore, the cold condition's load combinations listed in Table 2-1 have been performed two ways - one with the maximum decay heat load and another with no decay heat load. The combinations that result in larger stresses have been reported in this SAR as the cold combination.

Per regulatory Guide 7.8 (Reference 2-2), the cask must be able to resist brittle fracture failure under normal conditions of transport and hypothetical accident conditions at temperature as low as -20°F. Fracture critical parts of the cask are shown in Figure 2-23. For compliance with Category II fracture toughness requirements of NUREG/CR-1815, the nil ductility transition temperature ( $T_{NDT}$ ) of this steel with which these parts are fabricated must be less than the value determined by the equation:

$$T_{NDT} = LST - A$$

Where:

LST = Lowest service temperature (-20°F)

A = Value from Figure 7 of NUREG/CR 1815 (Reference 2-18) also shown in Figure 2-24

Table 2-7 tabulates the  $T_{NDT}$  required for the fracture critical components of the 8-120B cask except bolting.

For the bolting NUREG/CR-1815 does not provide any guidance. ASME Section III Subsection ND is used to specify the toughness requirements of the fracture-critical bolts. The lid bolts and the bolts attaching the lifting lugs with the cask body are considered to be fracture-critical. The toughness requirements for these bolts, based on article ND-2333 of the code are:

- Energy required – 30 ft-lb
- Lateral expansion = 15 mils

The Charpy V-Notch test must be performed at -20°F using ASTM A-370 standard.

For grossly dewatered resin contents, a minimum amount of free volume (i.e., ullage and/or interstitial void space) within the secondary container is required to allow for free thermal expansion (i.e., freezing) of the water in accordance with 10 CFR 71.87(d). For the NCT cold condition, the temperature of the contents is -40°F assuming zero insolation and no decay heat load.

Grossly dewatered resin consists of a mixture of resin media and water. The water content may be less than 20% of the secondary container volume or it may fill the entire interstitial void volume (i.e., water up to the top of the resin bed). Under NCT cold conditions, water expands more than the resin material, primarily due to the phase change to ice. Therefore, the thermal expansion of grossly dewatered resin contents under NCT cold conditions is conservatively calculated assuming the contents are 100% water. The volume of ice at 32°F is 9.1% greater than the volume of water at 70°F. However, the volume of ice at -40°F is only 8.6% greater than the volume of water at 70°F due to contraction of the ice under decreasing temperature. The secondary container used for grossly dewatered resin contents is either made of carbon steel or a High Density Polyethylene (HDPE). The volumetric coefficient of thermal expansion of carbon steel is approximately one order of magnitude lower than that of HDPE. Therefore, the bounding thermal contraction of the secondary container internal volume is conservatively calculated based on HDPE. The internal volume of a HDPE secondary container contracts by approximately 0.8% at 32°F and by approximately 2.2% at -40°F. Based on the volumetric expansion of water and HDPE, the minimum free volume required to permit free thermal expansion of the grossly dewatered resin contents within the secondary container under NCT cold conditions is:

$$\text{@ } 32^{\circ}\text{F: } V_{\text{FREE}} = 1 - [(1 - 0.008)/(1 + 0.091)] = 0.091 \text{ (9.1\%)}$$

$$\text{@ } -40^{\circ}\text{F: } V_{\text{FREE}} = 1 - [(1 - 0.022)/(1 + 0.086)] = 0.099 \text{ (9.9\%)}$$

Therefore, a total available free volume of 10% in the form of ullage and/or interstitial void space is sufficient to permit free thermal expansion of grossly dewatered resin contents inside the secondary container under NCT cold conditions.

### 2.6.3 REDUCED EXTERNAL PRESSURE

10 CFR 71.71 (c)(3) requires that package be evaluated for a reduced external pressure of 3.5 psi. The MNOP of the 8-120B package is 35.0 psig (14.7 psi atmospheric pressure). With the external pressure reduced to 3.5 psi, the inside pressure of the package will be:

$$P_{\text{reduced external}} = 35.0 + 14.7 - 3.5 = 46.2 \text{ psi (conservatively use 50.0 psi)}$$

The load combination for the reduced external pressure is listed in Table 2-1 under “Minimum External Pressure”. Please note that this nomenclature is retained to be consistent with Regulatory Guide 7.8.

The stresses in the package under the reduced external pressure loading conditions have been performed in *EnergySolutions* Document ST-626 (Reference 2-13). Table 2-8 presents the maximum stresses in various components of the package. Figure 2-25 shows the plot of stress intensity contour in the cask body.

The stresses in the package under the reduced external pressure loading conditions are compared with their allowable values in Table 2-8. It is noticed from the comparison with the allowable values that all the components of the package experience stresses well below their allowable values. A minimum factor of safety of 2.43 occurs in the bolting ring.

### 2.6.4 INCREASED EXTERNAL PRESSURE

10 CFR 71.71 (c)(4) requires that package be evaluated for an increased external pressure of 20 psi. The MNOP of the 8-120B package is 35 psig (14.7 psi atmospheric pressure). To be conservative for this loading the package internal pressure is assumed to be the minimum (i.e., 0 psi) and the external pressure has been increased to 25 psi. The load combination for the increased external pressure is listed in Table 2-1

The stresses in the package under the increased external pressure loading conditions have been performed in *EnergySolutions* Document ST-626 (Reference 2-13). Table 2-9 presents the maximum stresses in various component of the package. Figure 2-26 shows the plot of stress intensity contour in the cask body.

The stresses in the package under the increased external pressure loading conditions are compared with their allowable values in Table 2-9. It is noticed from the comparison with the allowable values that all the components of the package experience stresses well below their allowable values. Of all components, a minimum factor of safety of 4.10 occurs in the inner shell.

### 2.6.5 VIBRATION

10 CFR 71.71 (c)(5) requires that “vibration normally incident to transport” be evaluated.

The 8-120B package consists of thick section materials that will be unaffected by vibration normally incident to transport, such as over the road vibrations.

## 2.6.6 WATER SPRAY

Not applicable, since the package exterior is constructed of steel.

## 2.6.7 FREE DROP

As described in Section 2.7.1 the analyses of the free drop of the package under NCT is performed in two steps. First the dynamic analyses of the package are performed using an *EnergySolutions* proprietary methodology outlined in document ST-551 (Reference 2-5) that utilizes the ANSYS/LS-DYNA computer code (Reference 2-11). The methodology was developed after a considerable amount of research and parametric studies for the accuracy of results. These studies included the choice of elements, mesh density, material damping, hourglass control, and, solution parameters and controls, etc. It was successfully validated against test results and is fully documented in an *EnergySolutions* proprietary document ST-551 (Reference 2-5). The sensitivity study of the modeling technique is documented in the *EnergySolutions* document ST-596 (Reference 2-29). A discourse on the use of foam properties in the LS-DYNA analyses of the casks is documented in the *EnergySolutions* document ST-618 (Reference 2-30). The methodology has also been used in a recently approved NRC cask package (3-60B).

Next, the detailed FEM analyses of the cask are performed using ANSYS. The analyses are performed in the three customary orientations – end, side and corner. All the load combinations listed in Table 2-1 are analyzed. The details of the package dynamic analyses are documented in *EnergySolutions* Document ST-625 (Reference 2-14). The documentation of the detailed FEM analyses of the package is provided in *EnergySolutions* Document ST-627 (Reference 2-15).

The summary of the results from the package dynamic analyses of the NCT free drop are presented in Table 2-10. The stresses in the cask under the load combinations involving the NCT free drop are described below.

### 2.6.7.1 End Drop

The following impact limiter reactions are obtained from *EnergySolutions* Document ST-625 (Reference 2-14).

Cold Conditions =  $1.556 \times 10^6$  lb (Table 2 and Figure 13 of Reference 2-14)

Hot Conditions =  $1.286 \times 10^6$  lb (Table 2 and Figure 16 of Reference 2-14)

For the NCT test in the end drop orientation, the maximum of the two reactions are used in the analyses.

The distribution of reactions and inertia loads used in the FEM analyses are identical to those described in Section 2.7.1.1 for the HAC loading, except that they have been linearly proportioned in the ratio of corresponding impact limiter reactions. The results obtained from the detailed FEM analysis of the cask are presented in Tables 2-11 and 2-12 for the hot and cold combinations, respectively.

Of all components, a minimum safety factor of 1.18 is computed for the loading combinations involving end drop.

#### 2.6.7.2 Side Drop

The following impact limiter reactions are obtained from *EnergySolutions* Document ST-625 (Reference 2-14).

Cold Conditions = 859,600 lb (Table 2 and Figure 19 of Reference 2-14)

Hot Conditions = 710,400 lb (Table 2 and Figure 22 of Reference 2-14)

For the NCT test in the side drop orientation, the maximum of the two reactions are used in the analyses.

The distribution of reactions and inertia loads used in the FEM analyses are identical to those described in Section 2.7.1.2 for the HAC loading, except that they have been linearly proportioned in the ratio of corresponding accelerations. The results obtained from the detailed FEM analysis of the cask are presented in Tables 2-13 and 2-14 for the hot and cold combinations, respectively.

Of all components, a minimum safety factor of 1.21 is computed for the loading combinations involving side drop.

#### 2.6.7.3 Corner Drop

The following impact limiter reactions are obtained from *EnergySolutions* Document ST-625 (Reference 2-14).

Cold Conditions = 318,800 lb (Table 2 and Figure 25 of Reference 2-14)

Hot Conditions = 278,500 lb (Table 2 and Figure 28 of Reference 2-14)

For the NCT test in the corner drop orientation, the maximum of the two reactions are used in the analyses.

The distribution of reactions and inertia loads used in the FEM analyses are identical to those described in Section 2.7.1.3 for the HAC loading, except that they have been linearly proportioned in the ratio of corresponding accelerations. The results obtained from the detailed FEM analysis of the cask are presented in Tables 2-15 and 2-16 for the hot and cold combinations, respectively.

Of all components, a minimum safety factor of 1.64 is computed for the loading combinations involving corner drop.

#### 2.6.8 CORNER DROP

Not applicable; the 8-120B package is not a fiberboard, wood, or fissile material package.

## 2.6.9 COMPRESSION

Not applicable; the 8-120B package weighs more than 11,000 lbs.

## 2.6.10 PENETRATION

The package is evaluated for the impact of the hemispherical end of a vertical steel cylinder of 1¼" diameter and 13 lb mass, dropped from a height of 40" on to the exposed surface of the package.

The penetration depth of the 13 lb 1¼" diameter rod dropped from a height of 40" is calculated from the Ballistic Research Laboratories (BRL) formula cited in Reference 2-17. For a steel target, the penetration depth is given by the formula:

$$\left(\frac{e}{d}\right)^{3/2} = \frac{DV_0^2}{1.12 \times 10^6 \times K_s^2}$$

Where,

- $e$  = penetration depth, inch
- $d$  = effective projectile diameter, inch = 1.25"
- $W$  = missile weight, lb = 13 lb
- $D$  = caliber density of the missile, lb/in<sup>3</sup> =  $W/d^3$
- $V_0$  = striking velocity of the missile, ft/sec
- $K_s$  = steel penetrability constant = 1.0

For a 40" drop of the rod, the striking velocity,

$$V_0 = (2 \times 32.2 \times 40/12)^{0.5} = 14.65 \text{ ft/sec}$$

$$D = 13/1.25^3 = 6.656 \text{ lb/in}^3$$

Solving the penetration equation, we get,

$$e = 1.25 \times \left(\frac{6.656 \times 14.65^2}{1.12 \times 10^6 \times 1^2}\right)^{2/3} = 0.0147''$$

The thickness of the 8-120B outer shell is 1½", the lid is 3¼" (min.), the outer baseplate is 3¼" the impact limiter skins and weather cover are 12 gauge = 0.105", and the lower impact limiter cover plate is ½". All these thickness are greater than 0.0147" required for penetration.

Therefore, the penetration test will not cause any damage to the package. It should be noted that in the penetration evaluation, no credit for the lead shielding and the inner shell has been taken.

## 2.7 HYPOTHETICAL ACCIDENT CONDITIONS

### 2.7.1 FREE DROP

The 8-120B package is shown to comply with the hypothetical accident conditions (HAC) test requirements by analytical methods in lieu of the physical tests. Advanced finite element methods have been employed in the analyses. A major assumption that is made in performing

these analyses is that the dynamic behavior of the 8-120B package, which consists of the cask body and the impact limiters, can be decoupled into a dynamic behavior of the impact limiters and a pseudo-static behavior of the cask body. The rationale for this assumption is based on the relative stiffness of the impact limiters and the cask body. The impact limiters are made of a shock absorbing polyurethane material, which is very low in density compared to the cask body which is primarily made from steel and lead, with stainless steel used for the seal rings. The fundamental periods of the two components are, therefore, sufficiently far apart that little or no interaction takes place between their dynamic responses during the drop loading. The overall dynamic analyses of the package, in various drop orientations, are performed separately and the reactions of the impact limiter on the cask body, obtained from these analyses are used in detailed finite element analyses of the cask body.

### Dynamic Analyses of the Package

Proprietary modeling techniques, developed by EnergySolutions, using an explicit dynamic finite element code, ANSYS/LS-DYNA (Reference 2-11), for the drop analysis of packages that use closed-cell cellular polyurethane foam impact limiters, have been employed to perform the drop analyses of the 8-120B package. The validation of the modeling techniques have been performed with the actual drop test data of a cask of similar size to the 8-120B. The details of the modeling techniques and the verification and validation with the test results are documented in an EnergySolutions proprietary document ST-551 (Reference 2-5). The EnergySolutions modeling techniques predict the acceleration results conservatively and the time-history trace of the analyses and test data are reasonably close to each other to validate the analysis.

The finite element model used for the analyses of the 8-120B package is described in details in EnergySolutions document ST-625 (Reference 2-14). Figures 2-27 and 2-28 show the finite element model. It is made of 8-node solid elements, 4-node shell elements, and 3-node spar elements.

Analyses of the 8-120B package have been performed in three customary drop orientations. The analyzed orientations are:

End Drop – The cask axis parallel to the drop direction (see Figure 2-29)

Side Drop – The cask axis perpendicular to the drop direction (see Figure 2-30)

Corner Drop – The C.G. of the cask directly over the impact point. The cask axis makes an angle of 38° with the vertical plane (see Figure 2-31).

The finite element transient analyses are performed for sufficiently large duration so that the primary as well as secondary impacts, if any, are included. The time-history data of the reaction forces between the package and the rigid contact surface are obtained for each load case (see Figure 2-32 for a typical plot). The time-history of the results are examined for various quantities such as the kinetic energy, internal energy, total energy, hourglass energy, and the external work (see Figure 2-33 for a typical plot). The time-history data of the maximum impact limiter crush are also obtained for each load case. The impact limiter attachment load time-histories are also obtained for each drop orientation.

The HAC drop tests, according to 10 CFR 71.73(b), must be performed at a constant temperature between -20°F and 100°F, which is most unfavorable for the feature under consideration. To envelop the entire spectrum of the temperature range, the dynamic analyses of the package are performed for two initial conditions – the cold condition (Ambient temperature -20°F) and the hot condition (ambient temperature 100°F). To be conservative, the larger of the two results are used for the detailed analyses of the cask body.

The details of the dynamic analyses of the 8-120B package, including the finite element model details, assumptions, boundary conditions, and the input and output data are included in the *EnergySolutions* document ST-627 (Reference 2-15).

The summary of the results from these analyses are presented in Table 2-17.

### Detailed Analyses of the Cask

The detailed analyses of the cask under various drop test conditions have been performed using advanced finite element modeling techniques. ANSYS finite element analysis code (Reference 2-11) has been employed to perform the analyses. Since for all the drop orientations (end, side, corner), at least one plane of symmetry exists, a one-half model has been employed in all the analyses.

The model of the cask is made using 3-dimensional 8-node structural solid elements (ANSYS SOLID185) to represent the major components of the cask, the bolting ring, the lid, and the bolts. The shell components of the cask - the inner and outer shells, and the baseplates have been represented in the finite element model by SOLSH190 elements.

Since the fire shield does not provide any structural strength to the cask, it is not included in the model.

The poured lead in the body is not bonded to the steel. It is free to slide over the steel surface. Therefore, the interface between the lead and the steel is modeled by pairs of 3-d 8 node contact element (CONTA174) and 3-d target (TARGE170) elements. These elements allow the lead to slide over the steel and at the same time prevent it from penetrating the steel surface. The interface between the two plates that form the lid is also modeled by the contact-target pairs. The transition from a coarser mesh to a finer mesh, as well as bondage between various parts of the model, is also modeled using these elements.

Figure 2-34 shows the outline of the model depicting the material numbering. Figure 2-35 shows the finite element grid of the lid, seal plate, bolts, and the cask. Figure 2-36 shows the finite element grid of the cask body without the lead.

To incorporate the loading combinations of Table 2-1 for various drop conditions, the analyses have been performed for three thermal conditions. The loading combinations in hot conditions have been performed per Regulatory Guide 7.8, which requires an ambient temperature of 100°F and the maximum internal decay heat load. The loading combination for the cold conditions, per Regulatory Guide 7.8, requires an ambient temperature of -20°F and the minimum internal decay heat load. It is not intuitively obvious that the minimum decay heat load in the cold conditions will result in a conservative estimate of thermal stresses in the package. Therefore, the cold

condition's load combinations listed in Table 2-1 have been performed two ways - one with the maximum decay heat load and another with the minimum decay heat load. The combinations that result in larger stresses have been reported in this SAR as the cold combination. The nodal temperatures for all the thermal conditions are obtained from the analyses in Section 3 and are applied to the structural models to get the appropriate load combinations.

The documentation of the detailed analyses of the cask, including the finite element model details, assumptions, boundary conditions, and the input and output data are included in the *EnergySolutions* document ST-627 (Reference 2-15). ANSYS finite element model grid convergence study has been performed in *EnergySolutions* document ST-608 (Reference 2-16). This document also provides the validation of the major modeling techniques used in the finite element analyses.

#### 2.7.1.1 End Drop

The following impact limiter reactions are obtained from *EnergySolutions* Document ST-625 (Reference 2-14).

$$\text{Cold Conditions} = 5.359 \times 10^6 \text{ lb} \quad (\text{Table 3 and Figure 31 of Reference 2-14})$$

$$\text{Hot Conditions} = 4.427 \times 10^6 \text{ lb} \quad (\text{Table 3 and Figure 35 of Reference 2-14})$$

The maximum of the two reactions is conservatively used for the analyses of all environmental conditions. The impact limiter reaction is converted to the rigid body acceleration by dividing the reaction by that portion of the mass of the package which causes this reaction. During the end drop test the impact limiter reaction is caused by the total mass of the package less the mass of one impact limiter, i.e.  $49,300 + 14,680 + 4,860 = 68,840$  lb (SAR Section 2.1.3). Since the FEM represents only  $\frac{1}{2}$  of the package, the total mass is divided by 2 in the calculation of the rigid body acceleration.

$$\text{Rigid body acceleration} = 2 \times 5.359 \times 10^6 / 68,840 = 155.7 \gg \text{Use } 160\text{g}$$

The value used for rigid body acceleration is conservatively set at 160g. The distribution of reactions and inertia loads used in the quasi-static FEM analyses are shown in Figure 2-37. The plot of the maximum stress intensities in the cask are shown in Figures 2-38 for the hot condition, in Figure 2-39 for the cold condition (maximum decay heat), and in Figure 2-40 for the cold condition (no decay heat). The results obtained from the detailed FEM analysis of the cask are presented in Tables 2-18 and 2-19 for the hot and cold combinations, respectively.

Of all components, a minimum safety factor of 1.02 is computed for the loading combinations involving end drop.

#### 2.7.1.2 Side Drop

The following impact limiter reactions are obtained from *EnergySolutions* Document ST-625 (Reference 2-14).

$$\text{Cold Conditions} = 3.937 \times 10^6 \text{ lb} \quad (\text{Table 3 and Figure 39 of Reference 2-14})$$

$$\text{Hot Conditions} = 3.403 \times 10^6 \text{ lb} \quad (\text{Table 3 and Figure 43 of Reference 2-14})$$

Conservatively use the maximum of the two reactions for the analyses of all environmental conditions. The impact limiter reaction is converted to the rigid body acceleration by dividing the reaction by that portion of the mass of the package which causes this reaction. During the side drop test the impact limiter reaction is caused by the total mass of the package less the mass of the two impact limiters, i.e.  $74,000 - 2 \times 4,860 = 64,280$  lb (Section 2.1.3). Since the FEM represents only  $\frac{1}{2}$  of the package the total mass is divided by 2 in the calculation of the rigid body acceleration.

$$\text{Rigid body acceleration} = 2 \times 3.927 \times 10^6 / 64,280 = 122.2g \gg \text{Use } 150g$$

The value used for the rigid body acceleration is conservatively set at 150g. The distribution of reactions and inertia loads used in the quasi-static FEM analyses are shown in Figure 2-41. The plot of the maximum stress intensities in the cask are shown in Figures 2-42 for the hot condition, in Figure 2-43 for the cold condition (maximum decay heat), and in Figure 2-44 for the cold condition (no decay heat). The results obtained from the detailed FEM analysis of the cask are presented in Tables 2-20 and 2-21 for the hot and cold combinations, respectively.

The minimum safety factor of 1.05 is computed for the loading combinations involving side drop. This minimum safety factor occurs in the lid bolts. Of all components, a minimum factor of safety on the containment boundary components is 1.05.

### 2.7.1.3 Corner Drop

The following impact limiter reactions are obtained from EnergySolutions Document ST-625 (Reference 2-14).

$$\text{Cold Conditions} = 2.103 \times 10^6 \text{ lb} \quad (\text{Table 3 and Figure 47 of Reference 2-14})$$

$$\text{Hot Conditions} = 2.000 \times 10^6 \text{ lb} \quad (\text{Table 3 and Figure 51 of Reference 2-14})$$

Conservatively use the maximum of the two reactions for the analyses of all environmental conditions. The impact limiter reaction is converted to the rigid body acceleration by dividing the reaction by that portion of the mass of the package which causes this reaction. During the corner drop test the impact limiter reaction is caused by the total mass of the package less the mass of one impact limiter, i.e.  $49,300 + 14,680 + 4,860 = 68,840$  lb (Section 2.1.3). Since the FEM represents only  $\frac{1}{2}$  of the package, the total mass is divided by 2 in the calculation of the rigid body acceleration.

$$\text{Rigid body acceleration} = 2 \times 2.103 \times 10^6 / 68,840 = 61.1 \gg \text{Use } 75g$$

The value used for rigid body acceleration is conservatively set at 75g. The distribution of reactions and inertia loads used in the quasi-static FEM analyses are shown in Figure 2-45. The plot of the maximum stress intensities in the cask are shown in Figures 2-46 for the hot condition, in Figure 2-47 for the cold condition (maximum decay heat), and in Figure 2-48 for the cold condition (no decay heat). The results obtained from the detailed FEM analysis of the cask are presented in Tables 2-22 and 2-23 for the hot and cold combinations, respectively.

Of all components, a minimum safety factor of 1.01 is computed for the loading combinations involving corner drop.

#### 2.7.1.4 Oblique Drop

The diameter of the 8-120B package impact limiter is 102 inches and the overall package height is 132 inches. The following analysis indicates that for the 8-120B package with the diameter approximately equal to its length, there is no slapdown effect. That is, the impact is not more severe than a side drop.

This section represents an analysis demonstrating that oblique impacts are not worst-case for casks having length-to-diameter ratios less than 1.37. Figure 2-49 illustrates a cask of length (l), and weight (W), dropped at an angle (a) measured from the horizontal plane. No energy absorption is initially assumed from the impact limiter of cask during primary impact (first contact of the lower end of the cask with the impact surface). This assumption results in the worst case (greatest) impact velocity of the higher end of the cask.

The angular momentum before and after impact can be estimated based on the following assumptions:

- The impact point does not slide along the horizontal impact surface.
- The rotational inertia of the cask can be approximated assuming a uniform density

$$I_{CG} = \frac{1}{4} \times M \times \left( r^2 + \frac{l^2}{3} \right)$$

solid cylinder, i.e. :

- The gravitational acceleration of the cask is neglected after the initial impact.

Then, before impact,

$$L_1 = M \times v_1 \times \left( \frac{1}{2} \times l - r \times \tan a \right) \times \cos a$$

And, after impact:

$$L_2 = I_i \times \omega_2$$

Where:

$L_1$  = angular momentum before impact

M = mass of cask

$v_1$  = impact velocity

$I_i$  = rotational inertia of cask about impact point

$$= I_{CG} + M \times R^2$$

$$= M \times \left( \frac{1}{4} \times r^2 + \frac{1}{12} \times l^2 + R^2 \right)$$

$\omega_2$  = angular velocity of cask following impact

Since no moments are applied to the cask, angular momentum is conserved, and  $L_1 = L_2$ :

$$M \times v_1 \times \left( \frac{1}{2} \times l - r \times \tan a \right) \times \cos a = M \times \left( \frac{1}{4} \times r^2 + \frac{1}{12} \times l^2 + R^2 \right) \times \omega_2$$

Solving for angular velocity:

$$\omega_2 = v_1 \times \frac{\left( \frac{1}{2} \times l - r \times \tan a \right) \times \cos a}{\frac{1}{4} \times r^2 + \frac{1}{12} \times l^2 + R^2}$$

In general, maximum angular velocity occurs when the impact angle equals zero.

The velocity of the secondary impact is given by:

$$v_s = l \times \omega_2$$

Then:

$$v_s = l \times v_1 \times \frac{\left( \frac{1}{2} \times l - r \times \tan a \right) \times \cos a}{\frac{1}{4} \times r^2 + \frac{1}{12} \times l^2 + R^2}$$

The limiting case can be taken as that for which the secondary impact velocity equals the initial impact velocity for the worst case angular velocity. Then,

$$v_s = v_1 \text{ at } a = 0$$

And:

$$\frac{\frac{1}{2} \times l^2}{\frac{1}{4} \times r^2 + \frac{1}{12} \times l^2 + R^2} = 1$$

From Figure 2-49,

$$R^2 = \frac{1}{4} \times l^2 + r^2$$

Therefore,

$$\frac{1}{2} \times l^2 = \frac{1}{4} \times r^2 + \frac{1}{12} \times l^2 + \frac{1}{4} \times l^2 + r^2$$

$$\frac{l^2}{r^2} = 7.50 \quad \text{and,} \quad \frac{l}{r} = 2.74$$

Implying that:

$$\frac{l}{d} = \frac{l}{2 \times r} = 1.37$$

Thus, for length-to-diameter ratios greater than 1.37, slapdown impacts may be more severe than a normal side drop. Since this analysis very conservatively neglects any energy absorption of the initial impact, this ratio may be taken as a lower bound, below which one may safely assume that secondary impact will be less severe than side drop impacts. Since the 8-120B cask has a length-to-diameter ratio of 1.29, the oblique drop is less severe than the side drop. Cask stresses in an oblique drop will be less than those experienced during a side drop.

#### 2.7.1.5 Lead Slump Evaluation

The 8-120B package experiences the largest acceleration during the end drop orientation. Analyses of the 8-120B package under various environmental conditions in this drop orientation have been performed in Section 2.7.1.1. The most severe environmental condition for the lead slump is the cold condition with no decay heat load. From the finite element model analysis the relative displacement at the lead-steel interface is obtained. Figure 2-50 shows the exaggerated displacement plot under this drop condition. The total relative displacement of the lead column (0.141 inch) is reported as the lead-slump. However, it should be noted that in considering this value to be the lead slump, the elastic recovery of the lead and steel has been conservatively neglected.

#### 2.7.1.6 Impact Limiter Attachment Evaluation

The impact limiter attachment loads for each drop condition are obtained from the FEM analyses described in Section 2.7.1. These loads are presented in Table 2-24. The maximum load in an individual attachment under any of the HAC events is 35,350 lb (EnergySolutions document ST-625, Reference 2-14). The following evaluation shows that the impact limiter attachments are capable of withstanding this load. Each impact limiter attachment point is fabricated from ASTM A516 Grade 70 material.

Considering failure for an equivalent state of stress which produces a maximum shear stress of:

$$\tau_{failure} = \frac{F_u}{\sqrt{3}} = \frac{70,000}{\sqrt{3}} = 40,415 \text{ psi}$$

The impact limiter attachment eye tear-out stress is:

$$\tau = \frac{35,350}{2 \times 0.5 \times (2 - 0.5 \times 0.9375)} = 23,086 \text{ psi} < 40,415 \text{ psi} \quad \text{O.K.}$$

Each impact limiter attachment is welded on to the 1" thick inner ring of impact limiter with 6" long 1/2" fillet weld on each side and to the impact limiter skin with smaller size fillet weld. Ignoring any contribution from the impact limiter skin welds, the weld shear stress is:

$$\tau = \left[ \left( \frac{35,350 \times (2.875 - 1)}{6^2} \right)^2 + \left( \frac{35,350}{2 \times 6 \times 0.707 \times 0.5} \right)^2 \right]^{0.5} = 17,708 \text{ psi} < 40,415 \text{ psi} \quad \text{O.K.}$$

The top and bottom impact limiters are interconnected at eight attachment points with 1” diameter shank ratchet binders. The ratchet binder has a working load limit of 9,000 lbs with ultimate load equal to 5 times the working load limit = 9,000 × 5 = 45,000 lbs

Maximum attachment point load = 35,350 lbs < 45,000 lbs O.K.

Therefore, the impact limiter attachments can withstand the maximum applied load under any of the HAC events.

### 2.7.1.7 Shell Buckling

Buckling, per Regulatory Guide 7.6 (Reference 2-3), is an unacceptable failure mode for the containment vessel. The intent of this guideline is to make large deformations unacceptable because they would compromise the validity of linear assumptions and quasi-linear allowable stresses as given in Paragraph C.6 of NRC Regulatory Guide 7.6.

The remainder of this subsection defines techniques and criteria used in subsequent sections of this Safety Analysis Report to demonstrate that containment vessel buckling does not occur.

#### Euler Column Buckling

From Reference 2-23, p. 104, the critical axial buckling load for a self-weight load combined with an added axial force is:

$$P_{cr} = \frac{m \times E \times I}{l^2}$$

Where:

m = tabulated function of n

$$n = \frac{4 \times q \times l^3}{\pi^2 \times E \times I}$$

q = distributed axial load intensity

$$= 2 \times \pi \times R \times w \times a \times t$$

l = half length of cylinder

E = Young's modulus = 27.8 × 10<sup>6</sup> psi

$$I = \pi \times R^3 \times t$$

R = cylinder radius

t = cylinder thickness

w = weight density = 0.283 lb/in<sup>3</sup>

a = acceleration in g's

This mode of buckling applies to the outer shell of the cask, composed of a  $1\frac{1}{2}$ -inch thick plate.

$$\begin{aligned} l &= 39.25 \text{ in.} \\ R &= 35.5 \text{ in.} \\ t &= 1.5 \text{ in.} \\ I &= 210,827 \text{ in}^2 \\ q &= 94.69a \text{ lb/in.} \end{aligned}$$

And:

$$n = 3.96 \times 10^{-7} \times a$$

For:

$$\begin{aligned} a &= 169 \\ n &= 0 \end{aligned}$$

Therefore:

$$m = \frac{\pi^2}{4}$$

And:

$$P_{cr} = 9.4 \times 10^9 \text{ lb.}$$

### Axial Stress Limits

According to Reference 2-24, p. 230, a thin-wall cylinder is considered “moderately long” if

$$c \times Z > \frac{\pi^2 \times K_{co}}{2\sqrt{3}}$$

Where:

c = correlation factor dependent on R/t

$$Z = \frac{L^2}{R \times t} \times \sqrt{1 - m^2}$$

$K_{co} = 1$  for simply supported edges (conservative)

L = length of cylinder

R = mean radius of cylinder

t = wall thickness

m = Poisson's ratio

The following two sets of properties correspond to the inner and outer shells of the cask sidewall.

	<u>Inner Shell</u>	<u>Outer Shell</u>
$t_i$	= 0.75 in	$t_o$ = 1.5 in
$R_i$	= 31.375 in	$R_o$ = 35.5 in
$L_i$	= 76 in	$L_o$ = 79.5 in
m	= 0.3	m = 0.3

For both shells,

$$\frac{\pi^2 \times K_{co}}{2\sqrt{3}} = 2.849$$

Then:

$$R_i/t_i = 41.83$$

$$R_o/t_o = 23.67$$

$$Z_i = 234$$

$$Z_o = 113$$

From Reference 2-24, Fig. 10-9, p. 230.

$$c_i = 0.70$$

$$c_o = 0.55$$

For both shells,

$$c \times Z > \frac{\pi^2 K_{co}}{2\sqrt{3}}$$

Therefore, both will be treated as moderately long cylinders.

From Reference 2-24, p. 229:

$$\sigma_c = \frac{\pi^2 \times K_c \times E}{12 \times (1 - m^2)} \times \left(\frac{t}{L}\right)^2$$

$\sigma_c$  = elastic buckling stress

E = Young's modulus

$$= 27.8 \times 10^6 \text{ psi}$$

$$\sigma_c = \frac{4\sqrt{3}}{\pi^2} \times c \times Z$$

$$\sigma_{ci} = 281,353 \text{ psi}$$

$$\sigma_{co} = 390,240 \text{ psi}$$

### Hoop Stress Limits

From Reference 2-24, p. 236:

$$\sigma_c = \frac{\pi^2 \times K_p \times E}{12 \times (1 - m^2)} \times (t/L)^2$$

Where:

$K_p$  = function of Z (Reference 2-24, Fig. 10-15, p. 237)

Then:

$$\begin{aligned} K_{pi} &= 13 \\ K_{po} &= 9 \\ \sigma_{ci} &= 31,810 \text{ psi} \\ \sigma_{co} &= 80,503 \text{ psi} \end{aligned}$$

Critical Buckling Stress

$\sigma_{cr}$  for the above cases can be found by solving the following equation (from Reference 2-24, p. 265):

$$\sigma_{cr} - \eta \times \sigma_c = 0$$

Where:

$\eta$  = plasticity coefficient

The plasticity coefficient,  $\eta$ , is defined by the following equations for each of the various loading conditions:

For axial stresses, from Reference 2-24, p. 266:

$$\eta = \frac{\sqrt{E_s \times E_t}}{E}$$

For external pressure stress, from Reference 2-24, p. 236:

$$\eta = \frac{E_s}{E_t} \sqrt{\left(\frac{E_t}{E_s}\right)^{1/2} \times \left(\frac{1}{4} + \frac{3}{4} \times \frac{E_t}{E_s}\right)}$$

Where:

$E_t$  = tangent modulus =  $d\sigma/d\varepsilon$   
 $E_s$  = secant modulus =  $\sigma / \varepsilon$   
 $\sigma$  = stress  
 $\varepsilon$  = strain

For stresses below the proportional limit, conservatively assumed to be  $0.7 \times S_y$ :

$$\begin{aligned} E &= E_t = E_s \\ \text{and } \eta &= 1 \end{aligned}$$

For stresses above the proportional limit, stress is assumed to be a parabolic function of strain that is tangent to the elastic line at the proportional limit and has zero slope at the yield stress.

For:

$$S_y = 38,000 \text{ psi}$$

and:

$$E = 27.8 \times 10^6 \text{ psi}$$

Then, for:

$$0.7 \times S_y < \sigma < S_y$$

$$\sigma = A \times \varepsilon^2 + B \times \varepsilon + C$$

Where:

$$A = -1.6948 \times 10^{10}$$

$$B = 6.0233 \times 10^7$$

$$C = -1.5517 \times 10^4$$

Using this expression for stress, the critical buckling stress equation is solved:

$$A^2 \times \varepsilon_{cr}^5 + 2AB \times \varepsilon_{cr}^4 + \left[ 2AC + B^2 - 2A^2 \left( \frac{\sigma_e}{E} \right)^2 \right] \times \varepsilon_{cr}^3 + \left[ 2BC - 3AB \left( \frac{\sigma_e}{E} \right)^2 \right] \times \varepsilon_{cr}^2 + \left[ C^2 - \left( \frac{\sigma_e}{E} \right)^2 (2AC + B^2) \right] \times \varepsilon_{cr} - BC \left( \frac{\sigma_e}{E} \right)^2 = 0$$

Axial:

	<u>Inner</u>	<u>Outer</u>
$\varepsilon_{cr}$	$1.7578 \times 10^{-3}$	$1.7670 \times 10^{-3}$
$\eta$	0.13504	9.73727
$\sigma_{cr}$	37,994 psi	37,999 psi

Hoop:

$\varepsilon_{cr}$	$1.0678 \times 10^{-3}$	$1.5710 \times 10^{-3}$
$\eta$	0.91158	0.43138
$\sigma_{cr}$	28,997 psi	34,727 psi

The buckling stress limits are summarized in the following table

	<u>Inner Shell</u>	<u>Outer Shell</u>
Axial Membrane	37,994 psi	37,999 psi
Hoop Membrane	28,997 psi	34,727 psi

Evaluation of buckling of the cylindrical shells, for combined loading, is done using the technique described in Reference 2-24, p. 275:

$$\sigma_{cr} - \eta \times \sigma_i = 0$$

Where:

$\sigma_{cr}$  = combined load critical buckling stress intensity

$$\eta = \text{plasticity correction factor} = \frac{\sqrt{E_t \times E_s}}{E}$$

$$\sigma_i = \text{elastic buckling stress intensity} = \sqrt{\sigma_a^2 + \sigma_h^2 - \sigma_a \sigma_h}$$

$\sigma_a$  = elastic axial buckling stress limit

$\sigma_h$  = elastic hoop buckling stress limit

Values for the inner and outer shells are as follows:

	<u>Inner</u>	<u>Outer</u>
$\sigma_a$ , psi	281,353	390,240
$\sigma_h$ , psi	31,810	80,503
$\sigma_i$ , psi	266,874	356,865
$\eta$	0.14236	0.10648
$\sigma_{cr}$ (combined load)	37,993	37,998

In evaluating stress conditions for buckling of the shells, the individual stress components are compared to the allowable buckling stresses in the hoop and axial directions. The stress intensities are compared to the values of  $\sigma_{cr}$  above for combined loading.

### Evaluation

Evaluation of the 8-120B Cask body is performed for buckling under the NCT and HAC events. The two components that have the highest susceptibility to buckling are the inner and outer shells of the cask. Both the shells are subjected to axial compressive stresses under the 1-ft and 30-ft drop tests. In addition, the inner shell undergoes compressive hoop stress under the cold conditions. The coefficient of thermal expansion of the lead is much larger than that of the steel. The lead is poured in the cask body at the room temperature (70°F). At a temperature lower than 70°F, the lead shrinks more than the steel which causes an interference stress in the inner shell.

Stresses are calculated for the NCT and HAC conditions and compared with the buckling stresses calculated above. The axial stresses are calculated for the 1-ft drop test for the NCT conditions and 30-ft drop for the HAC conditions. The hoop stress in the inner shell is calculated at -40°F and is conservatively used for both NCT and HAC conditions.

Axial Stress Calculation

The axial stresses in inner and outer shells are calculated with the conservative assumption that the entire reaction load under a particular end drop test is reacted entirely by these shells.

- Inner shell outside radius = 31.75 in
- Inner shell inside radius = 31 in
- Outer shell outside radius = 36.6 in
- Outer shell inside radius = 35.1 in

Area of the two shells,

$$\text{Area} = \pi \times [(31.75^2 - 31^2) + (36.6^2 - 35.1^2)] = 485.7 \text{ in}^2$$

Largest reaction under the 1-ft drop test on the half model is  $1.556 \times 10^6$  lb (see Section 2.6.7.1). Therefore the axial stress in the shells under this loading is:

$$\sigma_{\text{axial}} = 2 \times 1.556 \times 10^6 / 485.7 = 6,407 \text{ psi}$$

Largest reaction under the 30-ft drop test on the half model is  $5.359 \times 10^6$  lb (see Section 2.7.1.1). Therefore the axial stress in the shells under this loading is:

$$\sigma_{\text{axial}} = 2 \times 5.359 \times 10^6 / 485.7 = 22,067 \text{ psi}$$

Using a safety factor of 2 for NCT and 1.34 for the HAC tests, the factored axial stresses are as follows:

$$\begin{aligned} \text{NCT } \text{F.S.} \times \sigma_{\text{axial}} &= 2 \times 6,407 = 12,814 \text{ psi} \\ \text{HAC } \text{F.S.} \times \sigma_{\text{axial}} &= 1.34 \times 22,067 = 29,570 \text{ psi} \end{aligned}$$

Hoop Stress Calculation

Hoop stresses are calculated in the inner shell using the closed-form solutions from Roark and Young (Reference 2-26).

- Inner shell mean radius = 31.375 in
- Inner shell thickness = 0.75 in
- Lead column mean radius = 33.425 in
- Lead column thickness = 3.35 in
- Shell-lead interface radius = 31.75 in
- Coefficient of thermal expansion of lead at -40°F =  $15.65 \times 10^{-6}$  in/in-°F
- Coefficient of thermal expansion of steel at -40°F =  $6.4 \times 10^{-6}$  in/in-°F
- Elastic Modulus of lead at -40°F =  $2.46 \times 10^6$  psi
- Elastic Modulus of steel at -40°F =  $30 \times 10^6$  psi

Differential thermal expansion at the steel-lead interface,

$$\Delta_{\text{diff}} = 31.75 \times (15.65 - 6.4) \times 10^{-6} \times (70 + 40) = 0.0323 \text{ in}$$

Assuming that the interface pressure is  $q$ , the radial deformation of the steel shell and lead column is calculated based on the formulas from Reference 2-26 as follows:

$$\Delta_{\text{steel}} = q \times 31.375^2 / (30 \times 10^6 \times 0.75)$$

$$\Delta_{\text{lead}} = q \times 33.425^2 / (2.46 \times 10^6 \times 3.35)$$

Equating the sum of these deformations with the differential thermal expansion, we get

$$q \times [31.375^2 / (30 \times 10^6 \times 0.75) + 33.425^2 / (2.46 \times 10^6 \times 3.35)] = 0.0323$$

or,  $q = 180.12$  psi

The hoop stress in the inner shell under this pressure is:

$$\sigma_{\text{hoop}} = 180.12 \times 31.375 / 0.75 = 7,535 \text{ psi}$$

Using a safety factor of 2 for NCT and 1.34 for the HAC tests, the factored hoop stresses are as follows:

$$\text{NCT F.S.} \times \sigma_{\text{hoop}} = 2 \times 7,535 = 15,070 \text{ psi}$$

$$\text{HAC F.S.} \times \sigma_{\text{hoop}} = 1.34 \times 7,535 = 10,097 \text{ psi}$$

Since the maximum of above inner shell stresses (15,070 psi) is less than the combined load critical buckling stress intensity (37,993 psi) calculated earlier in this Section, and the thinner inner shell (0.75 inches) stresses envelope that of the outer shell (1.50 inches thick), therefore the 8-120B cask buckling will not occur.

#### 2.7.1.8 Vent Port Evaluation

The 8-120B package has one penetration through the containment boundary that is closed with a bolt. This is the vent port. The vent port is recessed into the cask lid. The vent port is completely covered by the foam of the impact limiter. Therefore, during the HAC drop tests the vent port does not make contact with the impact surface.

#### 2.7.1.9 Closure Bolt Evaluation

The primary and secondary lid bolt stresses under various loading combinations that were obtained from the FEM analyses have been provided in the appropriate sections of the SAR. They have been compared with the corresponding design allowable values and typically show that a large factor of safety exists in the design of the bolts under all loading combinations. For the 30-ft side and corner drop loadings the primary lid bolt stresses were calculated using the approach shown in Section 7.3 of *EnergySolutions* document ST-627 (Reference 2-15) presented below.

The individual loads for the primary lid bolts are given in Tables 19 through 30 of *EnergySolutions* document ST-627 (Reference 2-15). Loads are calculated at two locations where the highest stresses occur; the root of the bolt shank and the lid interfaces.

Locations of bolts on the primary lid are identified by angle according to EnergySolutions document ST-627 (Reference 2-15). Maximum stresses in the bolts by location during the corner and side drops are shown in Figures 48 and 49 of EnergySolutions document ST-627 (Reference 2-15).

Below is a sample calculation for the bolt stresses from the tabulated FEM data. A sample of bolt load data from the FEM as given in Tables 19 through 30 of EnergySolutions document ST-627 (Reference 2-15) is below:

Load	<b>FX</b>	<b>FY</b>	<b>FZ</b>	<b>MX</b>	<b>MY</b>	<b>MZ</b>
	lbs	lbs	lbs	in-lbs	in-lbs	in-lbs
bolt4	-114,222	-4,322	-70,317	-3,492	-92,463	-2,618

$$F_{\text{Axial}} = FZ = 70,317\text{lbs}$$

$$V_{\text{Shear}} = \sqrt{(FX)^2 + (FY)^2} = \sqrt{114,222^2 + 4,322^2} = 114,304\text{lbs}$$

$$M = \sqrt{(MX)^2 + (MY)^2} = \sqrt{3,492^2 + 92,463^2} = 92,529\text{in-lbs}$$

$$T = MZ = -2,618 \text{ in-lbs (Neglected)}$$

The bolts are 2" - 8 UN:

$$\text{Bolt diameter} = d_{\text{bolt}} = 2.0 \text{ in}$$

$$\text{Bolt area} = A_{\text{stress area}} = 2.7665 \text{ in}^2$$

$$\sigma_{\text{axial}} = \frac{F_{\text{axial}}}{A_{\text{stress area}}} = \frac{F_{\text{axial}}}{2.7665} = \frac{70,317}{2.7665} = 25,417 \text{ psi}$$

Allowable bolt axial (average) stress = Allowable membrane stress = 105,000 psi

(per Table 2-2)

$$\sigma_{\text{axial}} = \sigma_{\text{average}} = 25,417 \text{ psi} < 105,000 \text{ psi}$$

O.K.

$$\sigma_{bending} = \frac{M}{S} = \frac{M}{\frac{\pi \times d_{bolt}^3}{32}} = \frac{32 \times 92,529}{\pi \times 2^3} = 117,812 \text{ psi}$$

$$\tau = \frac{V_{shear}}{A_{stress\ area}} = \frac{114,304}{2.7665} = 41,317 \text{ psi}$$

Allowable bolt shear stress = Smaller of (0.42S<sub>u</sub> and 0.6S<sub>y</sub>) = 63,000 psi

$$\tau = 41,137 \text{ psi} < 63,000 \text{ psi} \quad \text{O.K.}$$

$$\sigma_{axial+bending} = \sigma_{axial} + \sigma_{bending} = 25,417 + 117,812 = 143,229 \text{ psi}$$

Allowable membrane + bending stress = 150,000 psi (per Table 2-2)

$$\sigma_{axial+bending} = 143,229 \text{ psi} < 150,000 \text{ psi} \quad \text{O.K.}$$

Bolt axial-shear interaction (I.C.) is:

$$\text{I.C.} = \left( \frac{\sigma_{axial}}{105,000} \right)^2 + \left( \frac{\tau}{63,000} \right)^2 = \left( \frac{25,417}{105,000} \right)^2 + \left( \frac{41,317}{63,000} \right)^2 = 0.4887 < 1.0 \quad \text{O.K.}$$

Therefore, bolt design meets the design criteria established in Section 2.1.2.

Additionally, it is shown that under NCT loading conditions, the bolt torque provides sufficient preload in the bolts to overcome the loading arising from the thermal and pressure loadings. It is also shown that the minimum engagement length requirement for the specified bolts and the bolting ring material is also satisfied.

### Lid Bolt Torque Evaluation

In order to maintain the seal during the NCT, the 8-120B package primary and secondary lid bolts are tightened to a torque value of 500 ± 50 ft-lbs (lubricated). Under the NCT loading combinations listed in Table 2-1, the largest bolt loads are experienced due the loading of minimum external pressure, under which the package is subject to an internal pressure of 50 psig. The lid and bolting ring (ASTM A516 Grade 70) and bolt (ASTM A354 Grade BD) are fabricated from different material that have the same coefficient of thermal expansion (Table 2-4). The seal plate is made from ASTM A240 Type 304L with a higher coefficient of thermal expansion (Table 2-4). These components expand different amounts during the hot and cold environments. Therefore, in the cold environment the seal plate contracts more and as a result the bolts experience a loss of tension due to this relative expansion. The amount of loss of tension is conservatively calculated as follows:

Assume that the joint temperature is -40°F. Coefficient of thermal expansion of the seal plate material from Table 2-4 at 70°F is 8.5×10<sup>-6</sup> in/(in °F) and for bolt and lid materials is 6.4×10<sup>-6</sup> in/(in °F).

Primary Lid Bolts

Required Torque Calculation:

The effective length of the bolt for this relative expansion is the distance between the bolt-head to the top of the bolting ring (L) is:

$$L = 1.625" \text{ Primary lid} + 0.25" \text{ washer} + 0.25" \text{ seal plate} = 2.125 \text{ in}$$

The relative expansion of the bolt and seal ring is:

$$\delta = 0.25 \times (8.5 - 6.4) \times 10^{-6} \times (-40 - 70) = -5.775 \times 10^{-5} \text{ in}$$

Young's Modulus for the bolting material at 70°F is  $29.2 \times 10^6$  psi. Therefore, the loss of bolt stress due to relative thermal expansion is:

$$\sigma_{thermal} = 29.2 \times 10^6 \times 5.775 \times 10^{-5} / 2.125 = 794 \text{ psi}$$

For 2" diameter bolts, the preload lost is:

$$F_{thermal} = \pi/4 \times 2^2 \times 794 = 2,495 \text{ lb}$$

The Maximum internal pressure of the package is 50 psi, which occurs under minimum external pressure load combinations (see Table 2-1). For the total 20 primary lid bolts, the average bolt load under this pressure is:

$$F_{p-avg} = \pi \times \left(31 \frac{7}{16}\right)^2 \times 50 / 20 \quad \left(31 \frac{15}{16} - \frac{1}{2} = 31 \frac{7}{16} \text{ " is the radius of inner seal}\right)$$

$$= 7,762 \text{ lb}$$

The total required preload is:

$$F_{preload} = 2,495 + 7,762 = 10,257 \text{ lb}$$

Using the customary torque equation,

$$T = K \times D \times F$$

Where, T = torque

K = nut factor = 0.1 for lubricated condition

D = nominal diameter of the bolt = 2.0"

F = preload

The required torque is:

$$T = 0.1 \times 2.0 \times 10,257 = 2,052 \text{ in-lb} = 171 \text{ ft-lb}$$

Therefore, the specified torque of  $500 \pm 50$  ft-lb (lubricated) is sufficient to maintain the needed bolt preload for the NCT loading.

Bolt Engagement:

The 2"-8UN, Class 2A bolts are installed though 2" long threaded inserts which develop strengths equal or greater than that of the bolt.

Secondary Lid Bolts

Required Torque Calculation:

The effective length of the bolt for this relative expansion is the distance between the bolt-head to the top of the primary lid (L') is:

$$L' = 2.1875" \text{ Secondary lid} + 0.25" \text{ washer} = 2.4375"$$

For a 3/8" thick seal plate, the relative expansion of the bolt and seal ring is:

$$\delta = (0.375 \times (8.5 - 6.4) \times 10^{-6}) \times (-40 - 70) = -8.6625 \times 10^{-5}"$$

Young's Modulus for the bolting material at 70°F is  $29.2 \times 10^6$  psi. Therefore, the loss of bolt stress due to relative thermal expansion is:

$$\sigma_{thermal} = 29.2 \times 10^6 \times 8.6625 \times 10^{-5} / 2.4375 = 1,038 \text{ psi}$$

For 2" diameter bolts, the preload lost is:

$$F_{thermal} = \pi/4 \times 2^2 \times 1,038 = 3,261 \text{ lb}$$

The Maximum internal pressure of the package is 50 psi, which occurs under minimum external pressure load combinations (see Table 2-1). For the total 12 secondary lid bolts, the average bolt load under this pressure is:

$$F_{p-avg} = \pi \times \left(14 \frac{13}{16}\right)^2 \times 50 / 12 \quad \left(0.5 \times 28 \frac{3}{4} + 0.5 \times 1 \frac{7}{8} - \frac{1}{2} = 14 \frac{13}{16} \text{ " is the radius of inner seal}\right)$$

$$= 2,872 \text{ lb}$$

The total required preload is:

$$F_{preload} = 3,261 + 2,872 = 6,133 \text{ lb}$$

Using the customary torque equation,

$$T = K \times D \times F$$

Where,  $T$  = torque

$K$  = nut factor = 0.1 for lubricated condition

$D$  = nominal diameter of the bolt = 2.0"

$F$  = preload

The required torque is:

$$T = 0.1 \times 2.0 \times 6,133 = 1,227 \text{ in-lb} = 102 \text{ ft-lb}$$

Therefore, the specified torque of  $500 \pm 50$  ft-lb (lubricated) is sufficient to maintain the needed bolt preload for the NCT loading.

Bolt Engagement:

The 2"-8UN, Class 2A bolts are installed though 2" long threaded inserts which develop strengths equal or greater than that of the bolt.

1.1.1.1 Thermal-Shield Attachment Evaluation

The thermal-shield is attached to the secondary lid lifting lugs by three hitch pins. These pins have 1/2" diameter and are made of ASTM A-276 Gr. 304 stainless steel. In this section an evaluation is performed to show that the pins will provide enough strength to support the inertia of the thermal-shield during all the postulated hypothetical free drop tests.

The mass of the thermal-shield is calculated as follows (Reference: EnergySolutions drawing DWG-CSK-12CV01-EG-001-01, included in Section 1.0).

Mass of Item #1	= $0.28 \times \pi/4 \times 492 \times 0.25$	= 132 lb
Mass of Item #2	= $0.28 \times \pi/4 \times 492 \times 0.12$	= 63 lb
Mass of Item #3	= $7 \times 0.28 \times 5.58 \times 2.9375$	= 32 lb
Misc (10% of above)		= 23 lb
Total		= 250 lb

The ultimate tensile strength of ASTM A-276 Gr. 304 stainless steel is specified to be 75,000 psi. Taking 60% of this value as the shear strength, the shear strength of the pin material is  $0.6 \times 75,000 = 45,000$  psi. The total pin shear area is:

$$A = 3 \times 2 \times (\pi/4) \times 0.5^2 = 1.178 \text{ in}^2$$

Total shear load that can be resisted by the pins is:

$$V = 1.178 \times 45,000 = 53,010 \text{ lb}$$

Deceleration acceptable =  $53,010/250 = 212 \text{ g's}$

The largest deceleration is experienced by the package is 160 g's during the end drop test (see Section 2.7.1.1). Therefore, it is concluded that the thermal-shield will remain attached to the secondary lid during all the postulated free drop tests.

2.7.2 CRUSH

Not applicable; the package weighs more than 1,100 lb, and its density is larger than 62.4 lb/ft<sup>3</sup>.

2.7.3 PUNCTURE

The Nelms puncture relation (Reference 2-20, Page 18) is given as:

$$t = (W/S)^{0.71}$$

Where:

- t = shell thickness = 1 1/2 inches
- W = cask weight, lbs.
- S<sub>u</sub> = ultimate tensile strength of outer shell  
 = 70,000 psi

The package weight causing puncture is:

$$W = S \times t^{1.4}$$

The corresponding weight to cause puncture of the 1-1/2 inch outer shell is:

$$W_s = 70,000 \times 1.5^{14} = 123,488 \text{ lbs.}$$

The actual package weight is 74,000 lbs; therefore, the factor of safety for puncture resistance on an energy basis is:

$$F.S. = \frac{123,488}{74,000} = 1.67$$

When the package impacts the puncture pin, the force imposed upon the package is estimated as:

$$F_I = K_s \times A_I$$

$K_s$  = Dynamic flow pressure of steel = 45,000 psi (Reference 2-20, Page 64)

$R_c$  = Pin diameter = 6.0 inches

$$A_I = \frac{\pi}{4} \times (R_c)^2 = \frac{\pi}{4} \times (6.0)^2 = 28.27 \text{ in.}^2$$

$$F_I = (45,000) \times (28.27)$$

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

This force induces a moment at the midsection of the package. The moment is estimated as:

$$M = \frac{F \times l}{8} = \frac{(1.272 \times 10^6) \times (88)}{8} = 13.99 \times 10^6 \text{ in-lb}$$

Calculating the section properties of the outer shell at the midsection:

$$I = \frac{\pi(d_o^4 - d_i^4)}{64}$$

$$= \frac{\pi(73.2^4 - 70.2^4)}{64} = 2.172 \times 10^5 \text{ in}^4$$

Using these section properties gives a bending stress of:

$$S_b = \frac{M \times c}{I} = \frac{(13.99 \times 10^6) \times (36.6)}{2.172 \times 10^5} = \pm 2,357 \text{ psi}$$

Conservatively assuming that the compressive and tensile stresses occur at the same location, the stress intensity is 4,714 psi and the factor of safety is:

$$F.S. = \frac{70,000}{4,714} = 14.8$$

To evaluate the ability of the cask to withstand puncture from a 40-inch end drop onto a 6-inch diameter pin, the end of the cask will be treated as two simply supported plates with a central load. Since the end is comprised of two 3.25-inch thick plates which must have identical deflections, the energy of the drop will be divided evenly between the two plates.

Reference 2-27, p. 415, gives the following equation for the deflection of a centrally loaded circular plate:

$$\frac{w_o}{h} + A \times \left( \frac{w_o}{h} \right)^3 = B \times \left( \frac{P \times a^2}{E \times h^4} \right)$$

Where:

$w_o$  = deflection at center of plate, in.

$h$  = plate thickness, in.

$P$  = central load, lb.

$E$  = Young's modulus, psi

$a$  = plate radius, in.

$A = 0.272$  (simply supported plate, Ref. 2-29, p. 416)

$B = 0.552$  (simply supported plate, Ref. 2-29, p. 416)

The deformation energy can be found from:

$$u = \int_0^{\delta} P dw_o$$

$$= \frac{E \times h^4}{B \times a^2} \left[ \frac{\delta^2}{2h} + \frac{A \times \delta^4}{4h^3} \right]$$

This can be equated to the drop energy,  $\frac{W \times H}{2}$  to find the central deflection:

$$EhA\delta^4 + 2Eh^3\delta^2 - 2Ba^2WH = 0$$

$$\delta^2 = \frac{-2Eh^3 + \sqrt{(4E^2h^6 + 4EhA \times 2Ba^2WH)}}{2EhA}$$

$$\delta^2 = \frac{-2 + \sqrt{\left(4 + \frac{8ABa^2WH}{Eh^5}\right)}}{\frac{2A}{h^2}}$$

For:

$h = 3.25$  in.

$E = 29 \times 10^6$  psi

$$\begin{aligned} a &= 31 \text{ in.} \\ W &= 74,000 \text{ lb.} \\ H &= 40 \text{ in.} \end{aligned}$$

$$\delta^2 = \frac{-2 + \sqrt{\left(4 + \frac{8 \times 0.272 \times 0.552 \times 31^2 \times 74,000 \times 40}{29 \times 10^6 \times 3.25^5}\right)}}{\frac{2 \times 0.272}{3.25^2}} = 1.547 \text{ in}^2$$

Then:

$$\delta = 1.244 \text{ in.}$$

Solving for the force required to produce this deflection yields a value:

$$\frac{1.244}{3.25} + 0.272 \times \left(\frac{1.244}{3.25}\right)^3 = 0.552 \times \left(\frac{P \times 31^2}{29 \times 10^6 \times 3.25^4}\right)$$

$$P = 2.43 \times 10^6 \text{ lb}$$

However, using the dynamic flow pressure of the steel pin, the maximum force that can be exerted by the pin is given by:

$$\begin{aligned} F_{\max} &= A_p \times K_s \\ &= \frac{\pi(6^2)}{4} \times 45,000 \\ &= 1.27 \times 10^6 \text{ lb.} \end{aligned}$$

This force will produce the maximum deflection of the plates

$$\delta = 0.669 \text{ in.}$$

Reference 2-27, p. 415, gives the following equations for the maximum membrane and membrane plus bending stresses:

Membrane:

$$\sigma_1 = \frac{\alpha \times E \times \delta^2}{a^2}$$

Membrane-plus-bending:

$$\sigma_2 = \frac{\beta \times E \times \delta \times h}{a^2}$$

For:

$$\alpha = 0.407 \quad (\text{Ref. 2-29, p. 416})$$

$$\beta = 0.606$$

Then:

$$\sigma_1 = \frac{0.407 \times 29 \times 10^6 \times 0.669^2}{31^2}$$

$$\sigma_1 = 5,497 \text{ psi.}$$

$$\sigma_2 = \frac{0.606 \times 29 \times 10^6 \times 0.669 \times 3.25}{31^2}$$

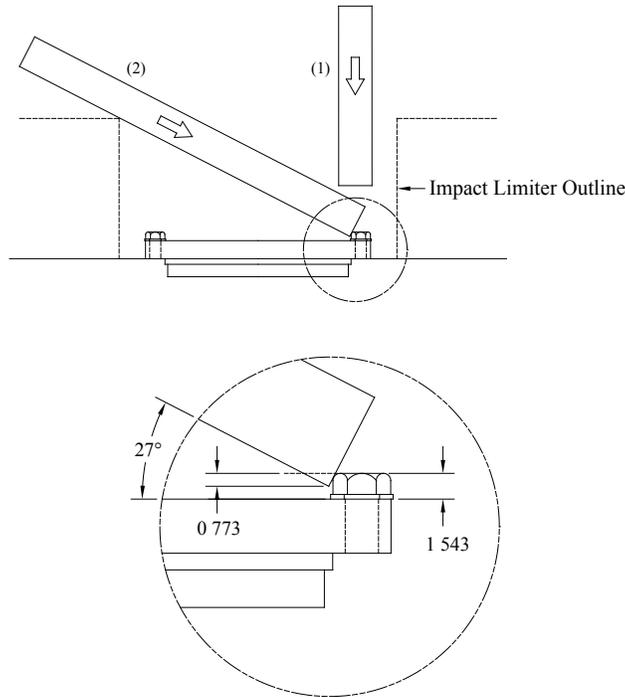
$$\sigma_2 = 39,761 \text{ psi.}$$

The minimum factor of safety is:

$$F.S. = \frac{70,000}{39,761} = 1.76$$

In the scenario of the puncture bar piercing through the top hollow portion of the impact limiter sheet-metal cover, it is also postulated that the puncture bar may contact the thermal shield and possibly the secondary lid bolts. Structural evaluation of the thermal-shield has been performed in Reference 2-31. Evaluate the deformation and/or damage to the thermal-shield in this scenario has been performed using a 3-dimensional ANSYS inelastic finite element model. It has been shown that the puncture bar may cause a minor damage to the shield near the central portion. Near the edge of the assembly the puncture bar may cause the shield-plates to deform all the way to the lid with only minor damages. The two stainless-steel plates will remain intact over most of the area, providing thermal resistance during the fire test.

The secondary lid bolts will remain covered by the thermal-shield in this scenario. However, a conservative evaluation of the bolts has been performed here with the assumption that the thermal-shield does not provide any cover to the bolts. Under this assumption, the rod impact on the bolthead is envisioned as shown in the following sketch.



In the two extreme cases, the rod may strike the bolthead as shown in the above sketch. If the rod strikes the bolthead as shown in (1) above, the bolt undergoes compression. The secondary lid comes in contact with the primary lid, and the rod can cause no damage to the lid as shown in the lid puncture evaluation provided above. If the rod strikes the bolthead as shown in (2) above, the shear-out of the bolthead is of concern. An evaluation is performed below to show that the shear-out of the bolthead is not possible in the scenario postulated here.

Based on the geometry of the impact limiter hollow section, the rod will have to be inclined at an angle of 27° from the lid surface to make contact with the bolthead in an orientation that may cause the maximum shear load on the bolthead. The bolts are specified to be 2” heavy head cap screws with flat washers.

- Maximum head thickness of 2” heavy head cap screws = 1.263”
- Maximum thickness of 2” washers = 0.28”
- Maximum projection above the lid surface = 1.263 + 0.28 = 1.543”

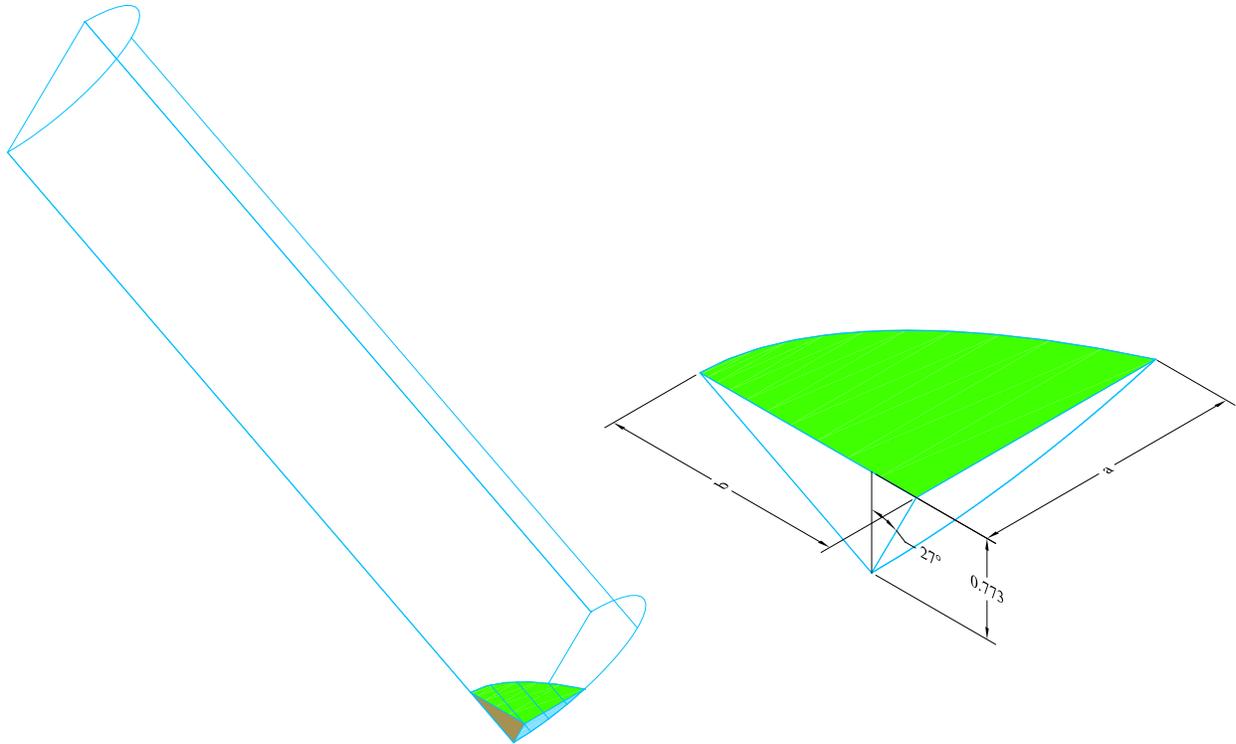
Assuming that the rod makes contact at approximately the mid-height of the projection, the height of the shear-plane on the rod is located at 0.77” as shown in the sketch.

The rod, according to the regulations (Reference 2-1) is specified to be mild steel. Typical value of the ultimate tensile strength of mild steel is 45,000 to 55,000 psi (e.g. A-675 Gr. 45). The bolt has been specified as ASTM-354 Gr. BD for which the ultimate tensile strength is 150,000 psi. Taking 60% of the ultimate tensile strength as the shear stress at failure, the shear strengths of the two materials are as follows:

- Rod material shear strength = 0.6×55,000 = 33,000 psi
- Bolt material shear strength = 0.6×150,000 = 90,000 psi

The bolt shear area is  $(\pi/4) \times 2^2 = 3.14 \text{ in}^2$ . The rod shear area is calculated as follows.

Consider the following sketch that shows half of the rod:



The shear area of the rod is a parabola which has a base  $2a$  and height  $b$  as shown in the sketch. The rod has a radius of 3" as specified in Reference 2-1. From the geometry above;

$$a = \sqrt{3^2 - (3 - 0.773 / \cos 27^\circ)^2} = 2.11''$$

$$b = 0.773 \times (\tan 27^\circ + \cot 27^\circ) = 1.911''$$

Area of the parabola:

$$A = (2/3) \times 2a \times b = (2/3) \times 2 \times 2.11 \times 1.911 = 5.38 \text{ in}^2$$

Thus,

$$\text{Rod shear strength} = 5.38 \times 33,000 = 177,540 \text{ lb}$$

$$\text{Bolt shear strength} = 3.14 \times 90,000 = 282,600 \text{ lb}$$

Since the bolt shear strength is much greater than that of the rod, it is concluded that the puncture bar will not cause any damage to the bolts in the scenario postulated here.

### Lead Shielding Deformation

After the puncture drop test the 8-120B cask may experience denting of the sidewall. The lead shielding behind the dent may experience a slight flattening which may result in a shielding loss in this region. A conservative evaluation of the maximum amount of lead deformation under

puncture drop test of 8-120B cask has been performed in Reference 2-15. It has been shown that the lead shielding deformation is limited to 0.458 inch. This deformation is used in Section 5 for the shielding calculations.

#### 2.7.4 THERMAL

The thermal evaluation of the 8-120B package for the HAC fire test specified in 10 CFR 71.73(c)(4) has been performed in Section 3.4. It has been shown in the free drop analyses that the rupture of the impact limiter skin near the point of impact is possible. The polyurethane foam is self-extinguishing and produces intumescent char when thermally degraded. The two impact limiters are assumed to provide thermal insulation.

Using the results of the thermal analysis of Section 3.4, structural evaluation of the package has been performed in this section. The finite element model described in Section 2.6 has been employed in the analyses. The details of the model, including the assumptions, modeling details, boundary conditions, and input and output data are included in the *EnergySolutions* document ST-637 (Reference 2-21).

##### 2.7.4.1 Summary of Pressure and Temperatures

Based on the thermal analysis of the package during the HAC fire test, presented in Section 3.4, the maximum temperatures in various parts of the package are presented in Table 3-2 and plotted in Figure 3-12. These temperatures are summarized here as follows:

Fire Shield	= 1,392°F
Outer Shell	= 464.4°F
Inner Shell	= 295.5°F
Lead	= 295.8°F
Primary Lid Seal	= 212.4°F
Secondary Lid Seal	= 266.0°F

It should be noted that the maximum temperature in various components of the package occur at different time instants. The maximum temperature of the cask cavity during the entire HAC fires test and subsequent cool-down is 320.5°F as shown in Figure 17 of *EnergySolutions* document TH-028 (Reference 2-28). Conservatively 325°F temperature is used in Section 3.4.3 for calculating the maximum internal pressure of the package during the HAC fire test. The calculated internal pressure of the package during the HAC fire test is 155.0 psig.

##### 2.7.4.2 Differential Thermal Expansion

The structural finite element model used for the analyses of the 8-120B package under HAC fire test uses temperature dependent material properties of the cask components. The differential thermal expansion of various components of the cask is automatically included in the stress evaluation of the package.

Differential thermal expansion between the grossly dewatered resin contents and the secondary container is evaluated to determine the total free volume (i.e., ullage and/or interstitial void space) that is required to permit free thermal expansion of the contents within the secondary

container. For the HAC fire condition, the maximum temperature of the contents is less than 240°F for the maximum decay heat load of 200 watts. Note that resin contents, which are dose limited, have a much lower decay heat load (e.g., less than 10 watts) and will experience lower temperatures. Nevertheless, as shown in Section 2.6.1.2, the minimum free volume required to permit free thermal expansion of the grossly dewatered resin contents within the secondary container under the NCT heat condition (i.e., at a bounding temperature of 200°F) is only 3.2%, compared to 9.9% free volume required for NCT cold conditions. Since the maximum temperature of the contents for the HAC fire condition is only slightly higher than that for the NCT heat condition, it is apparent that the total free volume required to permit free thermal expansion under NCT cold conditions is sufficient to allow free thermal expansion of grossly dewatered resin contents inside a secondary container under the HAC fire condition.

#### 2.7.4.3 Stress Calculations

The stresses in the package under the HAC fire test have been calculated in *EnergySolutions* document ST-637 (Reference 2-21). The loading combination used for the HAC fire test is listed in Table 2-1. Table 2-25 presents the maximum stresses in various component of the package.

#### 2.7.4.4 Comparison with Allowable Stresses

The stresses in the package under the HAC fire test are compared with their allowable values in Table 2-25. The allowable values in various components of the package are listed in Table 2-2. It is noticed from the comparison with the allowable values that all the components of the package experience stresses well below their allowable values. A minimum factor of safety of 1.73 occurs in the bolting ring.

#### 2.7.5 IMMERSION – FISSILE MATERIAL

Not applicable for 8-120B package; since it does not contain fissile material.

#### 2.7.6 IMMERSION – ALL PACKAGES

All the Type-B packages are required to meet the water immersion test specified in 10 CFR 71.73(c)(6). According to which, an undamaged package must be subjected to a pressure of 21.7 psig.

The package has been analyzed for an increased external pressure of 25 psig in Section 2.6.4. Therefore, the stresses presented in that section envelope those that will arise due to the immersion test.

#### 2.7.7 DEEP WATER IMMERSION TEST

Not applicable; 8-120B package does not contain irradiated nuclear fuel.

#### 2.7.8 SUMMARY OF DAMAGE

It has been demonstrated by several analyses performed in Section 2.7 that the 8-120B package can withstand the HAC test, specified in 10 CFR 71.73, including the free drop, puncture and

fire. During these drop tests the protective impact limiters may undergo some damage, which is summarized as follows:

- During the HAC drop tests, the impact limiter skin may buckle and/or rupture in the vicinity of impact. The rupture may expose a portion of the polyurethane foam that is contained inside the steel skin.
- During the puncture drop test on the sidewall of the package, the fire-shield which is designed to have a separation from the outer shell, may come in contact with the outer shell due to deformation of the helically wound wire. The loss of separation will only be in the close vicinity of the puncture bar end. This will decrease the thermal resistance in that local area. The temperature there may increase slightly from those calculated for the intact package. In the area of the outer shell surface, the temperatures are well within the acceptable value. No unacceptable stress increase is expected because of slight increase in the local temperature.
- During the puncture drop test on the impact limiters, the outer steel skin will deform significantly due to large compression of polyurethane foam at the impact point. This may expose a portion of the polyurethane foam that is contained inside the steel skin. In addition, the steel plates that cover the central hollow regions of the upper and lower impact limiters may be penetrated or completely dislodged by the puncture drop test, resulting in direct exposure of the secondary lid thermal shield and the cask bottom plate in these regions to the subsequent fire. The seating surface of the impact limiters, which includes the impact limiter attachments, will remain intact as shown in the analysis. Therefore, during the HAC fire test, the impact limiters will provide thermal insulation with a reduced efficiency. The temperature in the critical components of the cask will not vary significantly.
- Puncture drop test will not cause a direct impact with any of the port closure plates.

Based on the assessment of the above damage it is concluded that the 8-120B package can safely withstand the HAC free drop, puncture, and fire tests performed in sequence. The package structural components under these drop tests have been shown to meet the design criteria set forth in Section 2.1.2.

## **2.8 ACCIDENT CONDITIONS FOR AIR TRANSPORT OF PLUTONIUM**

Not applicable for 8-120B package since it is not transported by air.

## **2.9 ACCIDENT CONDITIONS FOR FISSILE MATERIAL PACKAGES FOR AIR TRANSPORT**

Not applicable for 8-120B package since it is not transported by air.

## **2.10 SPECIAL FORM**

Not applicable for 8-120B package since the package contents are not limited to special form.

## **2.11 FUEL RODS**

Not applicable for 8-120B package; since the contents do not include fuel rods.

## 2.12 APPENDIX

### 2.12.1 LIST OF REFERENCES

- (2-1) Code of Federal Regulations, Title 10, Part 71, Packaging and Transportation of Radioactive Material.
- (2-2) U.S. NRC Regulatory Guide 7.8, Revision 1, Load Combinations for the Structural Analysis of Shipping Casks for Radioactive Material, March 1989.
- (2-3) U.S. NRC Regulatory Guide 7.6, Revision 1, Design Criteria for the Structural Analysis of Shipping Cask Containment Vessels, 1978.
- (2-4) ASME Boiler & Pressure Vessel Code, American Society of Mechanical Engineers, New York, NY, 2001.
- (2-5) EnergySolutions Proprietary Document ST-551, Revision 3, Validation of the LS-DYNA Drop Analyses Results with the Test Data.
- (2-6) U.S. NRC Regulatory Guide 7.11, Fracture Toughness Criteria of Base Material for Ferritic Steel Shipping Cask Containment Vessel with a Maximum Wall Thickness of 4 inches (0.1 m), June 1991.
- (2-7) NUREG/CR-3854, Fabrication Criteria for Shipping Containers, March 1985.
- (2-8) NUREG 0481/SAND77-1872, An Assessment of Stress-Strain Data Suitable for Finite Element Elastic-Plastic Analysis of Shipping Containers, Sandia National Laboratories, 1978.
- (2-9) General Plastics Manufacturing Company, Last-A-Foam FR-3700 for Crash & Fire Protection of Nuclear Material Shipping Containers, June 1997.
- (2-10) NUREG/CR-3019, Recommended Welding Criteria for Use in the Fabrication of Shipping Containers for Radioactive Material, March 1985.
- (2-11) ANSYS/LS-DYNA, Computer Software, Version 12.1, ANSYS Inc., Canonsburg, PA, 2009.
- (2-12) Code of Federal Regulations, Title 49, Part 393, Parts and Accessories Necessary for Safe Operation.
- (2-13) EnergySolutions Document ST-626, Revision 0, Structural Analyses of the 8-120B Cask under Normal Conditions of Transport.
- (2-14) EnergySolutions Proprietary Document ST-625, Revision 0, Drop Analyses of the 8-120B Cask Using LS-DYNA Program.
- (2-15) EnergySolutions Document ST-627, Revision 1, Structural Analyses of the 8-120B Cask under Drop Conditions.
- (2-16) EnergySolutions Document ST-608, Revision 0, 3-60B Cask ANSYS Finite Element Model Grid Convergence Study.
- (2-17) Structural Analyses and Design of Nuclear Plant Facilities, ASCE Publication No. 58, American Society of Civil Engineers.

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- (2-18) NUREG/CR-1815, Recommendations for Protecting Against Failure by Brittle Fracture in Ferritic Steel Shipping Containers Up to Four Inches Thick, August 1981.
  - (2-19) An Introduction to the Design and Behavior of Bolted Joints, John H. Bickford, Marcel Dekker Inc., Publication, N.Y., 1981.
  - (2-20) Cask Designer's Guide, Shappert, L.B., ORNL-NSIC-68, Oak Ridge National Laboratory, 1970.
  - (2-21) EnergySolutions Document ST-637, Revision 0, Structural Analyses of the 8-120B Cask under Hypothetical Fire Accident Conditions.
  - (2-22) NUREG/CR-6407, Classification of Transportation Packaging and Dry Spent Fuel Storage System Components Accordance to Importance to Safety, February 1996.
  - (2-23) Theory of Elastic Stability, Timoshenko, Stephen P. and James M. Gere, Second Edition, McGraw-Hill Book Company, 1961.
  - (2-24) Structural Analysis of Shells, Baker, E.H., L. Kovalsky and F.L. Rish, Robert E. Krieger Publishing Co., 1981
  - (2-25) EnergySolutions Document ST-635, Revision 0, 8-120B Cask Regulatory Tie Down Evaluation
  - (2-26) Formulas for Stress and Strain, Roark, Raymond J. and Warren C. Young, Fifth Edition, McGraw Hill Book Company, 1975
  - (2-27) Theory of Plates and Shells, Timoshenko, S. and S. Woinowsky-Krieger, Second Edition, McGraw-Hill Book Company, 1959.
  - (2-28) EnergySolutions Document TH-028, Revision 1, Fire Transient Analyses of the 8-120B Cask Using Finite Element Models.
  - (2-29) EnergySolutions Document ST-596, Revision 1, 3-60B Cask ANSYS/LS-DYNA Model Sensitivity Analyses.
  - (2-30) EnergySolutions Document ST-618, Revision 1, Discourse on the Use of Foam Properties in the LS-DYNA Analyses of the Casks.
  - (2-31) EnergySolutions Document ST-0001, Revision 0, Structural Evaluation of the Thermal-Shields of the 8-120B & 10-160B Casks under Puncture Drop Conditions.

Table 2-1 - Summary of Load Combinations for Normal and Accident Condition Loading

Loading Conditions	Ambient Temperature (°F)	Insolation	Heat Load (Watt)	Pressure (psi)		Stress Table <sup>(2)</sup> or Reference
				Internal	External	
<b>NORMAL CONDITIONS<sup>(1)</sup></b>						
Hot Environment	100	✓	200	35		2-5
Cold Environment	-40		200	35		2-6
Increased External Pressure	-20		0		25	2-8
Minimum External Pressure	100	✓	200	50		2-7
Free Drop + Max. Internal Pressure	100	✓	200	35		2-10, 2-12 & 2-14
Free Drop + Min. Internal Pressure	-20		0		0	2-11, 2-13 & 2-15
<b>ACCIDENT CONDITIONS<sup>(1)</sup></b>						
Free Drop + Max. Internal Pressure	100	✓	200	35		2-17, 2-19 & 2-21
Free Drop + Min. Internal Pressure	-20		0		0	2-18, 2-20 & 2-22
Puncture						Section 2.7.3
Fire	1475		200	155		2-24

Notes:

- (1) These loading combinations have been derived from the NRC Regulatory Guide 7.8 (Reference 2-2).
- (2) See these tables for the stress analysis results of the corresponding loading combinations

Table 2-2 - Allowable Stresses

Material →		ASTM A240 Type 304L	ASTM A516 Gr. 70	ASTM A354 Gr. BD
Yield Stress, $S_y$	(psi)	25,000 <sup>(1)</sup>	38,000 <sup>(1)</sup>	130,000 <sup>(1)</sup>
Ultimate Stress, $S_u$	(psi)	70,000 <sup>(1)</sup>	70,000 <sup>(1)</sup>	150,000 <sup>(1)</sup>
Design Stress Intensity, $S_m$	(psi)	16,700 <sup>(1)</sup>	20,000 <sup>(1)</sup>	30,000 <sup>(1)</sup>
Normal Conditions	Membrane Stress	16,700 <sup>(2)</sup>	20,000 <sup>(2)</sup>	60,000 <sup>(3)</sup>
	Mem. + Bending Stress	25,050 <sup>(2)</sup>	30,000 <sup>(2)</sup>	90,000 <sup>(3)</sup>
Hypothetical Accident Conditions	Membrane Stress	40,080 <sup>(4)</sup>	48,000 <sup>(4)</sup>	105,000 <sup>(5)</sup>
	Mem. + Bending Stress	60,120 <sup>(4)</sup>	70,000 <sup>(4)</sup>	150,000 <sup>(5)</sup>

Notes:

- (1) From ASME B&PV Code 2001, Section II, Part D (Reference 2-4).
- (2) Established from Regulatory Guide 7.6 (Reference 2-3), Position 2.
- (3) Regulatory Guide 7.6 (Reference 2-3) does not provide any criteria. ASME B&PV Code, Section III, Subsection ND has been used to establish these criteria.
- (4) Established from Regulatory Guide 7.6 (Reference 2-3), Position 6.
- (5) Regulatory Guide 7.6 (Reference 2-3) does not provide any criteria. ASME B&PV Code, Section III, Appendix F has been used to establish these criteria.

Table 2-3 - Stress Component Definition

	ASME Definition	8-120B Cask Incorporation
Primary (General) Membrane, $P_m$ [ RG 7.6, B-2 & B-4 WB-3213.6 & WB-3213.8]	Average primary stress across solid section. Excludes discontinuities and concentrations. Produced by pressure and mechanical loads.	The stresses caused by thermal expansion (contraction) are also included besides those caused by pressure and mechanical loading. The total stress over a section, <i>if meeting the allowable of membrane stress</i> , has been categorized as primary membrane. Otherwise, the stresses obtained from the FEA have been linearized to obtain the membrane component.
Primary Bending, $P_b$ [ RG 7.6, B-2 & B-4 WB-3213.7 & WB-3213.8]	Component of primary stress proportional to distance from centroid of solid section. Excluding discontinuities and concentrations. Produced by pressure and mechanical load.	The stresses caused by thermal expansion (contraction) are also included besides those caused by pressure and mechanical loading. The total stress over a section, <i>if meeting the allowable of membrane plus bending stress</i> , has been categorized as primary membrane plus bending stress. Otherwise, the stresses obtained from the FEA have been linearized to obtain the membrane plus bending component.
Secondary Membrane Plus Bending, $Q$ [ RG 7.6, B-3 WB-3213.9 ]	Self-equilibrating stress necessary to satisfy continuity of structure. Occurs at structural discontinuities. Can be caused by mechanical loads or by thermal expansion. Excludes local stress concentration.	The total stress over a section, <i>if meeting the allowable of membrane plus bending stress</i> , has been categorized as secondary membrane plus bending stress. Otherwise, the stresses obtained from the FEA have been linearized to obtain the membrane plus bending component.

Table 2-4 - Material Properties

Material	Temp. (°F)	Strength (ksi)			Young's Modulus (10 <sup>6</sup> psi)	Coefficient of Thermal Expansion (10 <sup>-6</sup> in/in °F)
		Yield (S <sub>y</sub> )	Ultimate (S <sub>u</sub> )	Membrane Allowable (S <sub>m</sub> )		
ASTM A240 Type 304L		(1)	(1)	(1)	(1)	(1)
	-20	25.0	70.0	16.7	28.8	-
	70	25.0	70.0	16.7	28.3	8.5
	100	25.0	70.0	16.7	-	8.6
	200	21.4	66.1	16.7	27.5	8.9
	300	19.2	61.2	16.7	27.0	9.2
	400	17.5	58.7	15.8	26.4	9.5
500	16.4	57.5	14.7	25.9	9.7	
ASTM A516 Gr. 70 Steel		(1)	(1)	(1)	(1)	(1)
	-20	38.0	70.0	20.0	30.3	-
	70	38.0	70.0	20.0	29.4	6.4
	100	38.0	70.0	20.0	-	6.5
	200	34.8	70.0	20.0	28.8	6.7
	300	33.6	70.0	20.0	28.3	6.9
	400	32.5	70.0	20.0	27.9	7.1
500	31.0	70.0	20.0	27.3	7.3	
ASTM A354 Gr. BD (Lid Bolts)		(1)	(1)	(1)	(1)	(1)
	-20	130	150	30	29.7	-
	70	130	150	30	29.2	6.4
	100	130	150	30	-	6.5
	200	119.1	150	30	28.6	6.7
	300	115	150	30	28.1	6.9
	400	111	150	30	27.7	7.1
500	105.9	150	30	27.1	7.3	
ASTM B29 Lead		(2)			(2)	(2)
	-20	-	-	-	2.43	15.65
	70	5	-	-	2.27	16.06
	100	-	-	-	2.21	16.22
	200	-	-	-	2.01	16.70
	300	-	-	-	1.85	17.33
	400	-	-	-	1.70	18.16
500	-	-	-	1.52	19.12	

Notes:

- (1) From ASME B&PV Code 2001, Section II, Part D (Reference 2-4).
- (2) From NUREG/CR 0481 (Reference 2-8)

Table 2-5 - Stress Intensities in 8-120B Cask under Hot Environment Loading

Component	Stress Category	Allowable S.I. (psi)	Calculated S.I. (psi) <sup>(1)</sup>	F.S. <sup>(2)</sup>
Primary Lid	P <sub>m</sub>	20,000	3,989	5.01
	P <sub>m</sub> + P <sub>b</sub>	30,000	3,989	7.52
Secondary Lid	P <sub>m</sub>	20,000	2,255	8.87
	P <sub>m</sub> + P <sub>b</sub>	30,000	2,255	13.30
Bolting Ring	P <sub>m</sub>	20,000	16,385	1.22
	P <sub>m</sub> + P <sub>b</sub>	30,000	16,385	1.83
Inner Shell	P <sub>m</sub>	20,000	13,872	1.44
	P <sub>m</sub> + P <sub>b</sub>	30,000	13,872	2.16
Outer Shell	P <sub>m</sub>	20,000	14,314	1.40
	P <sub>m</sub> + P <sub>b</sub>	30,000	14,314	2.10
Baseplate	P <sub>m</sub>	20,000	9,919	2.02
	P <sub>m</sub> + P <sub>b</sub>	30,000	9,919	3.02
Primary Lid Bolts	P <sub>m</sub>	60,000	12,516	4.79
	P <sub>m</sub> + P <sub>b</sub>	90,000	12,516	7.19
Secondary Lid Bolts	P <sub>m</sub>	60,000	4,189	14.32
	P <sub>m</sub> + P <sub>b</sub>	90,000	4,189	21.48

Notes:

- (1) Unless otherwise indicated in this column, the maximum stress intensity values have been conservatively reported as P<sub>m</sub> and P<sub>m</sub> + P<sub>b</sub> stress intensities.
- (2) Factor of Safety, F.S. = (Allowable S.I.) / (Calculated S.I.)
- (3) The stress values presented here are obtained from EnergySolutions Document ST-626 (Reference 2-13)

Table 2-6 - Stress Intensities in 8-120B Cask under Cold Environment Loading

Component	Stress Category	Allowable S.I. (psi)	Calculated S.I. (psi) <sup>(1)</sup>	F.S. <sup>(2)</sup>
Primary Lid	P <sub>m</sub>	20,000	3,695	5.41
	P <sub>m</sub> + P <sub>b</sub>	30,000	3,695	8.12
Secondary Lid	P <sub>m</sub>	20,000	2,102	9.51
	P <sub>m</sub> + P <sub>b</sub>	30,000	2,102	14.27
Bolting Ring	P <sub>m</sub>	20,000	4,177	4.79
	P <sub>m</sub> + P <sub>b</sub>	30,000	4,177	7.18
Inner Shell	P <sub>m</sub>	20,000	5,075	3.94
	P <sub>m</sub> + P <sub>b</sub>	30,000	5,075	5.91
Outer Shell	P <sub>m</sub>	20,000	4,778	4.19
	P <sub>m</sub> + P <sub>b</sub>	30,000	4,778	6.28
Baseplate	P <sub>m</sub>	20,000	2,312	8.65
	P <sub>m</sub> + P <sub>b</sub>	30,000	2,312	12.98
Primary Lid Bolts	P <sub>m</sub>	60,000	6,197	9.68
	P <sub>m</sub> + P <sub>b</sub>	90,000	6,197	14.52
Secondary Lid Bolts	P <sub>m</sub>	60,000	3,904	15.37
	P <sub>m</sub> + P <sub>b</sub>	90,000	3,904	23.05

Notes:

- (1) Unless otherwise indicated in this column, the maximum stress intensity values have been conservatively reported as P<sub>m</sub> and P<sub>m</sub> + P<sub>b</sub> stress intensities.
- (2) Factor of Safety, F.S. = (Allowable S.I.) / (Calculated S.I.)
- (3) The stress values presented here are obtained from EnergySolutions Document ST-626 (Reference 2-13)

Table 2-7 - Nil Ductility Temperature Requirements for  
 Fracture Critical Components of the 8-120B Cask

Component	Thickness (in)	A <sup>(1)</sup> (°F)	T <sub>NDT</sub> Req <sup>(2)</sup> (°F)
Bottom End Plate (Outside)	3.25	1	-21
Bottom End Plate (Inside)	3.25	1	-21
Inner Wall	0.75	-20	0
Outer Wall	1.5	-20	0
Primary Lid (Inside)	3.25	1	-21
Primary Lid (Outside)	3.25	1	-21
Secondary Lid (Inside)	3.25	1	-21
Secondary Lid (Outside)	3.25	1	-21
Bolting Ring	3.0	-2	-18

Notes:

- (1) Obtained from Figure 2-24.
- (2) T<sub>NDT</sub> determined according to ASTM Standard E208-81.

Table 2-8 - Stress Intensities in 8-120B Cask under Reduced External Pressure

Component	Stress Category	Allowable S.I. (psi)	Calculated S.I. (psi) <sup>(1)</sup>	F.S. <sup>(2)</sup>
Primary Lid	P <sub>m</sub>	20,000	4,488	4.46
	P <sub>m</sub> + P <sub>b</sub>	30,000	4,488	6.68
Secondary Lid	P <sub>m</sub>	20,000	2,612	7.66
	P <sub>m</sub> + P <sub>b</sub>	30,000	2,612	11.49
Bolting Ring	P <sub>m</sub>	20,000	8,216	2.43
	P <sub>m</sub> + P <sub>b</sub>	30,000	8,216	3.65
Inner Shell	P <sub>m</sub>	20,000	6,199	3.23
	P <sub>m</sub> + P <sub>b</sub>	30,000	6,199	4.84
Outer Shell	P <sub>m</sub>	20,000	7,133	2.80
	P <sub>m</sub> + P <sub>b</sub>	30,000	7,133	4.21
Baseplate	P <sub>m</sub>	20,000	4,476	4.47
	P <sub>m</sub> + P <sub>b</sub>	30,000	4,476	6.70
Primary Lid Bolts	P <sub>m</sub>	60,000	5,997	10.01
	P <sub>m</sub> + P <sub>b</sub>	90,000	5,997	15.01
Secondary Lid Bolts	P <sub>m</sub>	60,000	4,832	12.42
	P <sub>m</sub> + P <sub>b</sub>	90,000	4,832	18.63

Notes:

- (1) Unless otherwise indicated in this column, the maximum stress intensity values have been conservatively reported as P<sub>m</sub> and P<sub>m</sub> + P<sub>b</sub> stress intensities.
- (2) Factor of Safety, F.S. = (Allowable S.I.) / (Calculated S.I.)
- (3) The stress values presented here are obtained from EnergySolutions Document ST-626 (Reference 2-13)

Table 2-9 - Stress Intensities in 8-120B Cask under  
 Increased External Pressure and Immersion

Component	Stress Category	Allowable S.I. (psi)	Calculated S.I. (psi) <sup>(1)</sup>	F.S. <sup>(2)</sup>
Primary Lid	P <sub>m</sub>	20,000	2,743	7.29
	P <sub>m</sub> + P <sub>b</sub>	30,000	2,743	10.94
Secondary Lid	P <sub>m</sub>	20,000	1,077	18.57
	P <sub>m</sub> + P <sub>b</sub>	30,000	1,077	27.86
Bolting Ring	P <sub>m</sub>	20,000	3,027	6.61
	P <sub>m</sub> + P <sub>b</sub>	30,000	3,027	9.91
Inner Shell	P <sub>m</sub>	20,000	4,877	4.10
	P <sub>m</sub> + P <sub>b</sub>	30,000	4,877	6.15
Outer Shell	P <sub>m</sub>	20,000	2,554	7.83
	P <sub>m</sub> + P <sub>b</sub>	30,000	2,554	11.75
Baseplate	P <sub>m</sub>	20,000	2,812	7.11
	P <sub>m</sub> + P <sub>b</sub>	30,000	2,812	10.67
Primary Lid Bolts	P <sub>m</sub>	60,000	6,466	9.28
	P <sub>m</sub> + P <sub>b</sub>	90,000	6,466	13.92
Secondary Lid Bolts	P <sub>m</sub>	60,000	1,018	58.94
	P <sub>m</sub> + P <sub>b</sub>	90,000	1,018	88.41

Notes:

- (1) Unless otherwise indicated in this column, the maximum stress intensity values have been conservatively reported as P<sub>m</sub> and P<sub>m</sub> + P<sub>b</sub> stress intensities.
- (2) Factor of Safety, F.S. = (Allowable S.I.) / (Calculated S.I.)
- (3) The stress values presented here are obtained from EnergySolutions Document ST-626 (Reference 2-13)

Table 2-10 - Normal Condition Drop Test Summary

Drop Orientation	Thermal Environment	Maximum Impact Limiter Reaction <sup>(1)</sup> (lb)	Approximate Pulse Duration (msec)	Maximum Crush <sup>(2)</sup> (in)
End	Cold	$1.556 \times 10^6$	20	0.471
	Hot	$1.286 \times 10^6$	20	0.556
Side	Cold	$8.596 \times 10^5$	30	1.043
	Hot	$7.104 \times 10^5$	30	1.249
Corner	Cold	$3.188 \times 10^5$	125	4.0
	Hot	$2.785 \times 10^5$	125	4.8

Notes:

- (1) See Figures 13, 16, 19, 22, 25 and 28 of *EnergySolutions* Document ST-625 (Reference 2-14) for the time-history plots of the impact limiter reactions during various drop tests.
- (2) See Figures 15, 18, 21, 24, 27, and 30 of *EnergySolutions* Document ST-625 (Reference 2-14) for the time-history plots of the impact limiter crush during various drop tests.

Table 2-11 - Stress Intensities in 8-120B Cask under 1-ft End Drop – Hot Condition

Component	Stress Category	Allowable S.I. (psi)	Calculated S.I. (psi) <sup>(1)</sup>	F.S. <sup>(2)</sup>
Primary Lid	P <sub>m</sub>	20,000	15,086	1.33
	P <sub>m</sub> + P <sub>b</sub>	30,000	15,086	1.99
Secondary Lid	P <sub>m</sub>	20,000	12,890	1.55
	P <sub>m</sub> + P <sub>b</sub>	30,000	12,890	2.33
Bolting Ring	P <sub>m</sub>	20,000	12,994	1.54
	P <sub>m</sub> + P <sub>b</sub>	30,000	12,994	2.31
Inner Shell	P <sub>m</sub>	20,000	16,983	1.18
	P <sub>m</sub> + P <sub>b</sub>	30,000	16,983	1.77
Outer Shell	P <sub>m</sub>	20,000	6,837	2.93
	P <sub>m</sub> + P <sub>b</sub>	30,000	6,837	4.39
Baseplate	P <sub>m</sub>	20,000	8,980	2.23
	P <sub>m</sub> + P <sub>b</sub>	30,000	8,980	3.34
Primary Lid Bolts	P <sub>m</sub>	60,000	6,209	9.66
	P <sub>m</sub> + P <sub>b</sub>	90,000	6,209	14.50
Secondary Lid Bolts	P <sub>m</sub>	60,000	15,983	3.75
	P <sub>m</sub> + P <sub>b</sub>	90,000	15,983	5.63

Notes:

- (1) Unless otherwise indicated in this column, the maximum stress intensity values have been conservatively reported as P<sub>m</sub> and P<sub>m</sub> + P<sub>b</sub> stress intensities.
- (2) Factor of Safety, F.S. = (Allowable S.I.) / (Calculated S.I.)

Table 2-12 - Stress Intensities in 8-120B Cask under 1-ft End Drop – Cold Condition

Component	Stress Category	Allowable S.I. (psi)	Calculated S.I. (psi) <sup>(1)</sup>	F.S. <sup>(2)</sup>
Primary Lid	P <sub>m</sub>	20,000	14,529	1.38
	P <sub>m</sub> + P <sub>b</sub>	30,000	14,529	2.06
Secondary Lid	P <sub>m</sub>	20,000	11,767	1.70
	P <sub>m</sub> + P <sub>b</sub>	30,000	11,767	2.55
Bolting Ring	P <sub>m</sub>	20,000	9,959	2.01
	P <sub>m</sub> + P <sub>b</sub>	30,000	9,959	3.01
Inner Shell	P <sub>m</sub>	20,000	15,787 <sup>(3)</sup>	1.27
	P <sub>m</sub> + P <sub>b</sub>	30,000	15,787 <sup>(3)</sup>	1.90
Outer Shell	P <sub>m</sub>	20,000	6,655	3.01
	P <sub>m</sub> + P <sub>b</sub>	30,000	6,655	4.51
Baseplate	P <sub>m</sub>	20,000	15,550	1.29
	P <sub>m</sub> + P <sub>b</sub>	30,000	15,550	1.93
Primary Lid Bolts	P <sub>m</sub>	60,000	4,115	14.58
	P <sub>m</sub> + P <sub>b</sub>	90,000	4,115	21.87
Secondary Lid Bolts	P <sub>m</sub>	60,000	13,075	4.59
	P <sub>m</sub> + P <sub>b</sub>	90,000	13,075	6.88

Notes:

- (1) Unless otherwise indicated in this column, the maximum stress intensity values have been conservatively reported as P<sub>m</sub> and P<sub>m</sub> + P<sub>b</sub> stress intensities.
- (2) Factor of Safety, F.S. = (Allowable S.I.) / (Calculated S.I.)
- (3) The stress intensity values reported here have been obtained by averaging the values in the vicinity of the highest local stress. The high local stresses resulted from the modeling constraint in this area. See Figures 50, 51 and Appendix 2 of *EnergySolutions* Document ST-627 (Reference 2-15).

Table 2-13 - Stress Intensities in 8-120B Cask under 1-ft Side Drop – Hot Condition

Component	Stress Category	Allowable S.I. (psi)	Calculated S.I. (psi) <sup>(1)</sup>	F.S. <sup>(2)</sup>
Primary Lid	P <sub>m</sub>	20,000	12,159 <sup>(3)</sup>	1.64
	P <sub>m</sub> + P <sub>b</sub>	30,000	12,159 <sup>(3)</sup>	2.47
Secondary Lid	P <sub>m</sub>	20,000	6,058	3.30
	P <sub>m</sub> + P <sub>b</sub>	30,000	6,058	4.95
Bolting Ring	P <sub>m</sub>	20,000	13,360	1.50
	P <sub>m</sub> + P <sub>b</sub>	30,000	13,360	2.25
Inner Shell	P <sub>m</sub>	20,000	14,098	1.42
	P <sub>m</sub> + P <sub>b</sub>	30,000	14,098	2.13
Outer Shell	P <sub>m</sub>	20,000	10,564	1.89
	P <sub>m</sub> + P <sub>b</sub>	30,000	10,564	2.84
Baseplate	P <sub>m</sub>	20,000	10,536	1.90
	P <sub>m</sub> + P <sub>b</sub>	30,000	10,536	2.85
Primary Lid Bolts	P <sub>m</sub>	60,000	34,995	1.71
	P <sub>m</sub> + P <sub>b</sub>	90,000	34,995	2.57
Secondary Lid Bolts	P <sub>m</sub>	60,000	10,982	5.46
	P <sub>m</sub> + P <sub>b</sub>	90,000	10,982	8.20

Notes:

- (1) Unless otherwise indicated in this column, the maximum stress intensity values have been conservatively reported as P<sub>m</sub> and P<sub>m</sub> + P<sub>b</sub> stress intensities.
- (2) Factor of Safety, F.S. = (Allowable S.I.) / (Calculated S.I.)
- (3) Obtained from the model after removing the elements in the bolt hole vicinity. See Appendix 2 of EnergySolutions Document ST-627 (Reference 2-15).

Table 2-14 - Stress Intensities in 8-120B Cask under 1-ft Side Drop – Cold Condition

Component	Stress Category	Allowable S.I. (psi)	Calculated S.I. (psi) <sup>(1)</sup>	F.S. <sup>(2)</sup>
Primary Lid	P <sub>m</sub>	20,000	12,720 <sup>(3)</sup>	1.57
	P <sub>m</sub> + P <sub>b</sub>	30,000	12,720 <sup>(3)</sup>	2.36
Secondary Lid	P <sub>m</sub>	20,000	6,849	2.92
	P <sub>m</sub> + P <sub>b</sub>	30,000	6,849	4.38
Bolting Ring	P <sub>m</sub>	20,000	15,824	1.26
	P <sub>m</sub> + P <sub>b</sub>	30,000	15,824	1.90
Inner Shell	P <sub>m</sub>	20,000	16,531	1.21
	P <sub>m</sub> + P <sub>b</sub>	30,000	16,531	1.81
Outer Shell	P <sub>m</sub>	20,000	15,289	1.31
	P <sub>m</sub> + P <sub>b</sub>	30,000	15,289	1.96
Baseplate	P <sub>m</sub>	20,000	13,015	1.54
	P <sub>m</sub> + P <sub>b</sub>	30,000	13,015	2.31
Primary Lid Bolts	P <sub>m</sub>	60,000	44,518	1.35
	P <sub>m</sub> + P <sub>b</sub>	90,000	44,518	2.02
Secondary Lid Bolts	P <sub>m</sub>	60,000	10,604	5.66
	P <sub>m</sub> + P <sub>b</sub>	90,000	10,604	8.49

Notes:

- (1) Unless otherwise indicated in this column, the maximum stress intensity values have been conservatively reported as P<sub>m</sub> and P<sub>m</sub> + P<sub>b</sub> stress intensities.
- (2) Factor of Safety, F.S. = (Allowable S.I.) / (Calculated S.I.)
- (3) Obtained from the model after removing the elements in the bolt hole vicinity. See Appendix 2 of EnergySolutions Document ST-627 (Reference 2-15).

Table 2-15 - Stress Intensities in 8-120B Cask under 1-ft Corner Drop – Hot Condition

Component	Stress Category	Allowable S.I. (psi)	Calculated S.I. (psi) <sup>(1)</sup>	F.S. <sup>(2)</sup>
Primary Lid	P <sub>m</sub>	20,000	9,642	2.07
	P <sub>m</sub> + P <sub>b</sub>	30,000	9,642	3.11
Secondary Lid	P <sub>m</sub>	20,000	6,664	3.00
	P <sub>m</sub> + P <sub>b</sub>	30,000	6,664	4.50
Bolting Ring	P <sub>m</sub>	20,000	9,559	2.09
	P <sub>m</sub> + P <sub>b</sub>	30,000	9,559	3.14
Inner Shell	P <sub>m</sub>	20,000	12,201	1.64
	P <sub>m</sub> + P <sub>b</sub>	30,000	12,201	2.46
Outer Shell	P <sub>m</sub>	20,000	6,847	2.92
	P <sub>m</sub> + P <sub>b</sub>	30,000	6,847	4.38
Baseplate	P <sub>m</sub>	20,000	5,307	3.77
	P <sub>m</sub> + P <sub>b</sub>	30,000	5,307	5.65
Primary Lid Bolts	P <sub>m</sub>	60,000	24,600	2.44
	P <sub>m</sub> + P <sub>b</sub>	90,000	24,600	3.66
Secondary Lid Bolts	P <sub>m</sub>	60,000	13,534	4.43
	P <sub>m</sub> + P <sub>b</sub>	90,000	13,534	6.65

Notes:

- (1) Unless otherwise indicated in this column, the maximum stress intensity values have been conservatively reported as P<sub>m</sub> and P<sub>m</sub> + P<sub>b</sub> stress intensities.
- (2) Factor of Safety, F.S. = (Allowable S.I.) / (Calculated S.I.)

Table 2-16 - Stress Intensities in 8-120B Cask under 1-ft Corner Drop – Cold Condition

Component	Stress Category	Allowable S.I. (psi)	Calculated S.I. (psi) <sup>(1)</sup>	F.S. <sup>(2)</sup>
Primary Lid	P <sub>m</sub>	20,000	9,634	2.08
	P <sub>m</sub> + P <sub>b</sub>	30,000	9,634	3.11
Secondary Lid	P <sub>m</sub>	20,000	4,372	4.57
	P <sub>m</sub> + P <sub>b</sub>	30,000	4,372	6.86
Bolting Ring	P <sub>m</sub>	20,000	8,668	2.31
	P <sub>m</sub> + P <sub>b</sub>	30,000	8,668	3.46
Inner Shell	P <sub>m</sub>	20,000	8,930	2.24
	P <sub>m</sub> + P <sub>b</sub>	30,000	8,930	3.36
Outer Shell	P <sub>m</sub>	20,000	8,437	2.37
	P <sub>m</sub> + P <sub>b</sub>	30,000	8,437	3.56
Baseplate	P <sub>m</sub>	20,000	4,637	4.31
	P <sub>m</sub> + P <sub>b</sub>	30,000	4,637	6.47
Primary Lid Bolts	P <sub>m</sub>	60,000	17,360	3.46
	P <sub>m</sub> + P <sub>b</sub>	90,000	17,360	5.18
Secondary Lid Bolts	P <sub>m</sub>	60,000	8,322	7.21
	P <sub>m</sub> + P <sub>b</sub>	90,000	8,322	10.81

Notes:

- (1) Unless otherwise indicated in this column, the maximum stress intensity values have been conservatively reported as P<sub>m</sub> and P<sub>m</sub> + P<sub>b</sub> stress intensities.
- (2) Factor of Safety, F.S. = (Allowable S.I.) / (Calculated S.I.)

Table 2-17 - Hypothetical Accident Condition Drop Test Summary

Drop Orientation	Thermal Environment	Maximum Impact Limiter Reaction <sup>(1)</sup> (lb)	Approximate Pulse Duration (msec)	Maximum Crush <sup>(2)</sup> (in)
End	Cold	$5.359 \times 10^6$	20	3.529
	Hot	$4.427 \times 10^6$	20	4.354
Side	Cold	$3.937 \times 10^6$	25	5.814
	Hot	$3.403 \times 10^6$	25	7.182
Corner	Cold	$2.103 \times 10^6$	100	14.907
	Hot	$2.000 \times 10^6$	100	17.060

Notes:

- (1) See Figures 31, 35, 39, 43, 47, and 51 of *EnergySolutions* Document ST-625 (Reference 2-14) for the time-history plots of the impact limiter reactions during various drop tests.
- (2) See Figures 34, 38, 42, 46, 50 and 54 of *EnergySolutions* Document ST-625 (Reference 2-14) for the time-history plots of the impact limiter crush during various drop tests.

Table 2-18 - Stress Intensities in 8-120B Cask under 30-ft End Drop – Hot Condition

Component	Stress Category	Allowable S.I. (psi)	Calculated S.I. (psi) <sup>(1)</sup>	F.S. <sup>(2)</sup>
Primary Lid	P <sub>m</sub>	48,000	22,900 <sup>(3)</sup>	2.10
	P <sub>m</sub> + P <sub>b</sub>	70,000	50,220 <sup>(3)</sup>	1.40
Secondary Lid	P <sub>m</sub>	48,000	39,223	1.22
	P <sub>m</sub> + P <sub>b</sub>	70,000	39,223	1.78
Bolting Ring	P <sub>m</sub>	48,000	36,835	1.30
	P <sub>m</sub> + P <sub>b</sub>	70,000	36,835	1.90
Inner Shell	P <sub>m</sub>	48,000	45,432	1.06
	P <sub>m</sub> + P <sub>b</sub>	70,000	45,432	1.54
Outer Shell	P <sub>m</sub>	48,000	23,422	2.05
	P <sub>m</sub> + P <sub>b</sub>	70,000	23,422	2.99
Baseplate	P <sub>m</sub>	48,000	42,473	1.13
	P <sub>m</sub> + P <sub>b</sub>	70,000	42,473	1.65
Primary Lid Bolts	P <sub>m</sub>	105,000	14,241	7.37
	P <sub>m</sub> + P <sub>b</sub>	150,000	14,241	10.53
Secondary Lid Bolts	P <sub>m</sub>	105,000	45,267	2.32
	P <sub>m</sub> + P <sub>b</sub>	150,000	45,267	3.31

Notes:

- (1) Unless otherwise indicated in this column, the maximum stress intensity values have been conservatively reported as P<sub>m</sub> and P<sub>m</sub> + P<sub>b</sub> stress intensities.
- (2) Factor of Safety, F.S. = (Allowable S.I.) / (Calculated S.I.)
- (3) Obtained from the stress linearization over the cross-section. See Appendix 2 of *EnergySolutions* Document ST-627 (Reference 2-15).

Table 2-19 - Stress Intensities in 8-120B Cask under 30-ft End Drop – Cold Condition

Component	Stress Category	Allowable S.I. (psi)	Calculated S.I. (psi) <sup>(1)</sup>	F.S. <sup>(2)</sup>
Primary Lid	P <sub>m</sub>	48,000	23,190 <sup>(3)</sup>	2.07
	P <sub>m</sub> + P <sub>b</sub>	70,000	50,170 <sup>(3)</sup>	1.40
Secondary Lid	P <sub>m</sub>	48,000	38,045	1.26
	P <sub>m</sub> + P <sub>b</sub>	70,000	38,045	1.84
Bolting Ring	P <sub>m</sub>	48,000	27,167	1.77
	P <sub>m</sub> + P <sub>b</sub>	70,000	27,167	2.58
Inner Shell	P <sub>m</sub>	48,000	38,466	1.25
	P <sub>m</sub> + P <sub>b</sub>	70,000	38,466	1.82
Outer Shell	P <sub>m</sub>	48,000	26,337	1.82
	P <sub>m</sub> + P <sub>b</sub>	70,000	26,337	2.66
Baseplate	P <sub>m</sub>	48,000	47,147	1.02
	P <sub>m</sub> + P <sub>b</sub>	70,000	47,147	1.48
Primary Lid Bolts	P <sub>m</sub>	105,000	8,528	12.31
	P <sub>m</sub> + P <sub>b</sub>	150,000	8,528	17.59
Secondary Lid Bolts	P <sub>m</sub>	105,000	42,463	2.47
	P <sub>m</sub> + P <sub>b</sub>	150,000	42,463	3.53

Notes:

- (1) Unless otherwise indicated in this column, the maximum stress intensity values have been conservatively reported as P<sub>m</sub> and P<sub>m</sub> + P<sub>b</sub> stress intensities.
- (2) Factor of Safety, F.S. = (Allowable S.I.) / (Calculated S.I.)
- (3) Obtained from the stress linearization over the cross-section. See Appendix 2 of *EnergySolutions* Document ST-627 (Reference 2-15).

Table 2-20 - Stress Intensities in 8-120B Cask under 30-ft Side Drop – Hot Condition

Component	Stress Category	Allowable S.I. (psi)	Calculated S.I. (psi) <sup>(6)</sup>	F.S. <sup>(5)</sup>
Primary Lid	P <sub>m</sub>	48,000	34,749 <sup>(1)</sup>	1.38
	P <sub>m</sub> + P <sub>b</sub>	70,000	60,341 <sup>(1)</sup>	1.16
Secondary Lid	P <sub>m</sub>	48,000	32,887	1.46
	P <sub>m</sub> + P <sub>b</sub>	70,000	32,887	2.13
Bolting Ring	P <sub>m</sub>	48,000	40,748 <sup>(2)</sup>	1.19
	P <sub>m</sub> + P <sub>b</sub>	70,000	40,748 <sup>(2)</sup>	1.73
Inner Shell	P <sub>m</sub>	48,000	36,700 <sup>(3)</sup>	1.31
	P <sub>m</sub> + P <sub>b</sub>	70,000	61,810 <sup>(3)</sup>	1.13
Outer Shell	P <sub>m</sub>	48,000	38,000 <sup>(3)</sup>	1.26
	P <sub>m</sub> + P <sub>b</sub>	70,000	55,470 <sup>(3)</sup>	1.26
Baseplate	P <sub>m</sub>	48,000	43,554	1.10
	P <sub>m</sub> + P <sub>b</sub>	70,000	43,554	1.61
Primary Lid Bolts	P <sub>m</sub>	105,000	24,034 <sup>(4)</sup>	4.37
	P <sub>m</sub> + P <sub>b</sub>	150,000	136,480 <sup>(4)</sup>	1.10
Secondary Lid Bolts	P <sub>m</sub>	105,000	50,990	2.06
	P <sub>m</sub> + P <sub>b</sub>	150,000	50,990	2.94

Notes:

- (1) Obtained from the model after removing the elements in the bolt hole vicinity. P<sub>m</sub> value reported here is the average value over the thickness. See Figure 52 and Appendix 2 of EnergySolutions Document ST-627 (Reference 2-15).
- (2) Obtained from the model after removing the elements in the bolt hole vicinity. See Appendix 2 of EnergySolutions Document ST-627 (Reference 2-15).
- (3) Obtained from the stress linearization over the cross-section. See Appendix 2 of EnergySolutions Document ST-627 (Reference 2-15).
- (4) Bolt stresses reported here were obtained from the bolt section evaluation using loading from the FEM analyses. See Section 7.3 and Table 19 of EnergySolutions Document ST-627 (Reference 2-15).
- (5) Factor of Safety, F.S. = (Allowable S.I.) / (Calculated S.I.)
- (6) Unless otherwise indicated in this column, the maximum stress intensity values have been conservatively reported as P<sub>m</sub> and P<sub>m</sub> + P<sub>b</sub> stress intensities.

Table 2-21 - Stress Intensities in 8-120B Cask under 30-ft Side Drop – Cold Condition

Component	Stress Category	Allowable S.I. (psi)	Calculated S.I. (psi) <sup>(6)</sup>	F.S. <sup>(5)</sup>
Primary Lid	P <sub>m</sub>	48,000	35,483 <sup>(1)</sup>	1.35
	P <sub>m</sub> + P <sub>b</sub>	70,000	62,481 <sup>(1)</sup>	1.12
Secondary Lid	P <sub>m</sub>	48,000	35,835	1.34
	P <sub>m</sub> + P <sub>b</sub>	70,000	35,835	1.95
Bolting Ring	P <sub>m</sub>	48,000	42,444 <sup>(2)</sup>	1.13
	P <sub>m</sub> + P <sub>b</sub>	70,000	42,444 <sup>(2)</sup>	1.65
Inner Shell	P <sub>m</sub>	48,000	30,040 <sup>(3)</sup>	1.60
	P <sub>m</sub> + P <sub>b</sub>	70,000	57,670 <sup>(3)</sup>	1.21
Outer Shell	P <sub>m</sub>	48,000	41,310 <sup>(3)</sup>	1.16
	P <sub>m</sub> + P <sub>b</sub>	70,000	59,250 <sup>(3)</sup>	1.18
Baseplate	P <sub>m</sub>	48,000	41,288	1.16
	P <sub>m</sub> + P <sub>b</sub>	70,000	41,288	1.70
Primary Lid Bolts	P <sub>m</sub>	105,000	25,417 <sup>(4)</sup>	4.13
	P <sub>m</sub> + P <sub>b</sub>	150,000	143,229 <sup>(4)</sup>	1.05
Secondary Lid Bolts	P <sub>m</sub>	105,000	55,207	1.90
	P <sub>m</sub> + P <sub>b</sub>	150,000	55,207	2.72

Notes:

- (1) Obtained from the model after removing the elements in the bolt hole vicinity. P<sub>m</sub> value reported here is the average value over the thickness. See Figure 54 and Appendix 2 of *EnergySolutions* Document ST-627 (Reference 2-15).
- (2) Obtained from the model after removing the elements in the bolt hole vicinity. See Appendix 2 of *EnergySolutions* Document ST-627 (Reference 2-15).
- (3) Obtained from the stress linearization over the cross-section. See Appendix 2 of *EnergySolutions* Document ST-627 (Reference 2-15).
- (4) Bolt stresses reported here have been obtained from the bolt section evaluation using the loading obtained from the FEM analyses. See Section 7.3 and Table 20 of *EnergySolutions* Document ST-627 (Reference 2-15).
- (5) Factor of Safety, F.S. = (Allowable S.I.) / (Calculated S.I.)
- (6) Unless otherwise indicated in this column, the maximum stress intensity values have been conservatively reported as P<sub>m</sub> and P<sub>m</sub> + P<sub>b</sub> stress intensities.

Table 2-22 - Stress Intensities in 8-120B Cask under 30-ft Corner Drop – Hot Condition

Component	Stress Category	Allowable S.I. (psi)	Calculated S.I. (psi) <sup>(5)</sup>	F.S. <sup>(4)</sup>
Primary Lid	P <sub>m</sub>	48,000	30,100 <sup>(1)</sup>	1.60
	P <sub>m</sub> + P <sub>b</sub>	70,000	69,570 <sup>(1)</sup>	1.01
Secondary Lid	P <sub>m</sub>	48,000	29,808	1.61
	P <sub>m</sub> + P <sub>b</sub>	70,000	29,808	2.35
Bolting Ring	P <sub>m</sub>	48,000	46,432 <sup>(2)</sup>	1.03
	P <sub>m</sub> + P <sub>b</sub>	70,000	46,432 <sup>(2)</sup>	1.51
Inner Shell	P <sub>m</sub>	48,000	32,880 <sup>(1)</sup>	1.46
	P <sub>m</sub> + P <sub>b</sub>	70,000	49,750 <sup>(1)</sup>	1.41
Outer Shell	P <sub>m</sub>	48,000	31,931	1.50
	P <sub>m</sub> + P <sub>b</sub>	70,000	31,931	2.19
Baseplate	P <sub>m</sub>	48,000	12,150	3.95
	P <sub>m</sub> + P <sub>b</sub>	70,000	12,150	5.76
Primary Lid Bolts	P <sub>m</sub>	105,000	22,261 <sup>(3)</sup>	4.72
	P <sub>m</sub> + P <sub>b</sub>	150,000	95,433 <sup>(3)</sup>	1.57
Secondary Lid Bolts	P <sub>m</sub>	105,000	56,020	1.87
	P <sub>m</sub> + P <sub>b</sub>	150,000	56,020	2.68

Notes:

- (1) Obtained from the stress linearization over the cross-section. See Appendix 2 of *EnergySolutions* Document ST-627 (Reference 2-15).
- (2) Obtained from the model after removing the elements in the bolt hole vicinity. See Appendix 2 of *EnergySolutions* Document ST-627 (Reference 2-15).
- (3) Bolt stresses reported here have been obtained from the bolt section evaluation using the loading obtained from the FEM analyses. See Section 7.3 and Tables 25 and 28 of *EnergySolutions* Document ST-627 (Reference 2-15).
- (4) Factor of Safety, F.S. = (Allowable S.I.) / (Calculated S.I.)
- (5) Unless otherwise indicated in this column, the maximum stress intensity values have been conservatively reported as P<sub>m</sub> and P<sub>m</sub> + P<sub>b</sub> stress intensities.

Table 2-23 - Stress Intensities in 8-120B Cask under 30-ft Corner Drop – Cold Condition

Component	Stress Category	Allowable S.I. (psi)	Calculated S.I. <sup>(4)</sup> (psi)	F.S. <sup>(3)</sup>
Primary Lid	P <sub>m</sub>	48,000	30,250 <sup>(1)</sup>	1.59
	P <sub>m</sub> + P <sub>b</sub>	70,000	69,090 <sup>(1)</sup>	1.01
Secondary Lid	P <sub>m</sub>	48,000	27,743	1.73
	P <sub>m</sub> + P <sub>b</sub>	70,000	27,743	2.52
Bolting Ring	P <sub>m</sub>	48,000	42,151 <sup>(2)</sup>	1.14
	P <sub>m</sub> + P <sub>b</sub>	70,000	42,151 <sup>(2)</sup>	1.66
Inner Shell	P <sub>m</sub>	48,000	38,757	1.24
	P <sub>m</sub> + P <sub>b</sub>	70,000	38,757	1.81
Outer Shell	P <sub>m</sub>	48,000	40,893	1.17
	P <sub>m</sub> + P <sub>b</sub>	70,000	40,893	1.71
Baseplate	P <sub>m</sub>	48,000	26,335	1.82
	P <sub>m</sub> + P <sub>b</sub>	70,000	26,335	2.66
Primary Lid Bolts	P <sub>m</sub>	105,000	20,456	5.13
	P <sub>m</sub> + P <sub>b</sub>	150,000	90,545	1.66
Secondary Lid Bolts	P <sub>m</sub>	105,000	51,222	2.05
	P <sub>m</sub> + P <sub>b</sub>	150,000	51,222	2.93

Notes:

- (1) Obtained from the stress linearization over the cross-section. See Appendix 2 of *EnergySolutions* Document ST-627 (Reference 2-15).
- (2) Obtained from the model after removing the elements in the bolt hole vicinity. See Appendix 2 of *EnergySolutions* Document ST-627 (Reference 2-15).
- (3) Factor of Safety, F.S. = (Allowable S.I.) / (Calculated S.I.)
- (4) Unless otherwise indicated in this column, the maximum stress intensity values have been conservatively reported as P<sub>m</sub> and P<sub>m</sub> + P<sub>b</sub> stress intensities.
- (5) Bolt stresses reported here have been obtained from the bolt section evaluation using the loading obtained from the FEM analyses. See Section 7.3 and Tables 26 and 29 of *EnergySolutions* Document ST-627 (Reference 2-15).

Table 2-24 - Maximum Impact Limiter Attachment Force during  
 Various HAC Drop Tests

Drop Orientation	Thermal Environment	Maximum Attachment Force <sup>(1)</sup> (lb)
End	Cold	12,796
	Hot	10,826
Side	Cold	35,350
	Hot	29,943
Corner	Cold	31,296
	Hot	30,986

Notes:

- (1) See Figures 33, 37, 41, 45, 49, and 53 of ST-625 (Reference 2-14) for the time-history plots of the maximum attachment forces during various drop tests.

Table 2-25 - Maximum Stress Intensities in 8-120B Cask HAC Fire

Component	Stress Category	Allowable S.I. (psi)	Calculated S.I. <sup>(1), (2)</sup> (psi)	F.S. <sup>(3)</sup>
Primary Lid	$P_m + P_b$	70,000	20,391	3.43
Secondary Lid	$P_m + P_b$	70,000	8,781	7.97
Bolting Ring	$P_m + P_b$	70,000	40,535	1.73
Inner Shell	$P_m + P_b$	70,000	26,802	2.61
Outer Shell	$P_m + P_b$	70,000	36,692	1.91
Baseplate	$P_m + P_b$	70,000	18,332	3.82
Primary Lid Bolts	$P_m + P_b$	150,000	45,904	3.27
Secondary Lid Bolts	$P_m + P_b$	150,000	16,357	9.17

Notes:

- (1) Unless otherwise indicated in the column, the maximum stress intensity values, obtained from the finite element model, have been conservatively reported as  $P_m + P_b$  stress intensities.
- (2) *EnergySolutions* Document ST-637 (Reference 2-21) presents the plot of temperature distribution and stresses in the cask at various time instants. The stress values presented here are the maximum stress in a particular component during the entire HAC fire.
- (3) Factor of Safety, F.S. = (Allowable S.I.) / (Calculated S.I.)

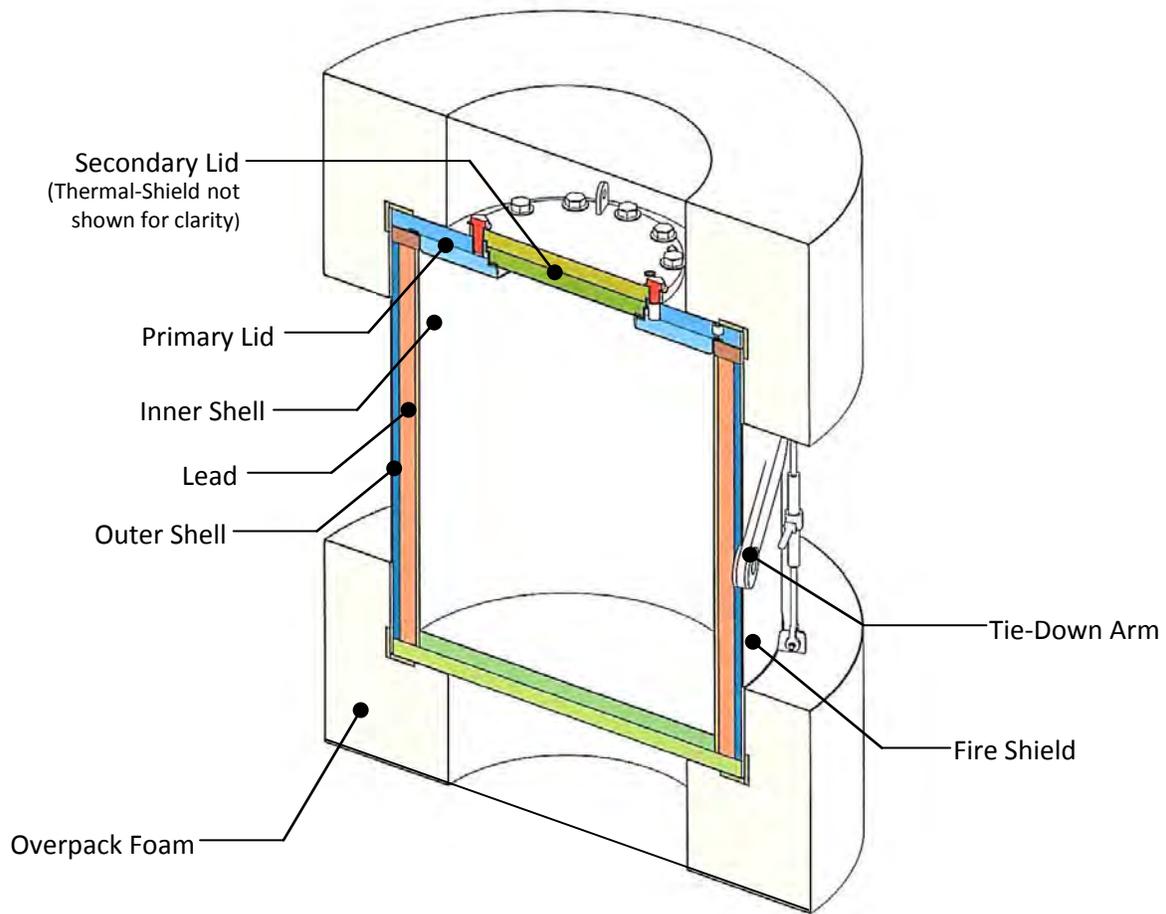


Figure 2-1 - Nomenclature of Components

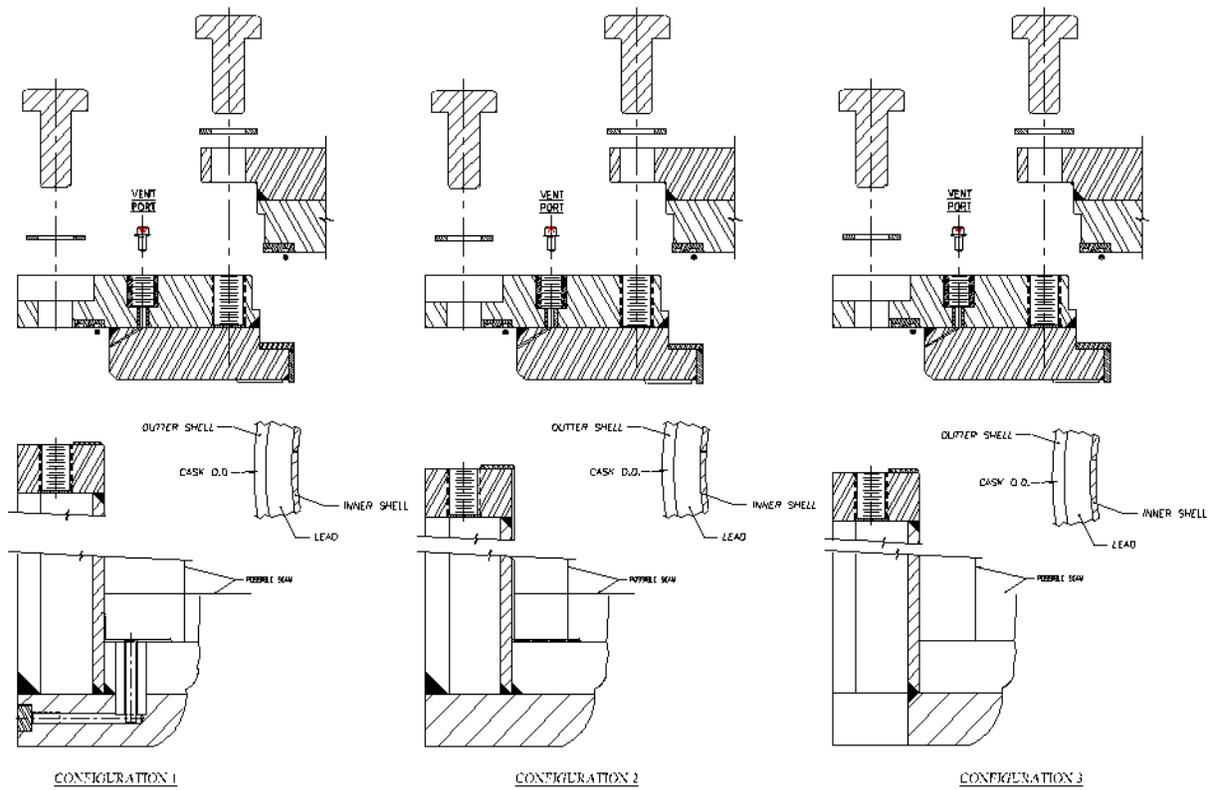


Figure 2-2 - 8-120B Cask - Containment Boundary  
(Shown Hatched)

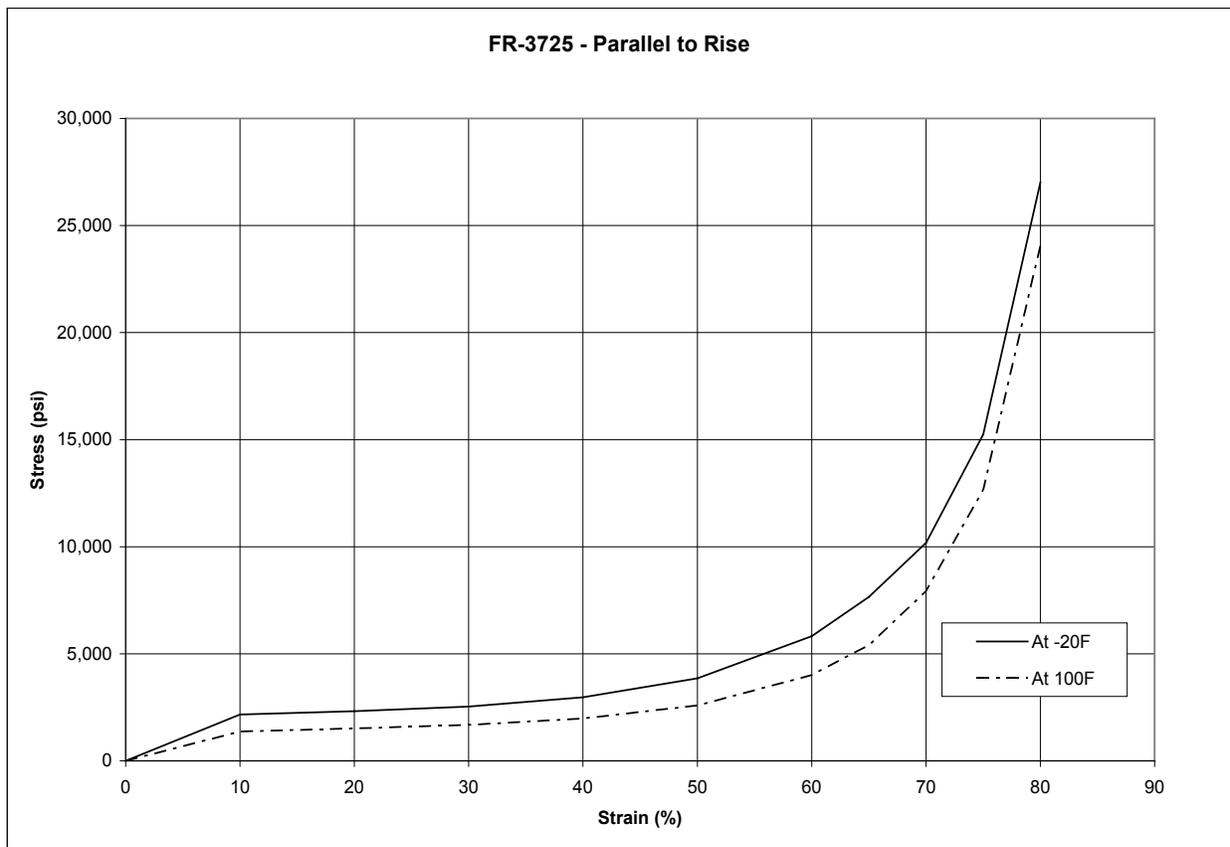


Figure 2-3 - Polyurethane Foam Stress-Strain Properties Parallel to Rise Direction  
(Source: General Plastics Last-A-Foam FR-3700 Sales Brochure)

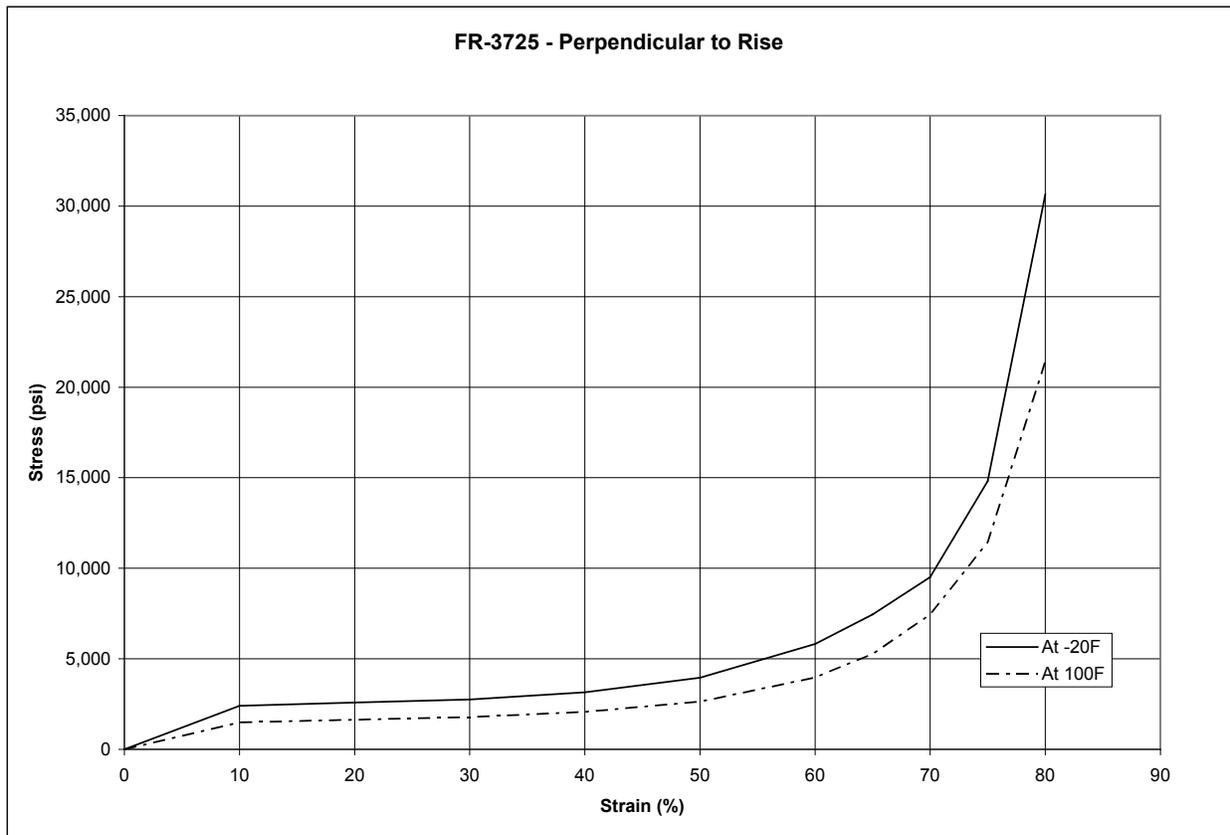
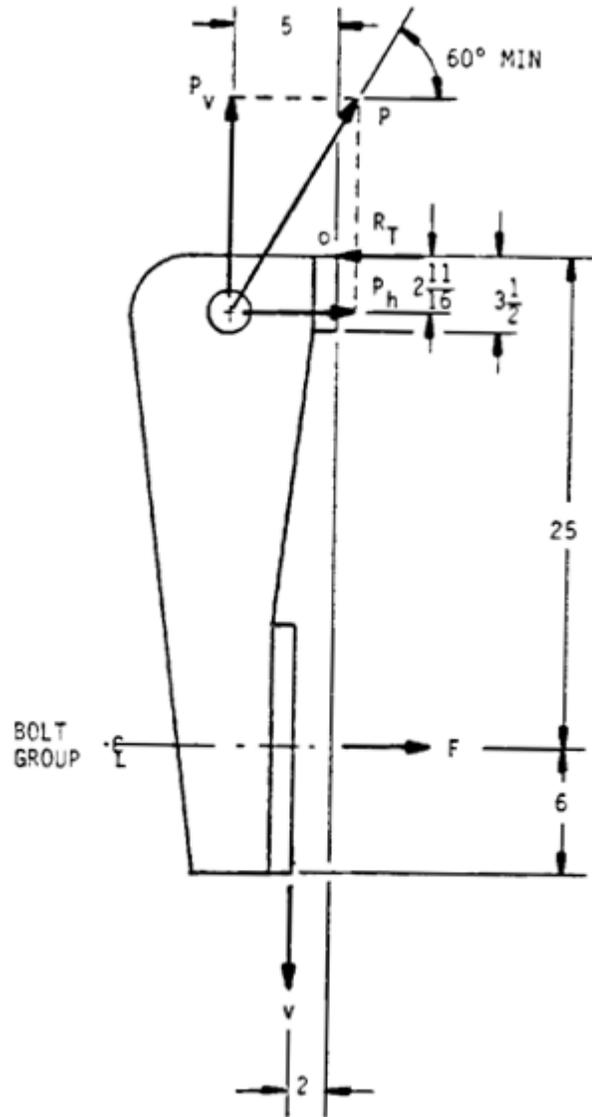


Figure 2-4 - Polyurethane Foam Stress-Strain Properties Perpendicular to Rise Direction  
(Source: General Plastics Last-A-Foam FR-3700 Sales Brochure)



$P$  = Lifting force on ear  
 $F$  = Tensile force on bolts  
 $V$  = Shear force on bolts  
 $R_T$  = Reaction force against top of cask with lid in place.

Figure 2-5 - Lifting Ear Free Body Diagram



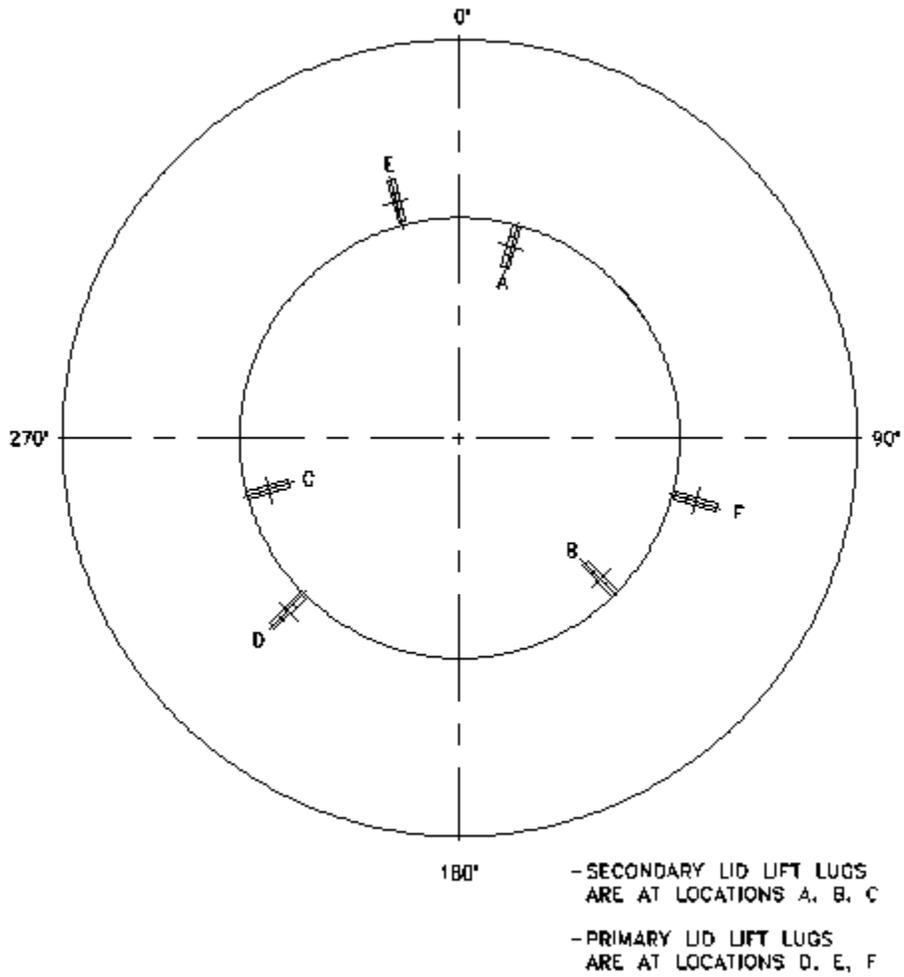


Figure 2-7 - Primary/Secondary Lid Lifting Lug Orientation

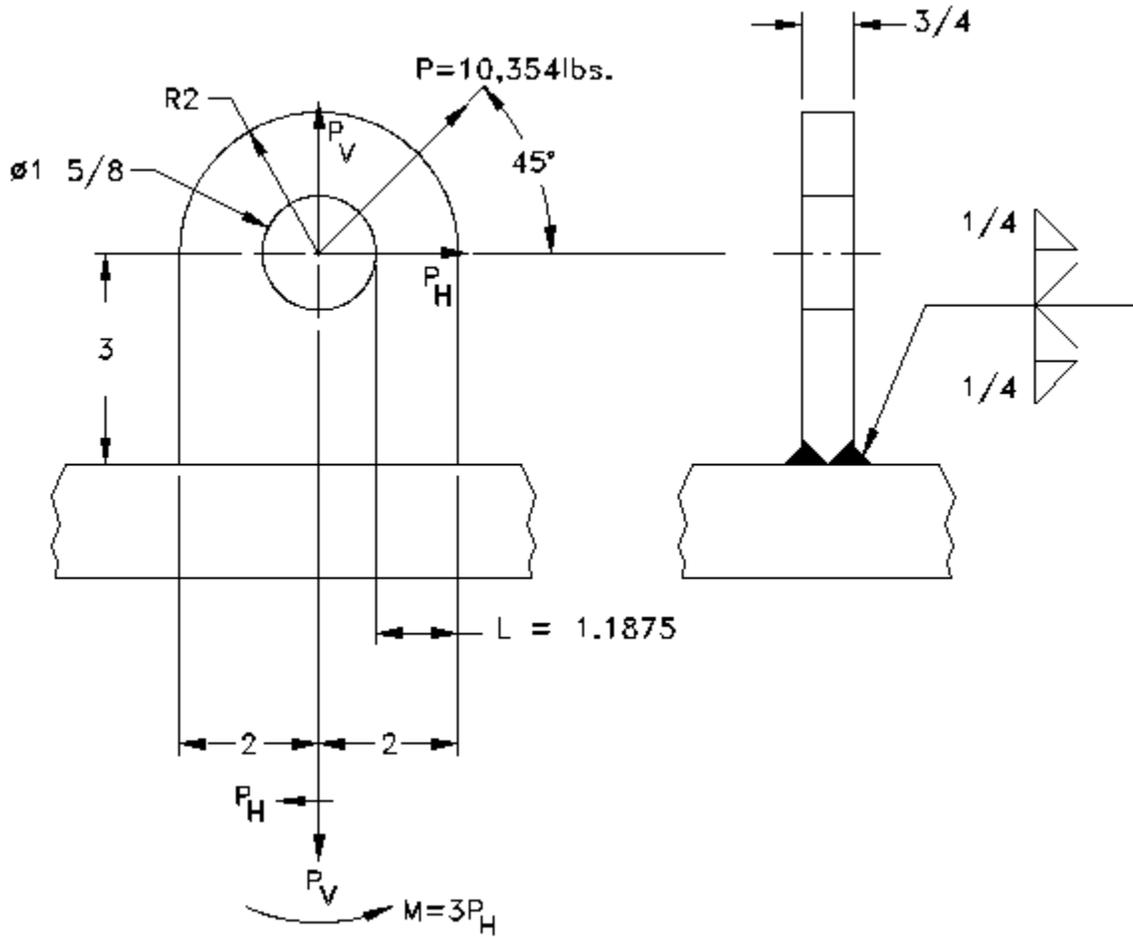


Figure 2-8 - Freebody Diagram of Lid Lifting Lug

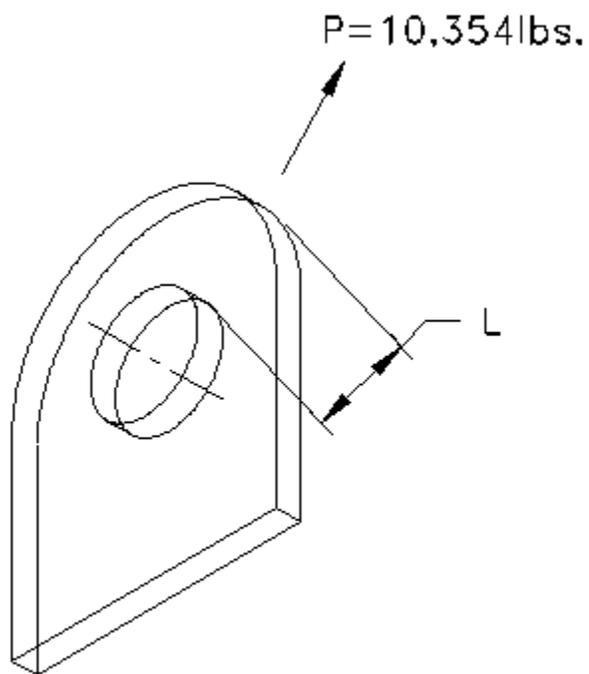


Figure 2-9 - Lid Lifting Lug Eye Tear-out Area

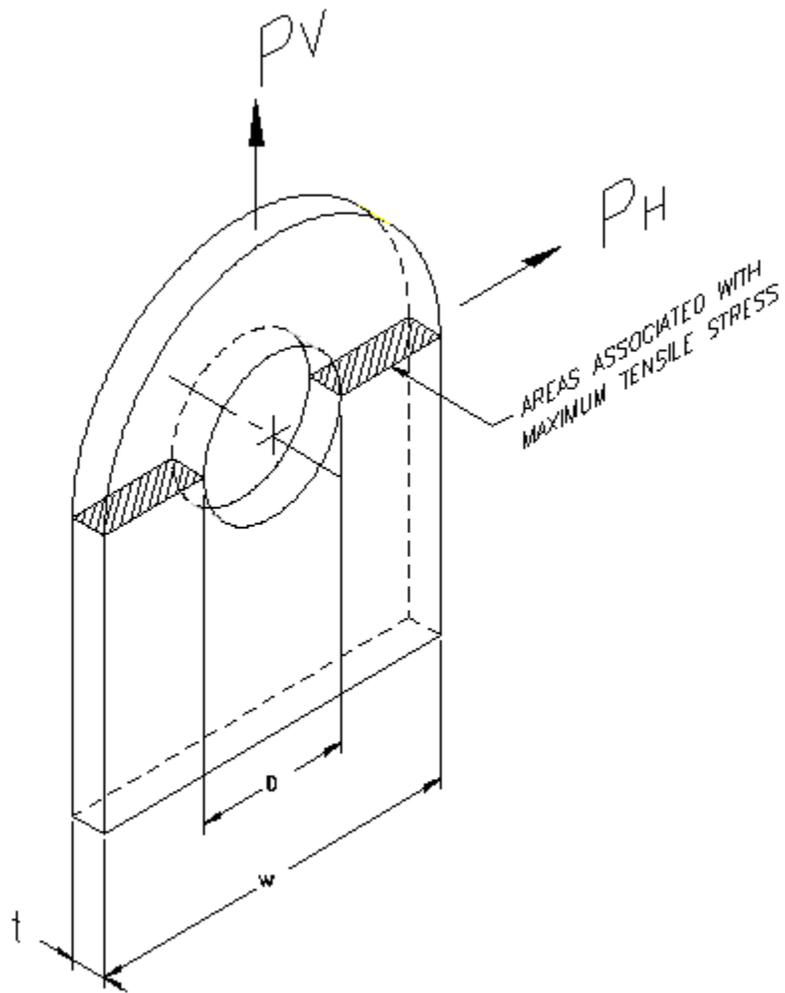


Figure 2-10 - Lid Lifting Lug Net Tensile Area

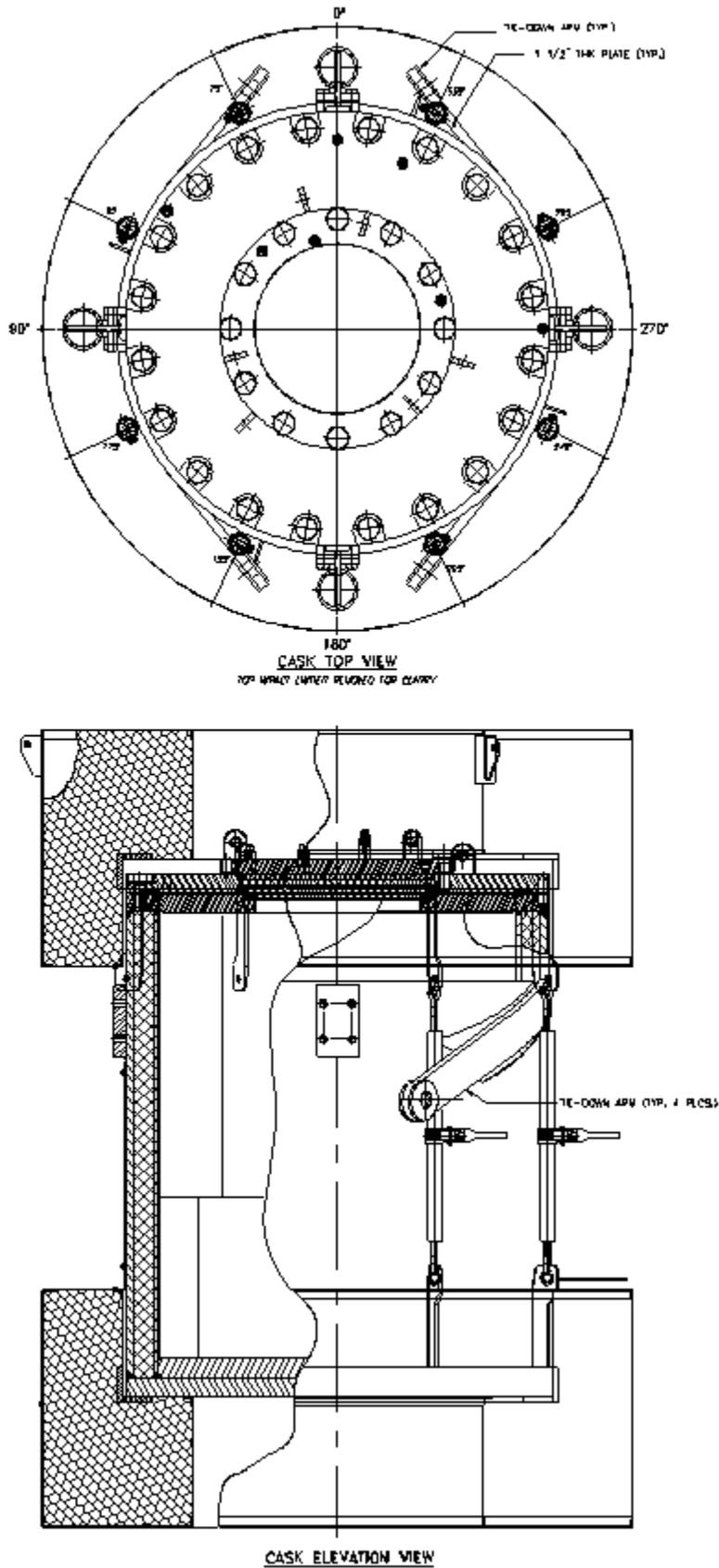
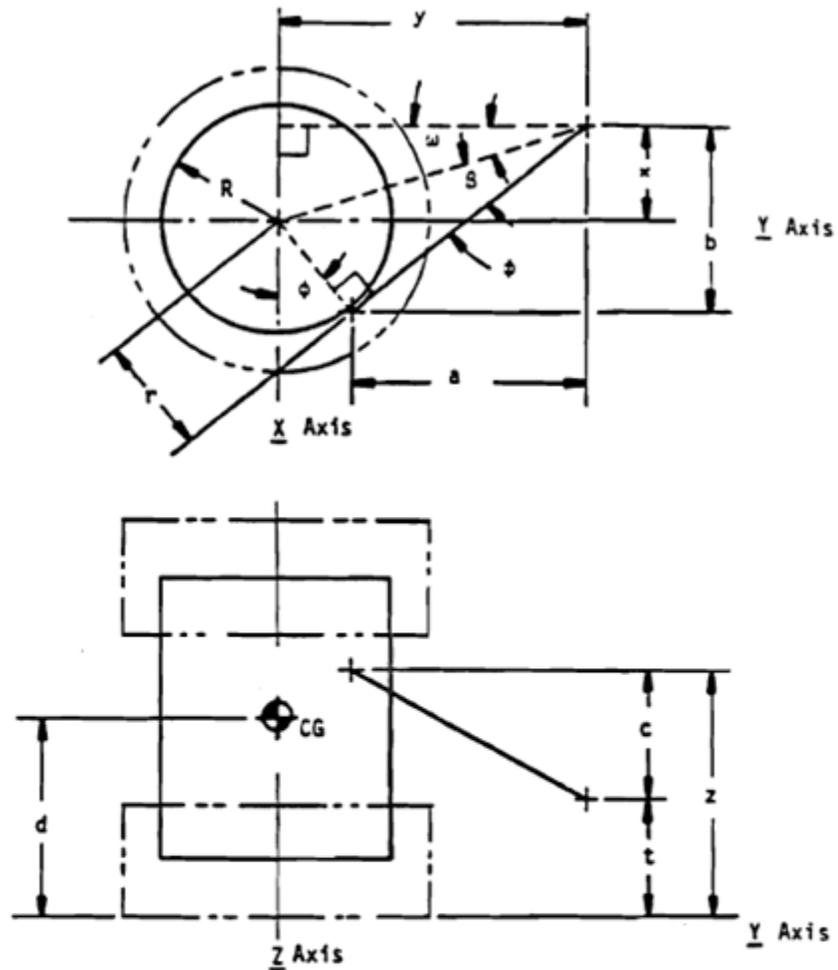


Figure 2-11 - Cask Tie Down Arm



- R = 36.75 = CASK RADIUS
- r = 37.5 = R+ TANGENT OFFSET
- d = 62.5 = CASK C.G. ELEV.
- t = 37.0 = TRAILER EAR ELEV.
- x = 30.0 = Y AXIS OFFSET
- y = 96.0 = X AXIS OFFSET
- z = 79.0 = CASK TANGENT ELEV.
- $\omega = 17.35^\circ = \text{ATN}(x/y)$
- $\beta = 21.89^\circ = \text{ASN}[r/(y/\cos\omega)]$
- $\phi = 39.25^\circ = \omega + \beta$
- a = 72.27 =  $y - r\sin\phi$
- b = 59.04 =  $x + r\cos\phi$
- c = 42.0 =  $z - t$
- L = 102.34 =  $(a^2 + b^2 + c^2)^{1/2}$

Figure 2-12 - Tie Down Arm Geometry

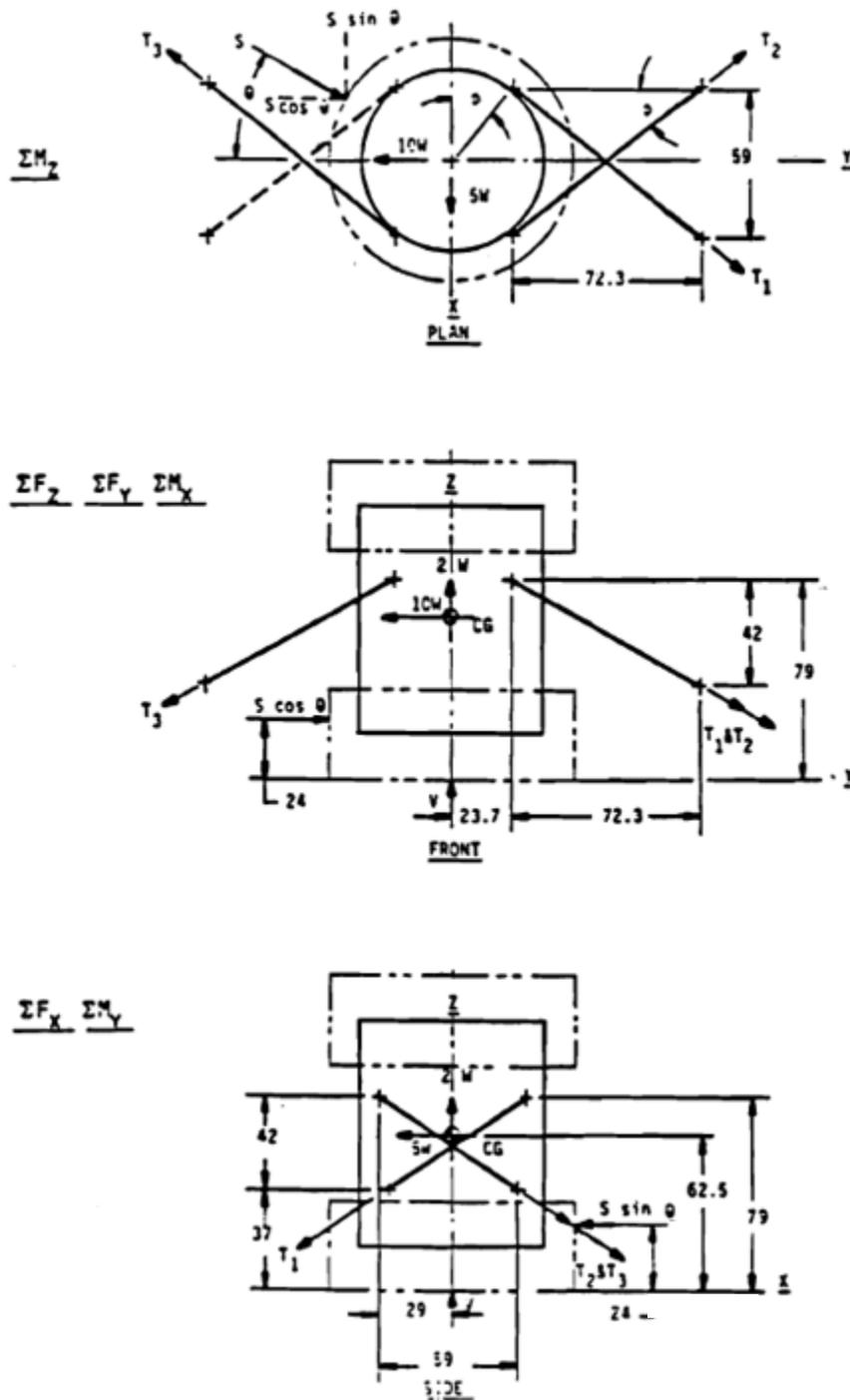


Figure 2-13 - Tie Down Free Body Diagram

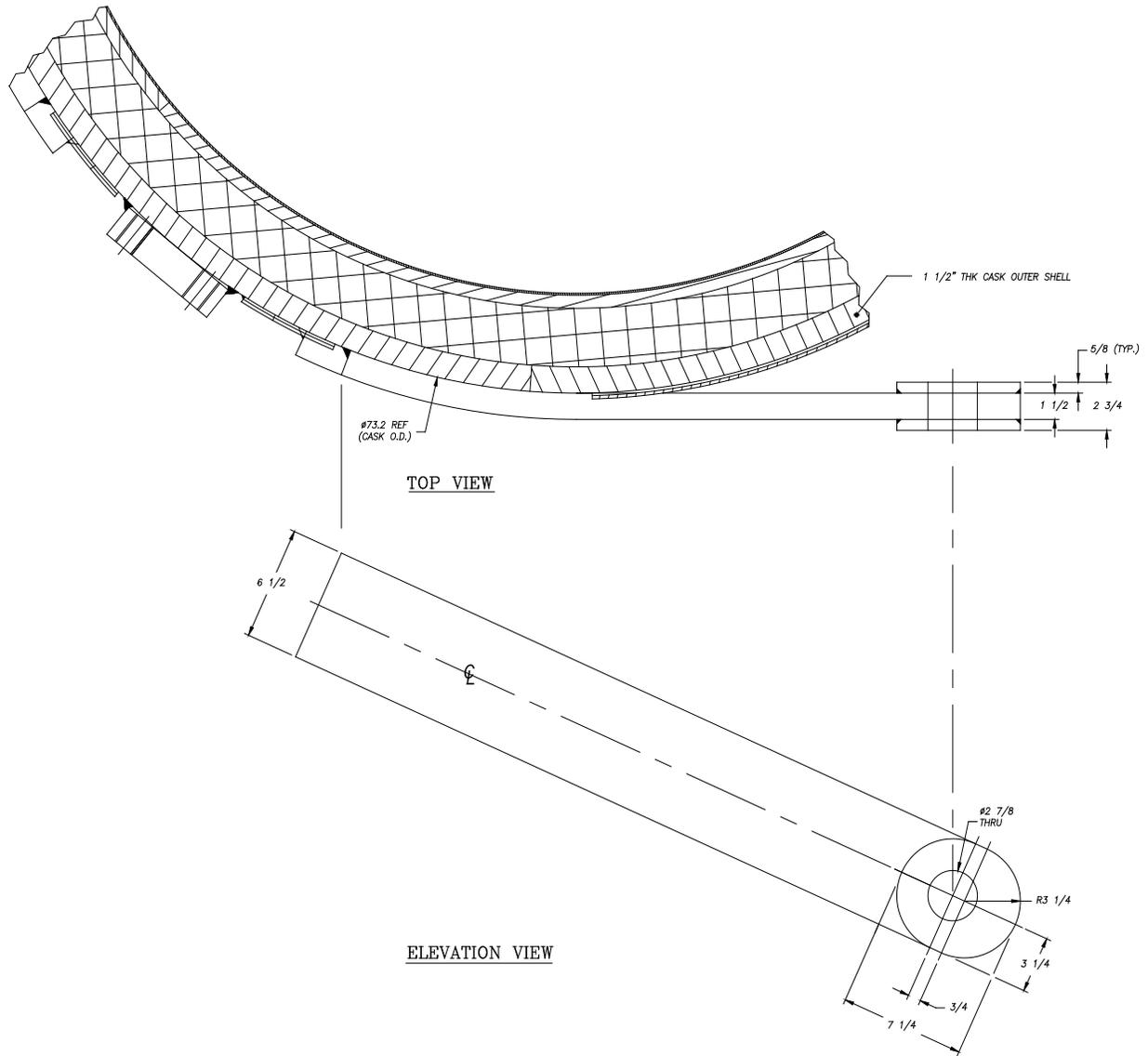


Figure 2-14 - Tie Down Arm Details

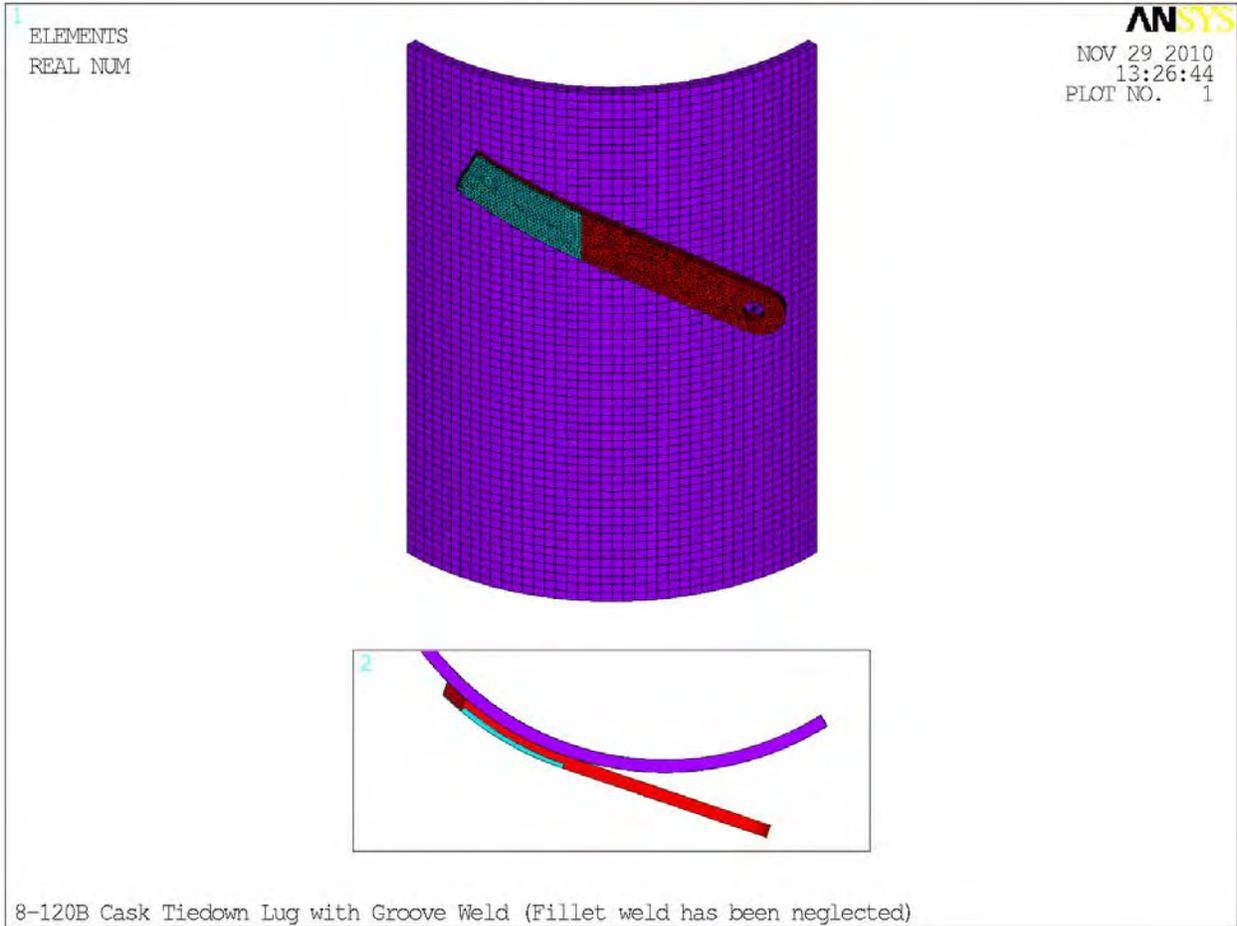


Figure 2-15 - FEM of 8-120B Cask Outer Shell & Tie-Down Arm

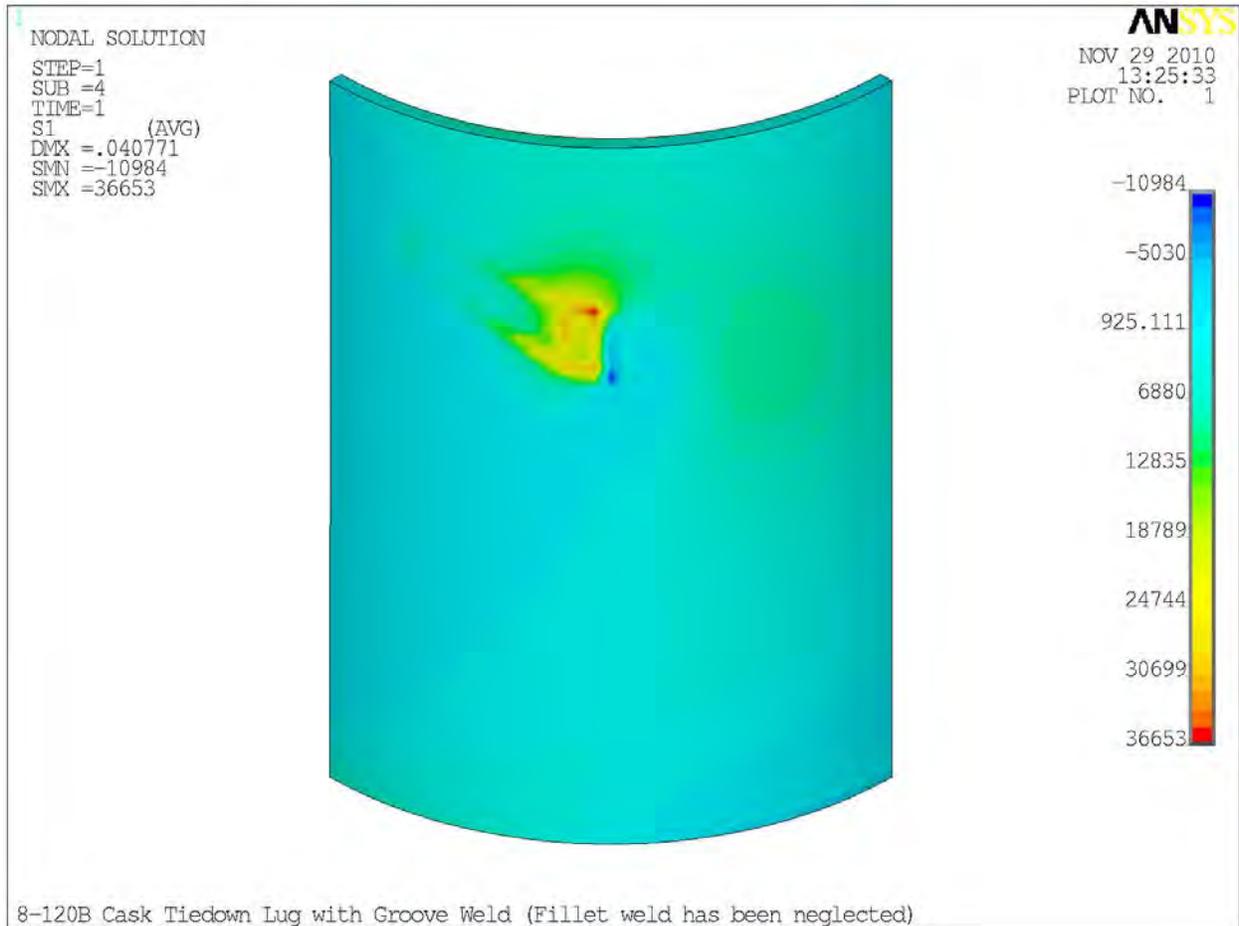


Figure 2-16 - 8-120B Cask Outer Shell Maximum Principal Stress

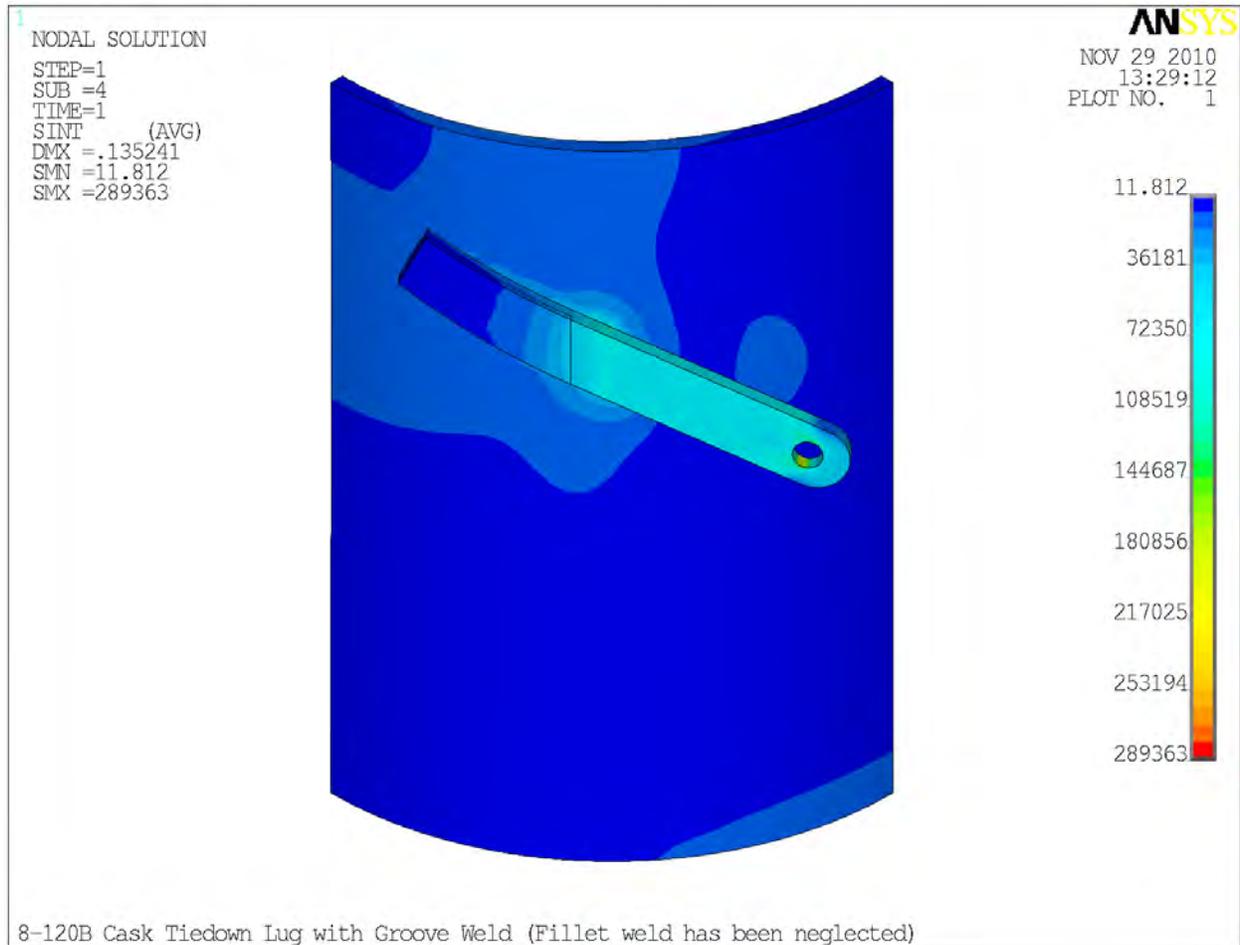


Figure 2-17 - 8-120B Cask Tie-Down Arm Maximum Stress Intensity

Note: The tie-down arm stresses shown in this figure include the local stresses at the point of load application and at the weld termination.

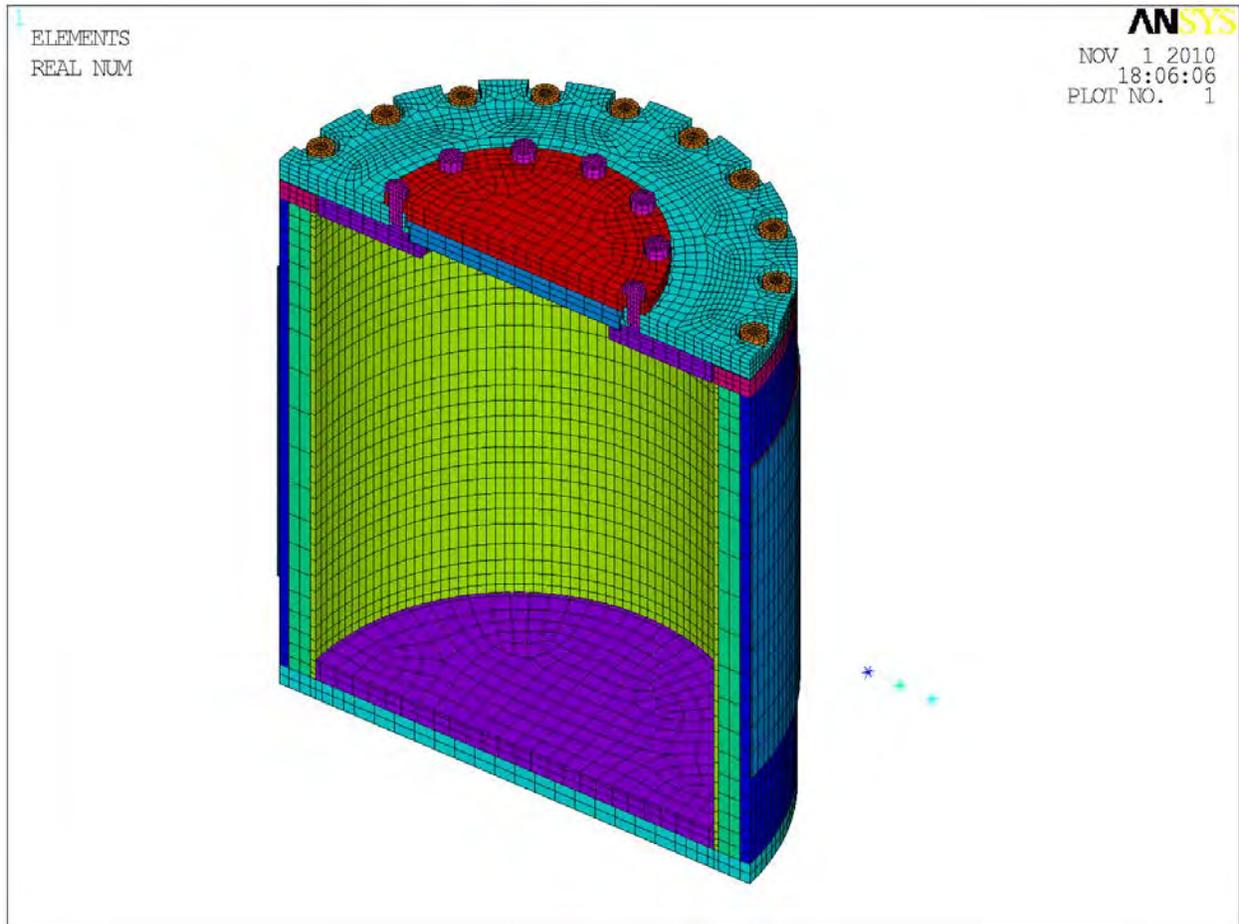


Figure 2-18 - The finite element model used in the analyses

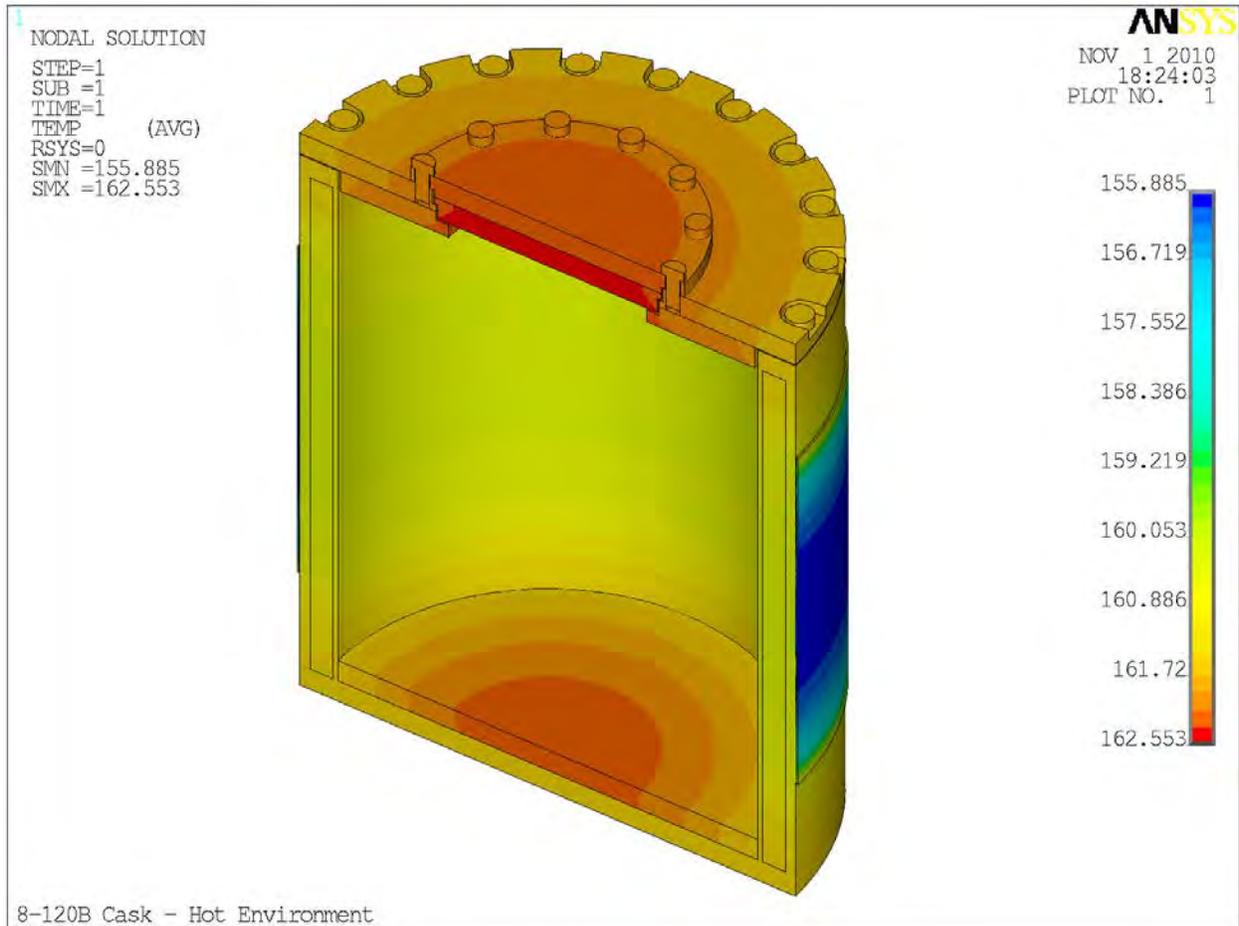


Figure 2-19 - Temperature Distribution - Hot Environment Loading

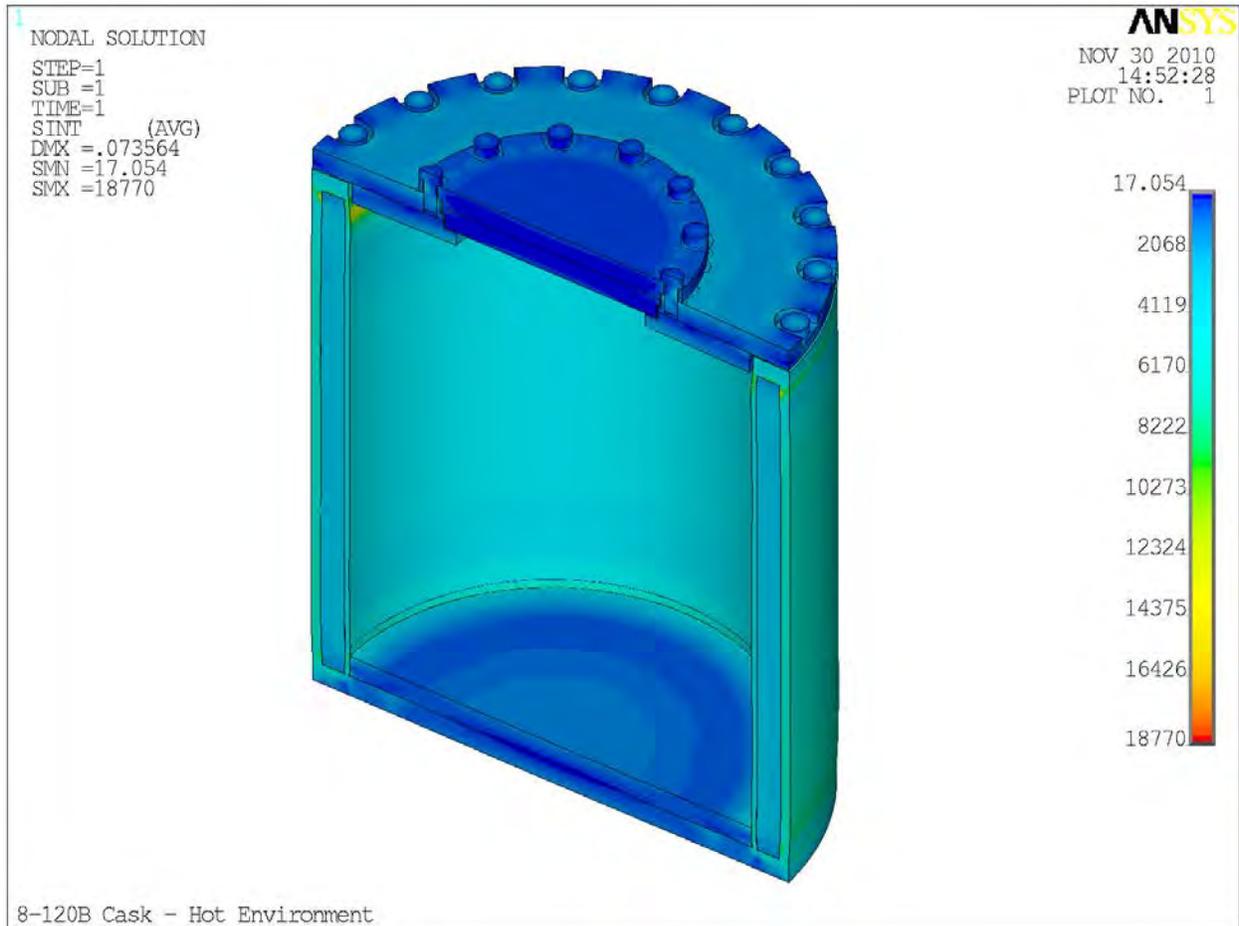


Figure 2-20 - Stress Intensity Contour Plot - Hot Environment Loading

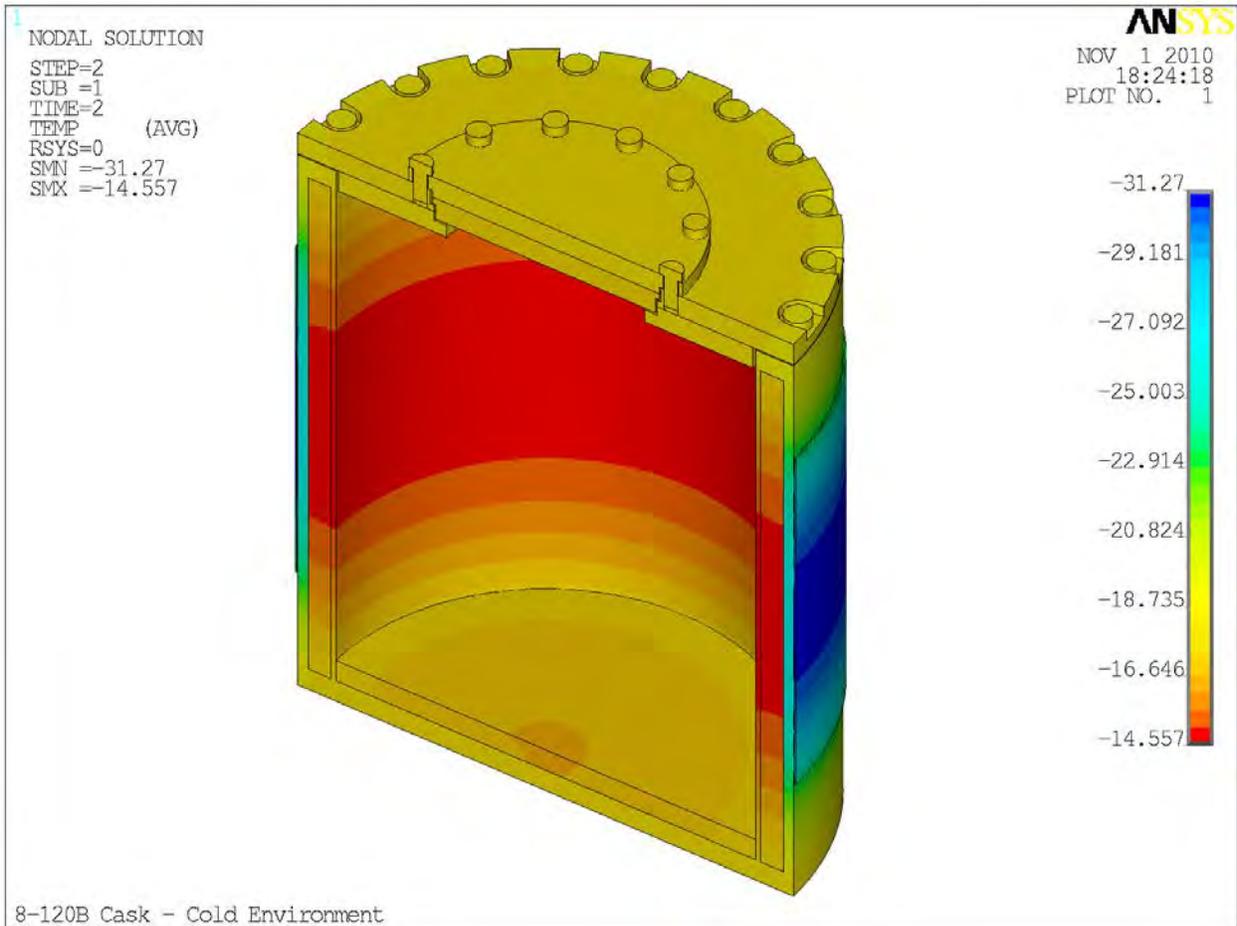


Figure 2-21 - Temperature Distribution - Cold Environment Loading

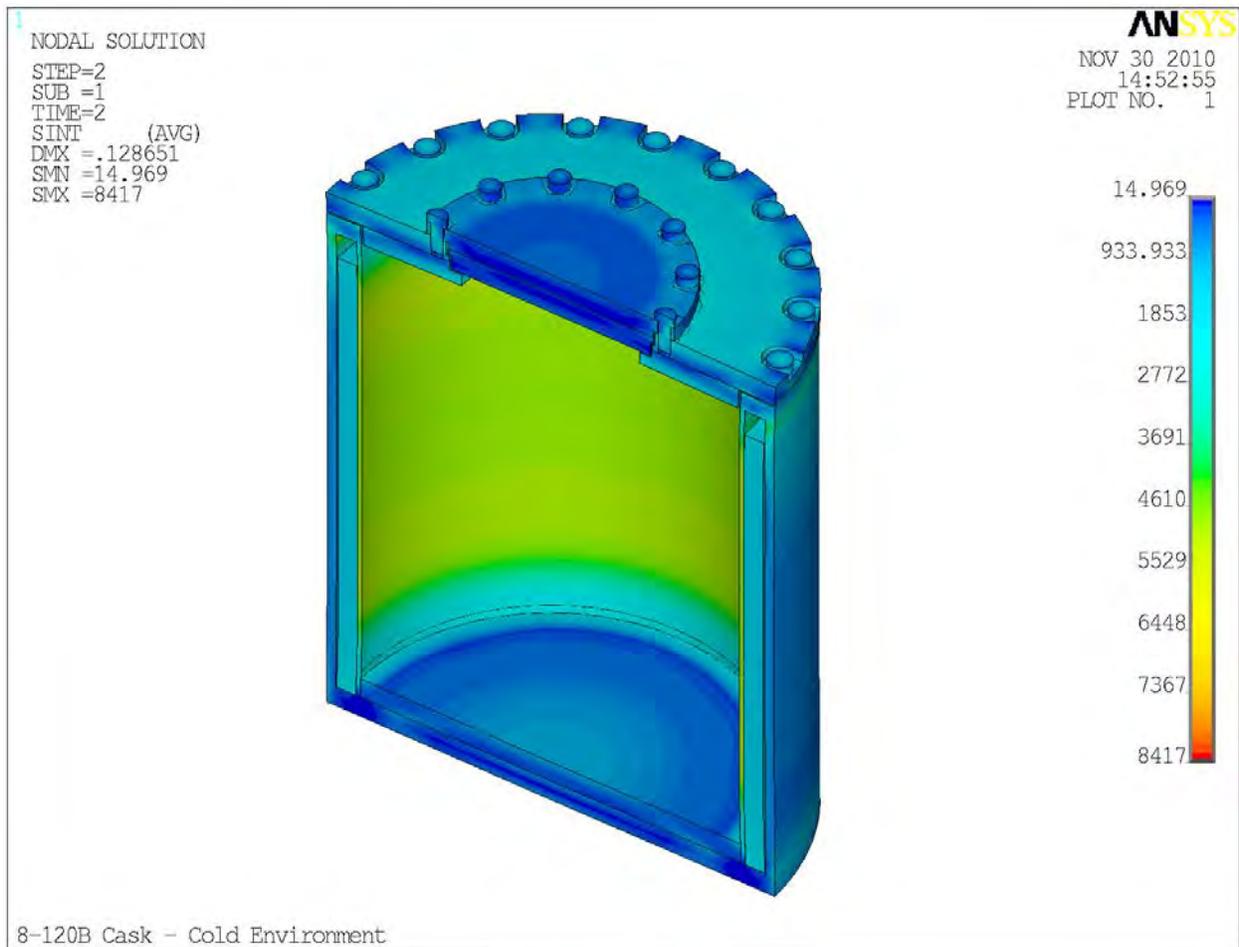


Figure 2-22 - Stress Intensity Contour Plot - Cold Environment Loading

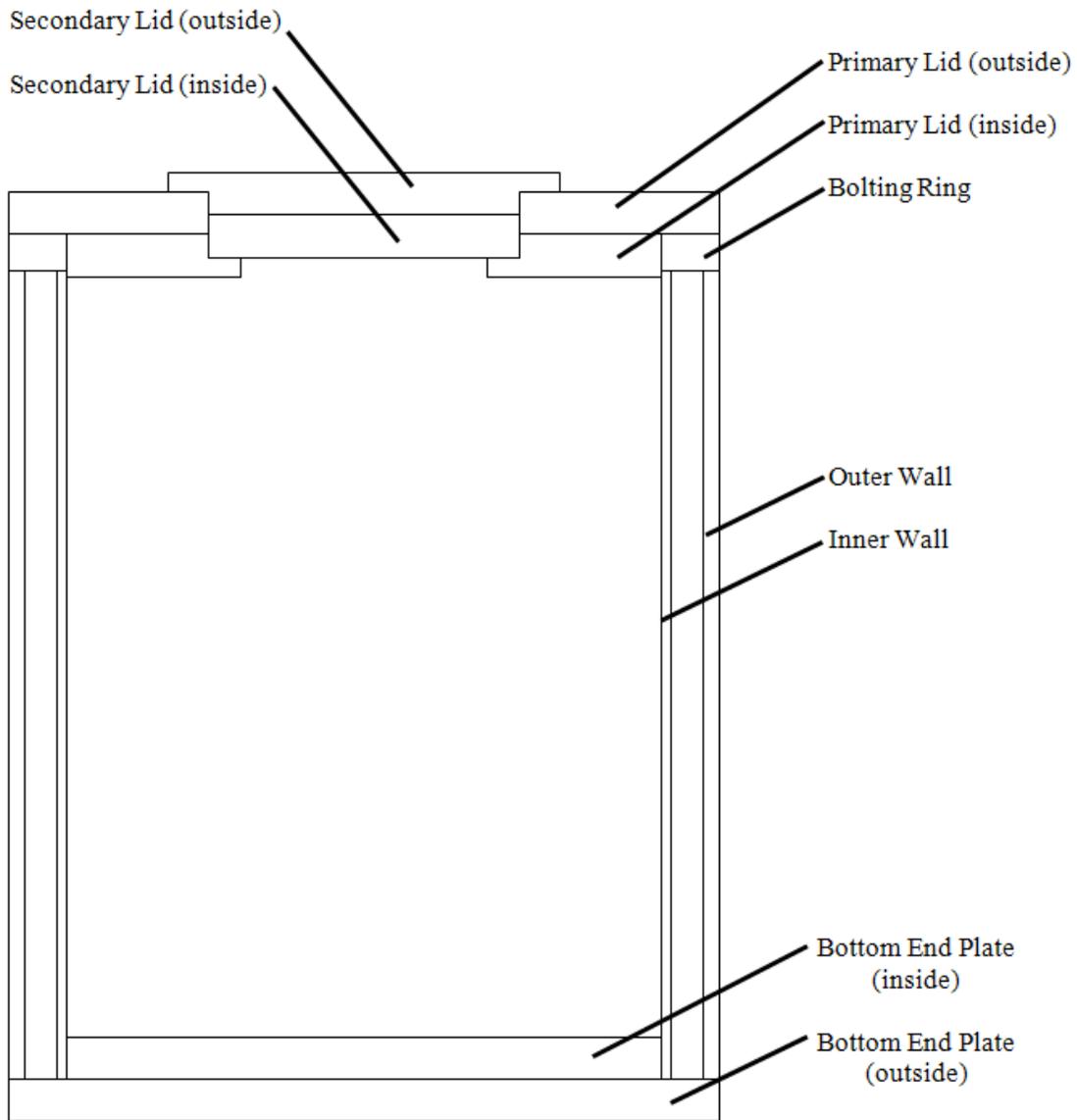


Figure 2-23 - Fracture Critical Cask Components

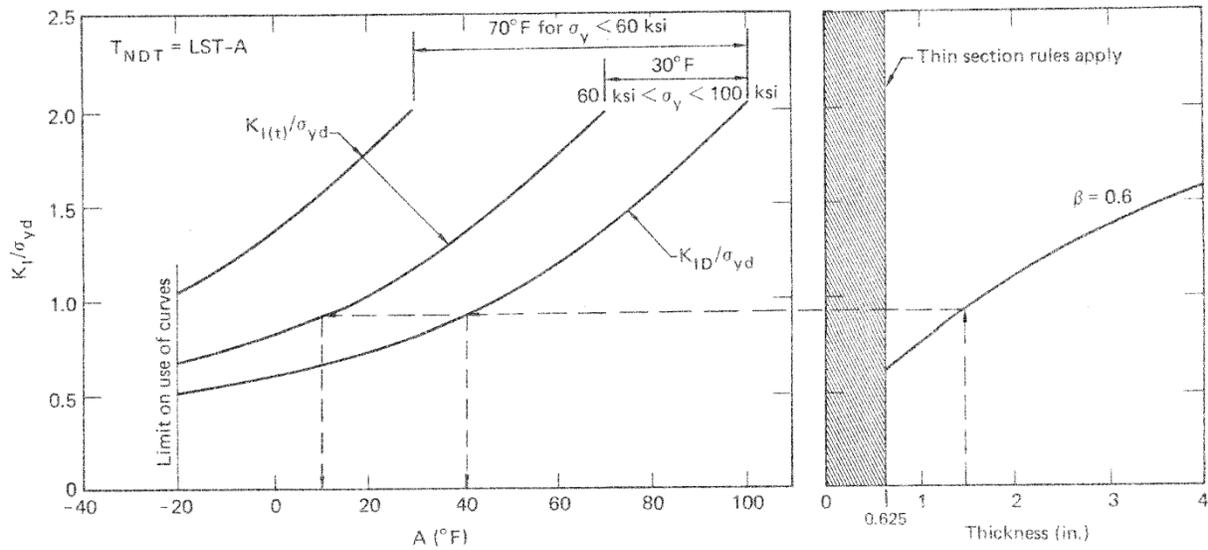


Figure 2-24 - Design Chart for Category II Fracture Critical Components

(From Figure 7 of Reference 2-18)

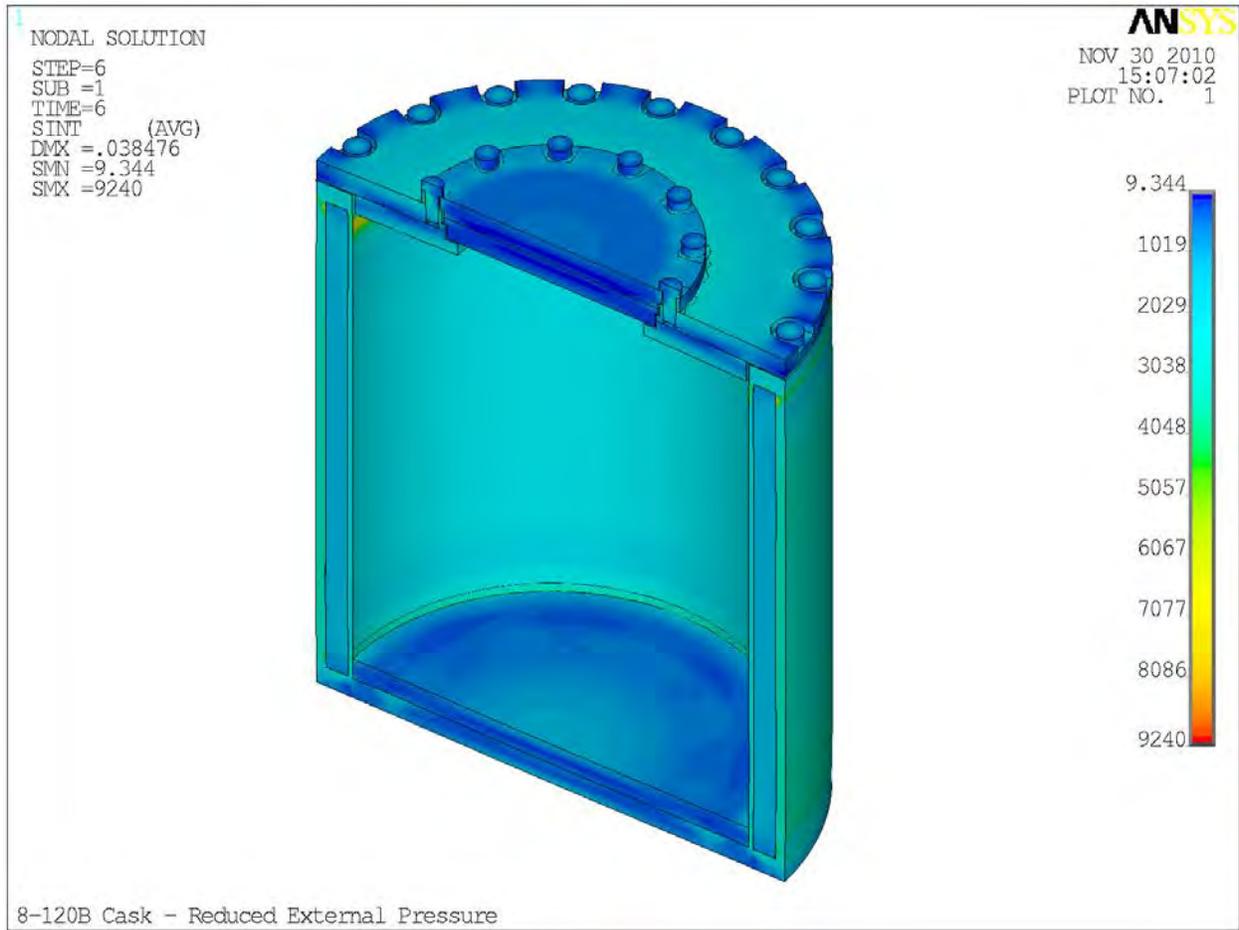


Figure 2-25 - Stress Intensity Contour Plot - Reduced External Pressure Loading

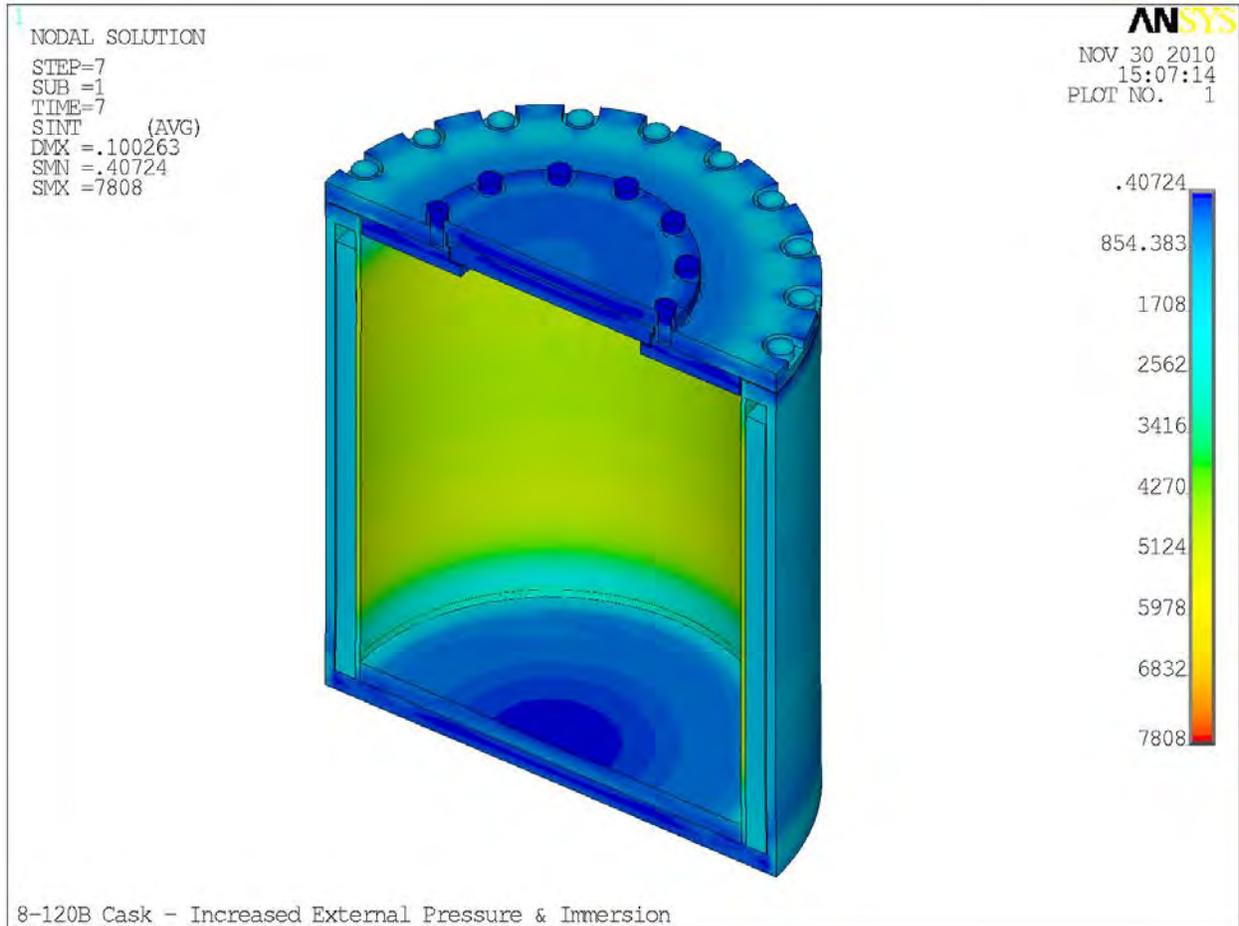


Figure 2-26 - Stress Intensity Contour Plot - Increased External Pressure and Immersion Loading

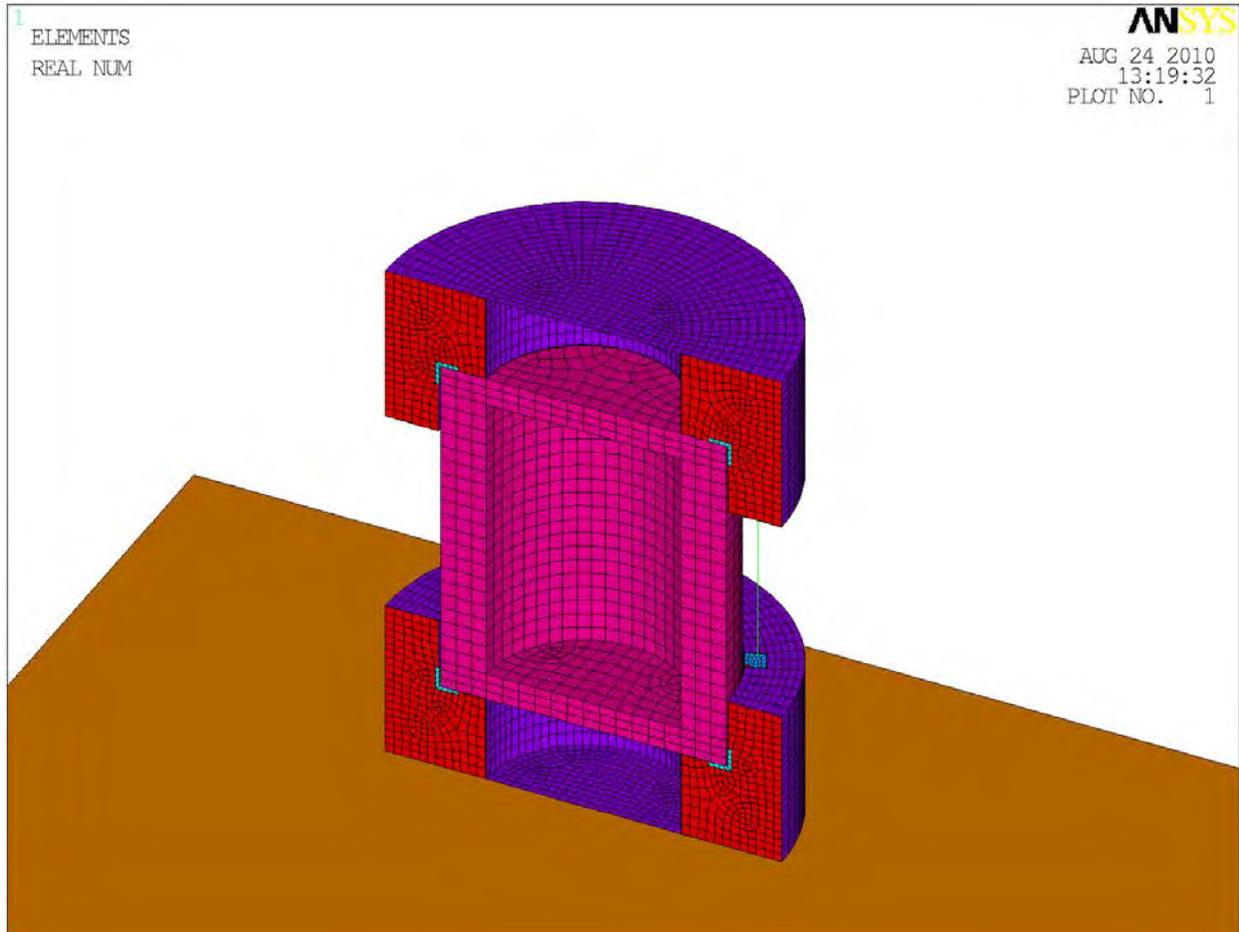


Figure 2-27 - LS-DYNA Model of the 8-120B Cask & Rigid Pad

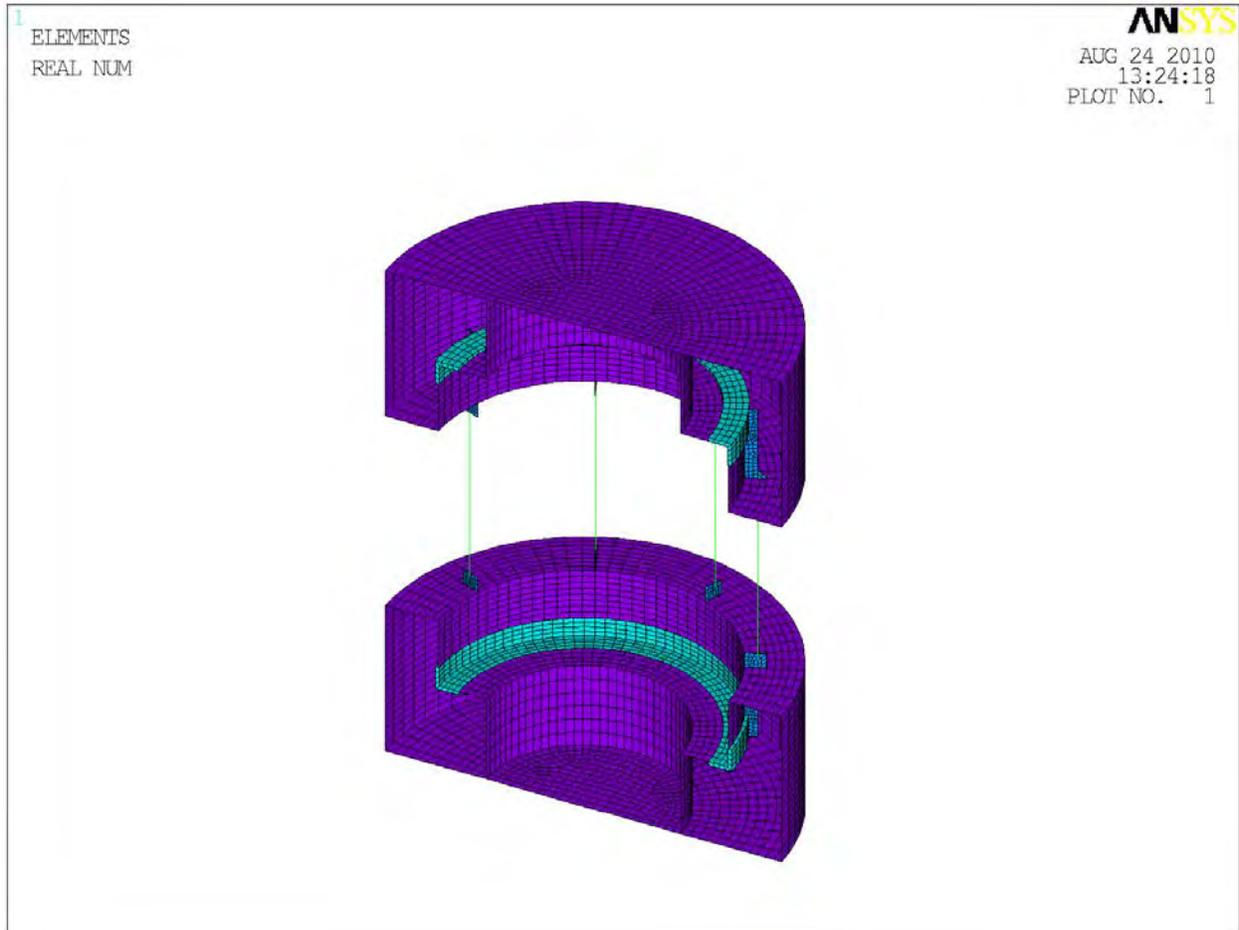


Figure 2-28 - The finite element model for the drop tests

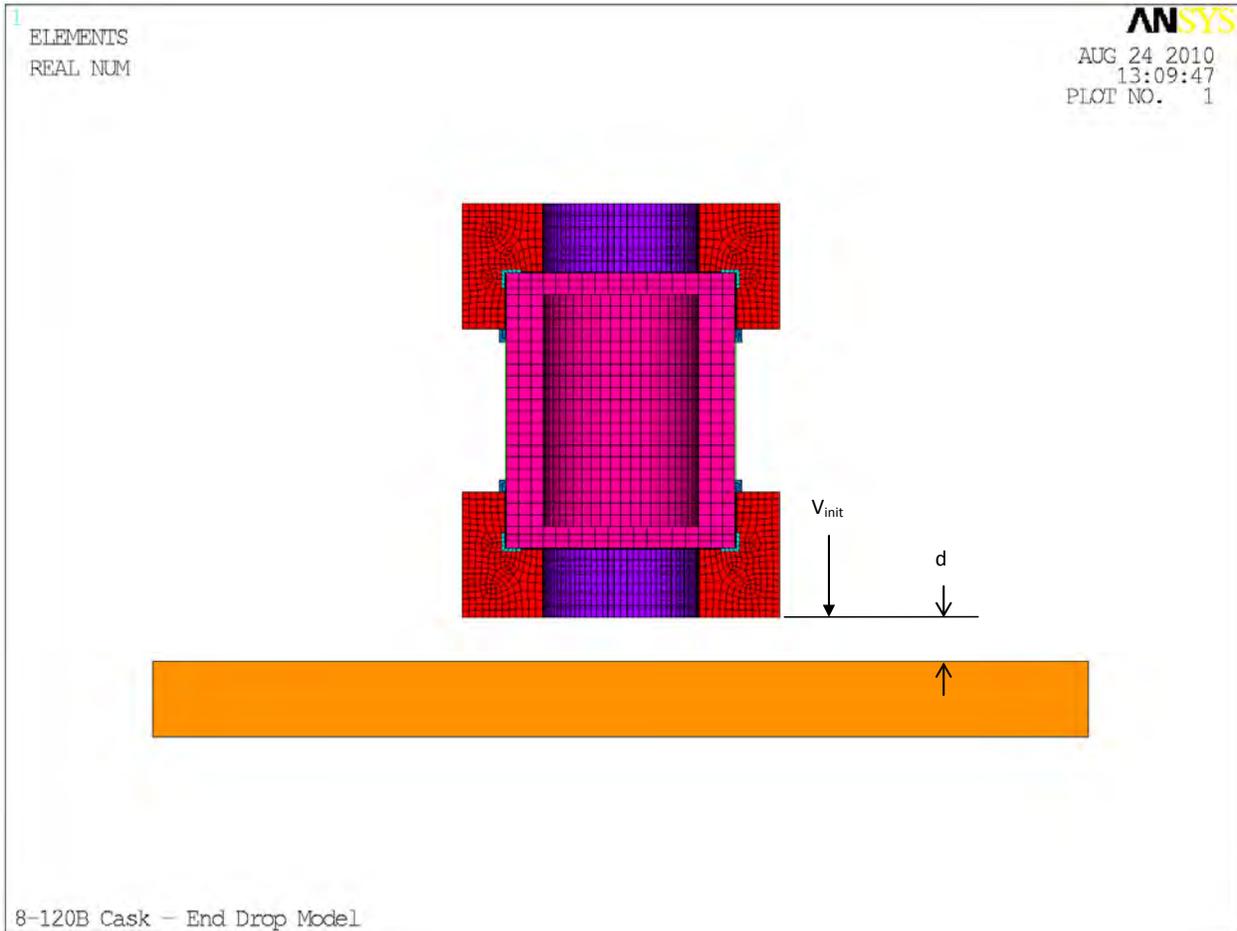


Figure 2-29 - End Drop – The cask axis parallel to the drop direction

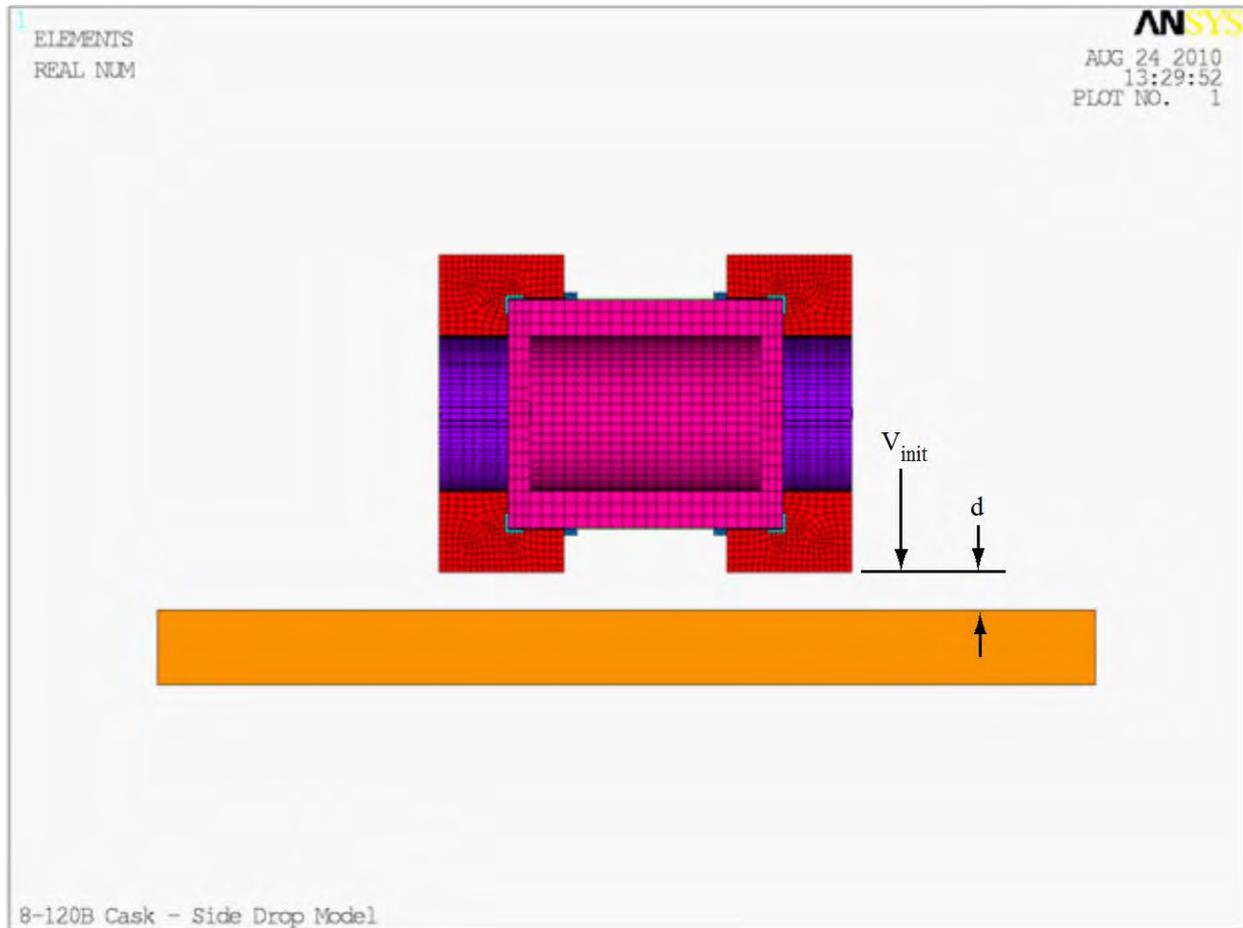


Figure 2-30 - Side Drop – The cask axis perpendicular to the drop direction

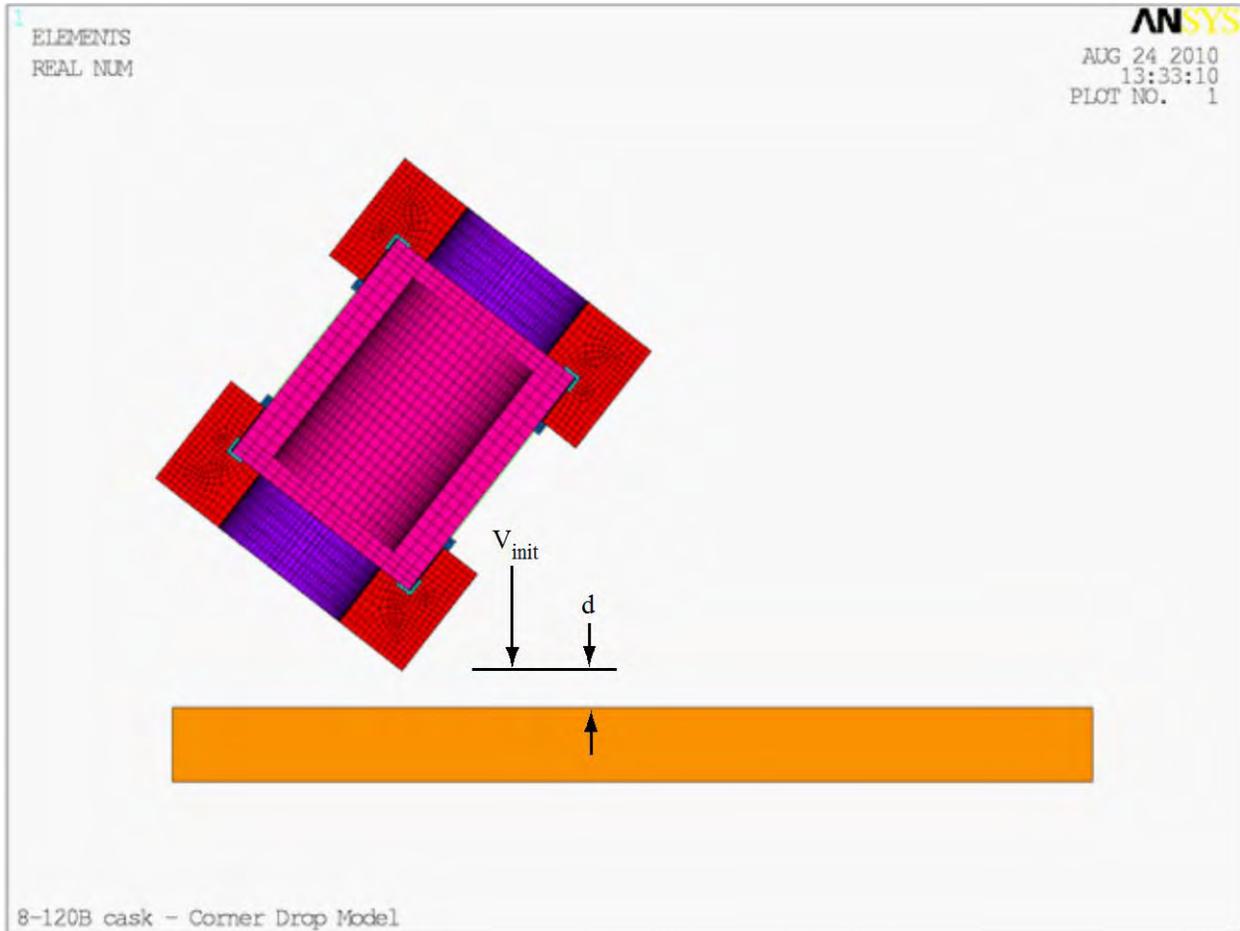


Figure 2-31 - Corner Drop – The C.G. of the cask directly over the impact point.

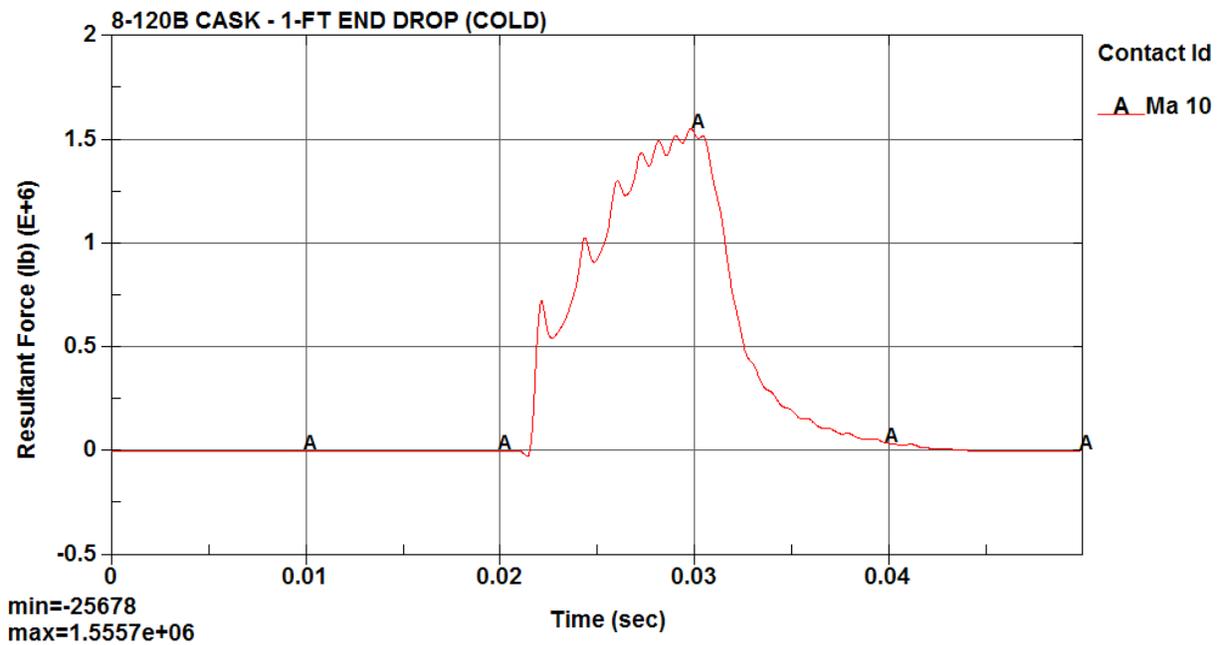


Figure 2-32 - Time-History Result, 1-Ft End Drop, Cold Condition (Resultant Force Plot)

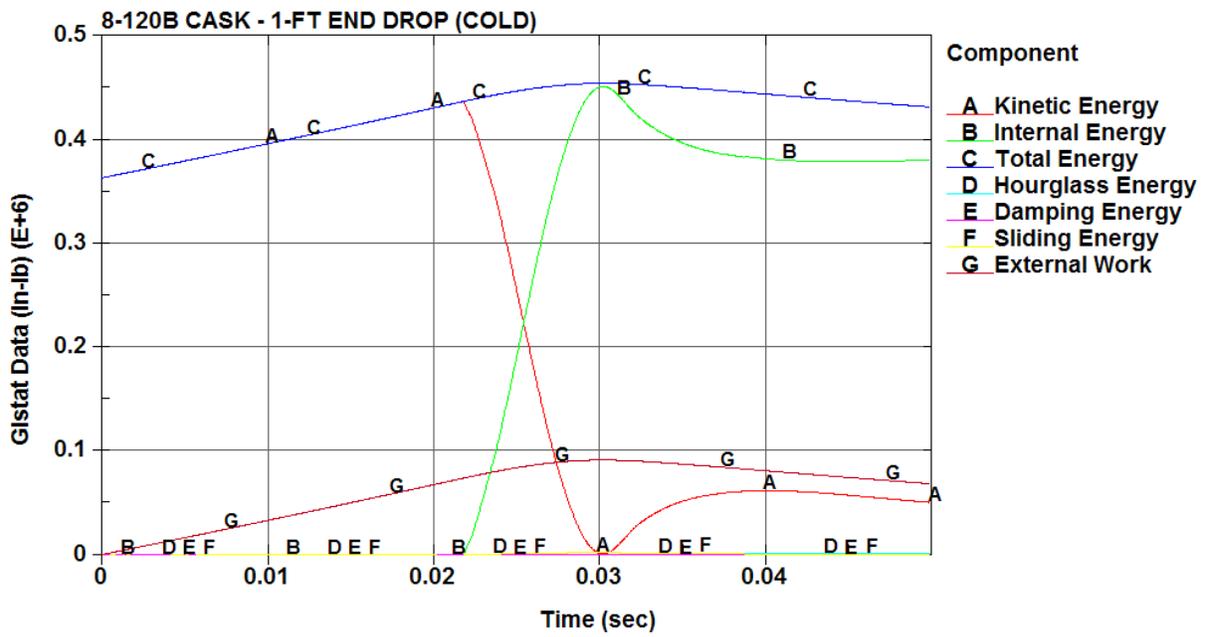


Figure 2-33 - Time-History Result, 1-Ft End Drop, Cold Condition (Energy Plots)

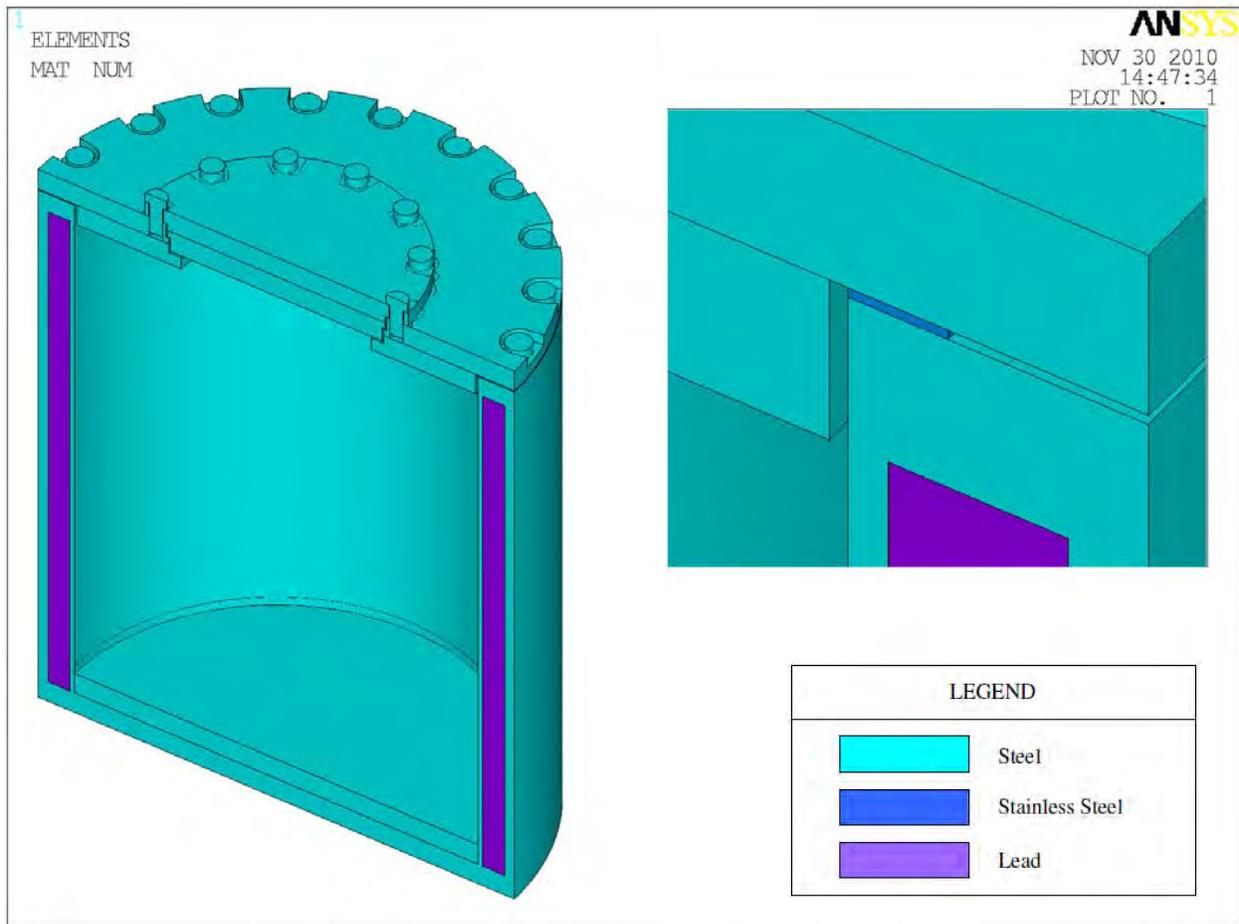


Figure 2-34 - Finite Element Model of the 8-120B Cask Identifying the Cask Components with Material

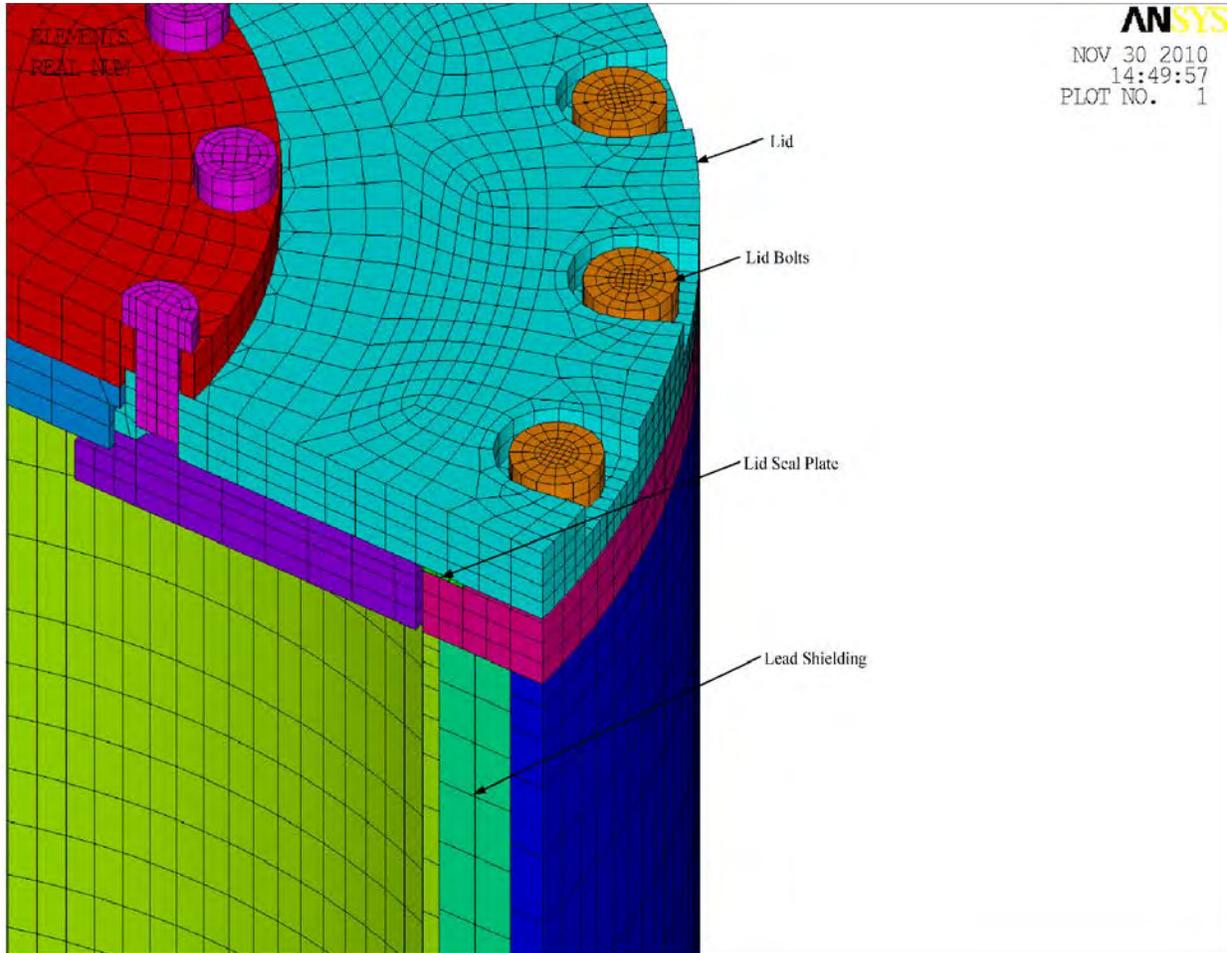


Figure 2-35 - The finite element grid of the lid, seal plate, bolts, and the cask

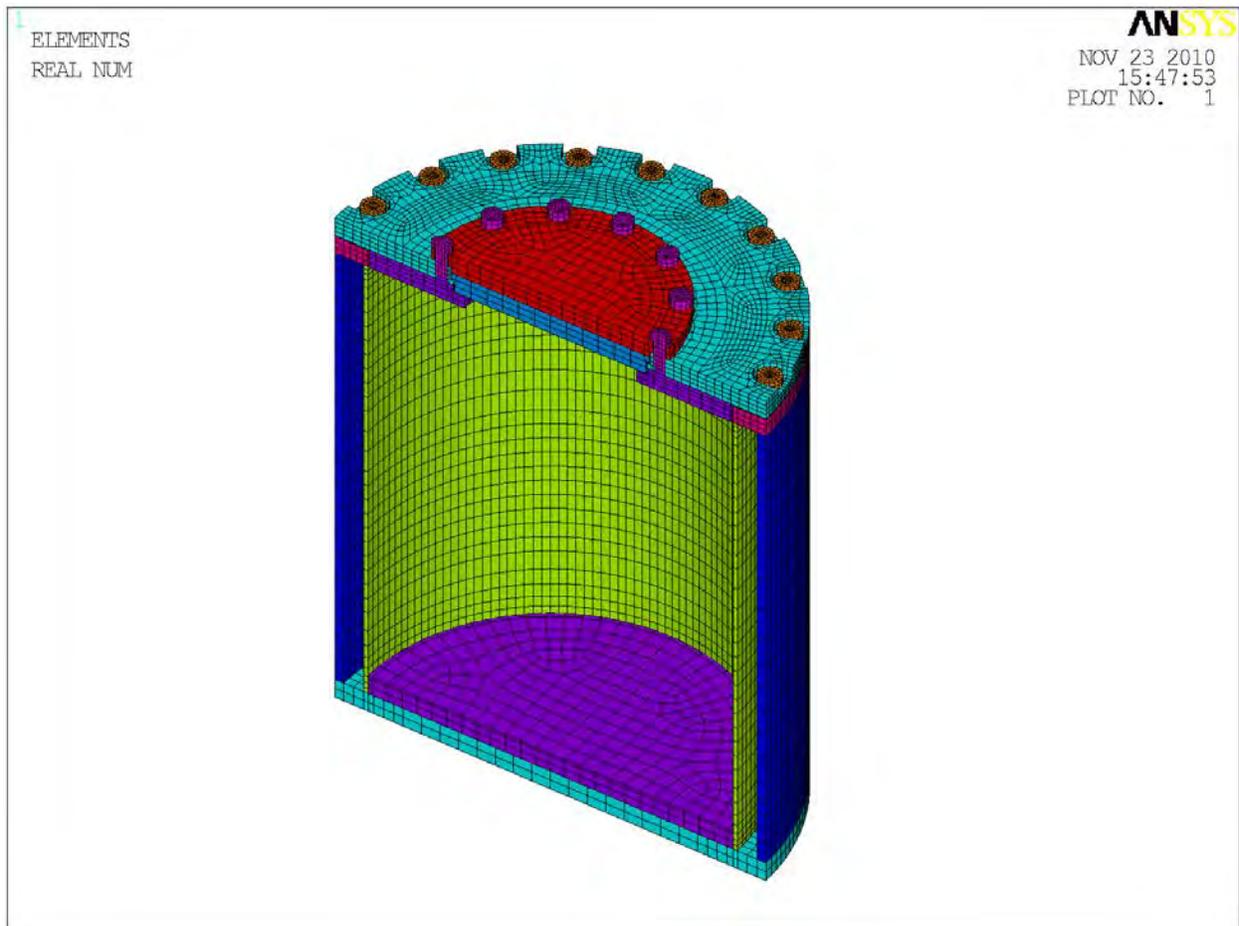


Figure 2-36 - The finite element grid of the cask body without the lead

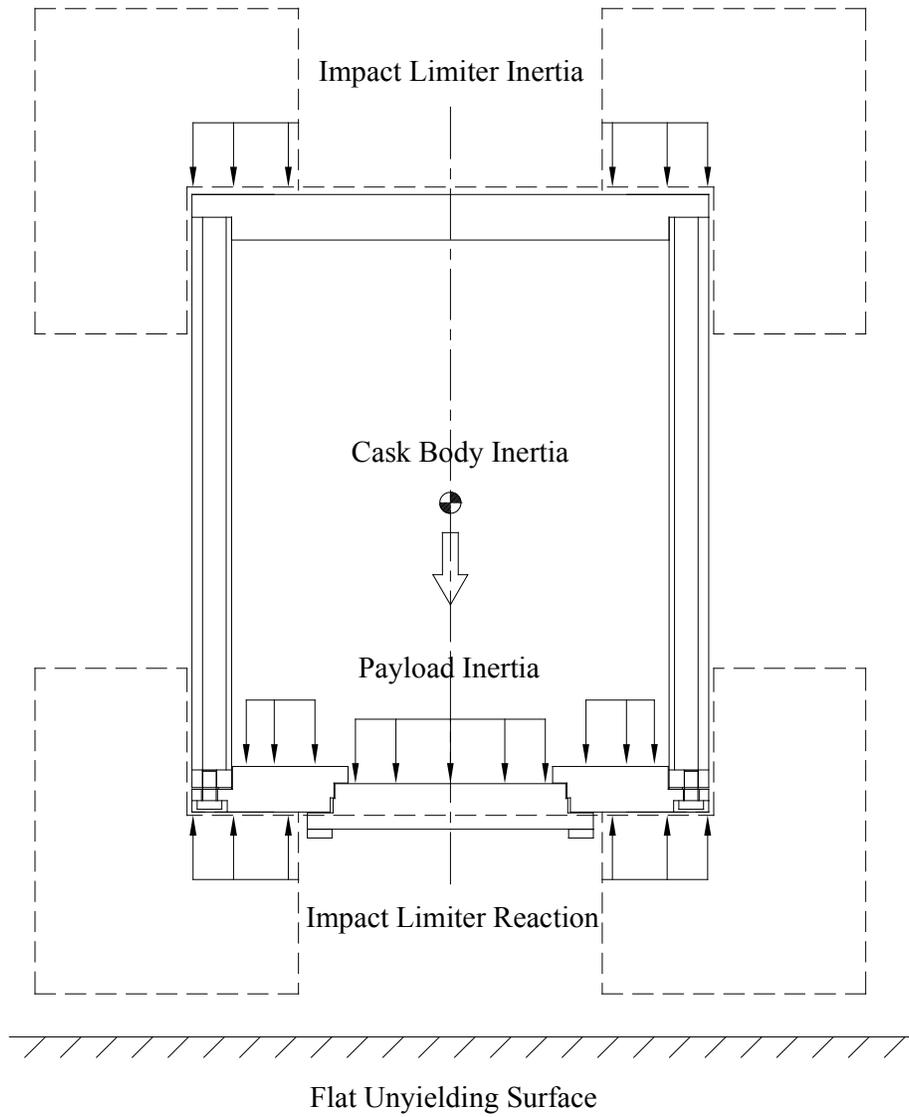


Figure 2-37 - Load Distribution on the Model During End Drop

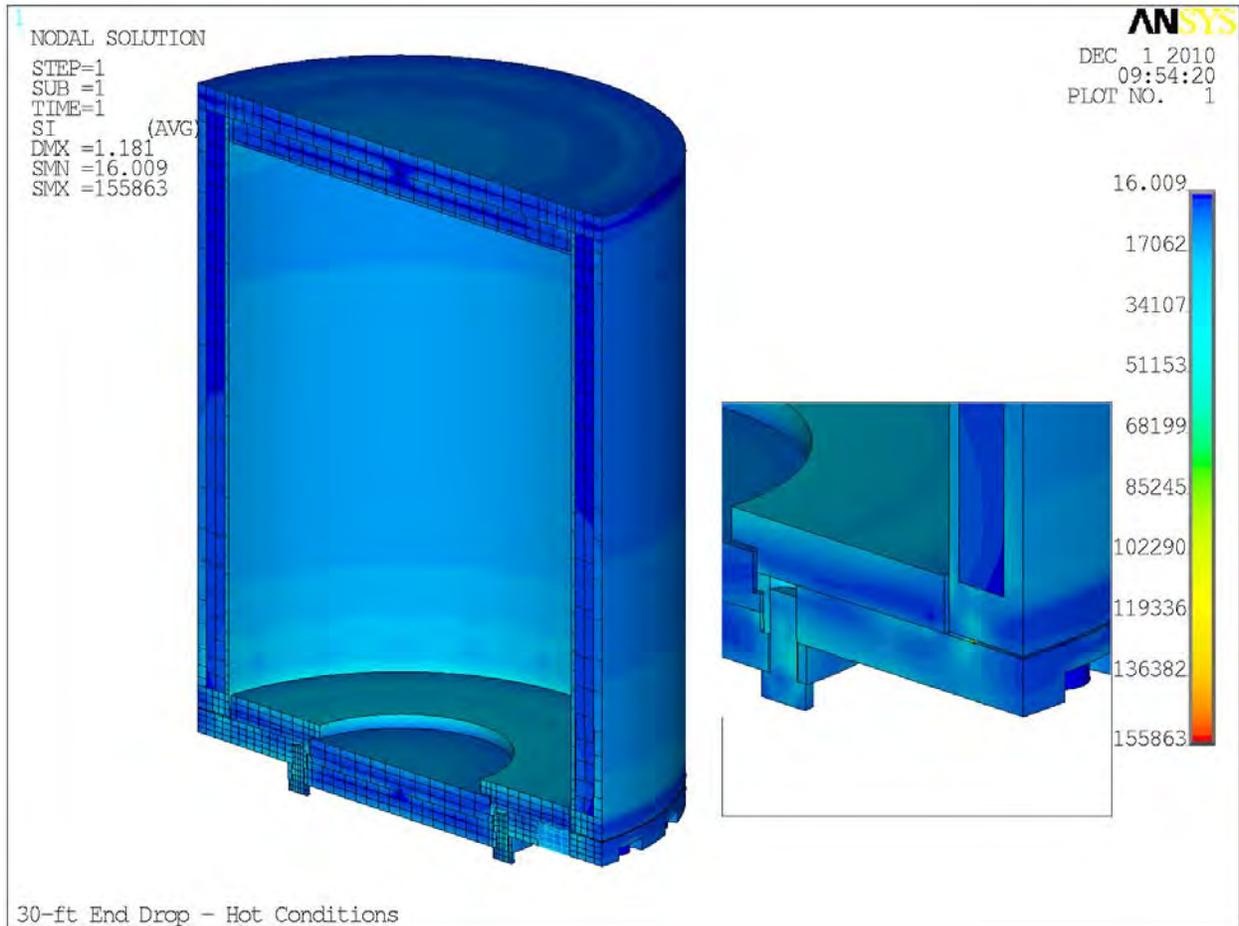


Figure 2-38 - Stress Intensity Plot – 30-ft End Drop – Hot Condition

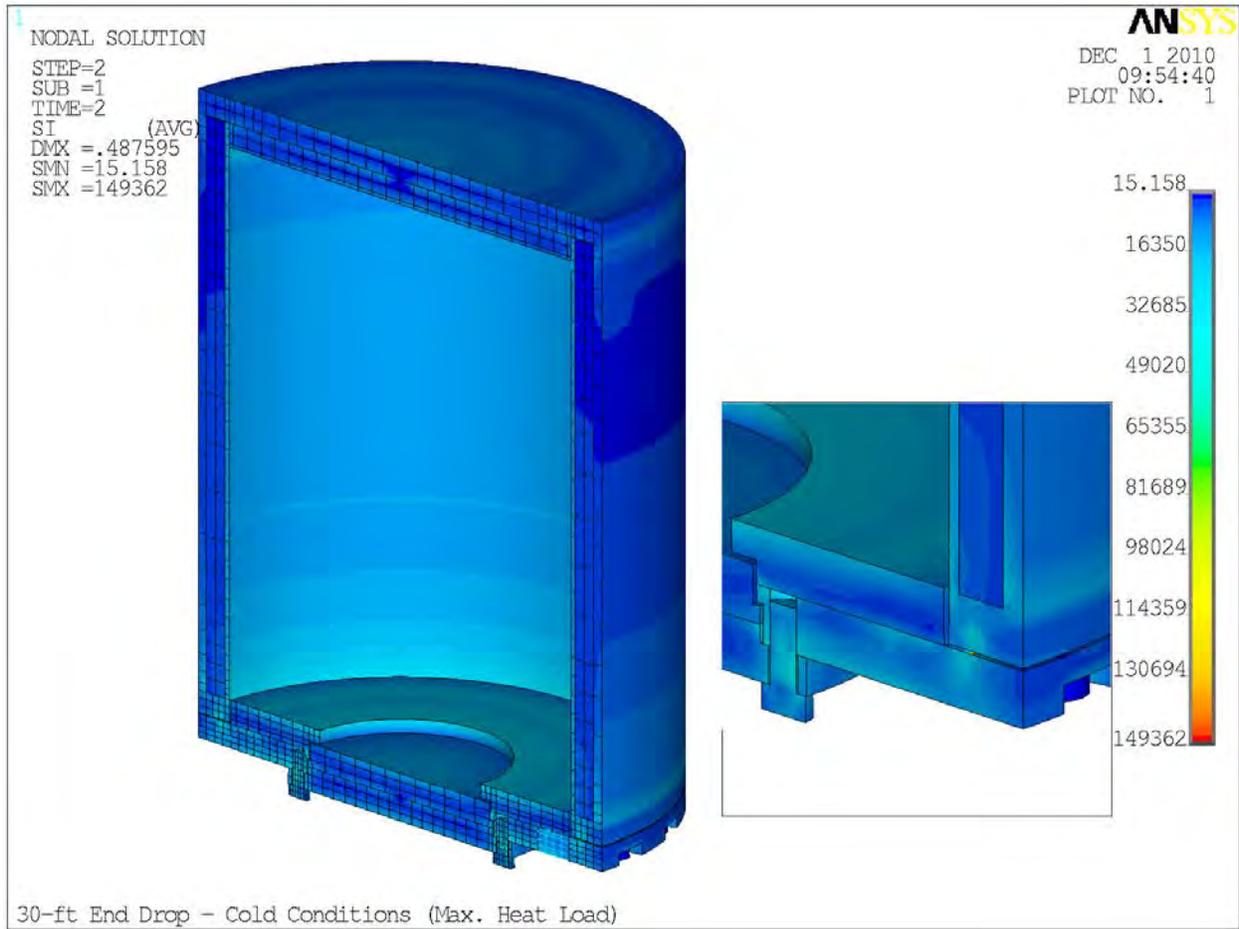


Figure 2-39 - Stress Intensity Plot – 30-ft End Drop – Cold Condition (Max. Heat Load)

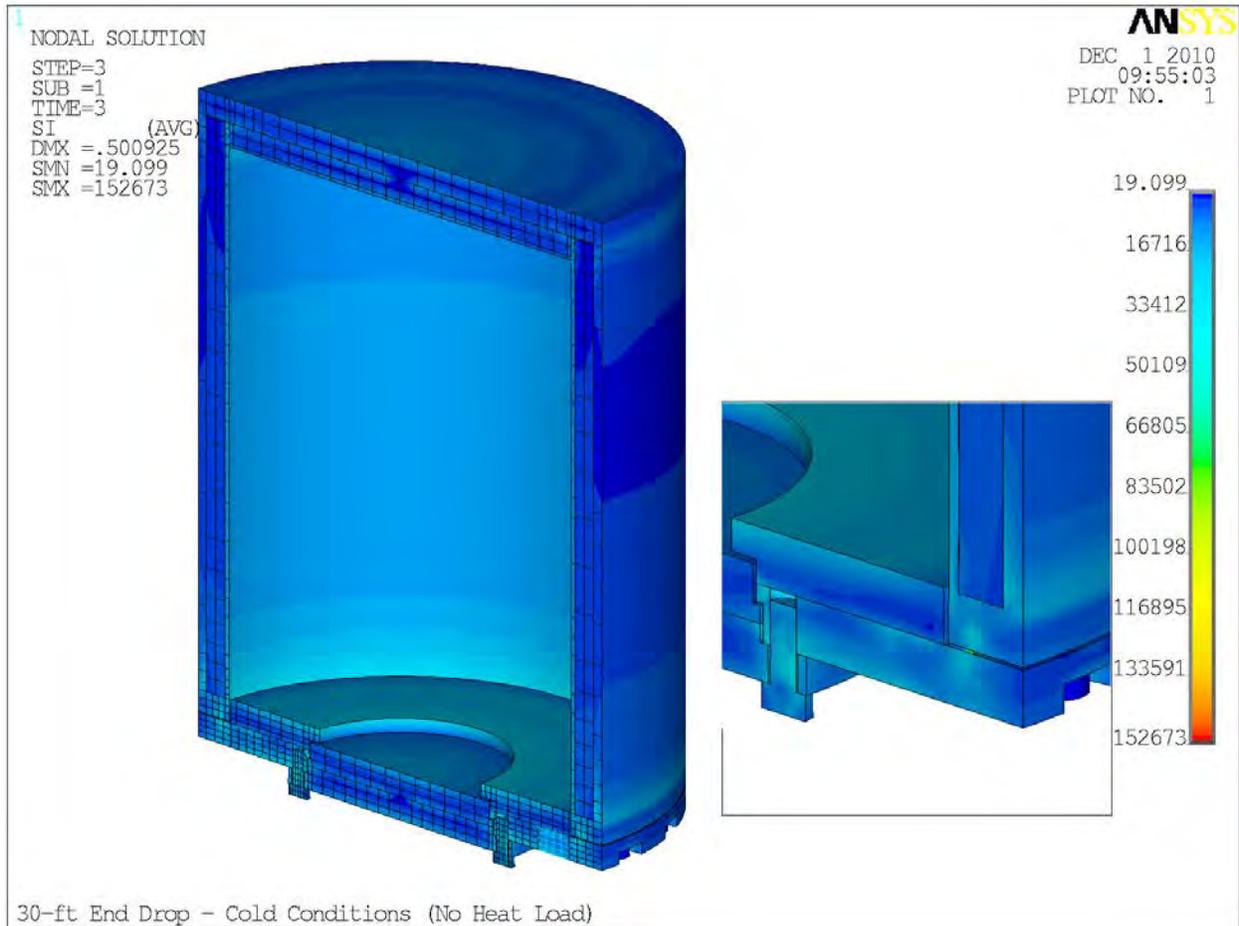


Figure 2-40 - Stress Intensity Plot – 30-ft End Drop – Cold Condition (No Heat Load)

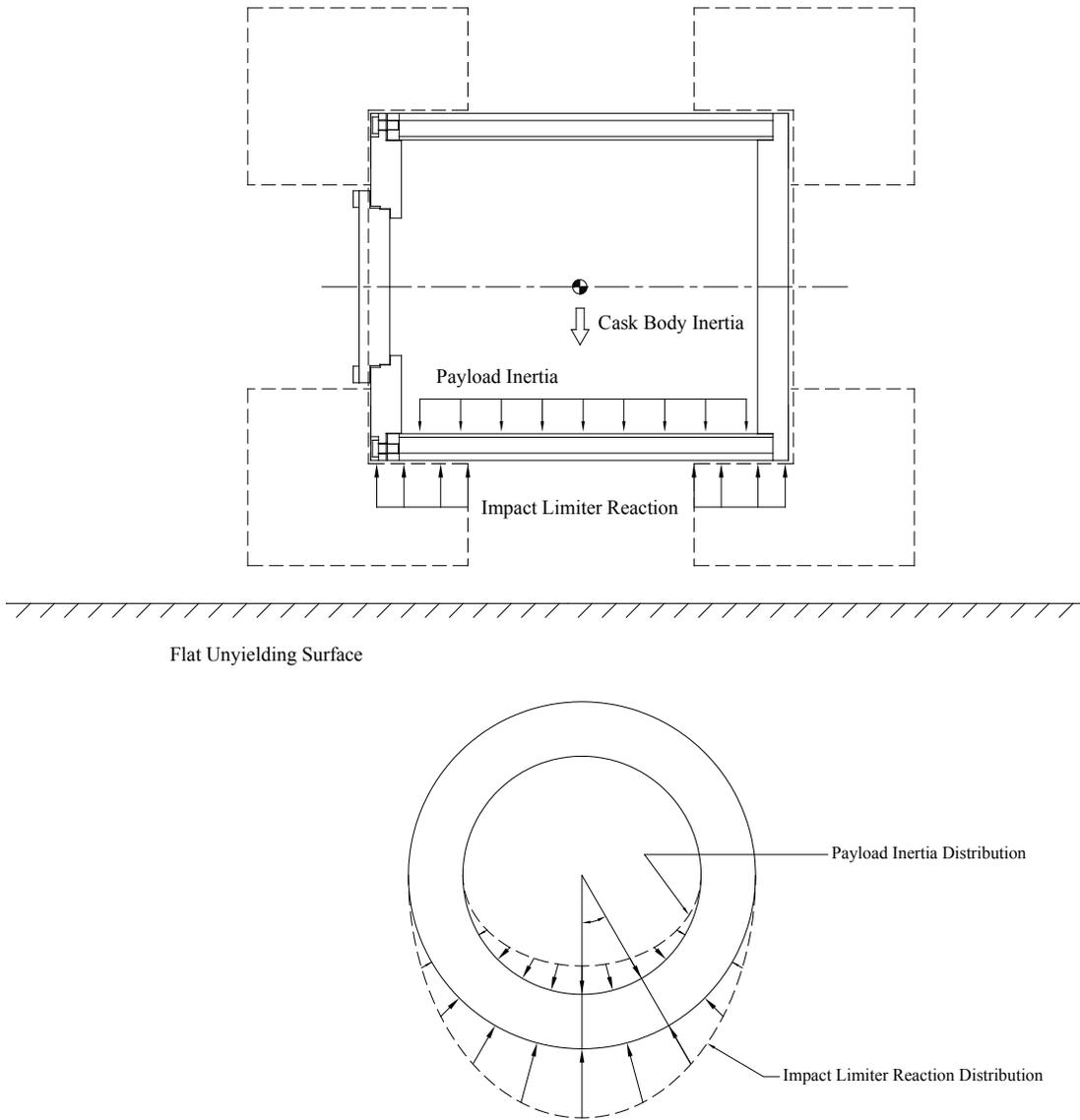


Figure 2-41 - Load Distribution on the Model During Side Drop

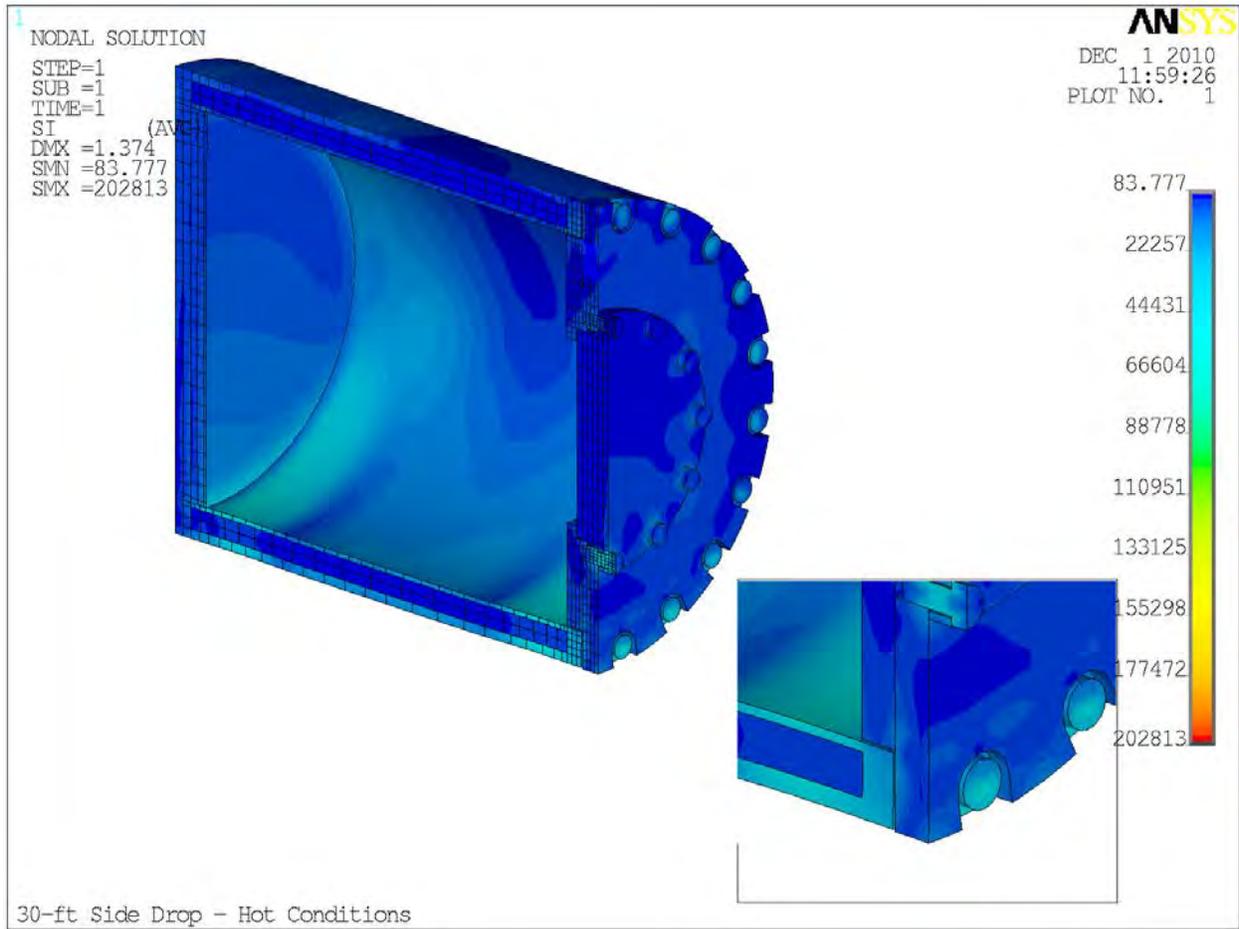


Figure 2-42 - Stress Intensity Plot – 30-ft Side Drop – Hot Condition

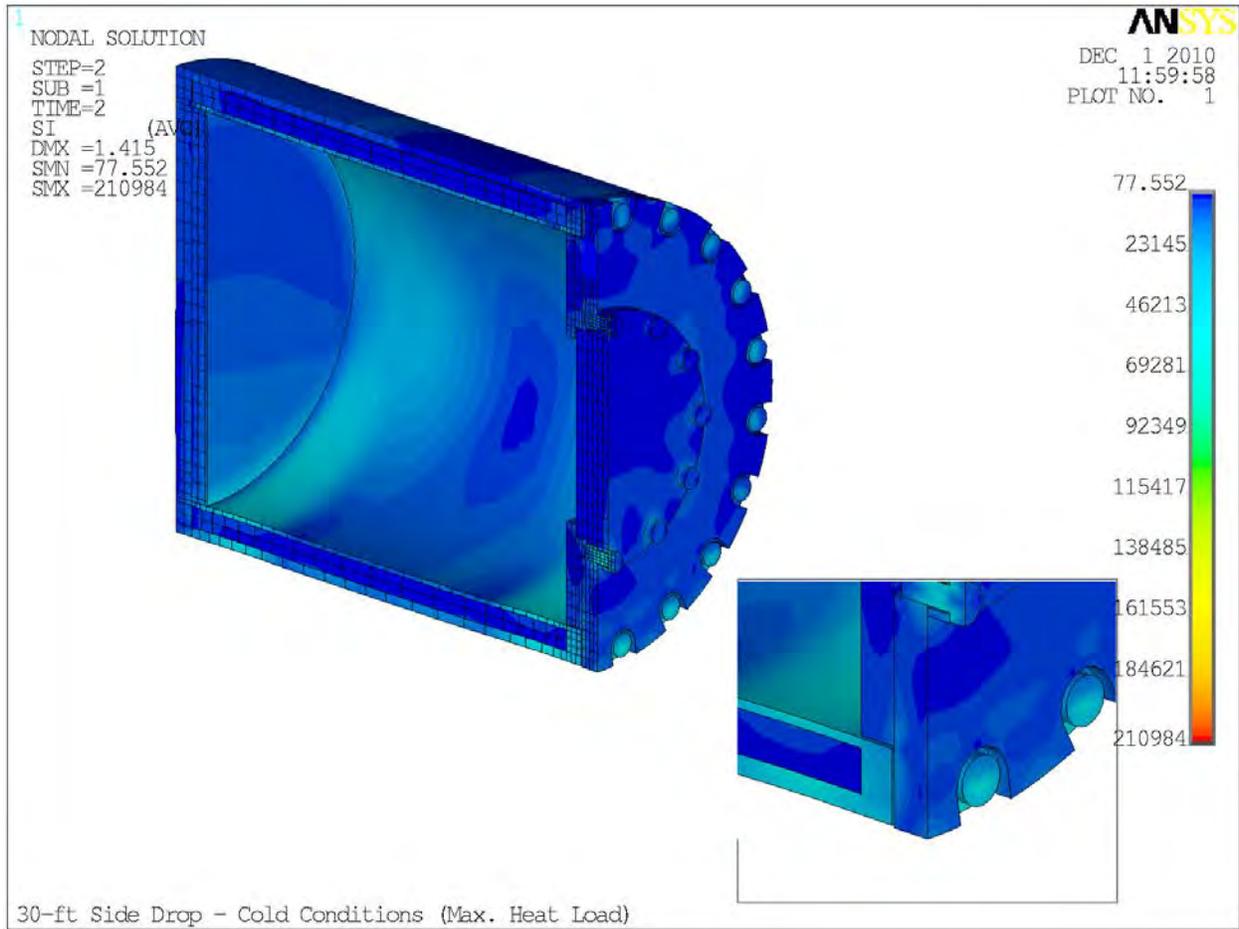


Figure 2-43 - Stress Intensity Plot – 30-ft Side Drop – Cold Condition (Max. Heat Load)

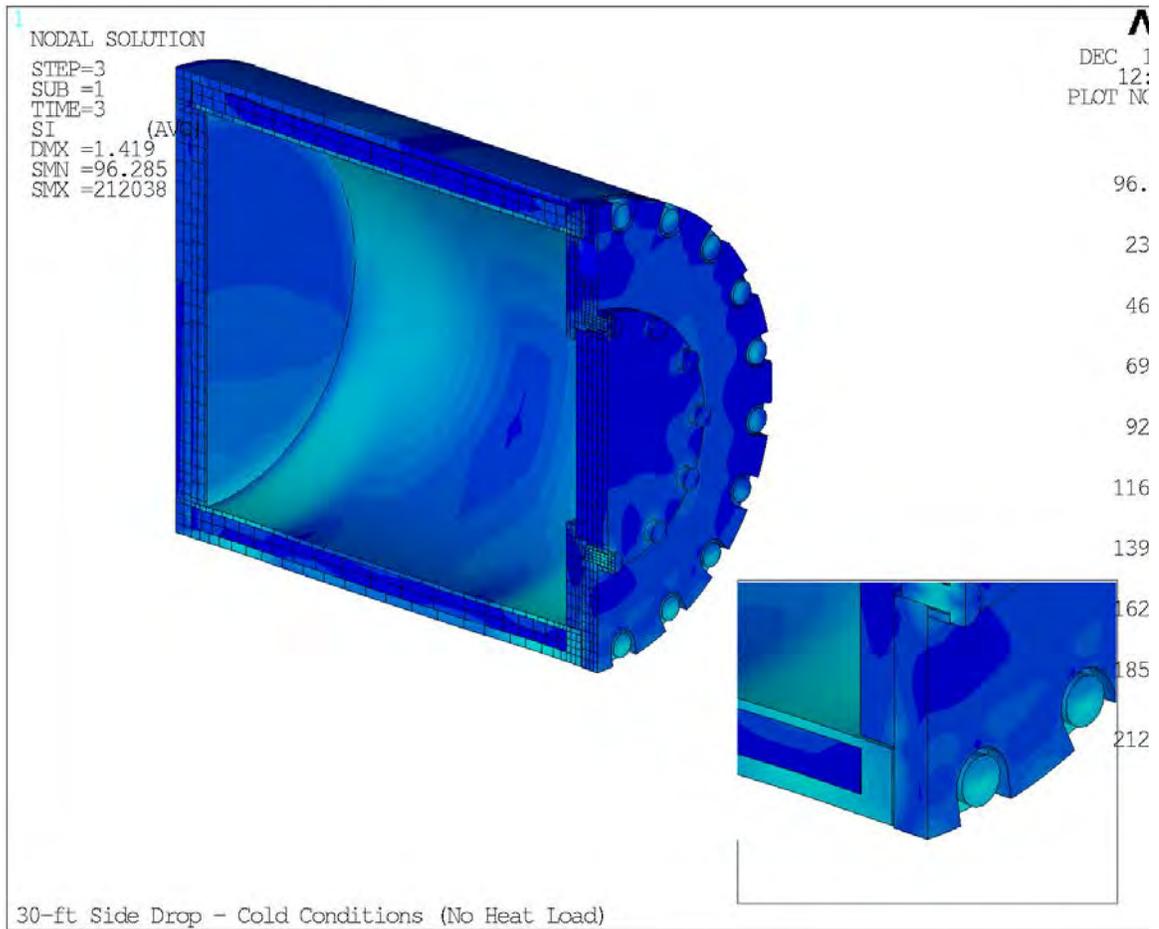


Figure 2-44 - Stress Intensity Plot – 30-ft Side Drop – Cold Condition (No Heat Load)

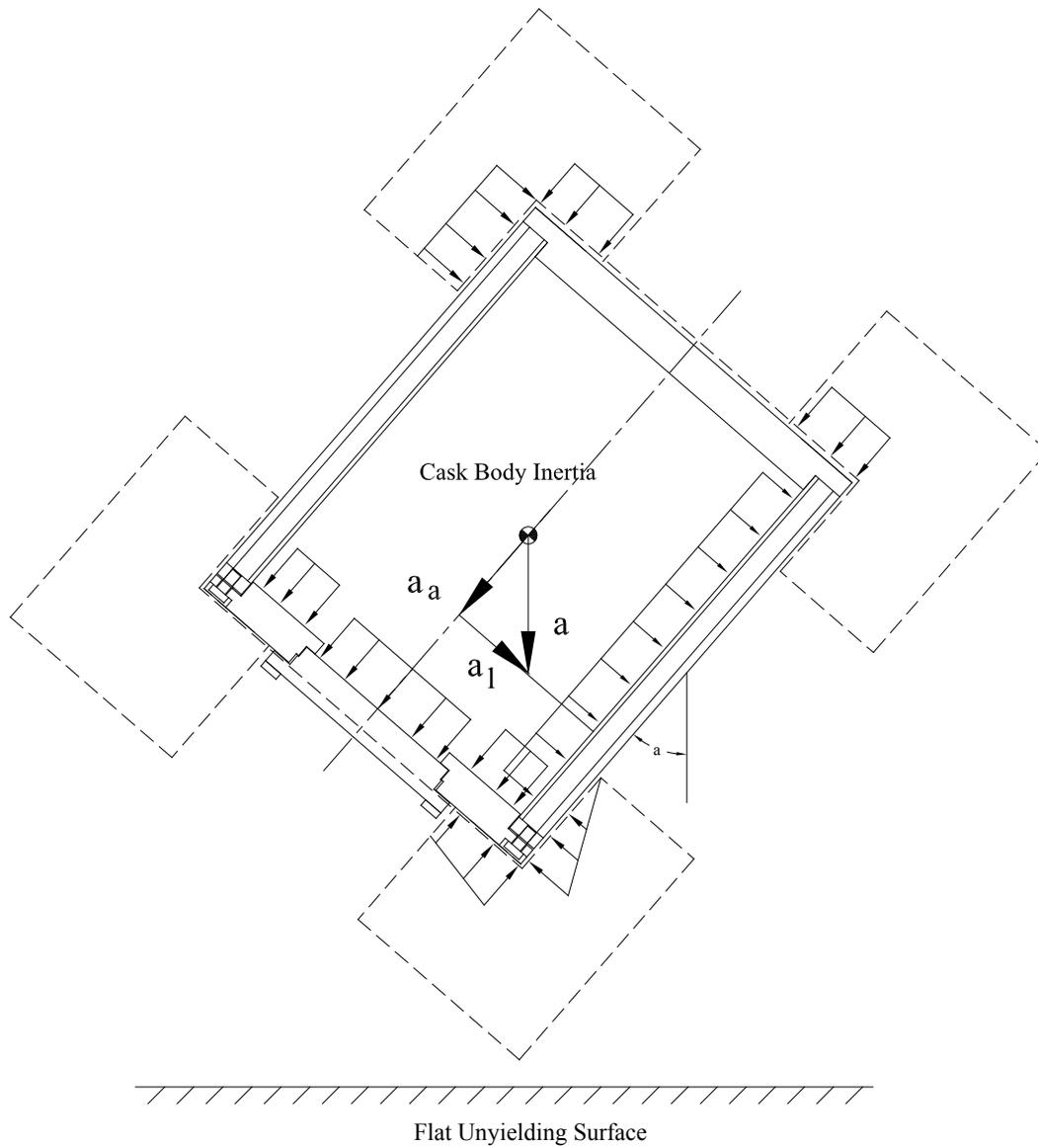


Figure 2-45 - Load Distribution on the Model During Corner Drop

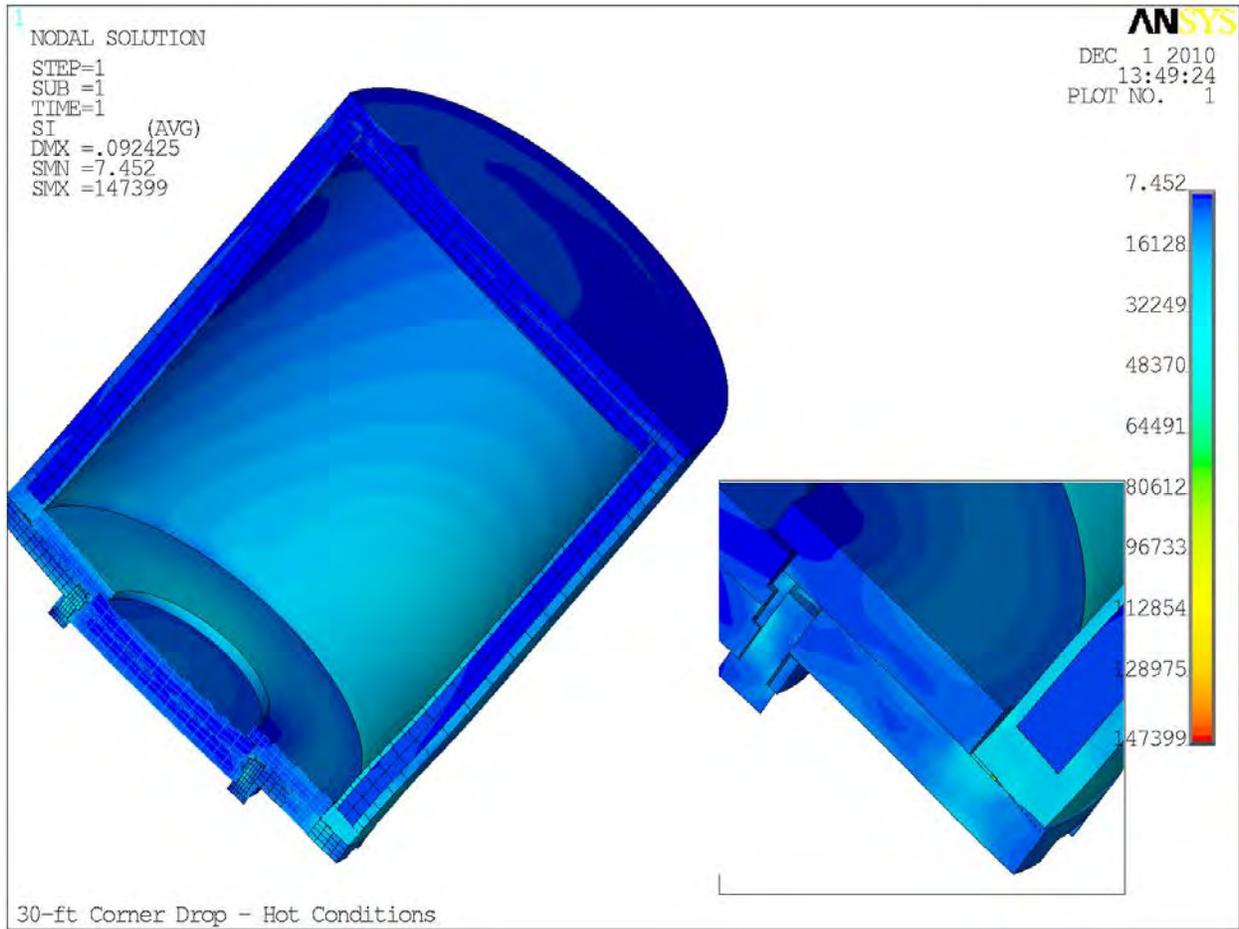


Figure 2-46 - Stress Intensity Plot – 30-ft Corner Drop – Hot Condition

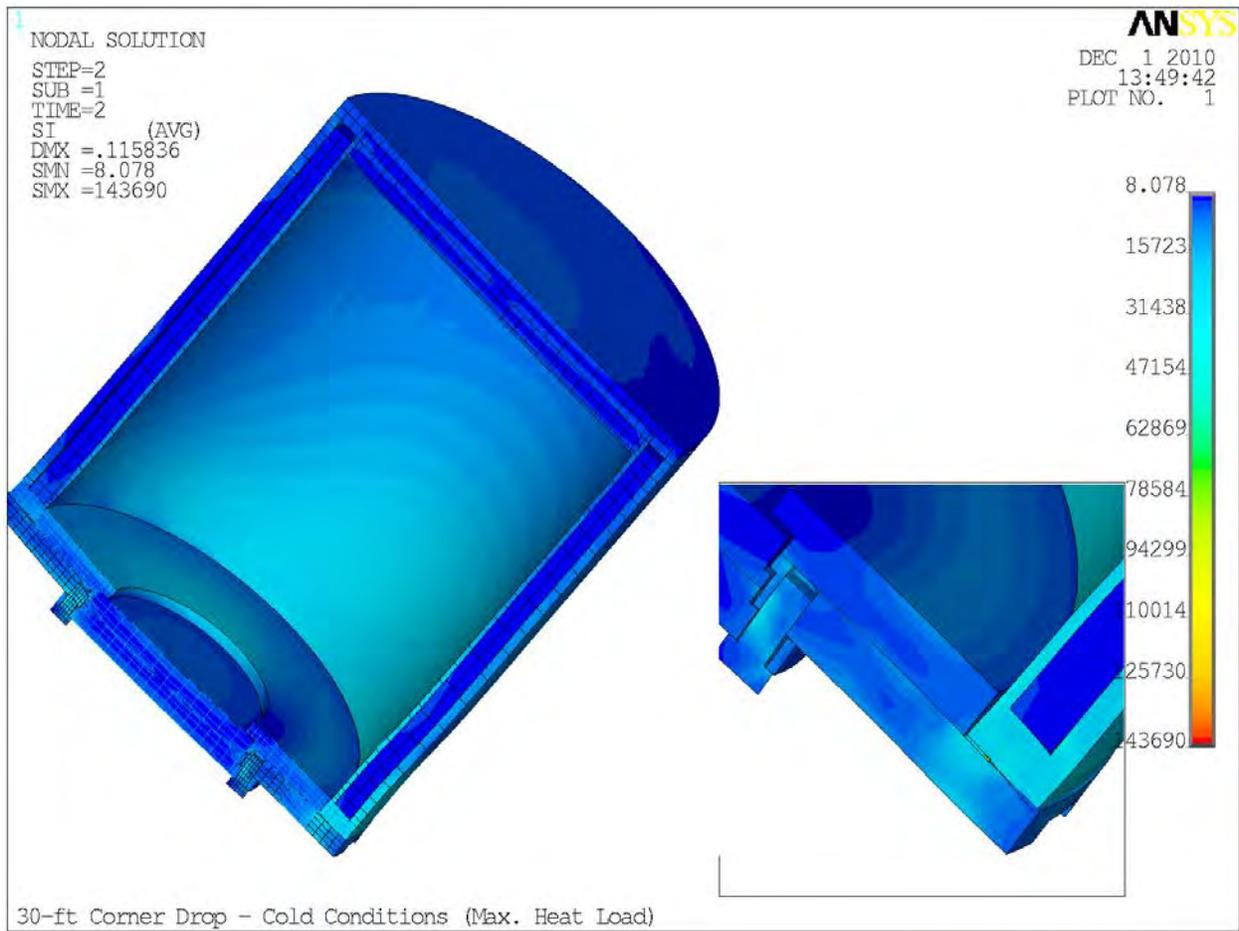


Figure 2-47 - Stress Intensity Plot – 30-ft Corner Drop – Cold Condition (Max. Heat Load)

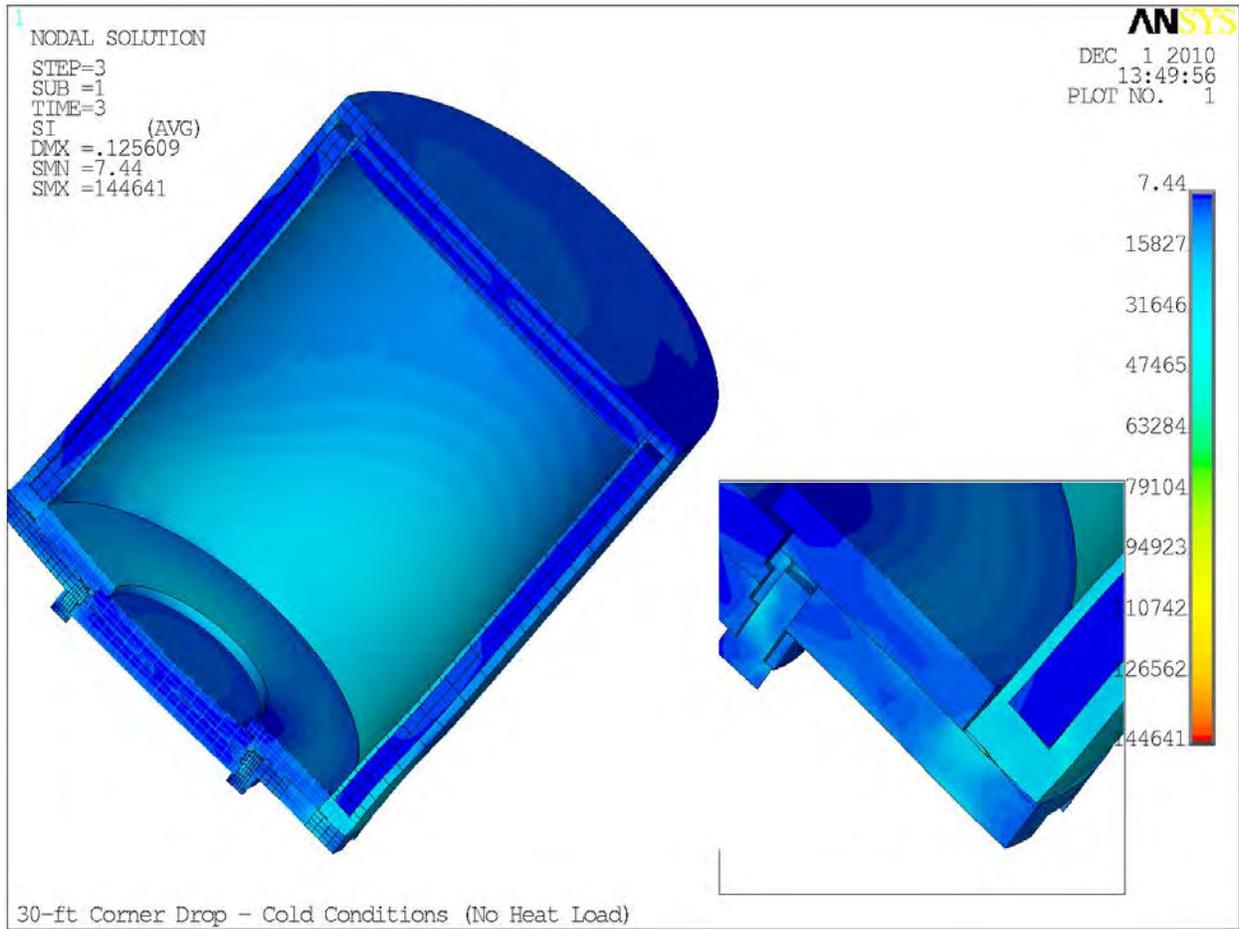


Figure 2-48 - Stress Intensity Plot – 30-ft Corner Drop – Cold Condition (No Heat Load)

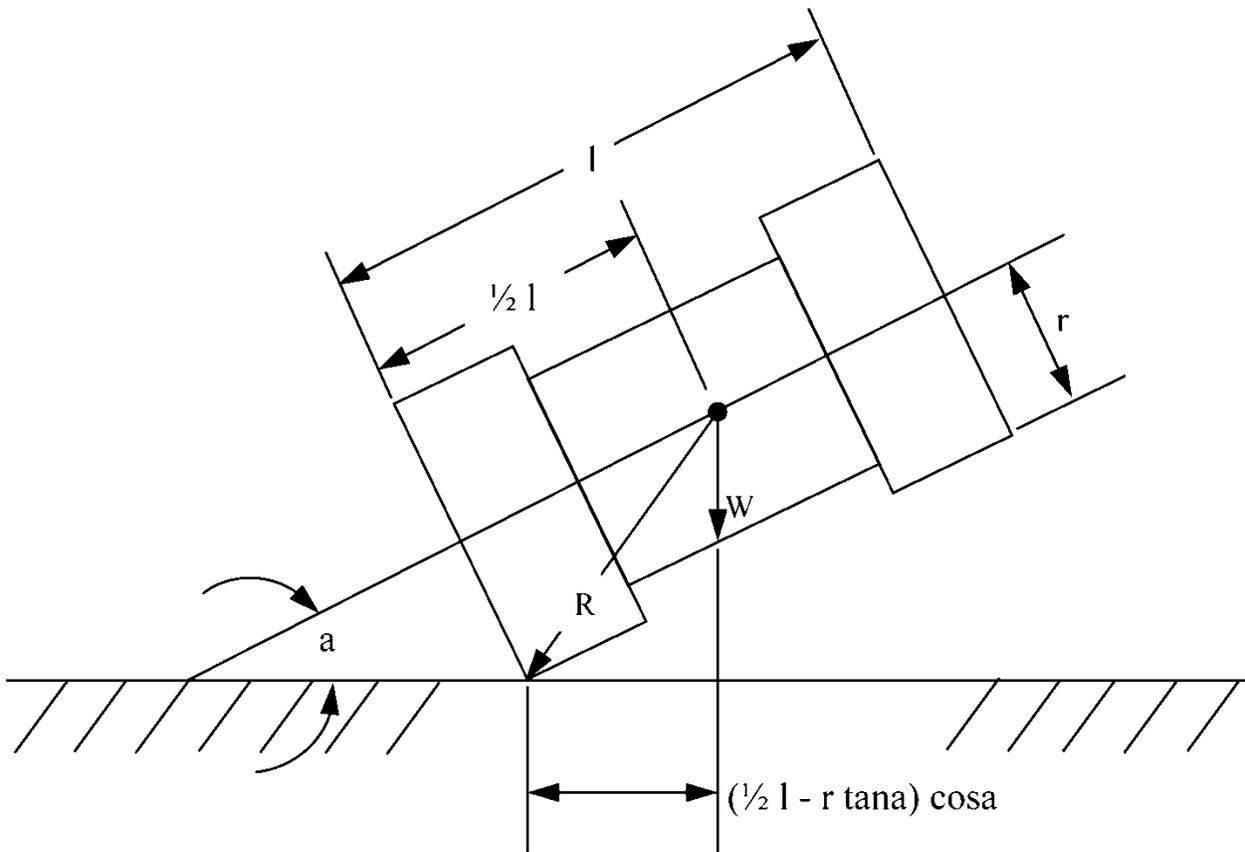


Figure 2-49 - Cask Oriented for Oblique Drop

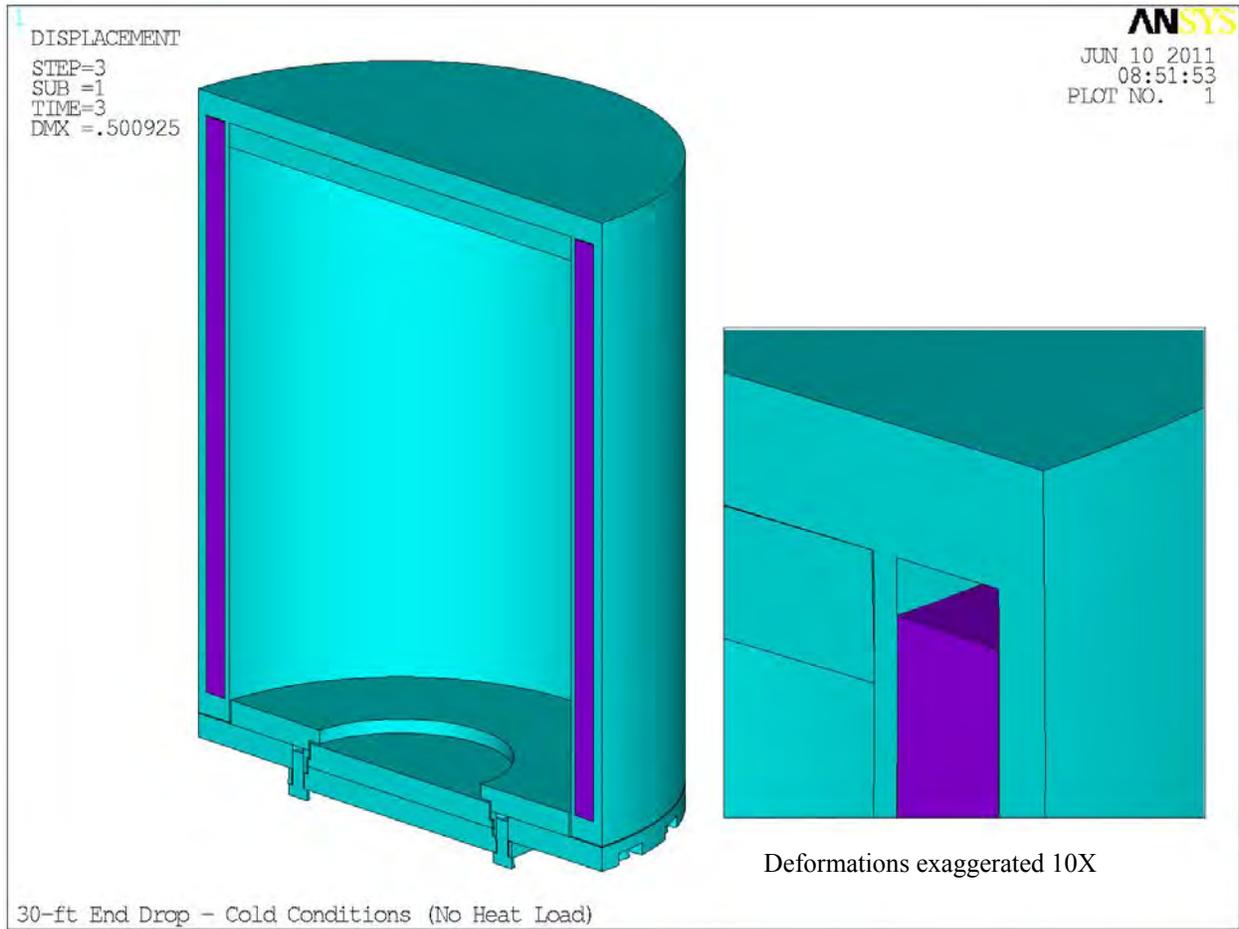


Figure 2-50 - Lead-Slump During the 30-ft End Drop Test

### **3.0 THERMAL EVALUATION**

This Section identifies, describes, discusses, and analyzes the principal thermal engineering design of the 8-120B package. Compliance with the performance requirements of 10 CFR 71 (Reference 3-1) is demonstrated.

#### **3.1 DESCRIPTION OF THERMAL DESIGN**

Two components contribute to the thermal protection of the cask body. These components are the impact limiters which provide thermal protection to the ends of the cask and the fire shield which protects the side walls between the impact limiters.

##### **3.1.1 DESIGN FEATURES**

Figure 3-1 shows the design features of the components contributing to the thermal protection of the cask. These components are identified in the figure with solid red color.

The fire shield is made of 3/16" steel sheet metal. In order to provide an air gap between the cask outer shell and the fire shield, 5/32" diameter wires are helically wrapped around the cask outer shell. The fire shield is welded to the cask body at the two ends. Cut-outs are provided in the fire shield in order to wrap around the tie down lugs and lifting ear pads.

The impact limiters are sheet metal enclosures filled with polyurethane foam which acts as insulation barrier to heat flow. The impact limiters are attached together with the help of turnbuckles on the ends of the cask as shown in Figure 3-1. The impact limiters remain attached to the cask body during the HAC drop tests (See Section 2.7). Therefore they provide thermal insulation to the cask during the NCT events and the fire test. The central portion of both, the top and the bottom, impact limiters contain a hollow region that is covered by sheet-metal (upper) or steel plate (lower). In the puncture drop test, which precedes the fire test, these covers may rupture and provide a direct path to the secondary lid and the baseplate. In order to protect the seals a thermal-shield is externally attached to the secondary lid.

##### **3.1.2 CONTENT'S DECAY HEAT**

The maximum decay heat of the waste component is 200 watt. The minimum decay heat of zero Watt is used in the evaluation of other limiting case.

##### **3.1.3 SUMMARY TABLES OF TEMPERATURES**

The maximum temperatures in various important components of the cask during the NCT events are summarized in Table 3-1. Table 3-2 summarizes the maximum temperature in these components during the HAC fire test. The time at which these components achieve the maximum temperature is also identified in Table 3-2. The results summarized in Table 3-1 and 3-2 are discussed in detail in Sections 3.3 and 3.4.

### 3.1.4 SUMMARY TABLE OF MAXIMUM PRESSURES

The summary of maximum pressures during the NCT and HAC fire test are provided in Table 3-3. The details of these pressure calculations are provided in Sections 3.3.2 and 3.4.3 for NCT and HAC fire test, respectively.

## 3.2 MATERIAL PROPERTIES AND COMPONENT SPECIFICATIONS

### 3.2.1 MATERIAL PROPERTIES

The material properties of the cask components used in the analysis of the 8-120B package are provided in Tables 3-4 through 3-6. Table 3-4 provides the temperature independent properties of the steel and lead components. Table 3-5 provides the temperature dependent specific heat and thermal conductivity of stainless steel, carbon steel and lead. Table 3-6 provides the temperature dependent density, specific heat and conductivity of air. Material properties have been obtained from standard references (References 3-2 through 3-6) and are identified in Tables 3-4 through 3-6.

### 3.2.2 COMPONENT SPECIFICATIONS

The metallic components that are important for the thermal performance of the package are made of steel. The non-metallic components are specified as follows:

- Elastomeric seals are used in the primary lid, secondary lid, and in the cask vent port for containment. The allowable elastomer type(s) and temperature resistances are specified in the drawings in Appendix 1.3, and in Section 8.2.5. Qualified compounds for the primary lid and secondary lid containment seals shall be suitable for low-temperature service down to -40 °F, continuous service up to the maximum allowable NCT seal temperature of 180 °F (which bounds the maximum calculated temperature for NCT, Table 3-1), and short-term service to the maximum allowable HAC seal temperature of 340 °F (which bounds the maximum calculated temperature for HAC, Table 3-2). The vent port seal shall likewise be suitable for low-temperature service down to -40 °F, continuous service up to the maximum allowable NCT seal temperature of 180 °F, and short-term service to the maximum allowable HAC seal temperature of 235 °F.
- Lead is specified to be ASTM B-29 commercial grade. The melting temperature is 622°F.
- Polyurethane foam used in the impact limiters shall meet the requirements in the drawings in Appendix 1.3, and in Section 8.2.5.

## 3.3 THERMAL EVALUATION FOR NORMAL CONDITIONS OF TRANSPORT

The thermal analyses of the 8-120B package under various loading conditions have been performed using finite element modeling techniques. ANSYS finite element analysis code (Reference 3-7) has been employed to perform the analyses. Two finite element models have been employed in performing the NCT thermal analyses. A three-dimensional solid model and a 2-dimensional axisymmetric model were used in the analyses. For the load cases in which the mechanical loading on the cask are non-uniform, a three dimensional finite element model was

used. To obtain the temperature distribution in the cask where the bolt loadings have no effect on the results, a two-dimensional axisymmetric finite element model has been used.

The cask geometry is symmetrical about a vertical plane, so a one-half model of the cask is represented in the 3-dimensional model. The impact limiters are not explicitly included in the finite element model. For NCT the impact limiters are conservatively represented by fully-isolated boundary conditions, and only the exposed portions of the fire shield and cask body are used for the heat rejection to the ambient.

Figure 3-2 shows the three-dimensional finite element model used in various thermal load analyses. Figure 3-3 shows the material property modeling of various components of the cask.

The internal heat load has been modeled in the FEM in two different ways - implicitly (in 3-d model) and explicitly (in 2-d model). In the implicit model the heat load is applied as a uniform flux over the cavity of the cask. This results in a conservative cask body temperature. However, the cavity temperature predicted is not conservative. To get a conservative prediction of the cask cavity temperature, the internal contents of the cask is explicitly represented in the 2-d model. The cask body structural evaluation has been performed with the implicit model results and the cask cavity temperature needed for the calculation of internal pressure has been obtained from the explicit model.

The cask body structural evaluation has been performed in Section 2 with the temperature results obtained in this section.

The details of the analyses, including the assumptions, modeling details, boundary conditions, and input and output data are included in *EnergySolutions* document TH-027 (Reference 3-8).

### 3.3.1 HEAT AND COLD

The finite element model described in Section 3.3 is analyzed for the following loading conditions:

- Hot Environment – This load case is based on the requirements of 10 CFR 71.71 (c) (1). The loading includes a 100° F ambient temperature, solar insolation, and maximum internal heat load. This loading is used as one of the extreme initial conditions for the normal conditions of transport (NCT) and hypothetical accident condition (HAC) test evaluation. The temperature distribution in the cask body under this loading condition is shown in Figure 3-4.
- Cold Environment – This load case is based on the requirements of 10 CFR 71.71 (c) (2). The loading includes a -40° F ambient temperature, no solar insolation, and maximum internal heat load. This loading is used as one of the extreme initial conditions for the normal conditions of transport (NCT) and hypothetical accident condition (HAC) test evaluation. The temperature distribution in the cask body under this loading condition is shown in Figure 3-5.
- Normal Hot - This load case is based on the requirements of 10 CFR 71.71 (b). The loading includes a 100° F ambient temperature, no solar insolation, and maximum

internal heat load. The temperature distribution in the cask body under this loading condition is shown in Figure 3-6.

- Normal Cold - This load case is based on the requirements of 10 CFR 71.71 (b). The loading includes a -20° F ambient temperature, no solar insolation, and maximum internal heat load. The temperature distribution in the cask body under this loading condition is shown in Figure 3-7.

The 2-d axisymmetric model, with the explicit heat loading, has been analyzed for the hot environment conditions. The temperatures results from this model have been used to report the waste and cavity temperatures. Figure 3-8 shows the temperature distribution in the cask and its internal contents.

The temperature distributions in the 8-120B cask under various conditions analyzed in this section are used in the structural analyses presented in Section 2. Under the cold conditions with minimum (zero) heat loading the body temperature of the cask reaches the ambient temperature in steady state. Therefore, no thermal analyses for this case are needed. On the other hand, with any amount of heat load, there exist temperature gradients in various parts of the cask. To capture these two effects, the evaluation of the cask in Section 2 has been performed for the two cold conditions one with the maximum internal heat load and another with minimum (zero) heat load. These two load cases envelope the conditions of maximum and minimum temperature gradient through the cask body.

The thermal analysis shows that under the normal conditions of transport there is no reduction in packaging effectiveness. The heat transfer capability of the components is not reduced under NCT, nor are there changes in material properties that affect structural performance, containment, or shielding. It has also been demonstrated that the maximum temperature of the accessible portion of the package is 160.6°F which is less than 185°F, required by 10 CFR 71.43(g), for an exclusive use shipment.

### 3.3.2 MAXIMUM NORMAL OPERATING PRESSURE

The maximum internal pressure of the cask is calculated assuming that the gas within the cask, a mixture of air, water vapor, oxygen, and hydrogen, behaves as an ideal gas. To determine the maximum internal pressure under normal conditions in the cask (MNOP) the temperature of the gas mixture within the cask was evaluated. The maximum temperature of the cask cavity under normal conditions is 197.87°F, (see Table 3-1). The gas mixture in the cavity is conservatively assumed to be 200°F.

The maximum pressure is the sum of three components:

1. The pressure due to the increased temperature of the gas in the cavity;
2. The pressure due to water in the cask (vapor pressure of water); and
3. The pressure due to generation of gas (hydrogen and oxygen) by radiolysis.

1. The cask on loading has an internal pressure equal to ambient, assumed to be 1 atm absolute (14.7 psia) at 70 °F (21.1 °C, 294.3 K) and defined as  $P_1$  in the equation below. Per the ideal gas

law, the increased partial pressure of the air initially sealed in the fixed volume of the cask at the ambient temperature as it is heated to 200 °F (93.3 °C, 366.5°K) is:

$$P_2 = P_1 \times \frac{T_2}{T_1} = (14.7 \text{ psia}) \times \frac{366.5 \text{ K}}{294.3 \text{ K}} = 18.31 \text{ psia}$$

2. Since the cask cavity is assumed to also contain water, the vapor pressure of water must be added to the pressure in the cavity. The vapor pressure contributed by water ( $P_{H_2O}$ ) in the cavity at 200°F (93.3 °C) is 11.52 psia (interpolated from the table Vapor Pressure of Water from 0 °C to 370 °C, page 6-15, from Reference 3-4, a copy of the table is attached as Attachment 3A). Adding the water vapor pressure at 200 °F to the partial pressure of the initially-sealed air at this temperature gives:

$$P_3 = P_2 + P_{H_2O} = 18.31 \text{ psia} + 11.52 \text{ psia} = 29.83 \text{ psia}$$

3. Further, the cask atmosphere is assumed to contain five volume percent (5 vol%) hydrogen ( $H_2$ ) gas due to radiolysis of the water. By stoichiometry of the water molecule ( $H_2O$ ), the cask atmosphere will also contain 2.5 vol% oxygen ( $O_2$ ) gas generated by radiolysis. Noting that partial pressures in an ideal gas mixture are additive and behave the same as ideal gas volume fractions or mole fractions, the partial pressure of hydrogen is described by the following equation:

$$P_{H_2} = 0.05 \times (P_{air} + P_{H_2O} + P_{H_2} + P_{O_2})$$

Combining  $P_{air}$  and  $P_{H_2O}$  into  $P_3$  per item 2 above, and noting that  $P_{O_2} = 0.5 \times P_{H_2}$ , gives:

$$P_{H_2} = 0.05 \times (P_3 + 1.5P_{H_2})$$

Solving this equation explicitly for  $P_{H_2}$  gives:

$$P_{H_2} = \frac{(0.05)P_3}{1 - (0.05)(1.5)} = \frac{(0.05)(29.83 \text{ psia})}{1 - (0.05)(1.5)} = 1.61 \text{ psia}$$

Recalling the stoichiometric relationship between hydrogen and oxygen liberated by radiolysis of water, and again combining the pressures of the initially sealed air and water vapor as  $P_3$ , the total pressure in the cask at 200 °F is:

$$P_{Total} = P_3 + 1.5P_{H_2} = 32.25 \text{ psia}$$

Therefore, the MNOP in gage pressure is calculated as:

$$MNOP = P_{Total} - P_1 = 32.25 \text{ psia} - 14.7 \text{ psia} = 17.6 \text{ psig}$$

The MNOP value is conservatively set at 35.0 psig for use in the cask structural analysis under normal conditions of transport (NCT).

### 3.3.3 THERMAL STRESSES

The structural evaluation of the package under the normal conditions of transport loading is performed in Reference (2-13). All the stresses are within the design allowable values established for 8-120B package.

### 3.4 HYPOTHETICAL ACCIDENT THERMAL EVALUATION

The thermal analyses of the 8-120B package under HAC fire conditions have been performed using finite element model, described in Section 3.3. A nonlinear thermal transient analysis is performed to obtain the time-history of the temperature in package.

The temperature results from the thermal analyses have been used for performing the structural evaluation of the 8-120B Cask under HAC fire. The maximum temperature of the cavity during the entire transient has been used for calculating the cask pressure during the HAC fire.

The impact limiters of the 8-120B package have been shown to remain attached to the cask body during the free drop tests. The effect of these drop tests is a local crushing of the foam, and possible rupture of the impact limiter skin. The puncture drop on the impact limiters will crush the foam and may also rupture the skin in the vicinity of the impact location. The rupture of the impact limiter skin after the drop and puncture tests may expose the polyurethane foam material to the fire. However, the polyurethane fire retardant characteristics will mitigate the effect of the direct exposure to fire due to formation of intumescent char. The intumescent char has the ability to seal large voids which could be caused by the impact damage. The char also provides a secondary thermal barrier which breaks down very slowly at 2000 to 2200°F.

The 5-gallon bucket tests performed by General Plastics where the open face of the bucket is exposed to direct fire show the formation of the char that prevents the fire from extending into the underlying foam. These tests also indicate that for the 1 3/4" foam thickness in the test, the effect of 30-minute fire has a minimal effect on the end opposite the exposed end. These tests were performed for various density foams and it was shown that the effectiveness of the foam is enhanced with the increasing foam density. With 25 lb/ft<sup>3</sup> foam density and a minimum foam thickness of 11" in the 8-120B cask package, the effect of exposure of a small portion of foam due to rupture during the drop and puncture test will not have a significant effect on the impact limiter performance during the fire. Therefore, the same boundary conditions at the interface between the cask and the impact limiter as those under the NCT (total thermal insulation) have been used for the HAC fire test analyses. However, the puncture drop test may result in failure of the steel covers on the central hollow region of the upper and lower impact limiters, which could result in the regions of the cask located underneath these covers being exposed directly to the fire. Therefore, the central hollow regions of the upper and lower impact limiters are conservatively modeled fully exposed for the HAC fire test.

The direct impact of the puncture bar on the sidewall of the cask will remove the air gap provided between the fire-shield and the cask body. The fire shield may come in contact with the cask body near the impact location. During the HAC fire test extra amount of heat will be input to the cask body locally near the impact point. Analyses have also been performed to evaluate the conditions in which the fire-shield is damaged during the puncture drop test. The fire is

assumed to hit the area directly where the puncture bar damages the fire shield. It has been shown that under these conditions the cask experiences locally high temperatures but they are within the acceptable limit for the materials. See Reference 3-10 for the details of this analysis.

The details of the analyses, including the assumptions, modeling details, boundary conditions, and input and output data are included in EnergySolutions document TH-028 (Reference 3-10).

### 3.4.1 INITIAL CONDITIONS

The initial temperature condition, used for the HAC fire test analysis is obtained by running the finite element model with the following boundary conditions:

- Internal heat load – 200 W
- Solar insolation - yes
- Heat Transfer to the ambient by radiation – yes
- Heat transfer to the ambient by natural convection – yes
- Ambient air temperature - 100°F

### 3.4.2 FIRE TEST CONDITIONS

The fire transient is run with the body temperature resulting from the above initial conditions. The fire transient is run for 30 minutes (1,800 sec) with the following boundary conditions:

- Internal heat load – 200 W
- Solar insolation - no
- Heat Transfer to the ambient by radiation – yes
- Heat transfer to the ambient by forced convection – yes
- Ambient air temperature - 1475°F

The end of fire analysis of the model is performed with the body temperature resulting from the above fire transient to 1801 sec with the following boundary conditions:

- Internal heat load – 200 W
- Solar insolation - no
- Heat Transfer to the ambient by radiation – yes
- Heat transfer to the ambient by natural convection – yes
- Ambient air temperature - 100°F

The cool-down analysis of the model is performed with the body temperature resulting from the above fire transient to 22,500 sec with the following boundary conditions:

- Internal heat load – 200 W
- Solar insolation - yes

- Heat Transfer to the ambient by radiation – yes
- Heat transfer to the ambient by natural convection – yes
- Ambient air temperature - 100°F

Figure 3-9 shows the boundary conditions used during the fire transient analysis.

### 3.4.3 MAXIMUM TEMPERATURES AND PRESSURE

From the analyses of the finite element model, a time-history data of the temperature in various components of the cask is obtained. The fire shield, outer shell, inner shell, lead, and seal were considered as the critical components of the cask. The temperatures at representative locations in these components are monitored during the entire fire and cool down transient analysis. The nodes that are monitored at these critical components are shown in Figure 3-10.

Figure 3-11 gives the plot of the time-history data at the representative nodes of the cask components. Figure 3-12 gives the same data in cask components that are not directly exposed to the fire. The maximum temperature of various components of the cask during the entire transient analysis is presented in Table 3-2. The temperature profile in the cask during the cool-down period is shown in Figure 3-13. The temperature profile of the cask cavity at the time when its internal contents attain the maximum temperature is shown in Figure 3-14. Figure 3-15 shows the temperature profile in the cask body with the damage to the fire shield caused during the puncture drop.

The scenario in which the hollow central portion of the impact limiters is breached during the puncture drop test that precedes the fire test has been analyzed in *EnergySolutions* document TH-0002 (Reference 3-11). In Reference 3-11 a finite element model of the secondary lid with the thermal shield is analyzed for the HAC fire test. The finite element model is reproduced in Figure 3-13. The temperature time-history plot of the representative seal locations is shown in Figure 3-14. Figure 3-15 shows the temperature contour plot of the secondary lid with the thermal-shield at the time when the seal temperature attains the maximum value.

The scenario in which the thermal-shield is also damaged during the puncture drop test is also addressed in Reference 3-11. An axisymmetric finite element model has been used to evaluate the maximum seal temperatures in the damaged condition. The finite element model is reproduced in Figure 3-16. The temperature time-history plot of the representative seal locations is shown in Figure 3-17. Figure 3-18 shows the temperature contour plot of the secondary lid with the damaged thermal-shield at 5,400 seconds after the fire initiation of the fire.

The maximum internal pressure of the cask is calculated assuming that the gas within the cask, a mixture of air, water vapor, oxygen, and hydrogen, behaves as an ideal gas. The average temperature of the air inside the cask is obtained from *EnergySolutions* document TH-0001 (Reference 3-12). In this document the HAC fire analysis of the 8-120B Cask is performed with the assumption that the lower hollow portion of the impact limiter has been breached during the puncture drop test that precedes the HAC fire test. Consequently, a portion of the baseplate is directly exposed to the fire, which results in the highest temperature of the cask cavity. The average cask air temperature calculated in Reference 3-11 is 266°F.

The gas mixture temperature in the cavity is conservatively assumed to be 275°F. Assuming 32.3 psia (see Section 3.3.2) exists inside the cask at 200°F, the pressure in the cask at 275°F,  $P_2$ , may be calculated by the ideal gas relationship:

$$P_2 = \frac{T_2}{T_1} \cdot P_1, \text{ where T is in degrees absolute}$$

$$P_2 = 35.9 \text{ psia}$$

The vapor pressure contributed by water in the cavity at 275°F is 45.4 psia (interpolated from the table Vapor Pressure of Water from 0 to 370 °C, page 6-15, from Reference 3-4, a copy of the table is attached as Attachment 3A).

Therefore, the maximum pressure during the HAC fire,

$$P_{\max} = 35.9 + 45.4 - 14.7 = 66.62 \text{ psig}$$

The value used for  $P_{\max}$  is conservatively set at 155 psig.

#### 3.4.4 MAXIMUM THERMAL STRESSES

The structural evaluation of the package under the HAC fire test conditions is performed in Section 2.7.4 of this SAR. The maximum thermal stresses in the package with the corresponding allowable stresses are compared in Table 2-23. All the stresses are within the design limits established for the 8-120B package.

#### 3.4.5 ACCIDENT CONDITIONS FOR FISSILE PACKAGES FOR AIR TRANSPORT

Not applicable.

### 3.5 APPENDIX

#### 3.5.1 LIST OF REFERENCES

- (3-1) Code of Federal Regulations, Title 10, Part 71, Packaging and Transportation of Radioactive Material.
- (3-2) Heat Transfer, J.P. Holman, McGraw Hill Book Company, New York, Fifth Edition, 1981.
- (3-3) Cask Designers Guide, L.B. Shappert, et. al, Oak Ridge National Laboratory, February 1970, ORNL-NSIC-68.
- (3-4) CRC Handbook of Chemistry and Physics, Robert C. Weast and Melvin J. Astel, eds., CRC Press, Inc., Boca Raton, Florida, 62nd ed., 1981.
- (3-5) ASME Boiler & Pressure Vessel Code, 2001, Section II, Part D, Materials, The American Society of Mechanical Engineers, New York, NY, 2001.
- (3-6) Rohsenow and Hartnett, Handbook of Heat Transfer, McGraw Hill Publication, 1973.

- (3-7) ANSYS, Release 12.1, ANSYS Inc., Canonsburg, PA, 2009
- (3-8) EnergySolutions Document No. TH-027, Rev.0, Steady State Thermal Analyses of the 8-120B Cask Using a 3-D Finite Element Model.
- (3-9) RH TRU Payload Appendices Rev. 0, June 2006 U.S. Department of Energy.
- (3-10) EnergySolutions Document No. TH-028, Rev.0, Hypothetical Fire Accident Thermal Analyses of the 8-120B Cask.
- (3-11) EnergySolutions Document No. TH-0002, Rev.2, Evaluation of Effectiveness of the Secondary Lid Thermal-Shields for the 8-120B and 10-160B Casks.
- (3-12) EnergySolutions Document No. TH-0001, Rev.1, HAC Fire Analyses of the 8-120B and 10-160B casks with Ruptured Impact Limiter Ends.

3.5.2 ATTACHMENT

This table gives the vapor pressure of water at intervals of 1° C from the melting point to the critical point.

T/°C	P/kPa	T/°C	P/kPa	T/°C	P/kPa	T/°C	P/kPa
0	0.61129	55	15.752	110	143.24	165	700.29
1	0.65716	56	16.522	111	148.12	166	717.83
2	0.70605	57	17.324	112	153.13	167	735.70
3	0.75813	58	18.159	113	158.29	168	753.94
4	0.81359	59	19.028	114	163.58	169	772.52
5	0.87260	60	19.932	115	169.02	170	791.47
6	0.93537	61	20.873	116	174.61	171	810.78
7	1.0021	62	21.851	117	180.34	172	830.47
8	1.0730	63	22.868	118	186.23	173	850.53
9	1.1482	64	23.925	119	192.28	174	870.98
10	1.2281	65	25.022	120	198.48	175	891.80
11	1.3129	66	26.163	121	204.85	176	913.03
12	1.4027	67	27.347	122	211.38	177	934.64
13	1.4979	68	28.576	123	218.09	178	956.66
14	1.5988	69	29.852	124	224.96	179	979.09
15	1.7056	70	31.176	125	232.01	180	1001.9
16	1.8185	71	32.549	126	239.24	181	1025.2
17	1.9380	72	33.972	127	246.66	182	1048.9
18	2.0644	73	35.448	128	254.25	183	1073.0
19	2.1978	74	36.978	129	262.04	184	1097.5
20	2.3388	75	38.563	130	270.02	185	1122.5
21	2.4877	76	40.205	131	278.20	186	1147.9
22	2.6447	77	41.905	132	286.57	187	1173.8
23	2.8104	78	43.665	133	295.15	188	1200.1
24	2.9850	79	45.487	134	303.93	189	1226.9
25	3.1690	80	47.373	135	312.93	190	1254.2
26	3.3629	81	49.324	136	322.14	191	1281.9
27	3.5670	82	51.342	137	331.57	192	1310.1
28	3.7818	83	53.428	138	341.22	193	1338.8
29	4.0078	84	55.585	139	351.09	194	1368.0
30	4.2455	85	57.815	140	361.19	195	1397.6
31	4.4953	86	60.119	141	371.53	196	1427.8
32	4.7578	87	62.499	142	382.11	197	1458.5
33	5.0335	88	64.958	143	392.92	198	1489.7
34	5.3229	89	67.496	144	403.98	199	1521.4
35	5.6267	90	70.117	145	415.29	200	1553.6
36	5.9453	91	72.823	146	426.85	201	1586.4
37	6.2795	92	75.614	147	438.67	202	1619.7
38	6.6298	93	78.494	148	450.75	203	1653.6
39	6.9969	94	81.465	149	463.10	204	1688.0
40	7.3814	95	84.529	150	475.72	205	1722.9
41	7.7840	96	87.688	151	488.61	206	1758.4
42	8.2054	97	90.945	152	501.78	207	1794.5
43	8.6463	98	94.301	153	515.23	208	1831.1
44	9.1075	99	97.759	154	528.96	209	1868.4
45	9.5898	100	101.32	155	542.99	210	1906.2
46	10.094	101	104.99	156	557.32	211	1944.6
47	10.620	102	108.77	157	571.94	212	1983.6
48	11.171	103	112.66	158	586.87	213	2023.2
49	11.745	104	116.67	159	602.11	214	2063.4
50	12.344	105	120.79	160	617.66	215	2104.2
51	12.970	106	125.03	161	633.53	216	
52	13.623	107	129.39	162	649.73	217	
53	14.303	108	133.88	163	666.25	218	
54	15.012	109	138.50	164	683.10	219	

Attachment 3A  
 Vapor Pressure of Water from 0° to 370° C

Table 3-1 - Summary of Maximum NCT Temperatures

Component	Maximum Calculated Temp.		Maximum Allowable Temperature (°F)
	Location (Node Nos.)	Value (°F)	
Fire Shield	40,028	160.6	185 <sup>(1)</sup>
Outer Shell	1,376	161.3	(2)
Inner Shell	10,521	161.5	(2)
Lead	14,411	161.4	622 <sup>(3)</sup>
Baseplate	2,430	162.3	(2)
Primary Lid	37,675	162.2	(2)
Secondary Lid	27,023	162.6	(2)
Primary Seal	25,430	161.6	180 <sup>(5)</sup>
Secondary Seal	37,678	162.2	180 <sup>(5)</sup>
Vent Seal	34,802	161.8	180 <sup>(5)</sup>
Impact Limiter	27,594	161.9	(2)
Cask Cavity	2,029	197.87	(4)
Waste Container	2,041	197.92	(2)

NOTES:

- (1) Based on the requirements of 10CFR71.43(g)
- (2) Set by stress conditions.
- (3) Melting point of lead.
- (4) Used for establishing the cask maximum normal operating pressure (MNOP).
- (5) Established based on the maximum calculated temperature.

Table 3-2 - Summary of Maximum Hypothetical Fire Temperatures

Component	Maximum Calculated Temp.			Maximum Allowable Temperature (°F)
	Location (Node Nos.)	Time (Sec.)	Value (°F)	
Fire Shield	42,910	1,800	1,392	N.A
Outer Shell	12,531	1,800.3	464.4	800
Inner Shell	8,015	4,461.7	295.5	800
Lead	14,338	4,461.7	295.8	622 <sup>(1)</sup>
Baseplate	2,430	936.48	206.3	800
Primary Lid	37,675	612.66	202.9	800
Secondary Lid	27,023	1,566.13	192.6	800
Primary Lid Seals	25,430	18,225	212.4	235 <sup>(2)</sup>
Secondary Lid Seals	-	-	338 <sup>(7)</sup>	340 <sup>(2)</sup>
Vent Seal	34,802	24,000	206.9	235 <sup>(2)</sup>
Impact Limiter	27,594	24,000	205.1	500 <sup>(4)</sup>
Cask Cavity	<sup>(3)</sup>	1,800	320.5	<sup>(5)</sup>
Waste Contents	2,013	40,289	239.7	<sup>(6)</sup>

NOTES:

- (1) Lead melting point temperature.
- (2) Established from the maximum calculated temperature.
- (3) Obtained from the temperature contour plot. See Figure 19.
- (4) Temperature at which the foam material shows 0% thermal decomposition. Obtained from the General Plastics' sales brochure.
- (5) Temperature used for calculating the cavity pressure.
- (6) Waste contents temperature is obtained for reference purpose.
- (7) Obtained from Reference 3-11.

Table 3-3 - Summary of Maximum Pressures during NCT and HAC Fire Test

Condition	Maximum Pressure (psig)	Reference
NCT	35.0	Section 3.3.2
HAC Fire Test	155	Section 3.4.3

Table 3-4 - Temperature-Independent Metal Thermal Properties

Material	Property	Reference: Page	Value
Steel	Density	4: 536	0.2824 lb/in <sup>3</sup>
	ε (Outside)	2: 648	0.8
	ε (Inside)	5:133	0.15
Lead	Density	4: 535	0.4109 lb/in <sup>3</sup>
	Spec. Heat	4: 535	0.0311 Btu/lb-°F
	Melting Point	6: B-29	621.5 °F

Table 3-5 - Temperature-Dependent Metal Thermal Properties

Temp. (°F)	Stainless Steel (Ref. 7)		Carbon Steel (Ref.7)		Lead (Ref.8)
	Sp. Heat Btu/lb-°F	Conductivity ×10 <sup>-3</sup> Btu/sec-in-°F	Sp. Heat Btu/lb-°F	Conductivity ×10 <sup>-3</sup> Btu/sec-in-°F	Conductivity ×10 <sup>-3</sup> Btu/sec-in-°F
70	0.117	0.199	0.104	0.813	0.465
100	0.117	0.201	0.106	0.803	0.461
150	0.120	0.208	0.109	0.789	0.455
200	0.122	0.215	0.113	0.778	0.448
250	0.125	0.222	0.115	0.762	0.441
300	0.126	0.227	0.118	0.748	0.435
350	0.128	0.234	0.122	0.731	0.428
400	0.129	0.241	0.124	0.715	0.422
450	0.130	0.245	0.126	0.701	0.415
500	0.131	0.252	0.128	0.683	0.409
550	0.132	0.257	0.131	0.667	0.402
600	0.133	0.262	0.133	0.648	0.395
650	0.134	0.269	0.135	0.632	0.389
700	0.135	0.273	0.139	0.616	0.389
750	0.136	0.278	0.142	0.600	0.389
800	0.136	0.282	0.146	0.583	0.389
900	0.138	0.294	0.154	0.551	0.389
1,000	0.139	0.306	0.163	0.519	0.389
1,100	0.141	0.315	0.172	0.484	0.389
1,200	0.141	0.324	0.184	0.451	0.389
1,300	0.143	0.336	0.205	0.417	0.389
1,400	0.144	0.345	0.411	0.380	0.389
1,500	0.145	0.354	0.199	0.363	0.389

Table 3-6 - Temperature-Dependent Air Thermal Properties

Temp. (°F)	Air (Ref.4)		
	Density $\times 10^{-5}$ lb/in <sup>3</sup>	Sp. Heat Btu/lb-°F	Conductivity $\times 10^{-7}$ Btu/sec-in-°F
70	4.3507	0.2402	3.4491
100	4.1117	0.2404	3.5787
150	3.7517	0.2408	3.9028
200	3.4676	0.2414	4.1759
250	3.2361	0.2421	4.4468
300	3.0307	0.2429	4.7037
350	2.8310	0.2438	4.9560
400	2.6730	0.2450	5.2037
450	2.5220	0.2461	5.4491
500	2.3964	0.2474	5.6875
550	2.2778	0.2490	5.9213
600	2.1684	0.2511	6.1435
650	2.0706	0.2527	6.3634
700	1.9803	0.2538	6.5810
750	1.8981	0.2552	6.7894
800	1.8177	0.2568	6.9954
900	1.6898	0.2596	7.4097
1,000	1.5712	0.2628	7.8032
1,100	1.4722	0.2659	8.1759
1,200	1.3848	0.2689	8.5440
1,300	1.3044	0.2717	8.8981
1,400	1.2350	0.2742	9.2847
1,500	1.1707	0.2766	9.7060

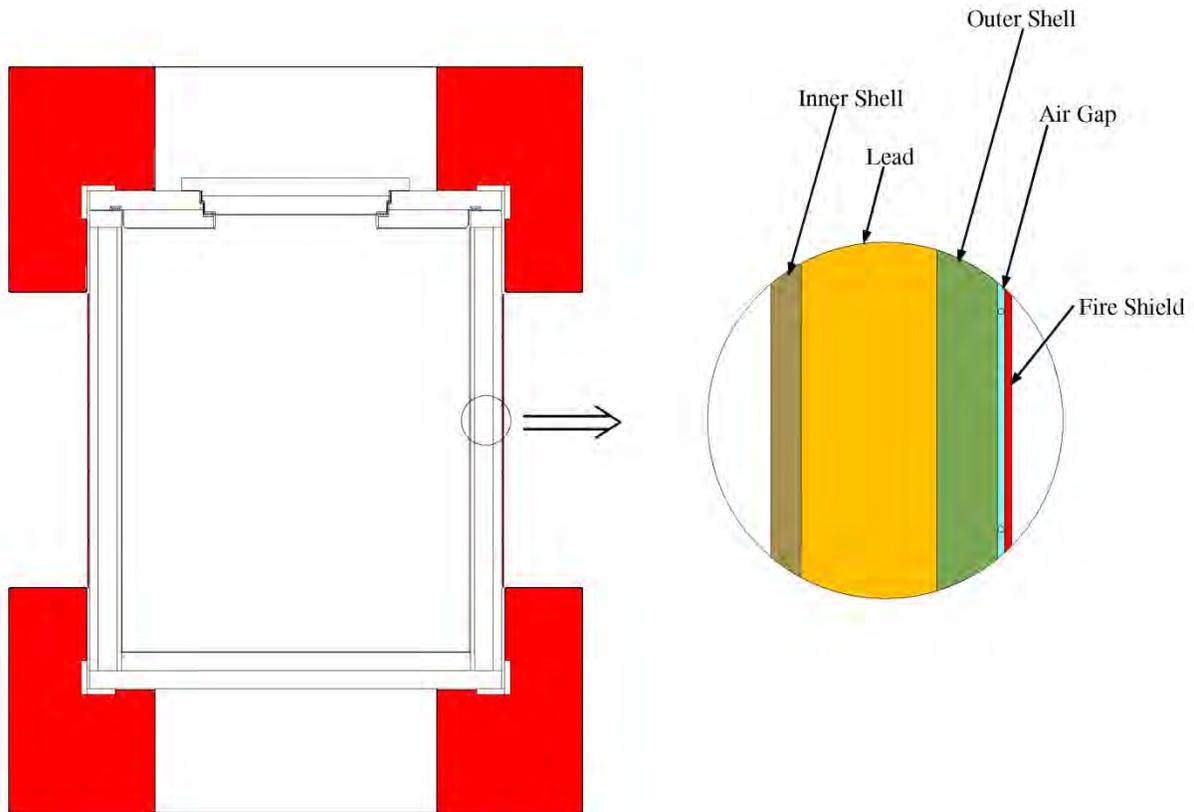


Figure 3-1 - 8-120B Cask Design Features Important to Thermal Performance

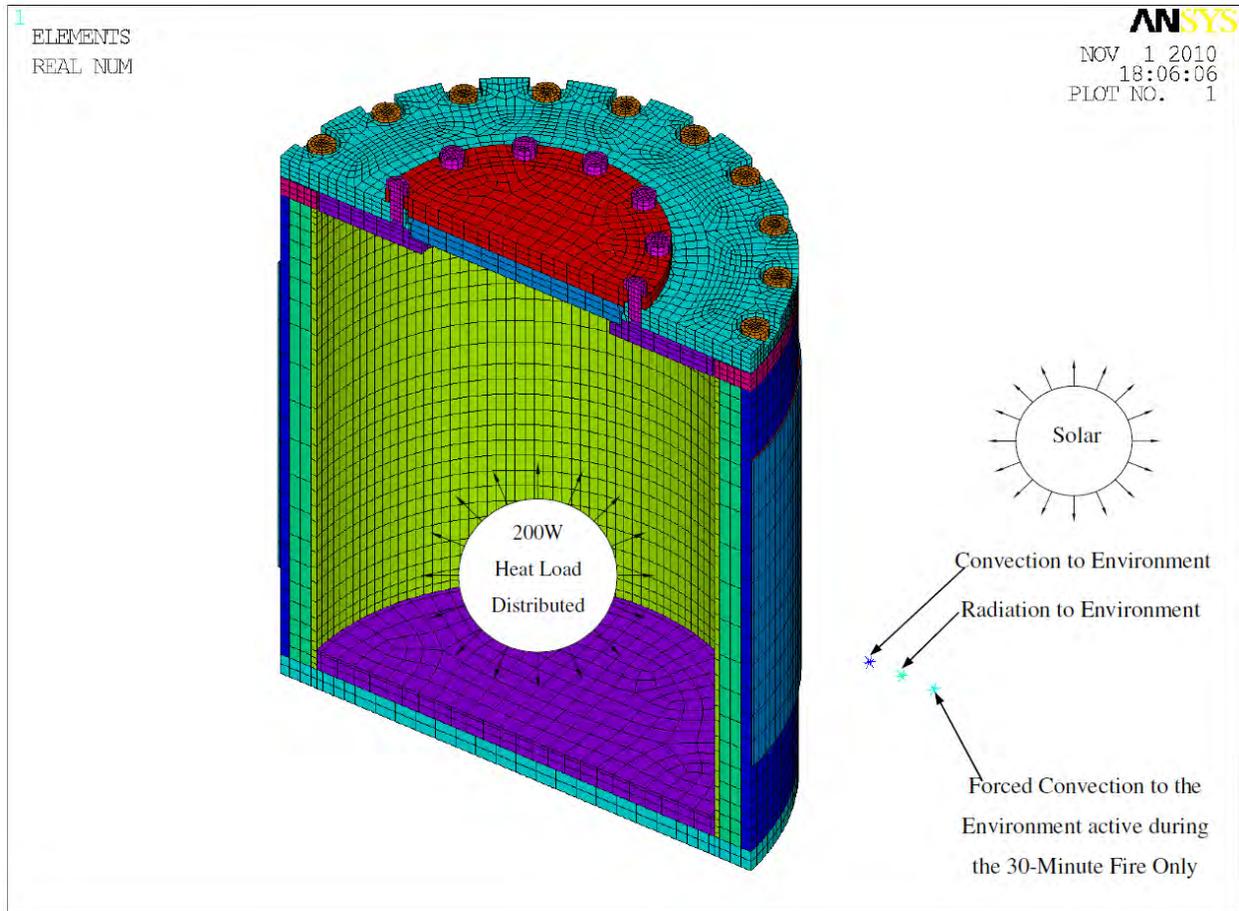


Figure 3-2 - Finite Element Model of the 8-120B Cask Used for the Thermal Analyses

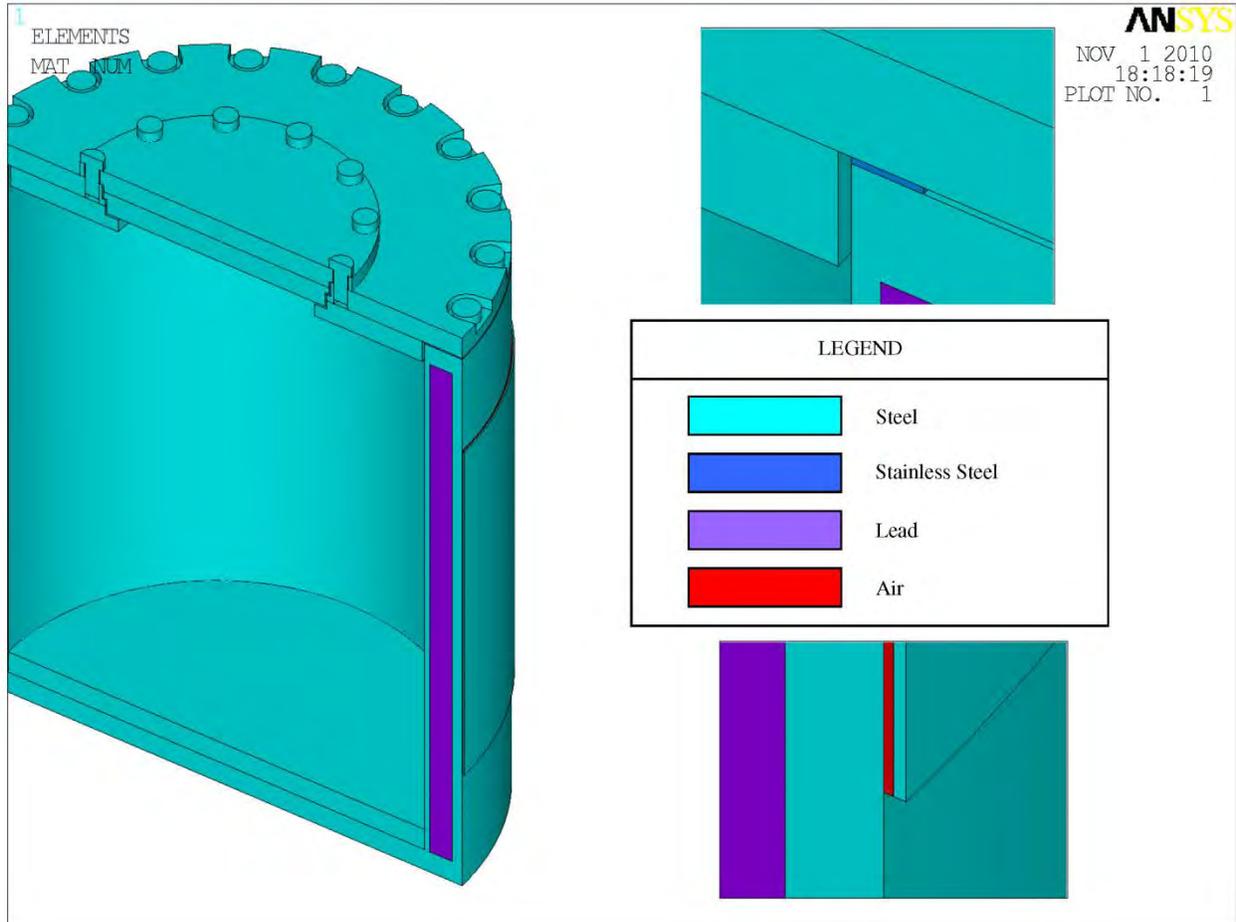


Figure 3-3 - Materials Used in the Finite Element Model

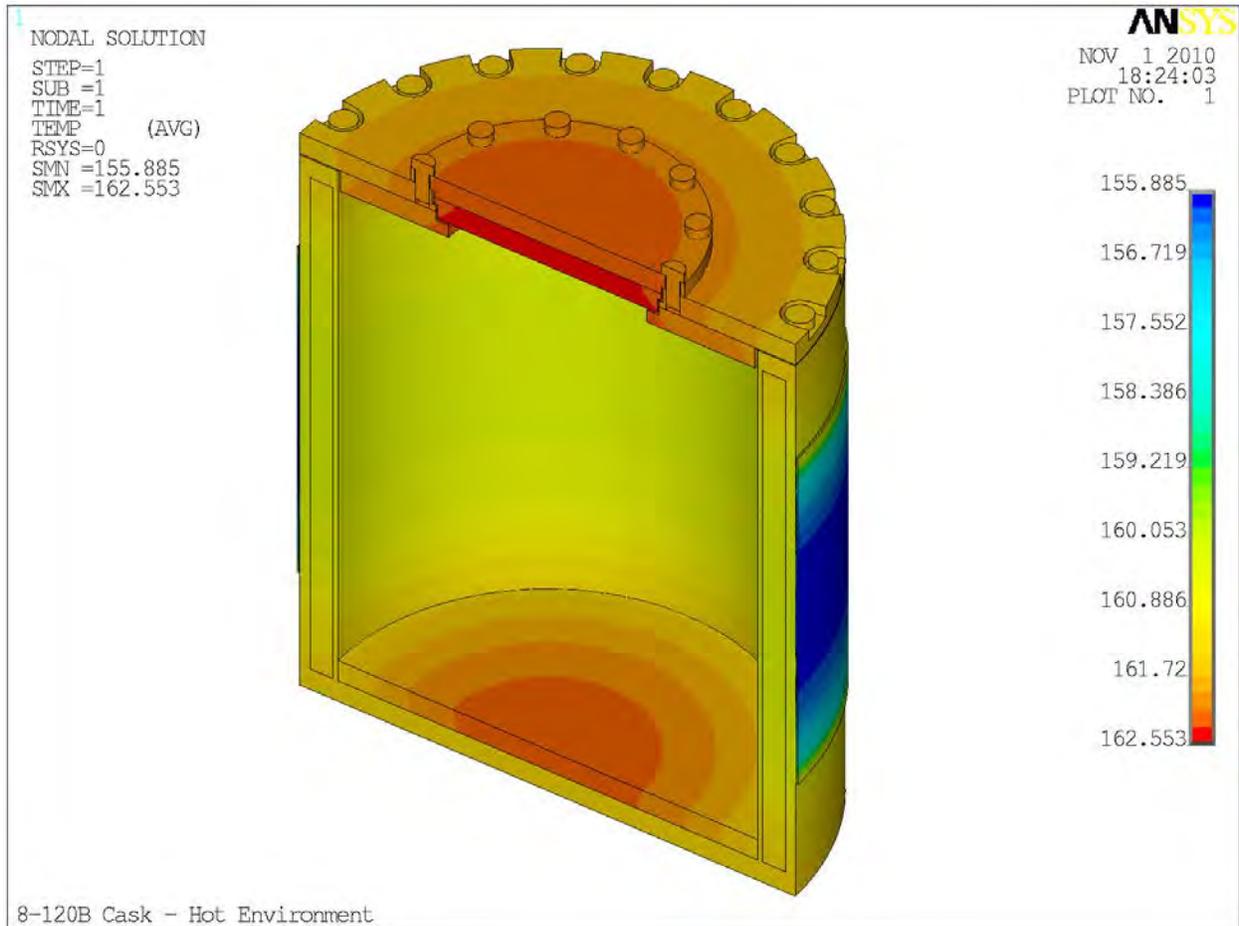


Figure 3-4 - Temperature Distribution – Hot Environment

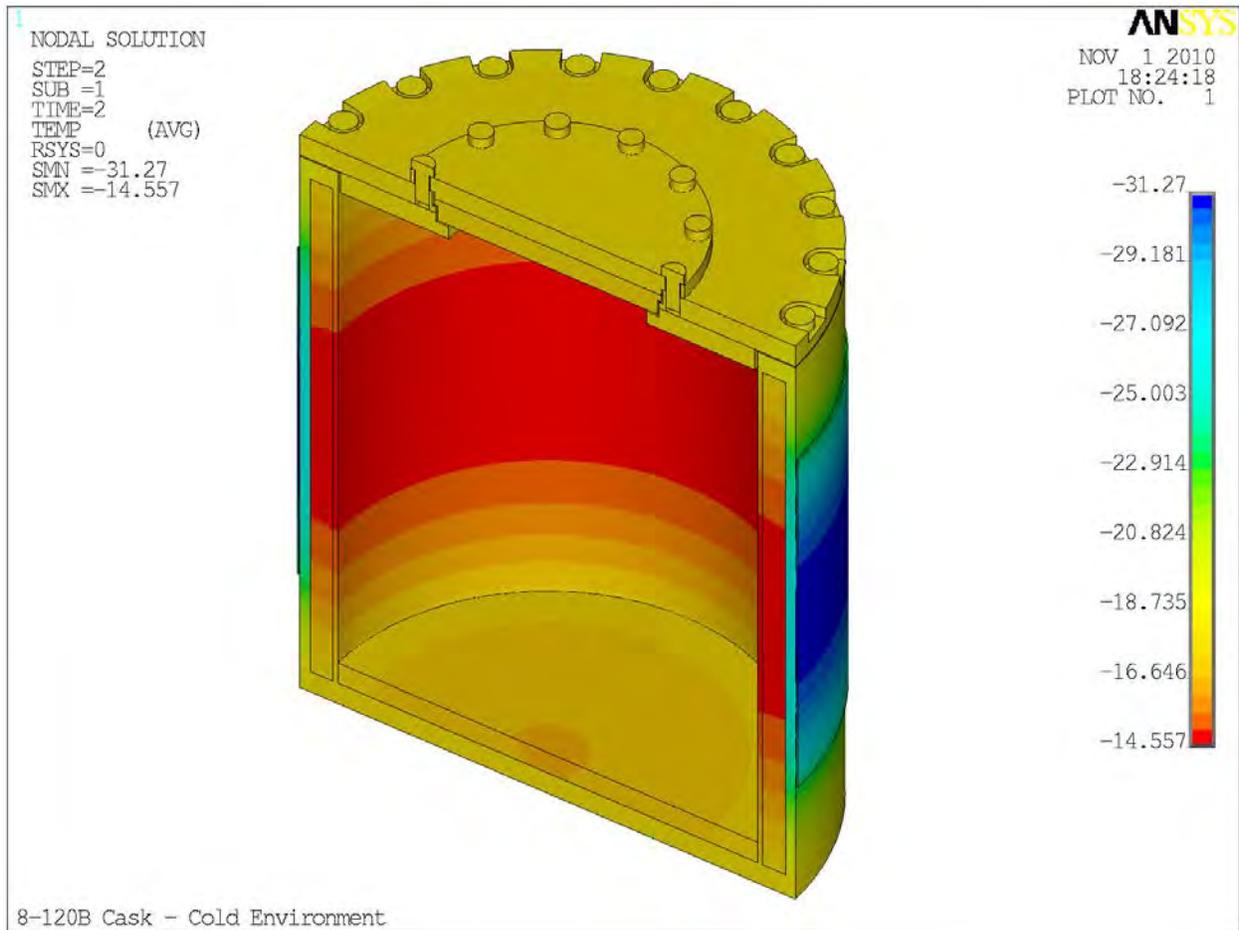


Figure 3-5 - Temperature Distribution – Cold Environment

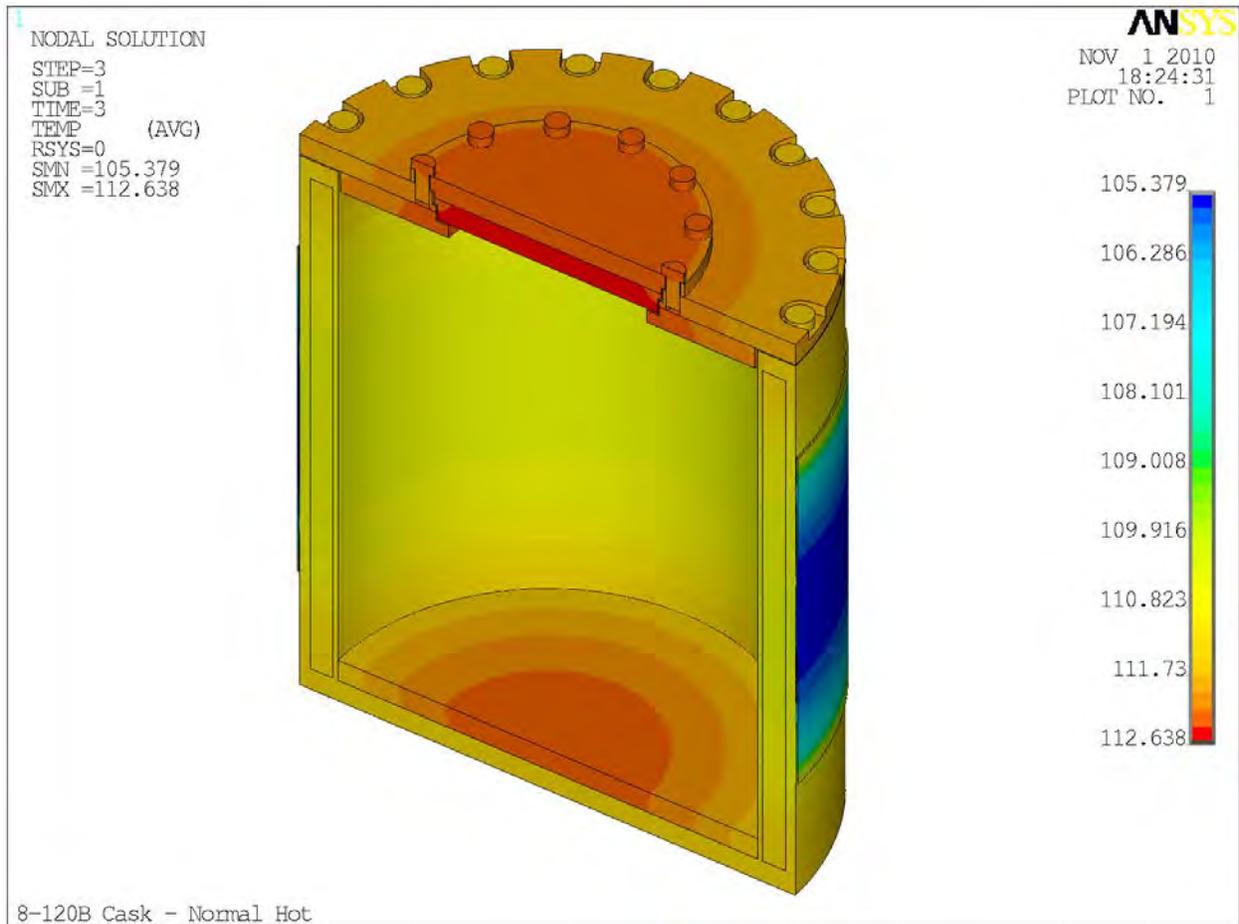


Figure 3-6 - Temperature Distribution – Normal Hot

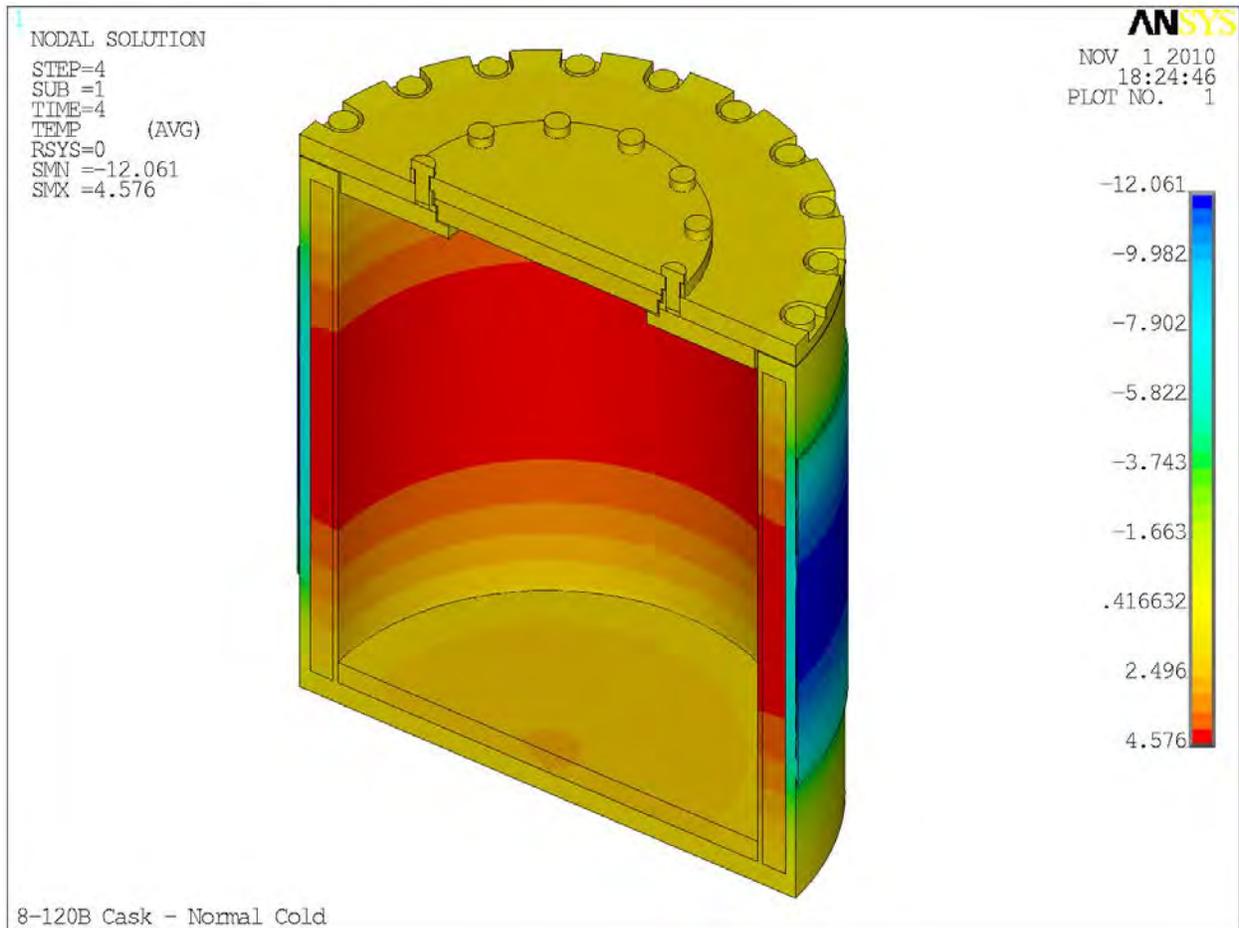


Figure 3-7 - Temperature Distribution – Normal Cold

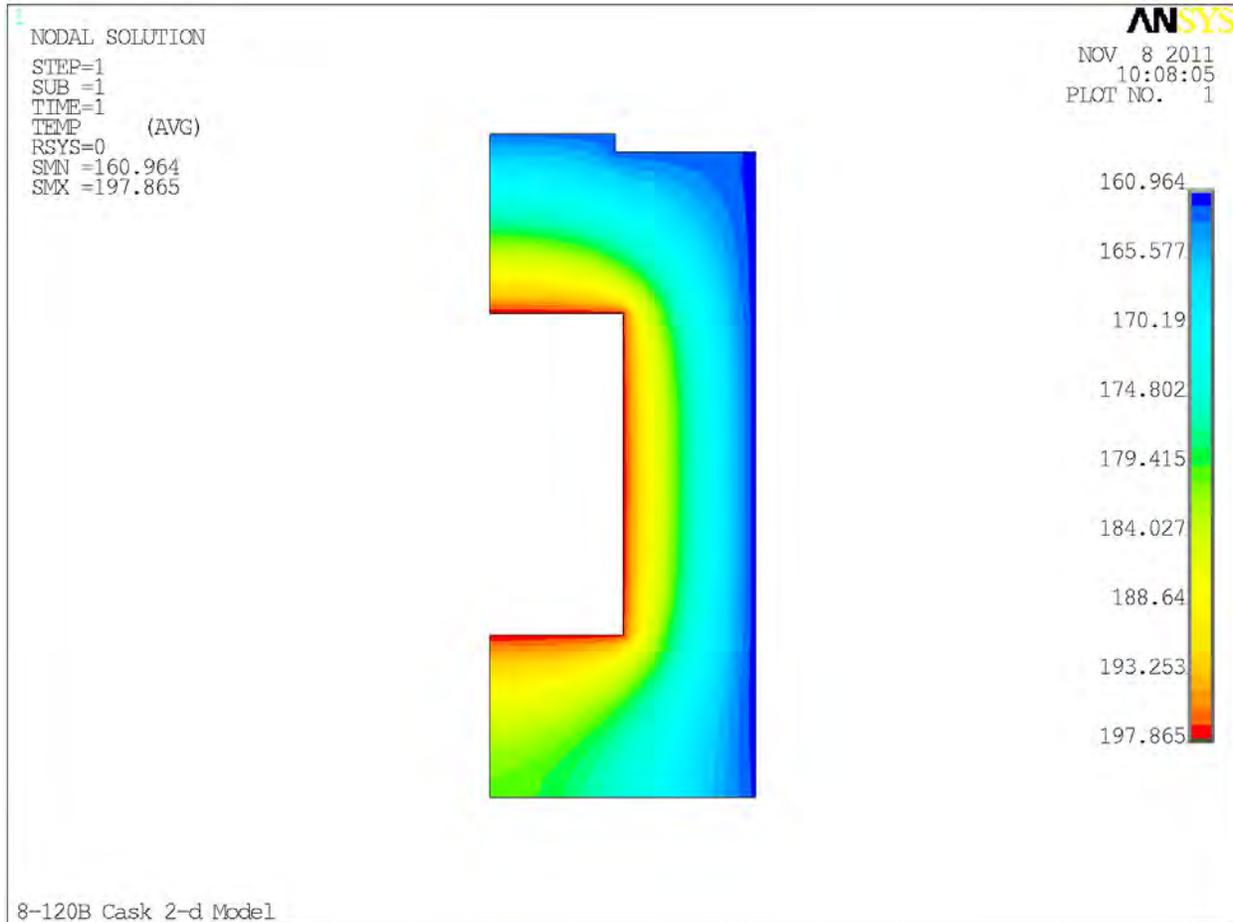


Figure 3-8 - Temperature Distribution in the Cask Cavity– Hot Environment

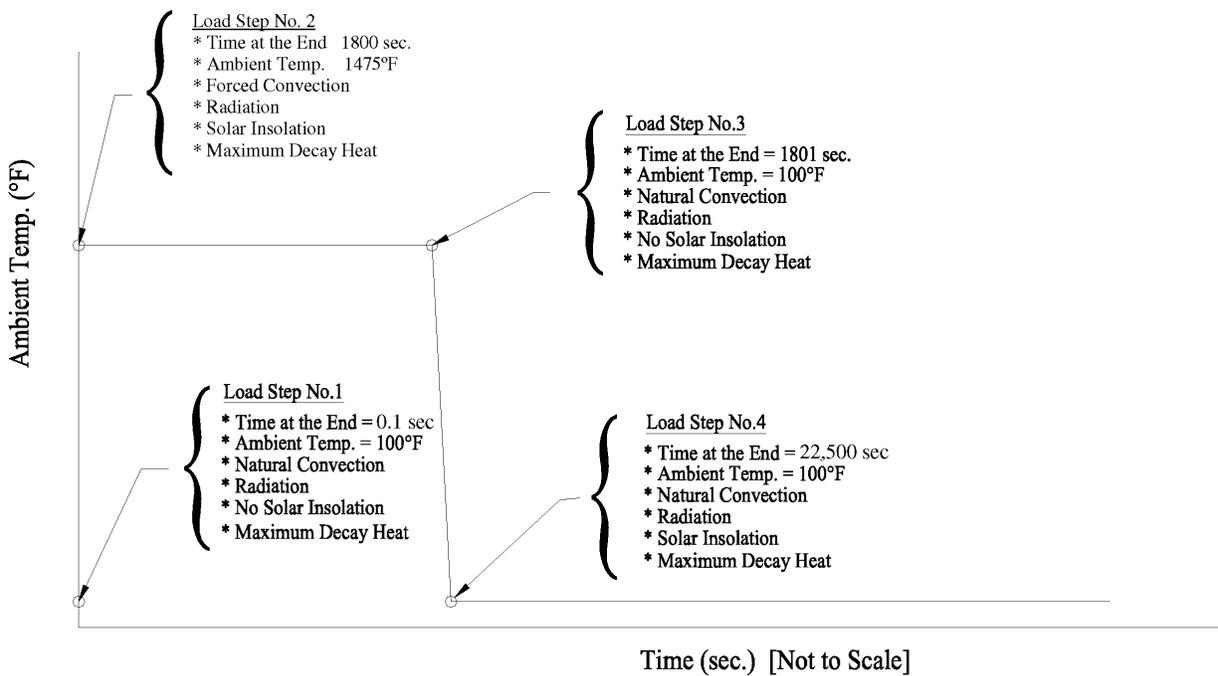


Figure 3-9 - HAC Fire Analysis Load Steps and Boundary Conditions

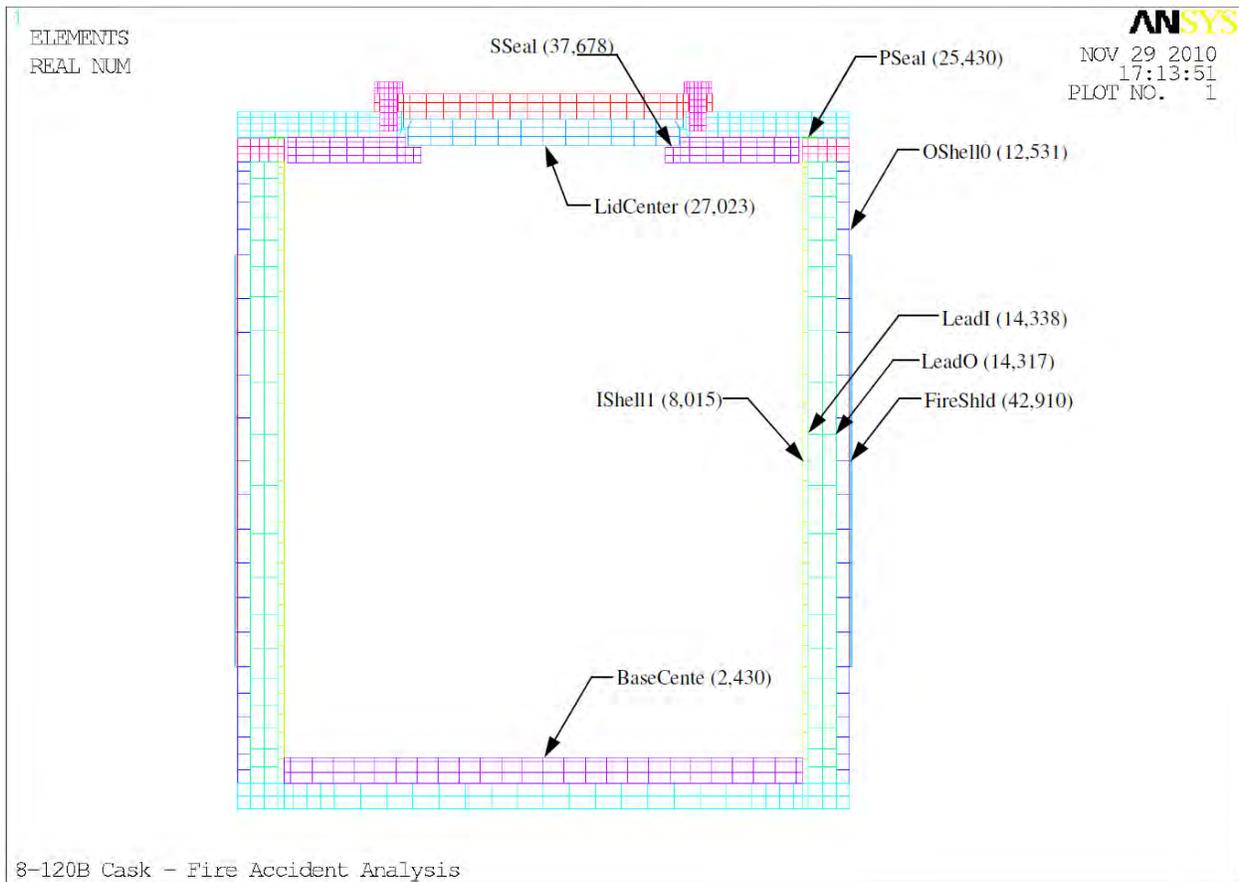


Figure 3-10 - Identification of the Nodes where Time-History is Monitored

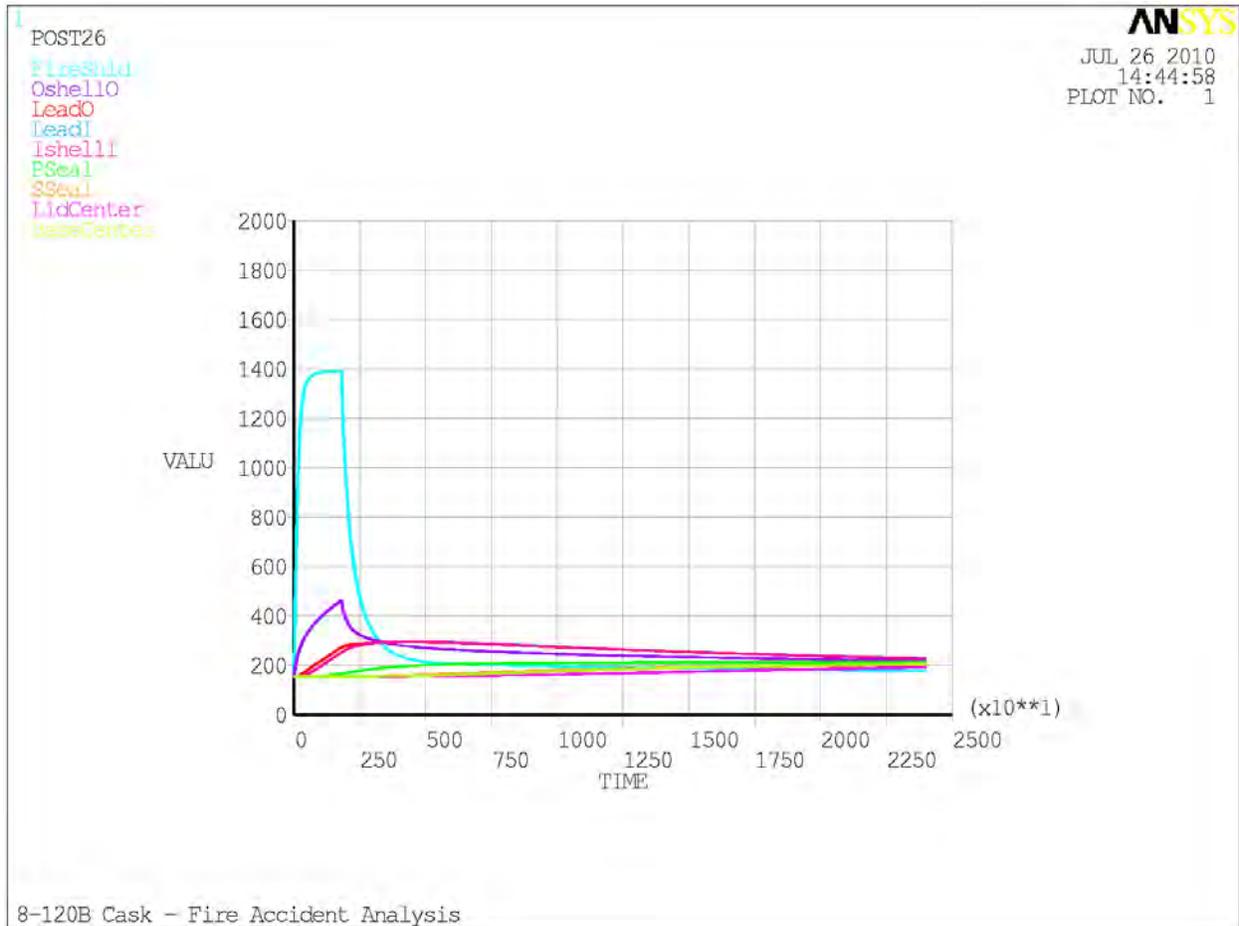
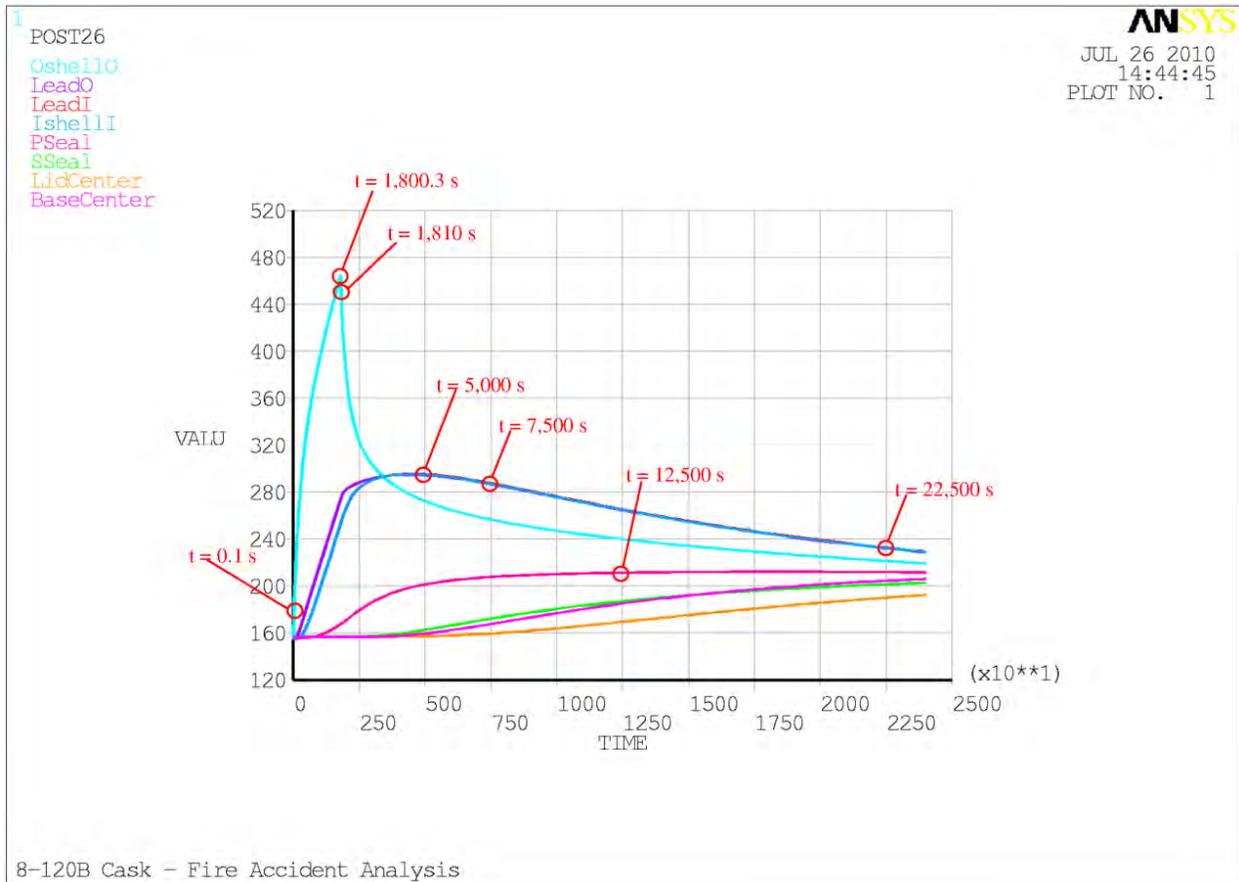


Figure 3-11 - Temperature Time-History Plot in Various Components of the Cask



**Figure 3-12 - Temperature Time-History Plot in Various Components of the Cask  
(Not Under Direct Contact with the Fire)**

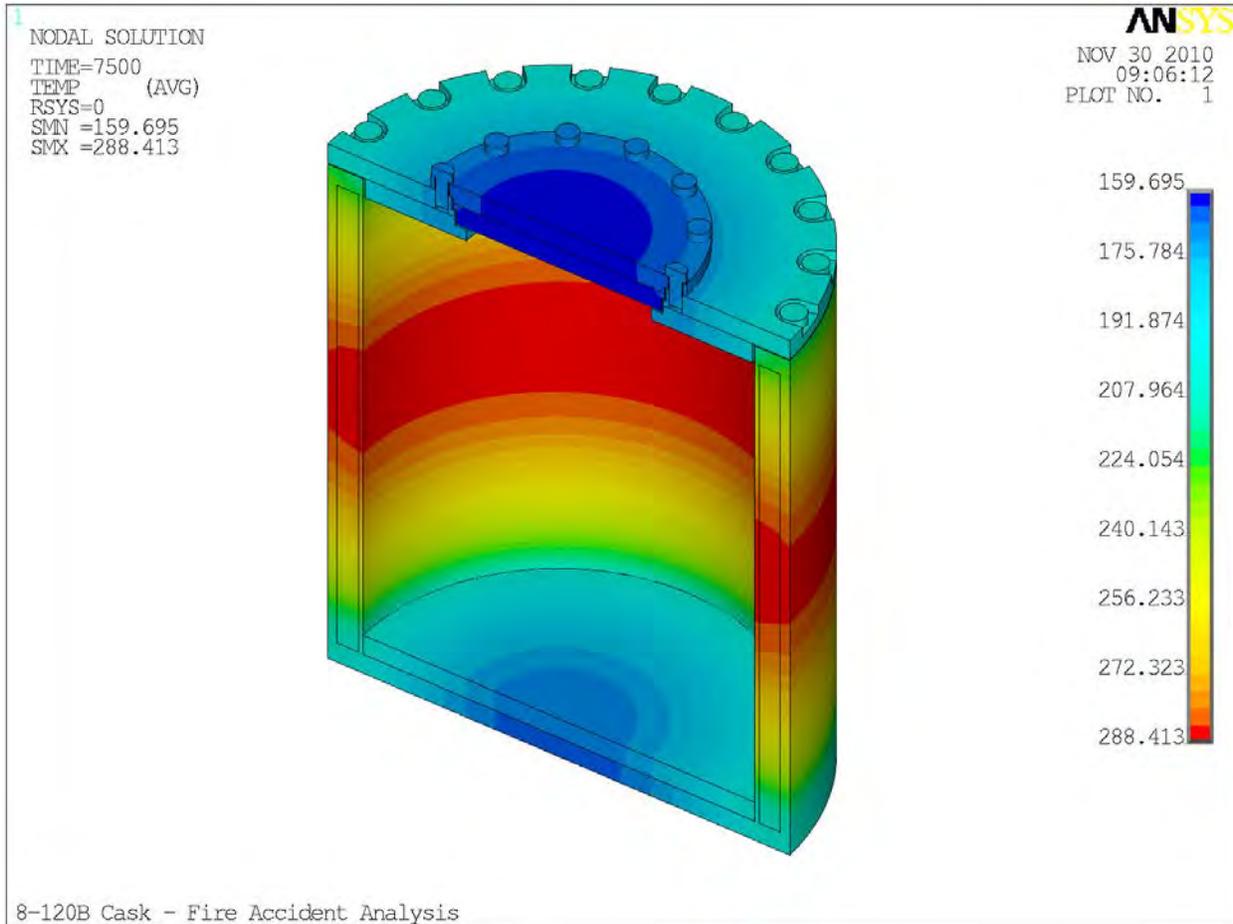


Figure 3-13 - Temperature Distribution – 7,500 Sec. After the Start of the Fire  
(Please refer to Reference 3-10 for temperature contour plots at various other times)

(From 2-d Model)

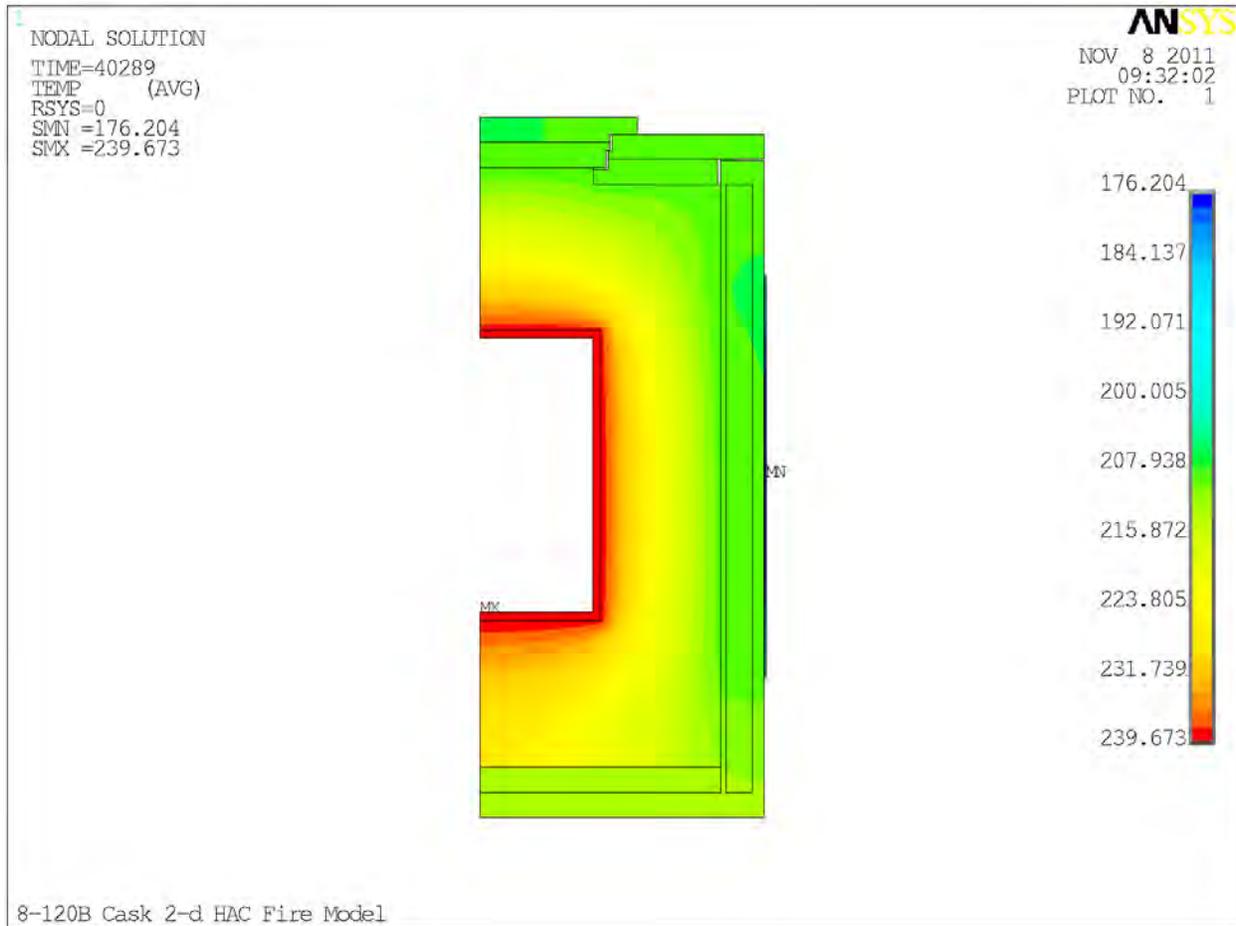


Figure 3-14 - Temperature Distribution in the Cask Cavity –  
40,289 Sec. After the Start of the Fire  
(From 2-d Model)

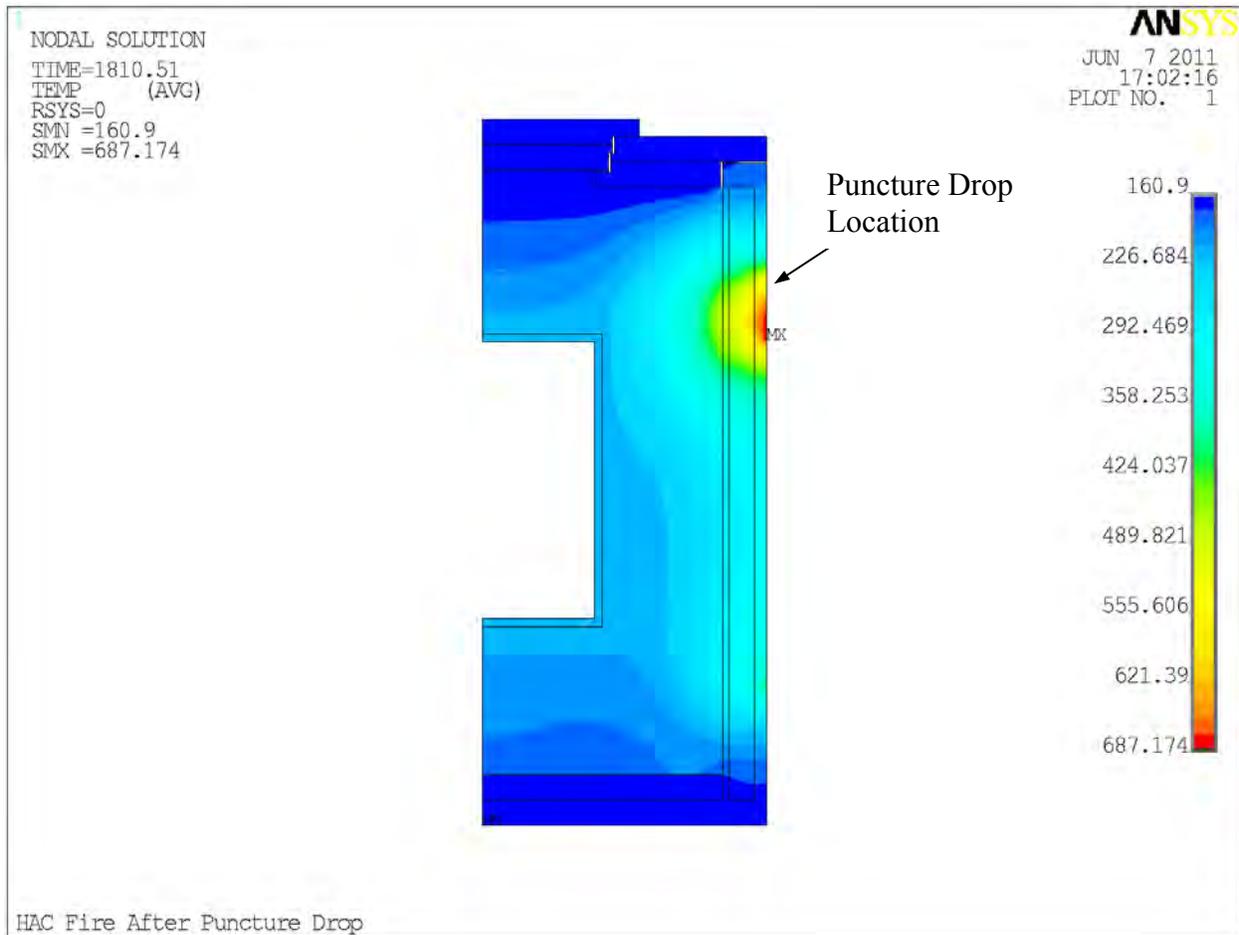


Figure 3-15 - Temperature Distribution in the Cask with Puncture Drop Damage –  
7,500 Sec. After the Start of the Fire

(From 2-d Model)

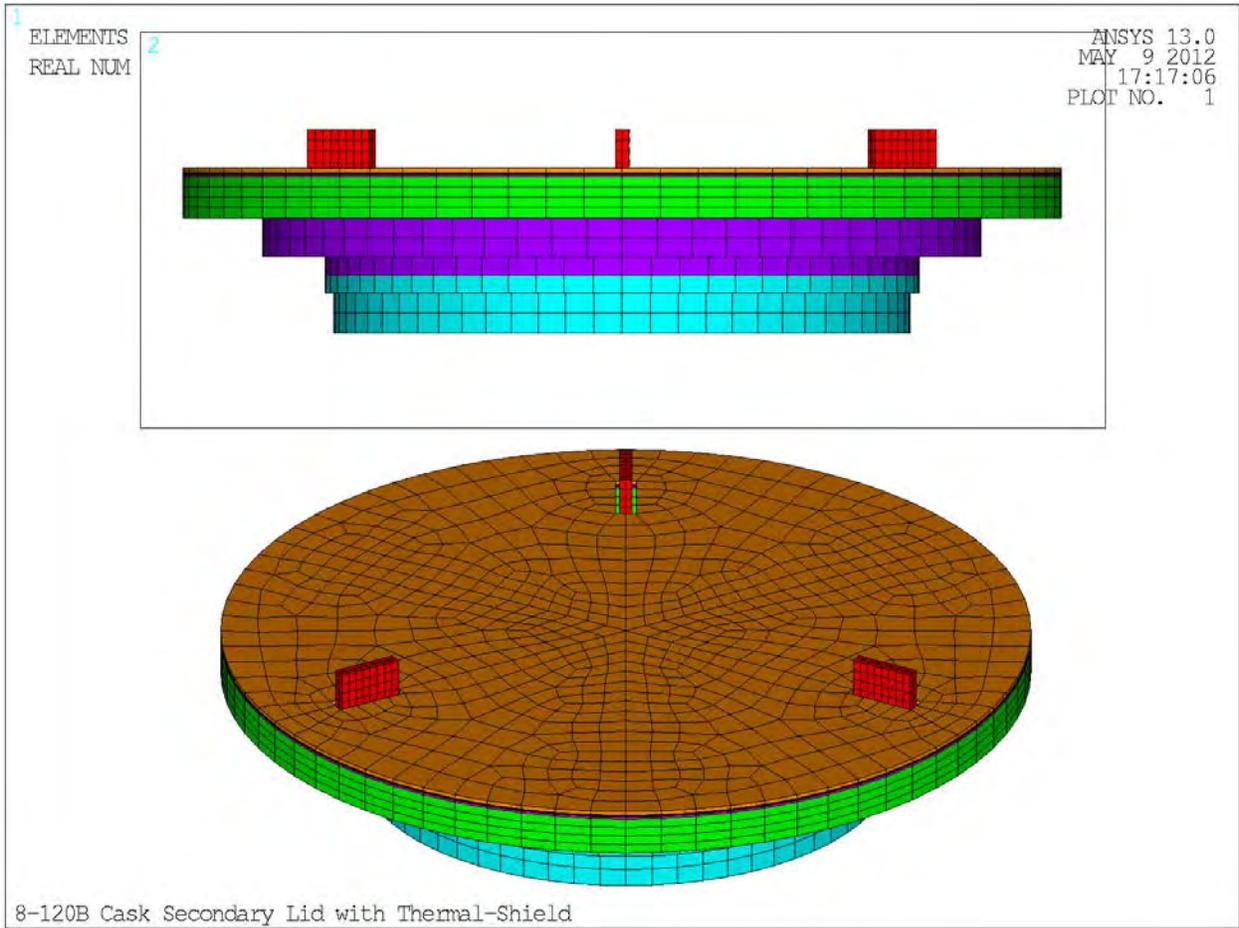


Figure 3-16 - 8-120B Cask Secondary Lid with Thermal-Shield - Complete FEM

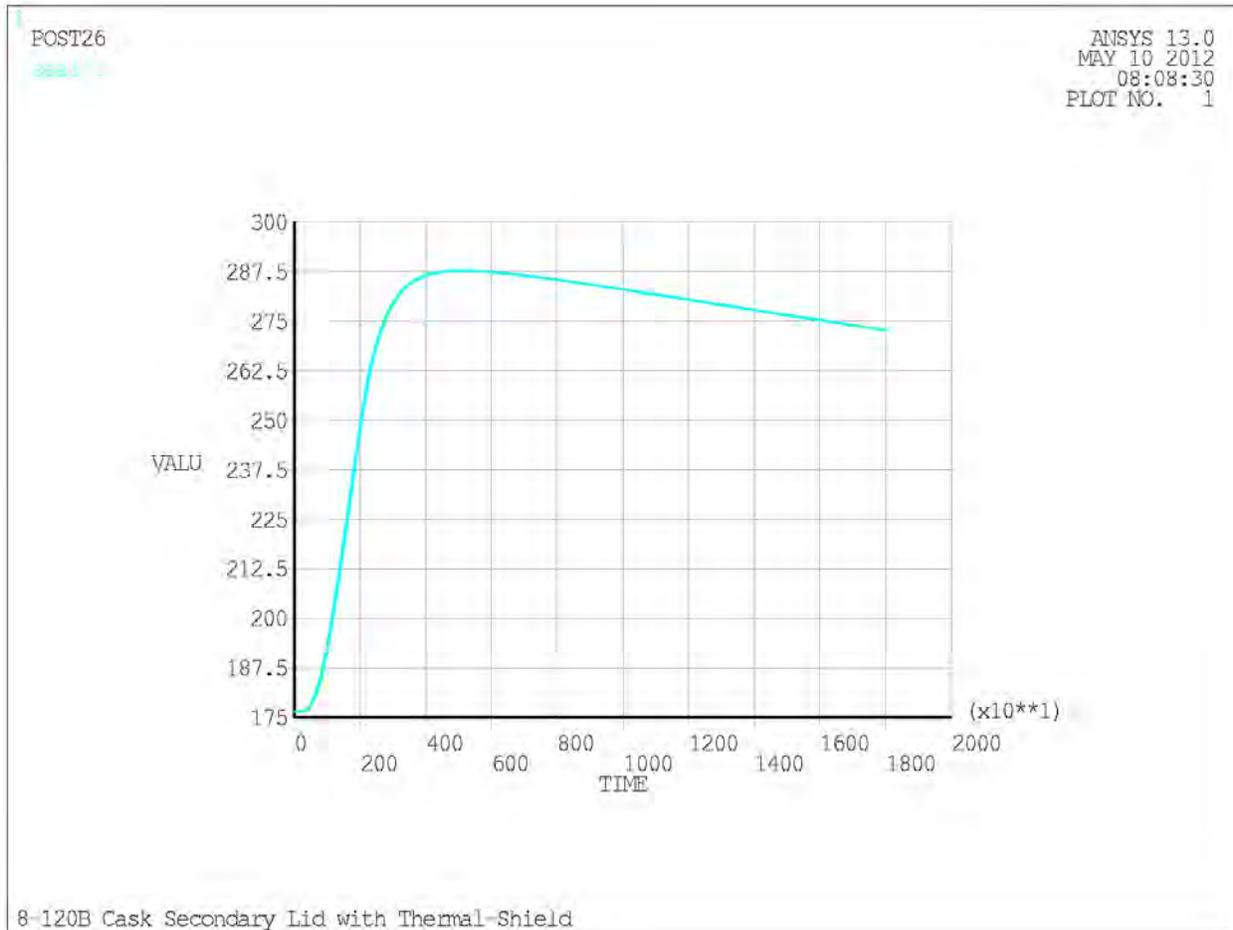


Figure 3-17 - 8-120B Cask Secondary Lid Seal Temperature Time-History Plot – With Thermal-Shield

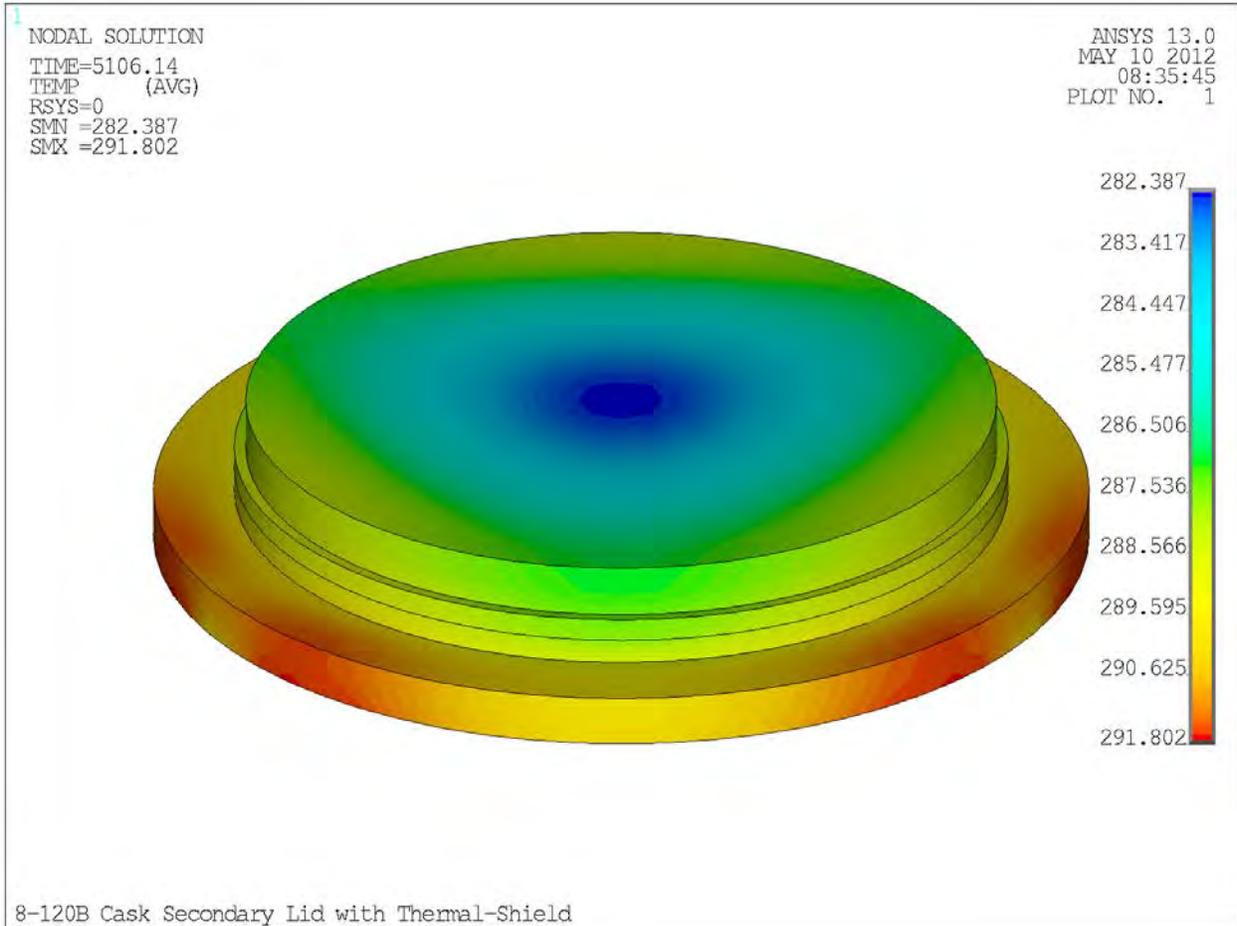


Figure 3-18 - 8-120B Cask Secondary Temperature Contour Plot at the Time When the Secondary Lid Seal Reaches the Peak Value - With Thermal-Shield

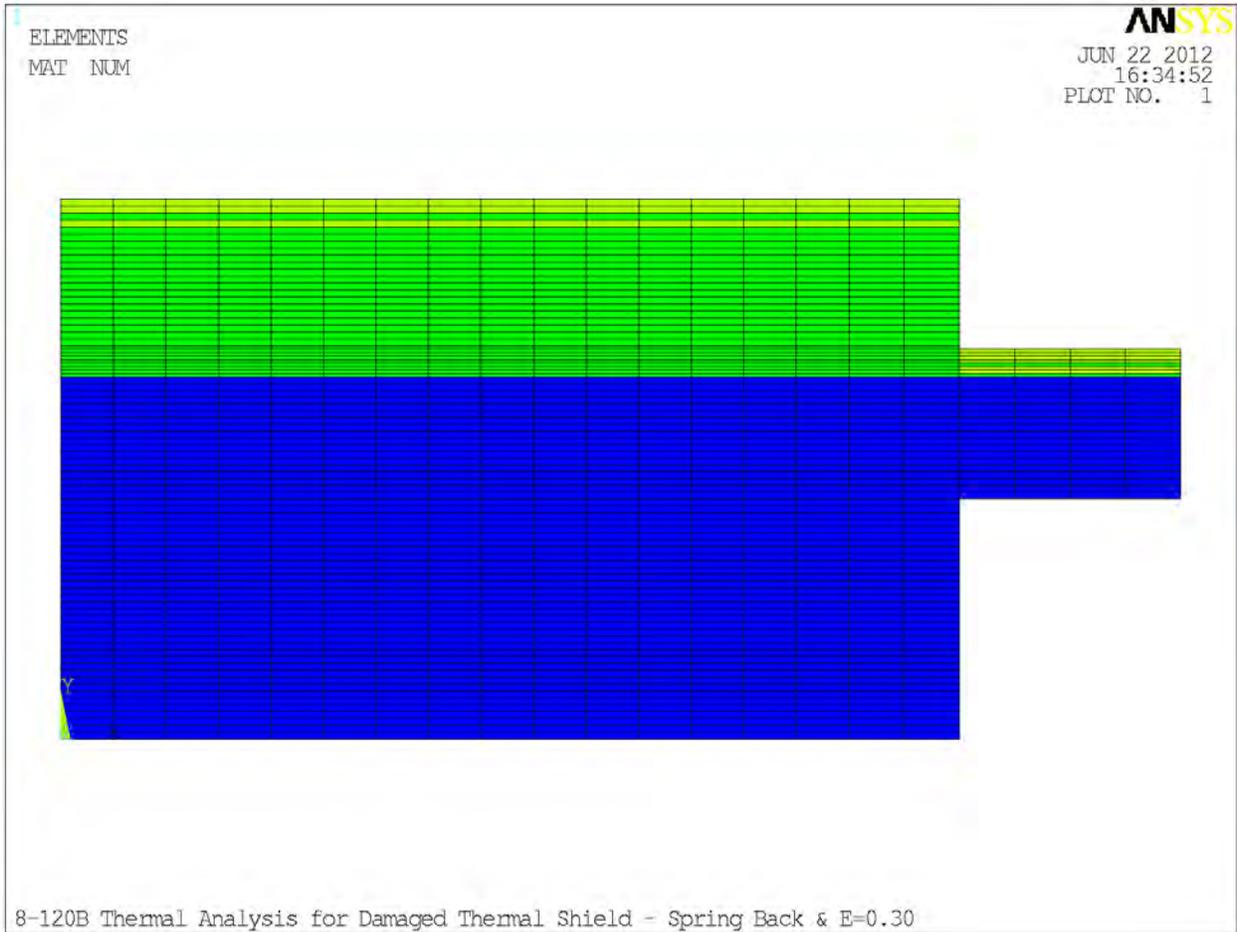


Figure 3-19 - 8-120B Cask Secondary Lid with Thermal-Shield (Damaged) – FEM

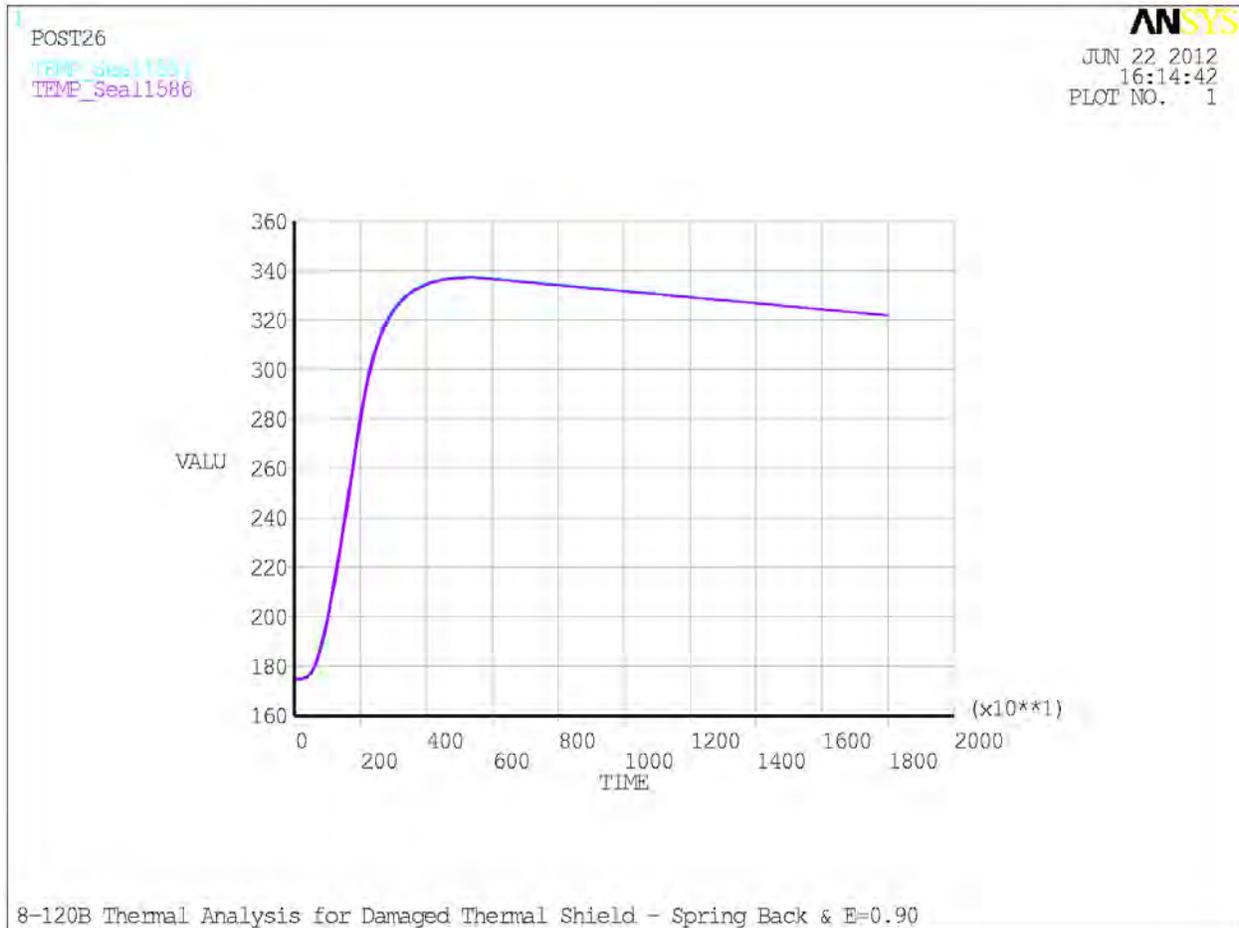


Figure 3-20 - 8-120B Cask Secondary Lid Seal Temperature Time-History Plot –  
With Thermal-Shield (Damaged)

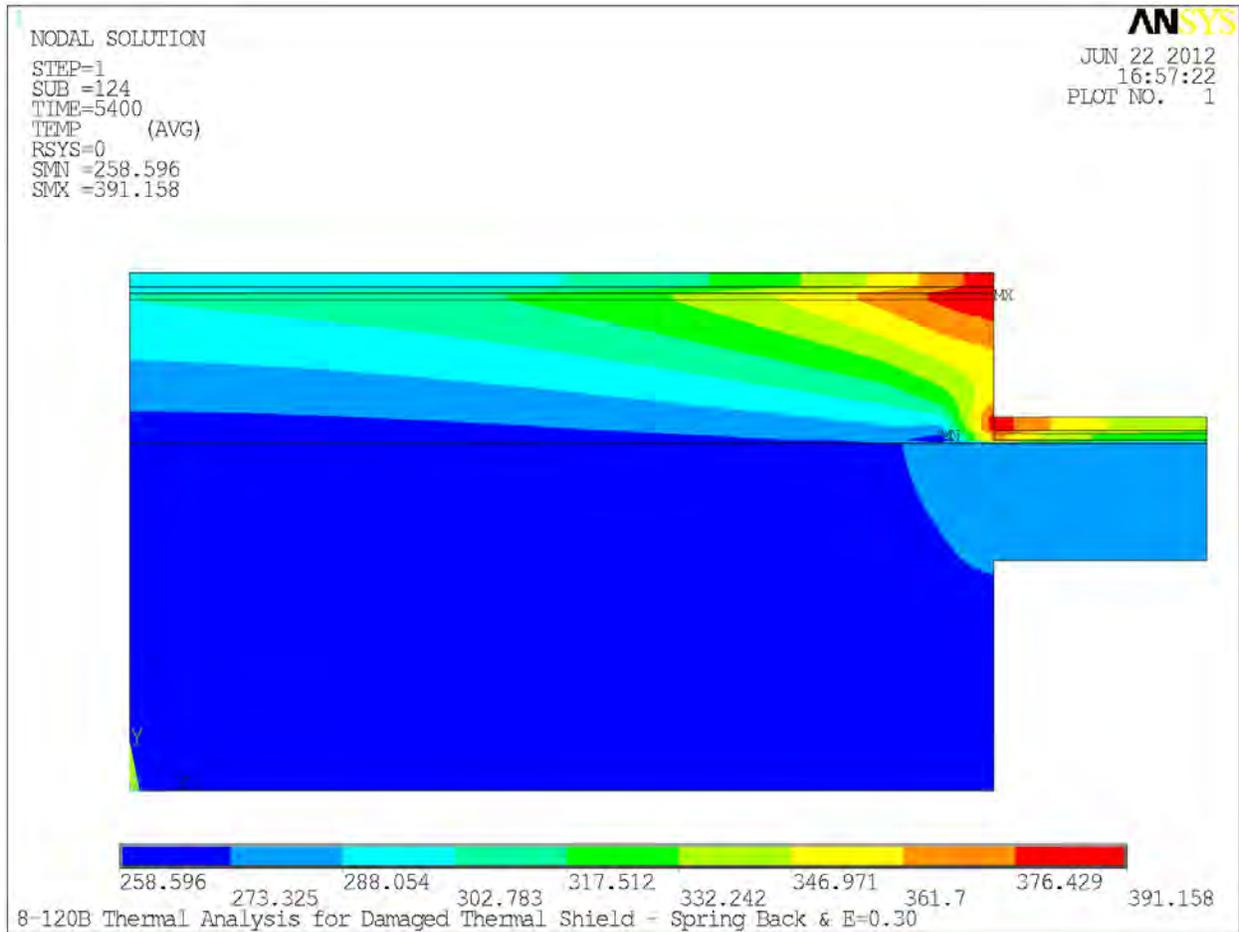


Figure 3-21 - 8-120B Cask Secondary Temperature Contour Plot at 5,400 Seconds after the Initiation of Fire

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## 4.0 CONTAINMENT

The 8-120B package containment boundary is designed, constructed, operated, and maintained to assure no loss or dispersal of radioactive contents under the tests specified in 10 CFR 71, §71.71 and §71.73. This chapter describes the package's containment system design and how it meets the containment requirements under NCT and HAC tests, and defines the criteria for leak-rate testing during package fabrication, use, maintenance, and repair.

### 4.1 DESCRIPTION OF CONTAINMENT SYSTEM

The 8-120B containment system is formed by the following components, as shown in Appendix 1.3, Sheet 6 of Drawing C-110-E-0007, where containment boundary components are highlighted by hatching:

- Cask Inner vessel:
  - inner shell,
  - bolting flange and seal ring,
  - inner bottom plate, and
  - all structural and pressure retaining welds on the containment boundary
- Cask primary lid:
  - outer plate and attached seal ring,
  - primary lid bolts and washers,
  - primary lid containment (innermost) seal,
  - vent port cap screw and seal, and
  - all structural and pressure retaining welds on the containment boundary
- Cask secondary lid:
  - outer plate,
  - secondary lid bolts and washers,
  - secondary lid containment (innermost) seal, and
  - all structural and pressure retaining welds on the containment boundary

The cask vessel containment shell is approximately 62 inches in diameter by 75 inches inside height. The shell is constructed from rolled carbon steel plate attached to a circular bottom plate by full-penetration welds. The top of the shell is joined to a thick bolting flange by full-penetration welds.

The primary lid is fabricated from two carbon steel plates. The outer primary lid plate is part of the containment boundary, as are two additional containment features: a welded seal ring with two dovetail grooves (for the containment and test seals), and a recessed vent port/seal. The primary lid is attached to the cask body with twenty recessed alloy steel bolts. Alignment pins (not part of the containment boundary) on the cask body bolting flange assure that the primary lid is always installed in the same orientation relative to the cask body. The vent port seal is captured by a cap screw plus an integral retainer that protects the seal from extrusion during use. The vent port cap screw and seal are located within a recess in the lid that protects them from damage in the HAC. A set screw (not part of the containment boundary) is located outboard of the vent port cap screw and seal for weather/debris protection.

The secondary lid is similarly fabricated from two carbon steel plates. The inner secondary lid plate is part of the containment boundary, as is a welded seal ring with two dovetail grooves (for the containment and test seals). The secondary lid is attached to the primary lid with twelve recessed alloy steel bolts. Alignment pins (not part of the containment boundary) on the primary lid assure that the secondary lid is always installed in the same orientation relative to the primary lid.

The containment boundary material and welds meet the requirement of Regulatory Guide 7.11 [4.2] for Category II packages with impact limiters. The containment bolts meet the impact-energy acceptance criteria of the bolting material in Section III, Division 1, Subsection ND, of the ASME Code at -20°F, in compliance with NUREG/CR-3854 [4.3]. The containment boundary material and bolts are procured to the highest Safety Classification "A" in accordance with NUREG/CR-6407 [4.4].

The containment seals are elastomeric material designed to provide sealing function under thermal conditions for both NCT (180 °F maximum allowable long-term temperature for all seals, see Section 3.1.3) and HAC (maximum allowable short-term temperatures of 235 °F for the primary lid and vent port seals, and 340 °F for the secondary lid seal, see Section 3.1.3).

Radiation can affect the properties of containment seal materials, reducing their resistance to compression set. According to published elastomer data [4.5], some elastomer compounds perform up to exposures of  $1 \times 10^7$  rad, and practically all elastomers suffer no change in their physical properties up to  $1 \times 10^6$  rad. The containment seals receive radiation exposure during shipment campaigns, plus during the short period of time when the unshielded seal is exposed to the payload during package loading and unloading. Assuming one shipment per week, a 7-day transport time, a conservative average payload contact exposure rate of 100 rad/hr, one inch of effective steel shielding from the lid structure during shipment time at the worst-case seal (the secondary lid containment seal), and one minute of direct-exposure time during each loading or unloading cycle, the bounding annual exposure is  $5.6 \times 10^5$  rads<sup>2</sup>. Since no significant loss of elastomer properties will occur at this range, replacement of the containment seal is controlled by general wear and damage considerations, and not radiation exposure. Appendix 1.3 and Section 8.2.5 contain the complete specifications for all three containment seals.

Positive closure of the containment boundary penetrations is assured by the threaded fasteners described above. These fasteners are torqued in accordance with the requirements of the drawing in Appendix 1.3. The containment penetrations will be covered by the impact limiters during transport, which will protect and prevent inadvertent operation of the fasteners. The structural analysis in Section 2.0 shows that the threaded fasteners remain securely closed if subjected to pressure that could arise inside the package.

The containment system does not include any valves or pressure relief devices, or any features to ensure continuous venting.

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<sup>2</sup> Transport exposure:  $365 \text{ days} * 24 \text{ hrs/day} * 100 \text{ rad/hr} * 0.64 \text{ attenuation} = 5.6\text{e}+05 \text{ rad}$   
Load/unload exposure:  $(52+52)*(1 \text{ min} /60 \text{ min/hr}) * 100 \text{ rad/hr} = 1.8\text{e}+02 \text{ rad}$

## **4.2 CONTAINMENT UNDER NORMAL CONDITIONS OF TRANSPORT**

### **4.2.1 NCT PRESSURIZATION OF THE CONTAINMENT VESSEL**

The package maximum normal operating pressure (MNOP) is conservatively set at 35.0 psig. Section 3.3.2 further discusses the NCT pressurization.

### **4.2.2 NCT CONTAINMENT CRITERION**

The package is designed to a “leaktight” containment criterion per ANSI N14.5 [4.1], therefore the containment criterion is  $10^{-7}$  ref-cm<sup>3</sup>/s air.

### **4.2.3 COMPLIANCE WITH NCT CONTAINMENT CRITERION**

Compliance with the NCT containment criterion is demonstrated by analysis. The structural evaluation in Section 2.6 shows that there would be no loss or dispersal of radioactive contents, and that the containment boundary, seal region, and closure bolts do not undergo any inelastic deformation when subjected to the conditions of §71.71. The maximum calculated NCT temperatures summarized in Table 3-1 show that the seals, bolts and containment system materials of construction do not exceed their allowable temperature limits when subjected to the conditions of §71.71.

## **4.3 CONTAINMENT UNDER HYPOTHETICAL ACCIDENT CONDITIONS**

The 8-120B package is designed, constructed, and prepared for shipment so that, under the tests specified in 10 CFR 71.73, the package meets the containment requirements of 10 CFR 71.51(a)(2).

### **4.3.1 PRESSURIZATION OF CONTAINMENT VESSEL**

The maximum internal pressure of the 8-120B package during the HAC fire is conservatively assumed to be 155 psig, as discussed in Section 3.4.3.

### **4.3.2 CONTAINMENT CRITERIA**

The 8-120B package is designed to a “leaktight” containment criterion of  $10^{-7}$  ref-cm<sup>3</sup>/s air per ANSI N14.5 [4.1].

### **4.3.3 COMPLIANCE WITH CONTAINMENT CRITERIA**

Compliance with the HAC containment criterion is demonstrated by analysis. The structural evaluation presented in Section 2.7 shows that there would be no loss or dispersal of radioactive contents, and that the containment boundary, seal region, and closure bolts do not undergo any inelastic deformation when subjected to the conditions of §71.73. The maximum calculated HAC temperatures summarized in Table 3-2 show that the seals, bolts, and containment system materials of construction do not exceed their allowable temperature limits when subjected to the conditions of §71.73.

#### 4.4 LEAKAGE RATE TESTS

Leakage rate tests of the 8-120B package are required during fabrication, periodically, after maintenance activities, and prior to each shipment as described in the following sections.

##### 4.4.1 FABRICATION LEAKAGE RATE TEST

Each 8-120B package containment system is leakage rate tested as described in Sections 8.1.3 and 8.2.4. Section 8.1.3 describes confirmatory leak testing of the as-built cask body assemblies built before April 1, 1999. Section 8.2.4 describes fabrication leak testing of the inner containment shell and lids for packages fabricated after April 1, 1999.

##### 4.4.2 MAINTENANCE LEAKAGE RATE TEST

Leakage rate testing is performed on each 8-120B package after maintenance, repair, or replacement of containment components to confirm that the performance of the containment system has not been degraded. Maintenance leakage rate testing must demonstrate that the affected items, components, and assemblies satisfy the “leaktight” containment criterion of  $10^{-7}$  ref-cm<sup>3</sup>/s air. Requirements for maintenance leakage rate testing are further described in Section 8.3.2.1.

##### 4.4.3 PERIODIC LEAKAGE RATE TEST

In order to demonstrate that the containment system has not degraded over an extended period, each 8-120B shipment requires that the package has been leakage rate tested to the “leaktight” containment criterion of  $10^{-7}$  ref-cm<sup>3</sup>/s air within the prior twelve months. Requirements for periodic leakage rate testing are further described in Section 8.3.2.1.

##### 4.4.4 PRE-SHIPMENT LEAKAGE RATE TEST

Each 8-120B package is leakage rate tested prior to shipment to confirm that the containment system is properly assembled for shipment. The pre-shipment leakage rate test is performed to demonstrate that there is no detectable leakage when tested to a sensitivity of  $1 \times 10^{-3}$  ref-cm<sup>3</sup>/s, as discussed further in Section 1.1.1.1.

#### 4.5 REFERENCES

- 4.1 ANSI N14.5-2014, *American National Standard for Leakage Tests on Packages for Shipment of Radioactive Materials*, American National Standards Institute, Inc., New York, 2014.
- 4.2 Regulatory Guide 7.11, *Fracture Toughness Criteria of Base Material for Ferritic Steel Shipping Cask Containment Vessels with a Maximum Wall Thickness of 4 Inches (0.1 m)*, U.S. Nuclear Regulatory Commission.
- 4.3 L. E. Fischer and W. Lai, *Fabrication Criteria for Shipping Containers*, U.S. Nuclear Regulatory Commission, NUREG/CR-3854 (UCRL-53544), March 1985.

4.4 J. W. McConnell, Jr., et. al., *Classification of Transportation Packaging and Dry Spent Fuel Storage System Components According to Importance to Safety*, U.S. Nuclear Regulatory Commission, NUREG/CR-6407 (INEL-95/0551), February 1996.

4.5 *Parker O Ring Handbook*, Parker Hannifin Corporation, ORD 5700, 2007.

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## 5.0 SHIELDING EVALUATION

### 5.1 DESCRIPTION OF SHIELDING DESIGN

The Model 8-120B packaging consists of a lead and steel containment vessel which provides the necessary shielding for the various radioactive materials to be shipped within the package. (Refer to Section 1.2.3 for packaging contents.) Tests and analysis performed under chapters 2.0 and 3.0 have demonstrated the ability of the containment vessel to maintain its shielding integrity under normal conditions of transport. Prior to each shipment, radiation readings will be taken based on individual loadings to assure compliance with applicable regulations as determined in 10CFR71.47 (see Section 7.1, step 7.1.21.3).

The 8-120B will be operated under “exclusive use” such that the contents in the cask will not create a dose rate exceeding 200 mrem/hr on the cask surface, or 10 mrem/hr at two meters from the outer lateral surfaces of the vehicle. The package shielding must be sufficient to satisfy the dose rate limit of 10CFR71.51(a)(2) which states that any shielding loss resulting from the hypothetical accident will not increase the external dose rate to more than 1000 mrem/hr at one meter from the external surface of the cask.

#### 5.1.1 SHIELDING DESIGN FEATURES

The cask side wall consists of an outer 1.5 inch thick steel shell surrounding 3.35 inches of lead and an inner containment shell wall of 0.75 inch thick steel and steel 12-gauge thick cladding.

The primary cask lid consists of two layers of 3.25 inch thick steel, giving a total material shield thickness of 6.5 inches of steel. This lid closure is made in a stepped configuration to eliminate radiation streaming at the lid/cask body interface.

A secondary lid is located at the center of the main lid, covering a 29.0 inch opening. The secondary lid is constructed of two 3.25 inch steel plates with multiple steps machined in the secondary lid. These match steps in the primary lid, eliminating radiation streaming pathways. A stainless steel thermal shield covers the secondary lid and is attached to the secondary lid lifting lugs. This axial thermal shield is conservatively ignored in the shielding evaluation.

The impact limiters and radial thermal barrier provide a small amount of additional shielding. The impact limiters have 12 gage steel skin; and the lower impact limiter has a ½” thick steel cover plate in the “hole.” The radial thermal barrier is 3/16” steel.

#### 5.1.2 MAXIMUM RADIATION LEVELS

The 8-120B package carries a range of contents, from small concentrated sources to large volume homogeneous materials and combinations of these, and may include nearly every radionuclide. In order to determine the maximum activity of any particular radionuclide or mixture of radionuclides, a series of evaluations of bounding source configurations over a range of gamma energies are performed. The resulting set of source limits ensure that any content meeting the source limit for the appropriate configuration and gamma energy will comply with

the most restrictive of the dose rate limits from 10 CFR 71.47 and §71.51. These evaluations are presented in Section 5.4.

In order to provide a concise summary of the results, the point source results for only Co-60 and Cs-137 are provided in Table 5-1. This table gives both normal and accident condition dose rates for the maximum Co-60 and Cs-137 point source in the cask.

Table 5-1 - Summary of Maximum Dose Rates (mrem/hr)

Condition	Package Surface		1 m from Surface		2m from 8' trailer
	Side	Top/Bottom	Side	Top/Bottom	Side
<b>NCT</b>					
Co-60 Source	190.0	75.1	NA	NA	3.1
Cs-137 Source	182.6	190.0	NA	NA	5.3
Allowable	200	200	NA	NA	10.0
<b>HAC</b>					
Co-60 Source	NA	NA	102.2	34.9	NA
Cs-137 Source	NA	NA	424.9	93.4	NA
Allowable	NA	NA	1000.0	1000.0	NA

The following assumptions were used to develop the values given in the table.

5.1.2.1 Normal Conditions

The source is modeled as a point source (1 cm dia x 1 cm high) at the location within the cask cavity that yields maximum peak cask exterior dose rates (i.e., at the top corner of the cavity, or on the side of the cask cavity at an elevation between the top and bottom impact limiters). Reference 5.7.2 includes a complete summary of the package response functions for all source configurations of interest.

5.1.2.2 Accident Conditions

1. Lead slump of 0.15” resulting from the accident drop analysis is incorporated in the model
2. Thinning of the lead shield layer due to the puncture drop is incorporated by reducing the lead thickness by 0.5”
3. The source is modeled as a point source (1 cm dia x 1 cm high) in the top corner of the cavity (partially up into the chamfer region at the bottom corner of the primary cask lid so that the bottom of the source is flush with the top of the lead). Reference 5.7.2 includes a complete summary of the package response functions for all source configurations of interest.

### 5.1.2.3 Conclusion

For the Co-60 point source case, the maximum allowable payload gamma source is governed by the 200 mrem/hr dose rate limit that applies on the cask body side, under NCT. The results determine a maximum allowable source strength of  $1.277 \times 10^{11}$   $\gamma$ /sec (1.73 Ci) for that isotope. At this source strength, the results show a dose rate of close to 200 mrem/hr on the package side surface, and dose rates that are well under their regulatory limits at all other locations. An administrative margin of 5% is then applied (to account for any uncertainties), which reduces the allowable Co-60 gamma source strength to  $1.213 \times 10^{11}$   $\gamma$ /sec (1.64 Ci). Because of the 5% administrative margin, the actual peak dose rate is 190.0 mrem/hr, as shown in Table 5-1.

For the Cs-137 point source case, the maximum allowable payload gamma source strength is governed by the 200 mrem/hr dose rate limit that applies on the package top surface, under NCT. The results determine a maximum allowable source strength of  $5.719 \times 10^{12}$   $\gamma$ /sec (77.3 Ci) for that isotope. At this source strength, the results show a dose rate of close to 200 mrem/hr on the package surface, and dose rates that are well under their regulatory limits at all other locations. An administrative margin of 5% is then applied (to account for any uncertainties), which reduces the allowable Cs-137 gamma source strength to  $5.433 \times 10^{12}$   $\gamma$ /sec (73.4 Ci). Because of the 5% administrative margin, the actual peak dose rate is 190.0 mrem/hr, as shown in Table 5-1.

As the results do not exceed the allowable dose rates, the 8-120B cask meets the shielding requirements of 10 CFR Part 71.

## 5.2 SOURCE SPECIFICATION

### 5.2.1 GAMMA SOURCE

Analyses are performed for idealized source configurations that bound any actual source configuration that may occur. These bounding configurations are: a point source at the center of the cask cavity in the NCT configuration, a point source at the side of the cask cavity in the NCT configuration, a point source at the top corner of the cask cavity in the NCT configuration, a point source in the top corner of the cask cavity in the HAC configuration, and a uniform mass of material within a defined source region, as described in Section 5.4, for both NCT and HAC configurations. Further details of the analyses are found in Ref. 5.7.2.

All of the analyses described above are performed for several gamma energy levels, ranging from 0.5 MeV to 3.5 MeV. Two specific isotope cases, Co-60 and Cs-137 (and the corresponding specific gamma energies) are also analyzed. The Cs-137 source includes an equilibrium amount of Ba-137m. The gamma energy and abundance of Co-60 and Cs-137 are shown in Table 5-2.

Table 5-2 - Gamma Energy and Abundance

<b>Radionuclide</b>	<b>Gamma Energy MeV</b>	<b>Abundance # of Gamma/decay</b>
<sup>60</sup> Co	1.176	1
	1.333	1
<sup>137</sup> Cs	0.662	0.85

### 5.2.2 NEUTRON SOURCE

There are no significant sources of neutron radiation in the radioactive materials carried in the 8-120B cask that result in measureable neutron doses outside the cask. A shielding analysis (SAR Chapter 5) for a cask with a similar geometry and shield materials (Ref. 5.7.4) shows that a 1.1 E+08 n/s neutron source produces a dose rate of 9.4 mrem/hr at 2m from the side of the trailer. Limiting the neutron emission rate from the 8-120B contents to less than 1 E+05 n/s will result in a dose rate less than 0.1 mrem/hr. Thus, setting the total neutron emission to less than 1 E+05 n/s will result in a neutron dose rate that is a small fraction of the transport limit.

### 5.2.3 BETA SOURCE

Significant beta emitters may be qualified as equivalent gammas as described in Section 5.4.4.

## 5.3 MODEL SPECIFICATION

### 5.3.1 DESCRIPTION OF RADIAL AND AXIAL SHIELDING CONFIGURATION

#### 5.3.1.1 Normal Conditions of Transport (NCT)

The walls of the 8-120B cask, 0.75” inner wall, a 12-gauge inner steel cladding, and a 1.5” outer steel wall, with a 3.35” lead layer between, are modeled as cylindrical shells around the cavity cylinder. The base and lid of the cask are two 3.25” steel plates, for a total thickness of 6.5”. Standard minimum sheet and plate tolerances are modeled, except for drawing items 4 and 9 which were modeled at maximum tolerance thickness as this positions the lid and point-source as high as possible with respect to the top of the lead. This geometry is shown in Figure 5-1; the impact limiters are not shown. The cask is transported upright, i.e., with the axis of the cylinder vertical. Doses are evaluated at contact with the cask sidewall, the impact limiter surface, and at 2m from the 8’ wide trailer. The impact limiter ends and side surfaces are modeled at reduced dimensions consistent with the maximum NCT impact limiter deformations in Table 2-10. Corner crush was not modeled because the peak dose rates do not occur at the corners.

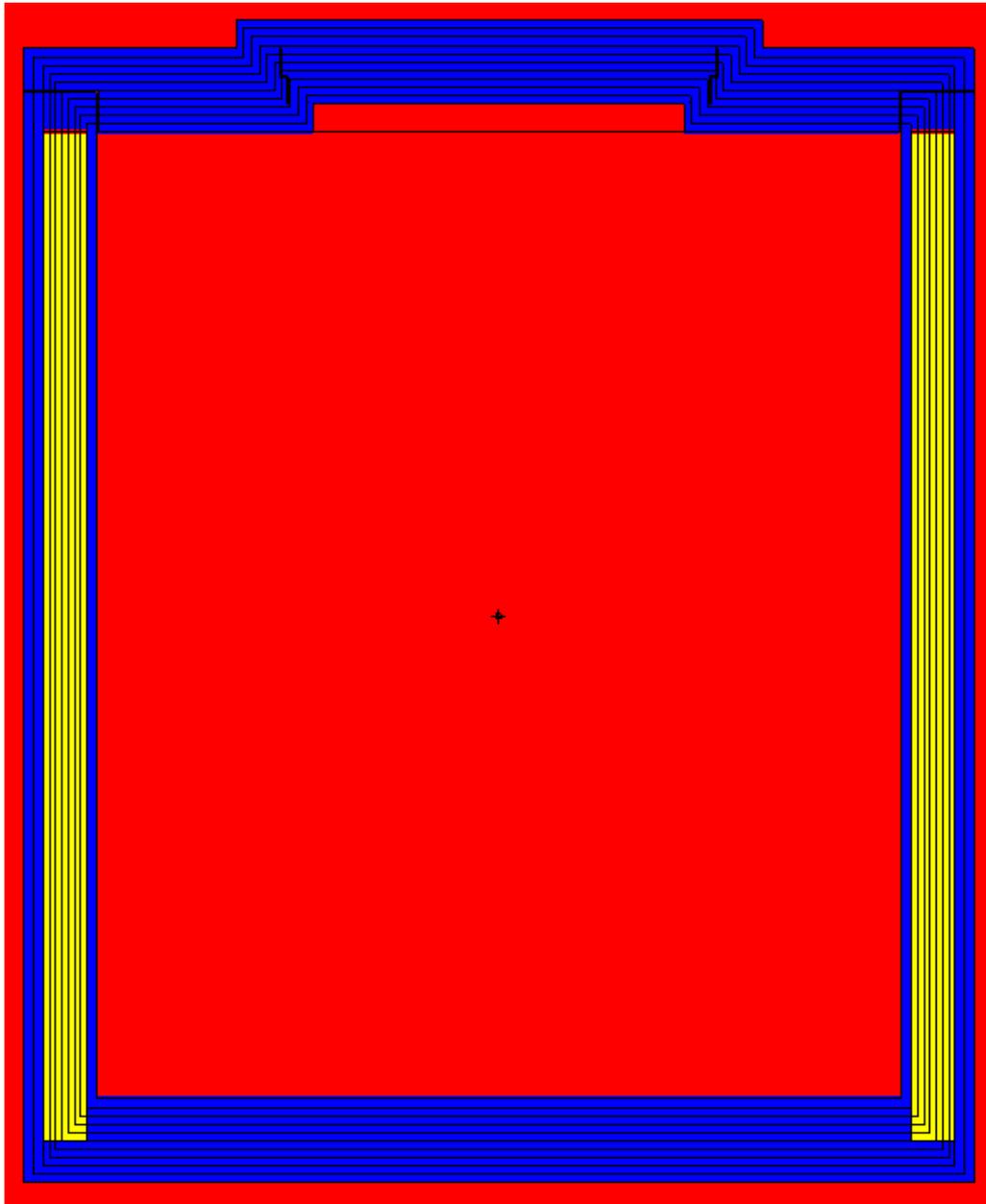


Figure 5-1 - Cask Model

### 5.3.1.2 Hypothetical Accident Conditions (HAC)

As discussed in Chapter 2, the hypothetical accident 30' drop results in a 0.15" lead slump and the puncture drop causes a local 1/2" thinning of the lead layer. The HAC model has a 0.15" air-filled void at the top of the lead shield layer. Also, to conservatively reflect the puncture drop thinning, the thickness of the radial lead shield is reduced by 1/2" in the HAC model. The impact limiters are conservatively ignored. The HAC model is shown in Figure 5-2. Doses are determined at 1 m from the sidewall and the lid.

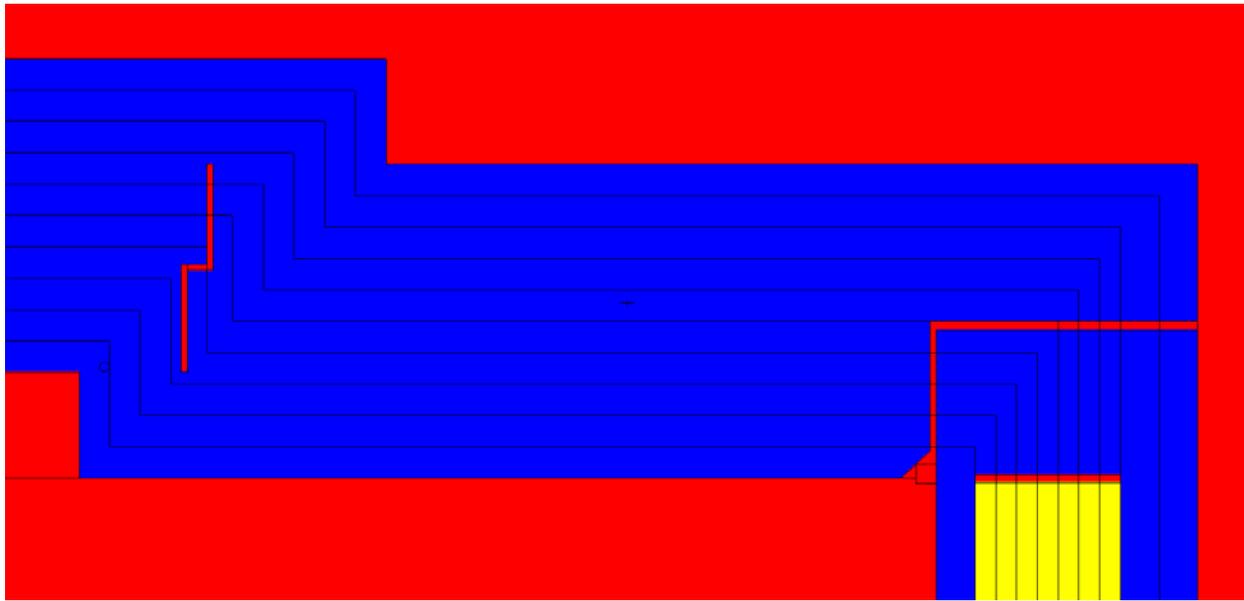


Figure 5-2 - HAC Cask Model

See Reference 5.7.2 for additional details of the MCNP models.

### 5.3.2 MATERIAL PROPERTIES

The compositions and densities of the materials modeled in the shielding analyses are described in Table 5-3 below. The table also lists the MCNP material/cross-section identifier (ZAID) for each modeled material.

Table 5-3 - Material Composition and Density

Material	Total Density (g/cc)	Composition	MCNP Z Aid
Carbon Steel	7.82	99% Fe 1% C	26000.84p 8000.84p
Lead	11.34	100% Pb	82000.84p
Air	0.001205	76.508% N 23.479% O 0.013% C	7000.84p 8000.84p 6000.84p

## 5.4 SHIELDING EVALUATION

The 8-120B package carries a range of contents, from small concentrated sources to large volume homogeneous materials and combinations of these, and may include nearly every radionuclide. In order to determine the maximum source strength of any particular radionuclide or mixture of radionuclides, a series of evaluations of bounding source configurations over a range of gamma energies are performed to determine the maximum source strength ( $\gamma/\text{sec}$ ) or maximum source strength density ( $\gamma/\text{sec}\cdot\text{g}$ ) for each combination of configuration and energy that results in the meeting the most restrictive of the dose rate limits from 10 CFR 71.47 and §71.51. The resulting set of source strength limits ensure that any content meeting the source strength limit for the appropriate configuration and gamma energy will comply with the §71.47 and §71.51 limits.

### 5.4.1 METHODS

The gamma dose rates were calculated using MCNP Version 5, rev. 1.51.

In addition to the point source locations noted in Section 5.2, a uniformly-distributed gamma source is modeled within the source region. The uniform mass that fills the defined source region is zirconium, iron, or aluminum, whichever has the more conservative (smaller) attenuation coefficient at the gamma energy thus bounding other contents materials. The uniform mass is set at a density of 9.0 g/cc, which exceeds the density of nearly all expected payloads. Since the distributed source analyses determine limits in source strength density ( $\gamma/\text{sec}\cdot\text{g}$ ), this density bounds all other lower density contents. Defined source regions include the entire cask interior cavity, a “55 gallon” source zone centered within the cavity and a 2.5 ft<sup>3</sup> source zone centered within the cavity. All the above source zones are modeled for the NCT cask configuration. For the HAC cask configuration, only the full-cask-cavity source zone is modeled.

For the normal condition of transport (NCT) cases, dose rates are tallied on the vertical surface two meters from the package/transporter side (i.e., 322 cm from the cask centerline), and on the package surface which includes the impact limiter side and end surfaces as well as the cask body side cylindrical surface that lies between the impact limiters.

For the HAC point source cases, the dose rates are tallied at two locations on the surface one meter from the cask body. One location lies on the radial one meter surface, directly across from

the source point (viewing the source point through the lead slump gap). The second location lies on the top one meter surface, directly above the source point, viewing the source point through the gap between the radial cask body and the lower part of the primary cask lid.

For the HAC distributed source cases, the dose rates are tallied over the entire spans of the surfaces that lie one meter from the side, top and bottom of the cask body.

For each of the analyses, the peak dose rates (per source gamma) that occur on each of the (NCT or HAC) regulatory surfaces described above are determined.

From these peak dose rates, limits are calculated over the range of gamma energies 0.5-3.5 MeV and for the radionuclides Co-60 and Cs-137. The limits are determined, in source strength ( $\gamma/\text{sec}$ ) for the point source configurations and in source strength density ( $\gamma/\text{sec}\cdot\text{g}$ ) for the distributed source cases. The regulatory dose rate limit for each surface is divided by the highest per-source-gamma dose rate for that surface, to yield a maximum source strength, in  $\gamma/\text{sec}$ . The lowest of the allowable source strengths is then selected as the limiting gamma source strength for that case. Then, for the distributed source cases (only), the allowable source strength is divided by the modeled source region mass to yield the allowable source strength density in  $\gamma/\text{sec}\cdot\text{g}$ .

#### Analysis Method Uncertainties and Conservatism

The MCNP-calculated dose rates are adjusted upwards to account for statistical uncertainty in the MCNP results before they are used to determine source limits. These statistical uncertainties (which are conservatively accounted for in the source limit calculations) are less than 5% for all MCNP results that govern payload source limits. Tallies with statistical uncertainties between 5% and 10 %, and those tallies that did not pass all 10 MCNP statistical checks, are evaluated to determine the suitability of the tally and rerun as necessary.

Uncertainties in the analyses performed to demonstrate that an upper-bound payload material density (of 9.0 g/cc) yields maximum cask exterior dose rates may result in an uncertainty of less than 1% in the final dose rate results. Uncertainties in evaluations performed to determine the most conservative payload material (element) to be modeled in the 0.5 MeV and 3.5 MeV gamma analyses may also result in an uncertainty of ~1% in the final dose rate results. Finally, cask exterior dose rate contributions from neglected beta sources (discussed below in Section 5.4.4) could increase the final dose rate results by as much as ~1%.

The above analytical uncertainties, which could yield as much as a 3% increase in cask exterior dose rates, will be more than offset by conservatism in the analysis method, for virtually all actual payloads. Conservatism includes modeling minimum steel plate thicknesses, neglecting all payload self shielding and concentrating the source into a point, in the worst possible cavity location, in the  $\gamma/\text{sec}$  limit calculations, modeling the entire cask cavity as being filled with the highest source strength density material (that occurs anywhere within the payload) in the  $\gamma/\text{sec}\cdot\text{g}$  limit calculations, rounding gamma energies up (to the nearest evaluated value) when determining source strength limits, and modeling the lowest attenuation material within the payload to determine the  $\gamma/\text{sec}\cdot\text{g}$  limit. Also, as discussed below in Section 5.4.4, the method used to treat beta sources is conservative by more than a factor of 100.

The sources of uncertainty and conservatism in the analyses are discussed in more detail in Reference 5.7.2.

Although the conservatisms in the analysis would more than offset any uncertainties, for virtually all actual payloads, all final payload source limits are reduced by an administrative margin of 5%, to account for uncertainties in the analysis.

#### 5.4.2 INPUT AND OUTPUT DATA

The MCNP input and output files are found in Reference 5.7.3. The input file lists the inputs that define the source dimensions, shield dimensions, materials and density, and source spectrum.

### 5.4.3 FLUX-TO-DOSE-RATE CONVERSION

The flux to exposure rate conversion factors are listed in Table 5-4 (Ref. 5.7.1).

Table 5-4 - Gamma-Ray-Flux-To-Dose-Rate  
 Conversion Factors (ANSI/ANS-6.1.1 1977)

GammaEnergy (MeV)	DCV (rem/hr) per ( $\gamma/\text{cm}^2\text{-sec}$ )
0.015	1.95E-06
0.025	8.01E-07
0.045	3.17E-07
0.08	2.61E-07
0.15	3.79E-07
0.30	7.59E-07
0.50	1.15E-06
0.65	1.44E-06
0.75	1.60E-06
0.90	1.83E-06
1.25	2.32E-06
1.75	2.93E-06
2.5	3.72E-06
3.5	4.63E-06
4.5	5.42E-06
5.5	6.19E-06
6.5	6.93E-06
7.5	7.66E-06
9.0	8.77E-06
12.0	1.10E-05

### 5.4.4 EXTERNAL RADIATION LEVELS AND SOURCE STRENGTH LIMITS

#### 5.4.4.1 Gamma Source Strength Limits

The results of the analyses of the bounding configurations are compared to the external radiation limits allowed for the various compliance locations identified in §71.47 and §71.51. The configuration, at each energy, that has the largest ratio of result to limit is set as the governing configuration from which the limits are established.

The final results of the shielding evaluation are the limits on payload gamma source strength ( $\gamma/\text{sec}$ ) and payload gamma source strength density ( $\gamma/\text{sec}\cdot\text{g}$ ), which vary as a function of gamma energy and payload configuration. These limits are presented, for all gamma energies and all

analyzed source configurations, in Table 5-5 below. The limits are presented graphically in Figure 5-3 and Figure 5-4.

Table 5-5 - Final Payload Source Strength and Source Strength Density Limits

Energy (MeV)	General Sources		Discrete Sources (shored at centroid)*		
	Source γ/sec	Source Density γ/sec-g	Source γ/sec	Source Density γ/sec-g	
				2.5 ft <sup>3</sup>	55 gal
	①	②	③	④	⑤
3.50	9.611E+09	4.434E+05	2.504E+11	2.957E+06	1.563E+06
2.75	1.285E+10	6.515E+05	3.293E+11	4.301E+06	2.281E+06
2.25	1.823E+10	1.065E+06	4.432E+11	6.800E+06	3.634E+06
1.83	3.040E+10	2.061E+06	6.404E+11	1.279E+07	6.869E+06
1.50	6.111E+10	4.938E+06	8.971E+11	2.920E+07	1.592E+07
1.17	2.142E+11	1.640E+07	1.528E+12	8.418E+07	6.173E+07
0.90	8.635E+11	5.539E+07	2.747E+12	2.796E+08	1.919E+08
0.70	2.131E+12	1.887E+08	5.088E+12	9.566E+08	6.366E+08
0.50	7.075E+12	1.298E+09	1.151E+13	6.529E+09	4.185E+09
Co-60	1.393E+11	1.182E+07	1.294E+12	6.169E+07	4.074E+07
Cs-137	2.580E+12	2.556E+08	5.768E+12	1.281E+09	8.536E+08

*\*For discrete source limits, use columns ③ and ④ when the payload object meets the 2.5 ft<sup>3</sup> size criteria, or columns ⑤ and ⑤ when it meets the 55 gallon size criteria. When the size meets neither criteria use columns ① and ②.*

The “general” source limits shown in the left side of Table 5-5 apply for payloads that fill most of the cask cavity or are not shored within a smaller volume at the cavity center. The discrete source limits shown in the right part of Table 5-5 may apply if the payload meets the size criteria and is shored to the center of the cask cavity. (There are also restrictions on height and diameter, for payloads qualified under the “2.5 ft<sup>3</sup>” and “55 gal” limits shown above in Table 5-5, which are discussed in Chapter 7 of this SAR.)

Detail of the calculations (and process) used to determine the payload source limits shown in Table 5-5 are found in Ref. 5.7.2. Note a 5% administrative margin is applied which effectively reduces all the source strength limits presented above in Table 5-5 by 5%. Application of the margin (as part of the sum of fractions method) is discussed below in Section 5.5.

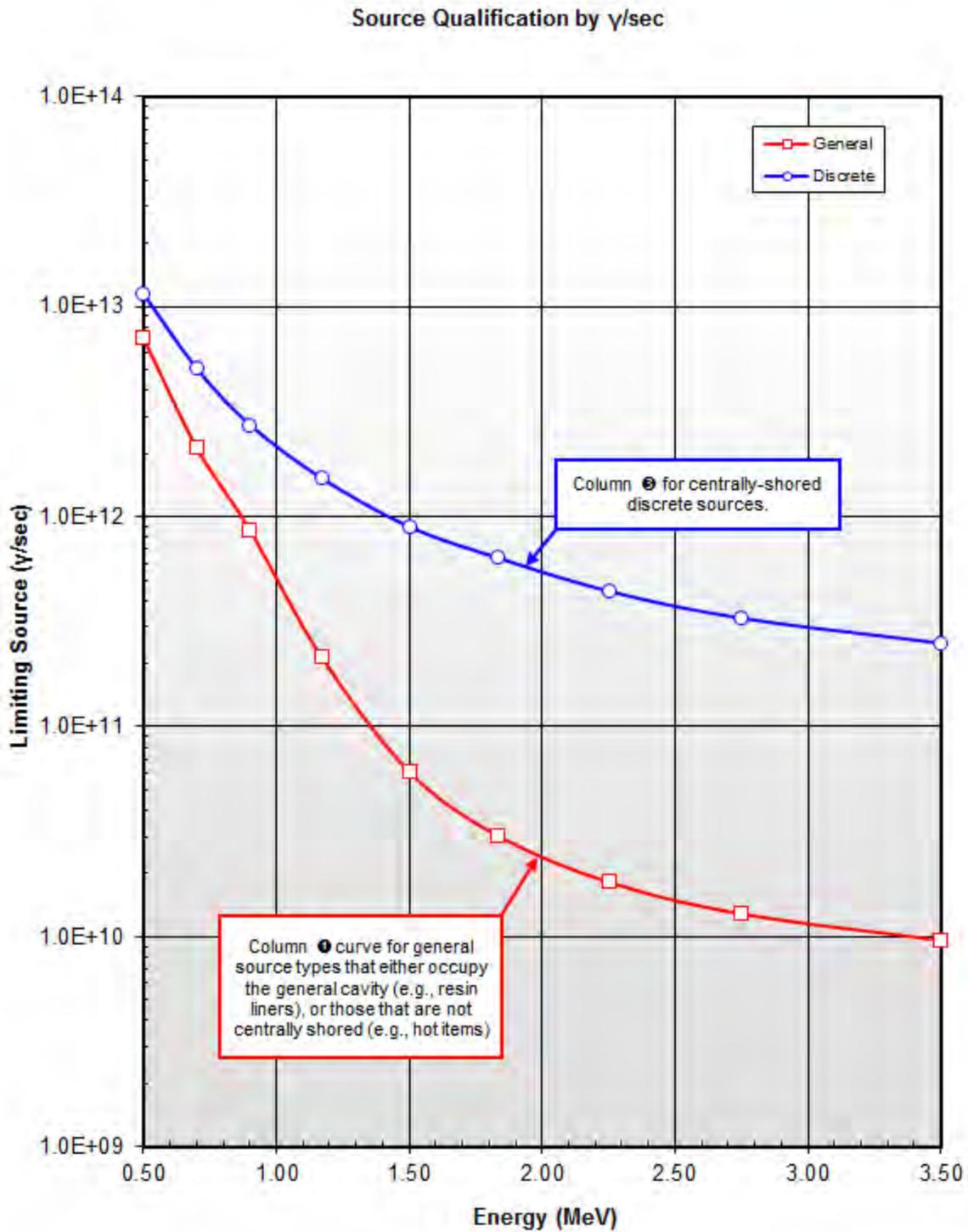


Figure 5-3 - Payload Gamma Source Strength Limit vs. Gamma Energy

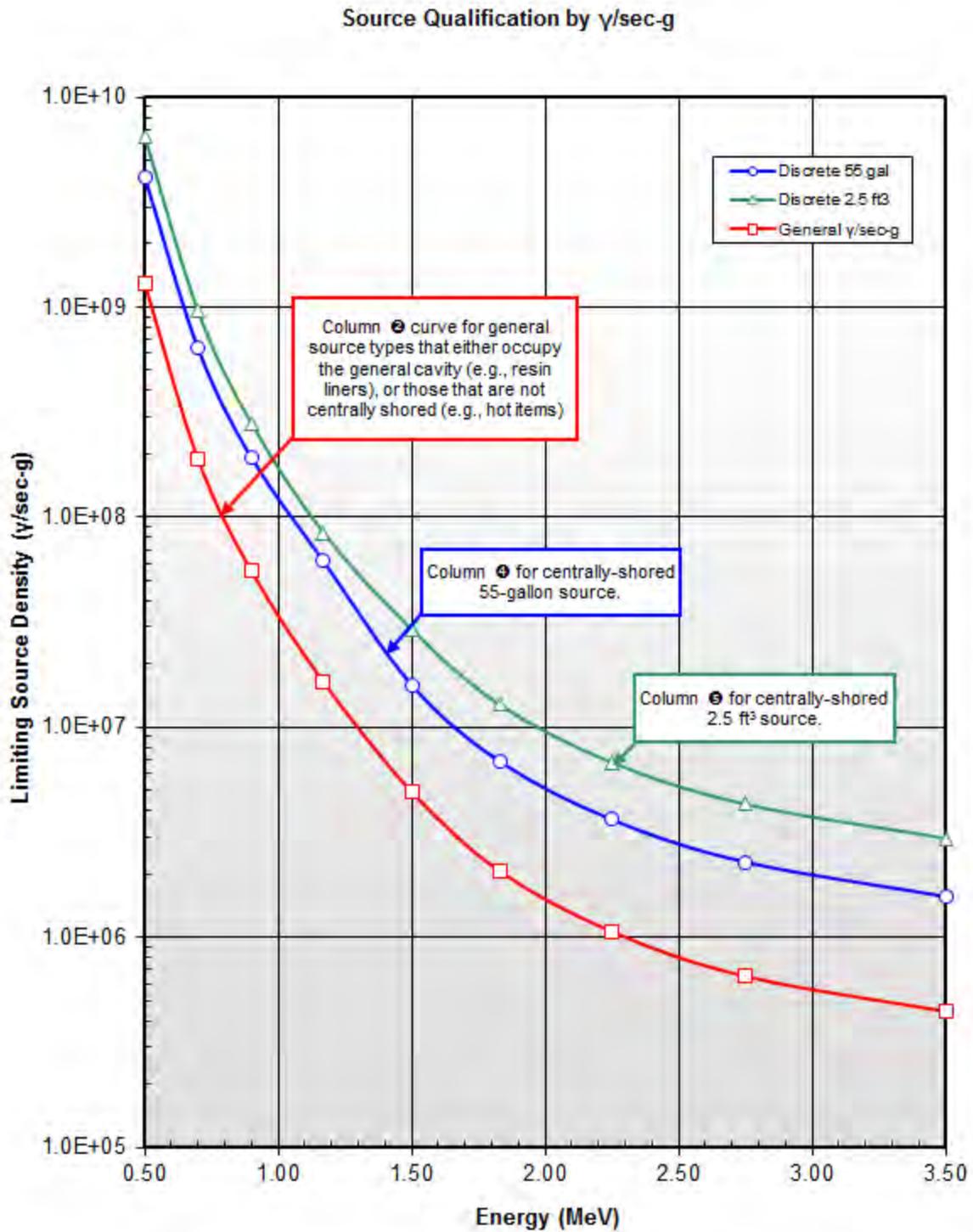


Figure 5-4 - Payload Gamma Source Strength Density Limit vs. Gamma Energy

#### 5.4.4.2 Beta Source Strength Limits

Beta particles lose their energy continuously as they pass through matter, emitting Bremsstrahlung gammas over their range. These Bremsstrahlung gammas, however, have the potential to be significant contributors to package dose rates because the allowable (3000 A<sub>2</sub>) source activity for betas can be much higher than for gamma emitters (e.g., as much as 42,000 Ci of <sup>32</sup>P vs. 4144 Ci of <sup>137</sup>Cs). The method for qualifying significant 8-120B beta emitters is to represent the beta emitter as an equivalent gamma emitter and treat it like any other gamma energy line per the methods described in Section 5.5.

This method is only applied to beta sources (pure beta emitters) with activities greater than 2E+12 betas per second, and peak beta energy levels between 0.3 MeV and 3.5 MeV. Isotopes with peak beta energies less than 0.3 MeV can be neglected. Isotopes with peak beta energies over 3.5 MeV may not be shipped in the cask. Beta source strengths less than 2E+12 betas per second do not contribute significantly to cask exterior dose rates and are, thus, not significant. See Ref. 5.7.2 for additional details and validating calculations.

The beta source can be converted to an equivalent gamma source by:

$$S_{\gamma} = S_{\beta} \cdot \frac{S_{\gamma}}{S_{\beta}}$$

where

$S_{\gamma}$  = equivalent monoenergetic gamma source strength,  $\gamma$ /sec, at the maximum beta energy  $E_{\max}$ .  
 $S_{\beta}$  = beta source strength,  $\beta$ /sec, at the beta energy spectrum for the nuclide of interest

and

$$\frac{S_{\gamma}}{S_{\beta}} = \left( \text{fraction of energy converted from betas to photons} \right) \left( \frac{\text{beta } E_{\text{avg}}}{\text{photon energy}} \right)$$

Conservatively assume all gammas are at the beta maximum energy  $E_{\max}$ , the energy ratio becomes:

$$\frac{S_{\gamma}}{S_{\beta}} = f \left( \frac{E_{\text{avg}}}{E_{\max}} \right)$$

where

$E_{\text{avg}}$  = average energy of the beta source distribution, MeV  
 $E_{\max}$  = maximum energy of the source distribution, MeV.

The fraction of the incident beta energy that is converted to gamma energy,  $f$ , is given by (Ref. 5.7.3).

$$f \cong 3.5 \times 10^{-4} Z E_{\max}$$

where

f = the fraction of the incident beta energy that is converted to gamma energy,  
 Z = atomic number of the absorber

So

$$\frac{S_{\gamma}}{S_{\beta}} = 3.5 \times 10^{-4} Z E_{\max} \left( \frac{E_{\text{avg}}}{E_{\max}} \right)$$

The resulting equation to convert a beta source to an equivalent gamma source at the beta's maximum energy is therefore:

$$S_{\gamma} = S_{\beta} (3.5 \times 10^{-4} Z E_{\text{avg}})$$

For a single material absorber, use the Z of the material. For compounds or mixtures, use a weighted average  $Z_w$ :

$$Z_w = \sum_{i=1}^n \left( \frac{m_i}{m_{\text{total}}} \cdot Z_i \right)$$

$Z_w$  should be determined, as described above, for both the waste payload and the wall of the secondary container (liner) that the waste resides in. Then, the higher of the two  $Z_w$  values should be conservatively used as the basis of the equivalent gamma source calculation. This conservatism is necessary since it is not known what fraction of the beta-to-gamma conversion occurs within the waste material and within the secondary container wall material.

The proposed method for qualifying significant 8-120B beta emitters is to represent the beta emitter as an equivalent gamma emitter and treat it like any other gamma energy line per the methods described in the remainder of this calculation. In this way, significant beta emitters can be accounted for along with other gamma emitters. The entire (equivalent) gamma source ( $S_{\gamma}$ ) is modeled at the same energy as the peak beta energy for the beta-emitting isotope. This gamma energy level is rounded up to the nearest (higher) gamma energy level for which source limits are presented in Table 5-5.

For common container and waste materials (for which Z is 26 or less), the formula above yields an equivalent gamma source that is less than 1% of the isotope's beta source. Furthermore, comparisons to rigorous MCNP beta shielding analyses show that the method (and formula) described above yields cask exterior gamma dose rates (due to payload beta emissions) that are conservative (high) by more than a factor of 100. Thus, a beta source will yield cask exterior dose rates that are only ~0.01% as high as the cask exterior dose rates produced by a gamma source of the same strength and energy level.

For the above reasons, the beta source for isotopes that emit both betas and gammas can be neglected, since any cask exterior dose rate contributions from the beta source will be negligible compared to those produced by the isotope's gamma source. Thus, the procedure described above is only to be used for pure beta-emitting isotopes with a significant beta source.

A procedure for evaluating beta emitters is included in Chapter 7 Attachment 1 which establishes limits for large activity beta sources.

## 5.5 PAYLOAD QUALIFICATION

Radioactive 8-120B contents must be qualified to ensure the shipment will meet the regulatory dose limits from §71.47 and §71.51

To qualify a payload, the cask user determines 1) a gamma source strength ( $\gamma/\text{sec}$ ) and 2) a gamma source strength density ( $\gamma/\text{sec}\cdot\text{g}$ ) for their payload, based on the gamma energy that applies for the payload, whether the payload is shored at the cavity centroid, and the size and volume of the payload. The payload qualifies for shipment in the 8-120B cask if it meets either one of the source strength or source strength density limits in Table 5-5. Note that when determining compliance with the source strength density limit, the highest source strength density (or “hottest”) section of the waste must be used (i.e., the “hottest” material that occurs anywhere within the waste or within any waste/payload item). Averaging of the source strength density, between payload items or within any payload item, is not allowed.

To qualify payloads that emit gammas at multiple energies or when portions of the payloads are radiologically different, a sum of fractions approach is used. For multiple payload items, the user performs a separate qualification evaluation for each payload item/energy, and then use a sum of fractions approach to qualify the overall cask payload. For each gamma energy or payload item, two fractions are determined, one based on the ratio of the payload source strength ( $\gamma/\text{sec}$ ) over the allowable source strength, and one based on the ratio of the source strength density ( $\gamma/\text{sec}\cdot\text{g}$ ) over the allowable source strength density. The lower of the two fractions is then selected, for each gamma energy or payload item. The resulting fractions are then summed. The total (sum of fractions) may not exceed 0.95.

Note that the qualification procedure is performed for each gamma energy emitted by the waste, and that the procedures performed for each gamma energy are completely independent. Thus, a payload item may qualify under the  $\gamma/\text{sec}$  limit for one gamma energy, and qualify under the  $\gamma/\text{sec}\cdot\text{g}$  limit for a different gamma energy (although this is unlikely). Each gamma energy is evaluated separately because a separate, independent shielding analysis is performed for each gamma energy. For each gamma energy, the  $\gamma/\text{sec}$  and  $\gamma/\text{sec}\cdot\text{g}$  limits are determined using shielding models that are bounding for any payload configuration. Thus, for each gamma energy, any payload that meets either the  $\gamma/\text{sec}$  limit or the  $\gamma/\text{sec}\cdot\text{g}$  limit (established for that gamma energy) will not yield cask exterior dose rates over regulatory limits. Cask exterior dose rate contributions from multiple gamma energies are effectively summed through the use of the sum of fractions approach described above.

When determining the  $\gamma/\text{sec}$  and  $\gamma/\text{sec}\cdot\text{g}$  limits, payload gamma energy levels are conservatively rounded up to the nearest (higher) gamma energy level for which source limits are presented in Table 5-5. Given this rounding, multiple payload gamma energies can be combined into a single, overall source, which is then compared to the source strength limits (shown in Table 5-5) which correspond to a gamma energy that is equal to or higher than that of all the gamma energies within the combined group.

This qualification process is shown in the flowchart below (Figure 5-5)

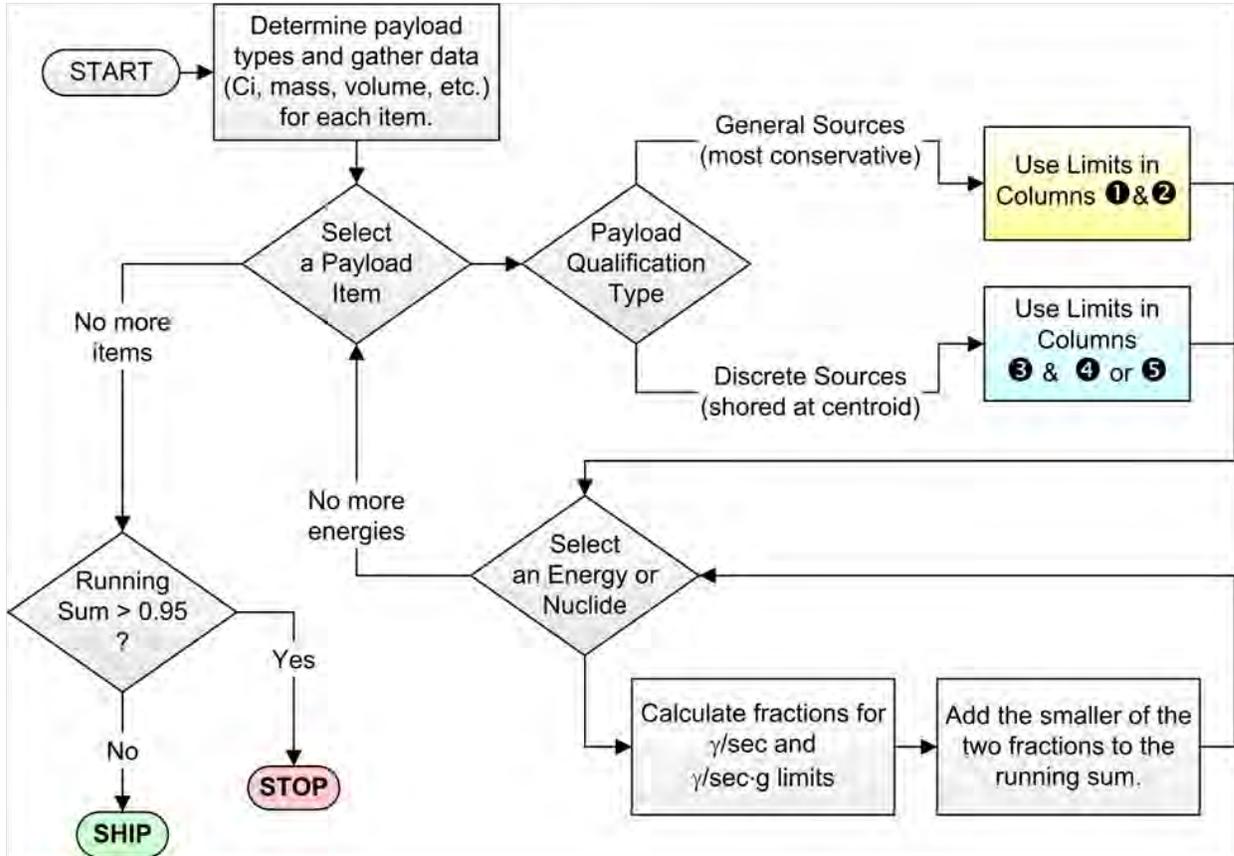


Figure 5-5 - Payload Qualification Flow Chart

## **5.6 CONCLUSION**

The cask shielding must be able to limit the dose rate to the limits of §71.47 and §71.51. This section demonstrates compliance with this requirement. Structural analysis (Section 2.0) demonstrates that the cask wall will not fail during the hypothetical accident. However, lead slump may occur during a drop giving an isolated region in the sidewall without lead. Lead slump cannot occur in the lid or bottom of the cask since lead is not present in these parts of the cask. With application of the source qualification process from Section 5.5, the contents will meet the dose rate limits.

## **5.7 REFERENCES**

- 5.7.1 ANSI/ANS 6.1.1-1977, "Neutron and Gamma-Ray Flux-to-Dose-Rate Factors."
- 5.7.2 ES Calculation, NU-391 Rev. 7, "8-120B Shielding Response"
- 5.7.3 Cember, H., "Introduction to Health Physics," Pergamon Press, 2<sup>nd</sup> Ed.
- 5.7.4 ES Document, 10-160B SAR, Consolidated Revision. 5, 2012

## **6.0 CRITICALITY EVALUATION**

Not applicable to the 8-120B package.

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## 7.0 OPERATING PROCEDURE

This chapter describes the general procedure for loading and unloading of the 8-120B Cask.

The maximum permissible activity is the lesser of the activity determined by: 1) Attachment 1 for beta and gamma emitters, 2) 3000 A<sub>2</sub>, or 3) having a decay heat of 200 watts. Radioactive contents are to be transported as exclusive use, per 10 CFR 71.4.

For contents that could radiolytically generate combustible hydrogen, see Attachment 2 for instructions on determination of hydrogen concentration.

Powdered solids shipments require that the most recent periodic leak test meets the requirements of Section 8.3.2.1 for leaktight status.

### 7.1 **LOADING THE PACKAGING**

**NOTE: Prior to loosening the impact limiter ratchet binders, inspect the exterior of the package for damage, e.g., large dents, gouges, tears to the impact limiter skin and thermal shield. Contact EnergySolutions if damage is present. The cask may not be used as a Type B package until the damage is assessed by EnergySolutions and repairs, if required, are made to achieve conformance with the drawings listed in the CoC.**

#### 7.1.1 Impact Limiter Removal

7.1.1.1 Loosen and disconnect ratchet binders from upper impact limiter.

7.1.1.2 Using suitable lifting equipment, remove upper impact limiter assembly. Care should be exercised to prevent damage to impact limiter during handling and storage.

#### 7.1.2 Secondary Lid Thermal Shield Removal

7.1.2.1 Remove the ball lock pins from each of the three retaining pins and remove the retaining pins from secondary lid lift lugs.

7.1.2.2 Using suitable lifting equipment, remove the secondary lid thermal shield. Care should be taken to prevent damage to thermal shield during handling and storage.

#### 7.1.3 Determine if cask must be removed from trailer for loading purposes. To remove cask from trailer:

7.1.3.1 Disconnect cask to trailer tie-down equipment.

7.1.3.1.1 Inspect cask lifting ear bolts for defects. Obtain replacement bolts as specified on the drawing listed in 5(a)(3) of the CoC

for any bolts that show cracking or other visual signs of distress.

7.1.3.1.2 Inspect cask lifting ear threaded holes for defects. Contact *EnergySolutions* if any bolt holes show signs of cracking or visual signs of distress.

7.1.3.2 Attach cask lifting ears and torque bolts to 200 ft-lbs.  $\pm$  20 ft-lbs. lubricated.

**NOTE: The cables used for lifting the cask must have a true angle, with respect to the horizontal of not less than 60°.**

7.1.3.3 Using suitable lifting equipment, remove cask from trailer and the lower impact limiter and place cask in level loading position.

**NOTE: In certain circumstances, loading may be accomplished through the secondary lid, into a pre-positioned waste liner that has been properly shored or into pre-positioned shoring, while the primary lid remains on the cask. Alternate “(A)” steps have been included to accommodate this situation.**

7.1.4 Loosen and remove the twenty (20) or twelve (12) bolts, which secure the primary or secondary lid to cask body, depending on which lid is to be removed for loading.

7.1.5 Inspect the bolts for defects. Obtain replacement bolts as specified on the drawing listed in 5(a)(3) of the CoC for any bolts that show cracking or other visual signs of distress.

**NOTE: The cables used for lifting either lid must have a true angle, with respect to the horizontal, of not less than 45°.**

7.1.6 Remove primary or secondary lid, depending on which lid is to be removed for loading, from cask body using suitable lifting equipment. Care should be taken during lid handling operations to prevent damage to cask or lid seal surfaces.

7.1.7 Inspect the bolts holes for defects. Contact *EnergySolutions* for any bolt holes that show signs of cracking or visual signs of distress.

7.1.8 Inspect cask interior for damage, loose materials or moisture. Clean and inspect seal surfaces. Replace seals when defects or damage is noted which may preclude proper sealing. Contact *EnergySolutions* if damage is present.

**NOTE: Radioactively contaminated liquids may be pumped out or removed by use of an absorbent material. Removal of any material from inside the cask shall be performed under the**

**supervision of qualified health physics personnel with the necessary H.P. monitoring and radiological health safety precautions and safeguards.**

**NOTE: When seals are replaced, leak testing is required as specified in Section 8.3.2.1.**

**NOTE: Verify intended contents meet the requirements of the Certificate of Compliance.**

**NOTE: Ensure the contents, secondary container, and packaging are chemically compatible, i.e., will not react to produce flammable gases.**

- 7.1.9 Depending on the method of loading, either:
- Place disposable liner, drums or other containers into the pre-positioned shoring and install additional shoring or bracing, if necessary, to restrict movement of contents during normal transport, or
  - Process liner as necessary, and cap using standard capping devices. Provide shoring if necessary to limit movement during transport, or if required by the radiological qualification procedure of Attachment 1.
- 7.1.10 Perform two independent physical verifications of the secondary container's closure system to ensure that it is properly closed and secured. This requirement is waived<sup>3</sup> for uniformly distributed resins, filters, and for solidified wastes with no dimension less than 1 cm.
- 7.1.11 Clean and inspect lid seal surfaces.
- 7.1.12 Replace the primary or secondary lid on the cask body, depending on which lid is to be removed for loading. Secure the lid by hand tightening all bolts.
- 7.1.12.1 Torque, using a star pattern, the lid bolts (lubricated) to 250 ft-lbs.  $\pm$  25 ft-lbs.
- 7.1.12.2 Re-Torque, using a star pattern, the lid bolts (lubricated) to 500 ft-lbs.  $\pm$  50 ft-lbs.

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<sup>3</sup> The basis for double verification is to assure that small, high-specific activity particles do not have the potential to migrate up into the annular gap between the primary lid and the cask bolting flange. Payloads containing any form of isotope sources, or containing highly activated fines, swarf, crud, or other hot particles less than 1 cm in size are therefore not exempt.

- 7.1.13 Replace the vent port cap screw and seal (if removed) and torque to 20 ft-lbs.  $\pm$  2 ft-lbs.
- 7.1.14 Leak test the primary lid and secondary lid O-rings and the vent port, in accordance with Section 8.3.2.2, prior to every shipment.<sup>4</sup>
- 7.1.15 If cask has been removed from trailer, proceed as follows to return cask to trailer:
  - 7.1.15.1 Using suitable lifting equipment, lift and position, cask into lower impact limiter on trailer in the same orientation as removed.
  - 7.1.15.2 Unbolt and remove cask lifting ears.
  - 7.1.15.3 Reconnect cask to trailer using tie-down equipment.
- 7.1.16 Installation of Upper Impact Limiter and Secondary Lid Thermal Shield
  - 7.1.16.1 Using suitable lifting equipment, lift, inspect for damage and install the secondary lid thermal shield.
  - 7.1.16.2 Install the three secondary lid thermal shield retaining pins into the secondary lid lift lugs and insert the ball lock pins into the retaining pins.
  - 7.1.16.3 Using suitable lifting equipment, lift, inspect for damage and install upper impact limiter on cask in the same orientation as removed.
- 7.1.17 Attach and hand tighten ratchet binders between upper and lower impact limiter assemblies.
- 7.1.18 Cover lift lugs as required.
- 7.1.19 Inspect package for proper placards and labeling.
- 7.1.20 Complete required shipping documentation.
- 7.1.21 Prior to shipment of a loaded package, the following shall be confirmed:
  - 7.1.21.1 That the consignee who expects to receive the package containing materials in excess of Type A quantities specified in 10 CFR

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<sup>4</sup> The pre-shipment leak test of the primary lid, secondary lid, and vent port seals is required before every 8-120B cask shipment, even if the lid bolts or vent port socket head cap screw have not been loosened during loading operations. This requirement is necessary to assure that the 8-120B cask containment system is properly assembled prior to every shipment since it should not be assumed that the containment system is properly assembled prior to loading operations.

- 20.1906(a) meets and follows the requirements of 10 CFR 20.1906, as applicable.
- 7.1.21.2 That trailer placarding and package labeling meet DOT specifications (49 CFR 172).
- 7.1.21.3 That all the applicable provisions of 10 CFR 71.87 are met including:
- a.) For grossly dewatered resin shipments, or shipments containing significant amounts of liquid, the secondary container(s) are adequately sealed and there is at least 10% available free volume in the form of ullage and/or interstitial void space for expansion of the liquid.
  - b.) The external radiation dose rates are less than or equal to 200 millirem per hour (mrem/hr) at the surface and less than or equal to 10 mrem/hr at 2 meters in accordance with 10 CFR 71.47 by performing radiation surveys. These surveys should be sufficient to ensure that a non-uniform distribution of radioactivity does not cause the surface or 2m limit to be exceeded.
  - c.) No temperature survey is required because the SAR thermal analysis demonstrates that by meeting the 200W decay heat limit, the temperature requirement of 10 CFR 71.43(g) is met.
- 7.1.21.4 That all security seals are properly installed.
- 7.1.21.5 Prior to shipping a loaded package, inspect the exterior of the cask for damage, e.g., large dents, gouges, tears to the impact limiter skin and thermal shield. Contact *EnergySolutions* if damage is present.
- 7.1.21.6 Prior to shipping a loaded package, confirm that the periodic leak test described in Section 8.3.2.1 has been performed. For shipments of powdered radioactive materials, confirm that most recent periodic leak test of the 8-120B demonstrated leaktight status.

## 7.2 UNLOADING THE PACKAGE

In addition to the following sequence of events for unloading a package, packages containing quantities of radioactive material in excess of Type A quantities specified in 10 CFR 20.1906(a) shall be received, monitored, and handled by the consignee receiving the package in accordance with the requirements of 10 CFR 20.1906, as applicable. Identification of packages containing greater than Type A quantities can be made by review of the shipping papers accompanying the shipment.

- 7.2.1 Move the unopened package to an appropriate level unloading area.
- 7.2.2 Perform an external examination of the unopened package. Record any significant observations.
- 7.2.3 Remove security seal(s), as required.
- 7.2.4 Impact Limiter Removal
  - 7.2.4.1 Loosen and disconnect ratchet binders from upper impact limiter.
  - 7.2.4.2 Using suitable lifting equipment, remove upper impact limiter assembly. Care should be exercised to prevent damage to impact limiter during handling and storage.
- 7.2.5 Secondary Lid Thermal Shield Removal
  - 7.2.5.1 Remove the ball lock pins from each of the three retaining pins and remove the retaining pins from secondary lid lift lugs.
  - 7.2.5.2 Using suitable lifting equipment, remove the secondary lid thermal shield. Care should be taken to prevent damage to thermal shield during handling and storage.
- 7.2.6 If cask must be removed from trailer, refer to Step 7.1.3.
- 7.2.7 Loosen and remove the twenty (20) primary lid bolts.  
**NOTE: The cables used for lifting the lid must have a true angle with respect to the horizontal of not less than 45 degrees.**
- 7.2.8 Using suitable lifting equipment, lift lid from cask using care during handling operations to prevent damage to cask and lid seal surfaces.
- 7.2.9 Remove contents.  
**NOTE: Radioactively contaminated liquids may be pumped out or removed by use of an absorbent material. Removal of any material from inside the cask shall be performed under the supervision of qualified health physics personnel with the necessary H.P. monitoring and radiological health safety precautions and safeguards.**
- 7.2.10 Assemble packaging in accordance with loading procedure (7.1.10 through 7.1.19).

### 7.3 PREPARATION OF EMPTY PACKAGING FOR TRANSPORT

- 7.3.1 Confirm the cavity is empty of contents as far as practicable

- 7.3.2 Survey the interior; decontaminate the interior if the limits of 49 CFR 173.428(d) are exceeded
- 7.3.3 Install the lid.
- 7.3.4 Install the lid closure bolts.
- 7.3.5 Torque, using a star pattern, the twenty (20) primary lid bolts (lubricated) to 250 ft-lbs.  $\pm$  25 ft-lbs.
- 7.3.6 Re-Torque, using a star pattern, the twenty (20) primary lid bolts (lubricated) to 500 ft-lbs.  $\pm$  50 ft-lbs.
- 7.3.7 Re-install the vent port cap screw with the seal. Torque the vent port cap screw to  $20\pm 2$  ft-lbs.
- 7.3.8 Decontaminate the exterior surfaces of the package as necessary.
- 7.3.9 Inspect the exterior and confirm it is unimpaired.
- 7.3.10 Using suitable lifting equipment, lift, inspect for damage and install the secondary lid thermal shield.
- 7.3.11 Install the three secondary lid thermal shield retaining pins into the secondary lid lift lugs and insert the ball lock pins into the retaining pins.
- 7.3.12 Using suitable lifting equipment, lift, inspect for damage and install upper impact limiter on cask in the same orientation as removed
- 7.3.13 Attach the tamper-indicating seals.
- 7.3.14 Confirm the requirements of 49 CFR 173.428 are met.

## Attachment 1

### Determination of Acceptable Beta and Gamma Source Strength

(see Chapter 5 for the derivation of the beta and gamma source strength limits)

#### Background and Definitions

8-120B contents (payloads) have acceptable beta and gamma sources when they can be shown to meet the requirements in Table 7-1 using the procedure described in this Attachment. Source qualification is based on a sum-of-fractions method, where sources are broken down into separate gamma energy lines and compared to the corresponding limit for that group. For some payloads, it may be necessary to subdivide the payload into separate items, determining fractions for each item by energy group then summing the fractions to determine acceptability.

Table 7-1 categorizes the limits into source strength ( $\gamma/\text{sec}$ ) and source strength density ( $\gamma/\text{sec}\cdot\text{g}$ ). For each energy, the fraction to be summed is the lowest of the  $\gamma/\text{sec}$  and  $\gamma/\text{sec}\cdot\text{g}$  fractions. Table 7-1 has five columns of limits, denoted ❶ through ❺. Depending on the nature of the payload, the user must select a pair of columns to use for each payload item, one  $\gamma/\text{sec}$  column and one  $\gamma/\text{sec}\cdot\text{g}$  column. The “general” payload columns (❶, ❷) are the most conservative and are suitable for any payload item. Higher limits are acceptable for special cases where a reduced volume item is shored about the centroid of the package cavity (e.g., an isotope source). These are termed “discrete” payload items, and are distinguished as follows:

- Use the 2.5 ft<sup>3</sup> limits (❸, ❹) when the payload item has a volume of 2.5 ft<sup>3</sup> (70,792 cm<sup>3</sup>) or less, a height of 28 inches (71.16 cm) or less, and a diameter of 17.65 inches (44.84 cm) or less, and is shored at the centroid of the cavity.
- Use the 55-gallon limits (❸, ❺) when the payload item has a volume of 7.7 ft<sup>3</sup> (218,868 cm<sup>3</sup>) or less, a height of 33.5 inches (85.1 cm) or less, and a diameter of 25.7 inches (65.3 cm) or less, and is shored at the centroid of the cavity.
- If the payload item does not meet the requirements of either the 2.5 ft<sup>3</sup> or 55-gallon definitions, regardless of shoring, then use the  $\gamma/\text{sec}$  limit for general sources ❶, and the general  $\gamma/\text{sec}\cdot\text{g}$  limit ❷.

Source limits from Table 7-1 may not be interpolated in energy. The proper procedure for gammas (and for equivalent bremsstrahlung gammas) is to round source energies up to the next higher energy level in Table 7-1.

For the purpose of qualification, the total  $\gamma/\text{sec}$  source strength for the entire payload is determined for each gamma energy group. Then, for each gamma energy group, the  $\gamma/\text{sec}\cdot\text{g}$  source strength density is conservatively determined based on the highest source strength (“hottest”) portion of the payload. Averaging of the source strength density is not allowed, either between payload items or within payload items. This conservative approach ensures that package dose rate limits will be met, even for payloads for which the source strength density is not uniform within its volume/mass, since the analysis and qualification is based on the highest source strength density material that occurs anywhere within the payload. Once the applicable  $\gamma/\text{sec}$  source strength and  $\gamma/\text{sec}\cdot\text{g}$  source strength density are determined for the payload, they are compared to the corresponding limits that are determined as discussed above.

For some payloads, use of the highest source strength density may be inappropriately conservative (e.g., payloads with a small mass of high source strength density material within a large mass of much lower source strength density material). The qualification methodology takes these payloads into consideration, and allows the payload to be separated into distinct components (or “payload items”), for which the qualification process is performed separately (e.g., one qualification for the high source strength density components/materials and another qualification for the low source strength density materials). As an example, for radiologically non-homogenous materials such as contaminated soil with hot “chunks”, the components would be the soil and the hotter particles.

Crud/contamination (or any similar finely distributed powder or granular) sources must be treated separately if there is a potential for redistribution (i.e., if the source is not chemically or physically bound to its substrate or bulk material). In such cases, the crud (or powder) source component must be qualified using only the  $\gamma$ /sec limits.

Gamma sources below 0.3 MeV may be neglected. Any sources with gamma energies above 3.5 MeV are not qualified at this time. Table 7-1 has two special rows for the common radioactive nuclides,  $^{60}\text{Co}$  and  $^{137}\text{Cs}$ ; and so their fractions may be calculated directly without breaking them down into their separate energy lines.

Pure beta emitters (e.g.,  $^3\text{H}$ ,  $^{32}\text{P}$ ,  $^{35}\text{S}$ ,  $^{90}\text{Sr}$ ,  $^{90}\text{Y}$ ) can affect package exterior gamma dose rates due to bremsstrahlung radiation. These emitters must therefore be qualified by converting the beta source strength into an equivalent bremsstrahlung (gamma) source and entering the equivalent gammas like any other gamma source line in the sum-of-fractions. Beta sources with maximum beta energies below 0.3 MeV or payload source strengths less than  $2\text{E}+12$   $\beta$ /sec may be neglected. Beta sources with peak beta energies over 3.5 MeV are not qualified at this time. Beta source strength from isotopes with significant gamma source strength may also be neglected. The method for converting betas is presented in the procedure below and the methodology is discussed in Chapter 5 of the SAR.

Payload items with densities between 0.0 and 9.0 g/cc are within the range of validity for Table 7-1  $\gamma$ /sec·g limits. Most materials fall within this range, with the exception of lead and some exotic metals. Do not consider liner, or other secondary container, materials when calculating density. Densities are for the basic material, and should not include voids. Radioactive payload items with densities above 9.0 g/cc must be qualified using the  $\gamma$ /sec limits alone.

In summary, all sources must be accounted for using the sum-of-fractions method described in the following procedure. The only sources which may be considered insignificant (and not included in the sum-of-fractions) are:

- Gammas with energies below 0.3 MeV,
- All pure beta emitters with peak energies below 0.3 MeV,
- Pure beta emitters with peak energies above 0.3 MeV when the combined source of all such betas is under  $2 \times 10^{12}$   $\beta$ /sec.
- Beta emissions from gamma-emitting isotopes.

Table 7-1 - Payload Source Strength and Source Strength Density Limits

Energy (MeV)	General Sources		Discrete Sources (shored at centroid)*		
	Source γ/sec	Source Density γ/sec-g	Source γ/sec	Source Density γ/sec-g	
				2.5 ft <sup>3</sup>	55 gal
	①	②	③	④	⑤
3.50	9.611E+09	4.434E+05	2.504E+11	2.957E+06	1.563E+06
2.75	1.285E+10	6.515E+05	3.293E+11	4.301E+06	2.281E+06
2.25	1.823E+10	1.065E+06	4.432E+11	6.800E+06	3.634E+06
1.83	3.040E+10	2.061E+06	6.404E+11	1.279E+07	6.869E+06
1.50	6.111E+10	4.938E+06	8.971E+11	2.920E+07	1.592E+07
1.17	2.142E+11	1.640E+07	1.528E+12	8.418E+07	6.173E+07
0.90	8.635E+11	5.539E+07	2.747E+12	2.796E+08	1.919E+08
0.70	2.131E+12	1.887E+08	5.088E+12	9.566E+08	6.366E+08
0.50	7.075E+12	1.298E+09	1.151E+13	6.529E+09	4.185E+09
Co-60	1.393E+11	1.182E+07	1.294E+12	6.169E+07	4.074E+07
Cs-137	2.580E+12	2.556E+08	5.768E+12	1.281E+09	8.536E+08

\*For discrete source limits, use columns ④ and ⑤ when the payload object meets the 2.5 ft<sup>3</sup> size criteria, or columns ③ and ⑤ when it meets the 55 gallon size criteria. When the size meets neither criteria use columns ① and ②.

Qualification Procedure

The Payload Qualification Flowchart (Figure 7-1) provides a graphical overview of the qualification process. The procedure below provides more detailed step-wise instructions.

1. Determine the number of types of material (payload items) in the payload. For each item, determine the configuration (i.e., general or discrete), isotopic source strength (in  $\gamma/\text{sec}$ ), isotopic source strength density (in  $\gamma/\text{sec}\cdot\text{g}$  for the hottest portion of the payload item), dimensions, volume, mass, and maximum mass density. Determine the payload totals for each parameter.
2. For payloads that include pure beta emitters with maximum beta energies  $> 0.3$  MeV and  $\sum S_{\beta} \geq 2\text{E}+12$   $\beta/\text{sec}$ , convert each beta source to an equivalent gamma source for each payload item.

- Confirm that no isotope peak beta energies are  $> 3.5$  MeV; materials with beta energies  $> 3.5$  MeV are unacceptable.
- The equivalent gamma source for each payload item,  $S_{\gamma}$ , equals  $3.5\text{E}-04 S_{\beta} Z_w E_{\beta\text{avg}}$  in gammas per sec; where:

$S_{\beta}$  is the beta source strength in  $\beta/\text{sec}$ ,

$Z_w$  is the weighted average  $Z$  of the beta-absorbing material; for a single material absorber, use the  $Z$  of the material, for compounds or mixtures, use a weighted average  $Z_w$ :

$$Z_w = \sum_{i=1}^n \left( \frac{m_i}{m_{total}} \cdot Z_i \right)$$

$Z_w$  is determined, as described above, for both the waste payload and the wall of the secondary container (liner) that the waste resides in, the higher of the two  $Z_w$  values is used, and

$E_{\beta\text{avg}}$  is the average energy of the beta in MeV.

- The resulting equivalent gamma source has strength  $S_{\gamma}$  at an energy of  $E_{\beta\text{max}}$ , the maximum beta energy.
  - Include the equivalent gamma source along with the other gamma source(s) determined in Step 3.
  - Equivalent gamma energies must be rounded up to the next higher energy level listed in Table 7-1.
3. For each gamma energy of each payload item (ignoring gamma energies below 0.3 MeV), calculate the total  $\gamma/\text{sec}$  for the payload item and the  $\gamma/\text{sec}\cdot\text{g}$  for the hottest (highest source strength density) portion of the item.
    - $^{60}\text{Co}$  and  $^{137}\text{Cs}$  may be treated like single “energies” since they have their own limits in Table 7-1.
    - Gamma energies must be rounded up to the next higher energy level listed in Table 7-1.

- If any gammas have energies above 3.5 MeV, the material is unacceptable for transport in the package.
  - For payloads with a large number of gammas, the gammas may be grouped into the energy groups in Table 7-1 and the total gamma sources can be determined for each group. The energies listed in Table 7-1 are the maximum energies for the groups.
  - Calculations of  $\gamma/\text{sec}\cdot\text{g}$  should not include the mass of liners or other secondary containers. For shipments containing grossly dewatered resins, the mass of free standing interstitial water should be discounted when calculating  $\gamma/\text{sec}\cdot\text{g}$ .
4. For each payload item, select the two appropriate limit columns (❶ through ❸) in Table 7-1: one each for  $\gamma/\text{sec}$  and  $\gamma/\text{sec}\cdot\text{g}$ . Base the  $\gamma/\text{sec}$  on the total  $\gamma/\text{sec}$  for the item, and the  $\gamma/\text{sec}\cdot\text{g}$  on the highest source strength density (“hottest”) portions of the item.
    - Confirm that the density of each payload item is less than  $9.0 \text{ g/cm}^3$ . Items with higher densities can only be qualified using the  $\gamma/\text{sec}$  limits because the  $\gamma/\text{sec}\cdot\text{g}$  limits are not valid for  $\rho \geq 9.0 \text{ g/cm}^3$ .
    - For “discrete” sources, confirm that the sources meet the shoring requirement and the volume and the physical dimension specifications listed in the beginning of this Attachment.
    - Crud/contamination (or powder) payload items can only be qualified using the  $\gamma/\text{sec}$  limits (Table 7-1, column ❶ or ❸).
  5. For each energy, calculate the  $\gamma/\text{sec}$  and  $\gamma/\text{sec}\cdot\text{g}$  fractions (i.e., payload item source/limit fraction). Select the smallest of each pair of fractions at each energy and add the resulting fraction to the running sum of fractions.
  6. Repeat Steps 4-5 for each payload item, adding the fractions to the running sum.
  7. If the sum-of-fractions is less than 0.95, the payload’s radiological source is acceptable.

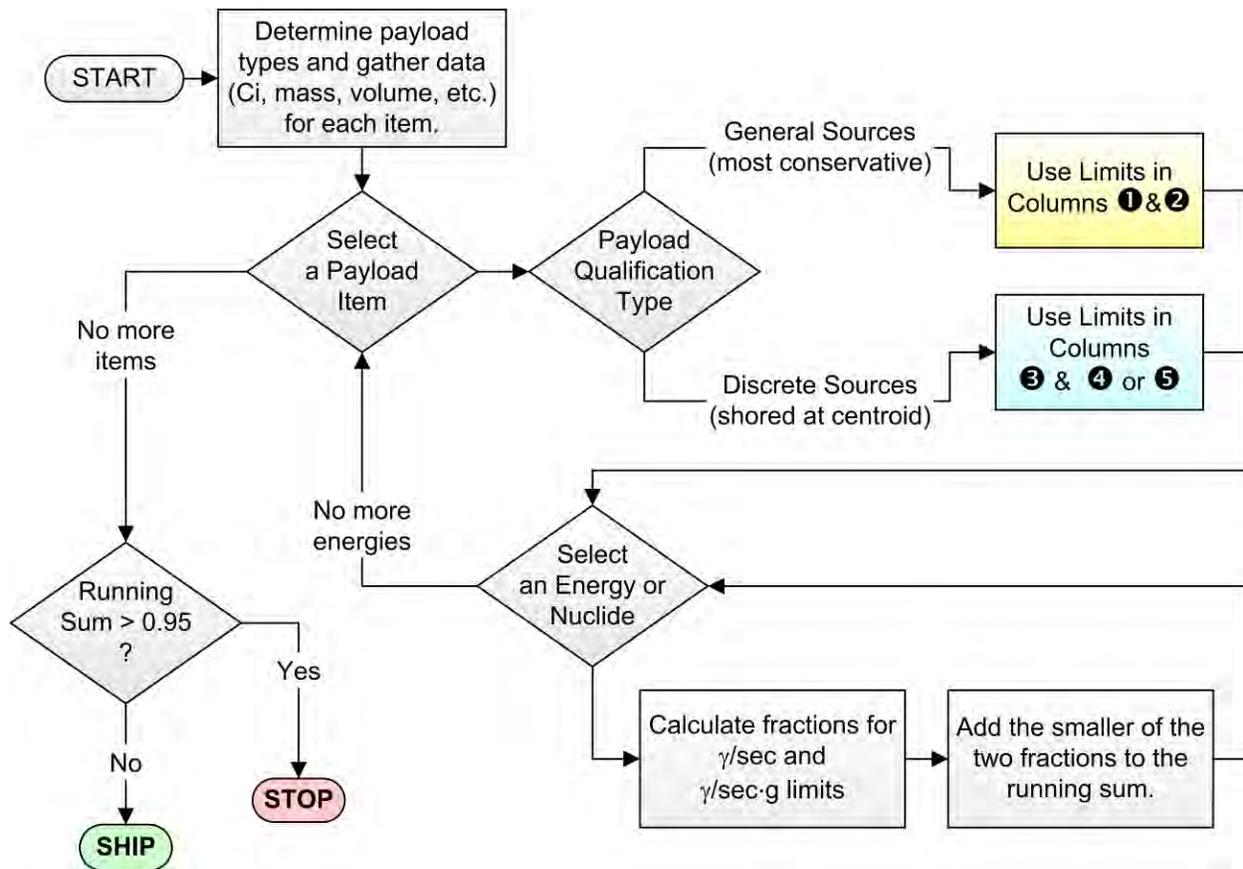


Figure 7-1 – Payload Qualification Flow Chart

Example 1 - Cs-137 Source Capsule

**Problem:** Determine the acceptability of a 50 Ci <sup>137</sup>Cs source to be centrally shored. The source is a metal capsule 2 cm in diameter by 10 cm long, and the Cs source pellet weighs 50 g.

**Step 1:** Characterize Source  
Given in the problem statement.

**Step 2:** Convert Beta Source to Equivalent Gamma Source  
Not applicable (Cs-137 is not a pure beta emitter).

**Step 3:** Calculate Gamma Source Strengths and Source Strength Densities  
The qualification Table has specific limits for <sup>137</sup>Cs, so it is not necessary to do the qualification by energy line. The source's Ci source strength must be converted to γ/sec and γ/sec·g in order to calculate the source/limit fractions. <sup>137</sup>Cs produces 0.85 gammas per decay with an energy of 0.66 MeV. The total source strength is

$$3.7 \times 10^{10} \frac{d}{Ci} \times \frac{0.85\gamma}{d} \times 50Ci = 1.57 \times 10^{12} \frac{\gamma}{sec},$$

and, dividing by 50 g, the total source strength density is 3.14E10 γ/sec·g.

**Step 4:** Select the Limits  
Since this payload is to be shipped in a shored configuration, the payload is a “discrete” type payload. The size fits within the defined envelope for the 2.5 ft<sup>3</sup> payload, therefore the column ③ and ④ limits apply for γ/sec and γ/sec·g, respectively.

**Steps 5-7** Sum the Fractions  
For this example, there is only one fraction to calculate<sup>5</sup>.

Line	Payload Item	Type	Shape (Discrete Only)	Energy (MeV), or Nuclide	Payload Source Term		Limits			Fractions, F		F <sub>min</sub>
					γ/sec	γ/sec·g	Energy	γ/sec	γ/sec·g	γ/sec	γ/sec·g	
1	Source	Discrete	2.5 ft3	Cs-137	1.57E+12	3.15E+10	Cs-137	③ 5.77E+12	④ 1.28E+09	2.73E-01	2.46E+01	2.73E-01
Sum: 2.73E-01												

Since the sum is less than 0.95, the source is an acceptable payload.

<sup>5</sup> Always perform calculations with the full precision for the limits shown in Table . In these examples, full precision data was used, but the number of digits is reduced for presentation purposes.

Example 2 – Solidified Process Waste

**Problem:** Determine the acceptability of a 100 ft<sup>3</sup> secondary container containing solidified process waste. The activity is uniformly distributed. The measured weight of the filled container is 13,100 lbs, and the weight of the empty container is 1,100 lbs. The isotopic activity, determined by analysis of samples of the waste, is:

5 Ci of <sup>60</sup>Co, 10 Ci of <sup>137</sup>Cs, 50 Ci of <sup>55</sup>Fe, 4 Ci of <sup>54</sup>Mn, and 20 Ci of <sup>90</sup>Sr

**Step 1:** Characterize Source

Given in the problem statement.

**Step 2:** Convert Beta Source to Equivalent Gamma Source

<sup>90</sup>Sr emits beta radiation through its own decay, plus the decay of its short-lived daughter product, <sup>90</sup>Y. So the beta production rate is 20 Ci \* 3.7E+10 d/Ci \* 2 = 1.5E+12 β/sec. Since this is below the threshold of 2E+12 β/sec, the beta production is not significant and can be disregarded.

**Step 3:** Calculate Gamma Source Strengths and Source Strength Densities

The qualification Table has specific limits for <sup>60</sup>Co and <sup>137</sup>Cs, but it will be necessary to do the qualification by energy line for the remaining nuclides. After converting the Ci data to gamma energy lines for the remaining nuclides (neglecting any gamma energy lines < 0.3 MeV), the following source data are to be used for qualification. The γ/sec·g source strength densities are based on 12,000 lbs, the actual weight of the radioactive material. The mass density is assumed to be uniform for the payload.

Energy (MeV), or Nuclide	Payload Source Term	
	γ/sec	γ/sec·g
Co-60	3.70E+11	6.80E+04
Cs-137	3.15E+11	5.78E+04
0.8348	1.48E+11	2.72E+04

**Step 4:** Select the Limits

Since this payload does not meet the definition of either of the two discrete shored configurations (2.5 ft<sup>3</sup> or 55 gal), it is a “general” type payload. The limits in columns ❶ and ❷ apply for γ/sec and γ/sec·g, respectively.

**Steps 5-7** Sum the Fractions

For this example, there are three lines: a <sup>60</sup>Co line, <sup>137</sup>Cs line, and one energy line representing <sup>54</sup>Mn (<sup>55</sup>Fe and <sup>90</sup>Sr are disregarded because <sup>55</sup>Fe gammas are below 0.3 MeV, and the <sup>90</sup>Sr betas are below 2E+12 β/sec).

Line	Payload Item	Type	Shape (Discrete Only)	Energy (MeV), or Nuclide	Payload Source Term		Limits			Fractions, F		F <sub>min</sub>
					γ/sec	γ/sec·g	Energy	γ/sec	γ/sec·g	γ/sec	γ/sec·g	
1	Solidified Waste Cont.	General		Co-60	3.70E+11	6.80E+04	Co-60	1.39E+11	1.18E+07	2.66E+00	5.75E-03	5.75E-03
2	Solidified Waste Cont.	General		Cs-137	3.15E+11	5.78E+04	Cs-137	2.58E+12	2.56E+08	1.22E-01	2.26E-04	2.26E-04
3	Solidified Waste Cont.	General		0.8348	1.48E+11	2.72E+04	0.9	8.63E+11	5.54E+07	1.71E-01	4.91E-04	4.91E-04
											Sum: 6.47E-03	

Since the sum is less than 0.95, the container is an acceptable payload.

Example 3 – Dewatered Resin Liner

**Problem:** Determine the acceptability of a 100 ft<sup>3</sup> steel secondary container containing dewatered resin. The activity is uniformly distributed. The measured weight of the filled container is 13,100 lbs; the weight of the empty container is 1,100 lbs. The isotopic activity, determined by analysis of samples of the waste, is: 5 Ci of <sup>60</sup>Co, 10 Ci of <sup>137</sup>Cs, 50 Ci of <sup>55</sup>Fe, 4 Ci of <sup>54</sup>Mn, and 30 Ci of <sup>90</sup>Sr. Also included is a 100 gram piece of activated metal, not shored, with an activity of 0.5 Ci of <sup>60</sup>Co. The activated metal is steel with a density of 8 g/cm<sup>3</sup>.

This differs from Example 2 in that there is more <sup>90</sup>Sr, and there is the additional piece of activated metal.

**Step 1:** Characterize Source

Given in the problem statement.

**Step 2:** Convert Beta Source to Equivalent Gamma Source

<sup>90</sup>Sr emits beta radiation through its own decay, plus the decay of its short-lived daughter product, <sup>90</sup>Y. So the total beta production rate is 30 Ci \* 3.7E+10 d/Ci \* 2 = 2.22E+12 betas/sec. Since this is above the threshold of 2E+12 betas/sec, the beta production must be considered. Using the procedure to convert beta into equivalent gamma radiation described in Attachment 1, the <sup>90</sup>Sr/<sup>90</sup>Y betas<sup>6</sup> will be treated as follows:

$$E_{\max\text{Sr}} = 0.54 \text{ MeV}, \quad E_{\text{avgSr}} = 0.19 \text{ MeV}$$

$$E_{\max\text{Y}} = 2.27 \text{ MeV}, \quad E_{\text{avgY}} = 0.93 \text{ MeV}$$

$$Z_{\text{Resin}} = 5.6, \quad Z_{\text{Steel}} = 26$$

$$Z_w = 26 \text{ (the higher of the resin } Z \text{ and the liner wall } Z)$$

$$S_{\gamma\text{Sr}} = (1.11\text{E}+12)(3.5\text{E}-04)(26)(0.19) = \underline{1.92\text{E}+08 \text{ } \gamma/\text{s @ } 0.54 \text{ MeV}}$$

$$S_{\gamma\text{Y}} = (1.11\text{E}+12)(3.5\text{E}-04)(26)(0.93) = \underline{9.39\text{E}+09 \text{ } \gamma/\text{s @ } 2.27 \text{ MeV}}$$

**Step 3:** Calculate Gamma Source Strengths and Source Strength Densities

This payload must be broken into two payload items, due to the physical and radiological differences between the resins and the activated metal.

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<sup>6</sup> Cember, H., "Introduction to Health Physics," Pergamon Press, 2<sup>nd</sup> Ed.

Resin Payload Item

Like Example 2, the following source data are to be used for qualification of the gamma emitters. The mass density is assumed to be uniform for the resin portion of the payload.

Energy (MeV), or Nuclide	Payload Source Term	
	γ/sec·g	γ/sec·g
Co-60	3.70E+11	6.80E+04
Cs-137	3.15E+11	5.78E+04
0.8348	1.48E+11	2.72E+04

Activated Metal Payload Item

<sup>60</sup>Co emits two gammas per disintegration, therefore the total source strength for the activated metal is (0.5 Ci)(2 γ/d)(3.7E+10 d/sec-Ci) = 3.7E+10 γ/sec. Dividing by the mass of 100 g, the source strength density is 3.7E+08 γ/sec. The mass density is assumed to be uniform for the 100 gram piece of metal.

Step 4: Select the Limits

Resin Payload Item - Since this payload item does not meet the definitions of either of the two discrete shored configurations (2.5 ft<sup>3</sup> or 55 gal), it is a “general” type payload. The limits in columns ❶ and ❷ apply for γ/sec and γ/sec·g, respectively.

Activated Metal Payload Item – This payload item is small and fits within the defined envelope for the 2.5 ft<sup>3</sup> payload, however it is not shored, and so the activated metal is also a “general” type payload item. Columns ❶ and ❷ apply for the γ/sec and γ/sec·g limits, respectively.

Steps 5-7 Sum the Fractions

For this example, there are six lines: 1-3 are for the resin gamma emitters, 4-5 are for the bremsstrahlung gammas produced by <sup>90</sup>Sr and <sup>90</sup>Y, and one line for the activated metal <sup>60</sup>Co.

Line	Payload Item	Type	Shape (Discrete Only)	Energy (MeV), or Nuclide	Payload Source Term		Limits			Fractions, F		F <sub>min</sub>
					γ/sec	γ/sec·g	Energy	γ/sec	γ/sec·g	γ/sec	γ/sec·g	
1	Resin	General		Co-60	3.70E+11	6.80E+04	Co-60	❶ 1.39E+11	❷ 1.18E+07	2.66E+00	5.75E-03	5.75E-03
2	Resin	General		Cs-137	3.15E+11	5.78E+04	Cs-137	❶ 2.58E+12	❷ 2.56E+08	1.22E-01	2.26E-04	2.26E-04
3	Resin	General		0.8348	1.48E+11	2.72E+04	0.9	❶ 8.63E+11	❷ 5.54E+07	1.71E-01	4.91E-04	4.91E-04
4	Resin (betas)	General		0.54	1.92E+08	3.53E+01	0.7	❶ 2.13E+12	❷ 1.89E+08	9.01E-05	1.87E-07	1.87E-07
5	Resin (betas)	General		2.27	9.39E+09	1.73E+03	2.75	❶ 1.29E+10	❷ 6.51E+05	7.30E-01	2.65E-03	2.65E-03
6	Metal	General		Co-60	3.70E+10	3.70E+08	Co-60	❶ 1.39E+11	❷ 1.18E+07	2.66E-01	3.13E+01	2.66E-01
Sum: 2.75E-01												

Since the sum is less than 0.95, the container is an acceptable payload.

Example 4 – Activated Waste with Non-Fixed Contamination

**Problem:** Determine the acceptability of a 100 ft<sup>3</sup> steel secondary container containing activated metal. The measured weight of the filled container is 7,100 lbs; the weight of the empty container is 1,100 lbs. The metal is composed of mildly activated steel, with non-fixed surface contamination. The contaminated surface area is estimated to be 500 ft<sup>2</sup>. There is one small piece of activated steel with a significantly higher activity. Determine whether this smaller item can be included in the shipment, and whether it needs to be shored. The isotopic activities, determined by analysis of samples of the waste, are as follows:

- Most of the steel has similar radiological properties. Based on an analysis of the highest-activity sample, the constituents are: 20 Ci of <sup>58</sup>Co, 30 Ci of <sup>60</sup>Co, and 20 Ci of <sup>54</sup>Mn.
- The small activated metal item has a mass of 100 g, dimensions of 1" x 1" x 24", with an activity of 6 Ci of <sup>60</sup>Co.
- The non-fixed crud contamination level, based on the highest-activity sample, is 50,000 dpm, which has been determined to be 50% <sup>55</sup>Fe, 30% <sup>137</sup>Cs, and 20% <sup>60</sup>Co. The contaminated surface area is 500 ft<sup>2</sup>.

**Step 1:** Characterize Source

Given in the problem statement.

**Step 2:** Convert Beta Source to Equivalent Gamma Source

Not applicable since the beta source is less than 2E+12 β/sec.

**Step 3:** Calculate Gamma Source Strengths and Source Strength Densities

100g Activated Metal Payload Item

<sup>60</sup>Co emits two gammas per disintegration, therefore the total source strength for the small activated metal item is (6 Ci)(2 γ/d)(3.7E+10 d/sec-Ci) = 4.44E+11 γ/sec. Dividing by the mass of 100 g, the source strength density is 4.44E+09 γ/sec. The mass density is assumed to be uniform for the small activated metal item.

Energy (MeV), or Nuclide	Payload Source Term	
	γ/sec	γ/sec·g
Co-60	4.44E+11	4.44E+09

Remaining Activated Metal Payload Item

<sup>60</sup>Co emits two gammas per disintegration, therefore the total <sup>60</sup>Co source strength for the activated metal is (30 Ci)(2 γ/d)(3.7E+10 d/sec-Ci) = 2.22E+12 γ/sec. The remaining nuclides, <sup>58</sup>Co and <sup>54</sup>Mn, were converted to individual energy lines<sup>7</sup> (E<0.3 MeV were neglected). Sources were divided by 2.72E+06 g (i.e., 6,000 lb) to obtain the γ/sec·g. The mass density of the metal is assumed to be uniform. The resulting sources are:

Energy (MeV), or Nuclide	Payload Source Term	
	γ/sec	γ/sec·g
Co-60	2.22E+12	8.16E+05
0.511	2.21E+11	8.12E+04
0.8108	7.36E+11	2.70E+05
0.8348	7.40E+11	2.72E+05
0.8639	5.45E+09	2.00E+03
1.6747	3.97E+09	1.46E+03

Crud Payload Item

50,000 dpm is equivalent to 2.25E-08 Ci per 100 cm<sup>2</sup>. The total source strength is therefore (2.25E-08 Ci/100cm<sup>2</sup>) (500 ft<sup>2</sup>)(929 cm<sup>2</sup>/ft<sup>2</sup>) = 1.05E-04 Ci. The nuclide breakdown is therefore: 5.23E-05 Ci of <sup>55</sup>Fe, 3.14E-05 Ci of <sup>137</sup>Cs, and 2.09E-05 Ci of <sup>60</sup>Co. <sup>55</sup>Fe can be neglected since it does not emit any gammas > 0.3 MeV. We can only use the γ/sec limit for qualification. The source inputs are therefore:

Energy (MeV), or Nuclide	Payload Source Term	
	γ/sec	γ/sec·g
Co-60	1.55E+06	
Cs-137	9.88E+05	

Step 4: Select the Limits

The 100g activated item would meet the size criteria for the 55-gallon discrete shored configuration if both the container were shored and the item was shored within the container, in which case its limits would be columns ③ and ⑤ for γ/sec and γ/sec·g, respectively. Otherwise, since it would be unshored, the limits in columns ① and ② would apply for γ/sec and γ/sec·g, respectively.

The remaining activated metal does not meet the definitions of either of the two discrete shored configurations (2.5 ft<sup>3</sup> or 55 gal), so it is a “general” type payload item. The limits in columns ① and ② apply for γ/sec and γ/sec·g, respectively.

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<sup>7</sup> MicroShield, Version 8.01, Grove Engineering.

The crud is free to move within the cavity and is therefore a “general” type payload item. Also, as discussed in the first section of this Attachment, crud must be qualified using the  $\gamma$ /sec limit. Thus, the limit in column ①, in  $\gamma$ /sec, applies for the crud.

Steps 5-7 Sum the Fractions

First we will try qualifying the payload without shoring the small activated item. Note that it is not acceptable to average the activated metal together with the small 100 g item.

Line	Payload Item	Type	Shape (Discrete Only)	Energy (MeV), or Nuclide	Payload Source Term		Limits			Fractions, F		F <sub>min</sub>
					$\gamma$ /sec	$\gamma$ /sec·g	Energy	$\gamma$ /sec	$\gamma$ /sec·g	$\gamma$ /sec	$\gamma$ /sec·g	
1	100g activated item	General	55 gal	Co-60	4.44E+11	4.44E+09	Co-60	① 1.39E+11	② 1.18E+07	3.19E+00	3.76E+02	3.19E+00
2	Remaining metal	General		Co-60	2.22E+12	8.16E+05	Co-60	① 1.39E+11	② 1.18E+07	1.59E+01	6.90E-02	6.90E-02
3	Remaining metal	General		0.511	2.21E+11	8.12E+04	0.7	① 2.13E+12	② 1.89E+08	1.04E-01	4.30E-04	4.30E-04
4	Remaining metal	General		0.8108	7.36E+11	2.70E+05	0.9	① 8.63E+11	② 5.54E+07	8.52E-01	4.88E-03	4.88E-03
5	Remaining metal	General		0.8348	7.40E+11	2.72E+05	0.9	① 8.63E+11	② 5.54E+07	8.57E-01	4.91E-03	4.91E-03
6	Remaining metal	General		0.8639	5.45E+09	2.00E+03	0.9	① 8.63E+11	② 5.54E+07	6.31E-03	3.61E-05	3.61E-05
7	Remaining metal	General		1.6747	3.97E+09	1.46E+03	1.83	① 3.04E+10	② 2.06E+06	1.31E-01	7.08E-04	7.08E-04
8	Crud	General		Co-60	1.55E+06		Co-60	① 1.39E+11	② 1.18E+07	1.11E-05		1.11E-05
9	Crud	General		Cs-137	9.88E+05		Cs-137	① 2.58E+12	② 2.56E+08	3.83E-07		3.83E-07

Sum: 3.27E+00

This approach does not pass. Since the discrete shored payload items have higher limits, we can try to see if shoring the 100g item will pass.

Line	Payload Item	Type	Shape (Discrete Only)	Energy (MeV), or Nuclide	Payload Source Term		Limits			Fractions, F		F <sub>min</sub>
					$\gamma$ /sec	$\gamma$ /sec·g	Energy	$\gamma$ /sec	$\gamma$ /sec·g	$\gamma$ /sec	$\gamma$ /sec·g	
1	100g activated item	Discrete	55 gal	Co-60	4.44E+11	4.44E+09	Co-60	③ 1.29E+12	③ 4.07E+07	3.43E-01	1.09E+02	3.43E-01
2	Remaining metal	General		Co-60	2.22E+12	8.16E+05	Co-60	① 1.39E+11	② 1.18E+07	1.59E+01	6.90E-02	6.90E-02
3	Remaining metal	General		0.511	2.21E+11	8.12E+04	0.7	① 2.13E+12	② 1.89E+08	1.04E-01	4.30E-04	4.30E-04
4	Remaining metal	General		0.8108	7.36E+11	2.70E+05	0.9	① 8.63E+11	② 5.54E+07	8.52E-01	4.88E-03	4.88E-03
5	Remaining metal	General		0.8348	7.40E+11	2.72E+05	0.9	① 8.63E+11	② 5.54E+07	8.57E-01	4.91E-03	4.91E-03
6	Remaining metal	General		0.8639	5.45E+09	2.00E+03	0.9	① 8.63E+11	② 5.54E+07	6.31E-03	3.61E-05	3.61E-05
7	Remaining metal	General		1.6747	3.97E+09	1.46E+03	1.83	① 3.04E+10	② 2.06E+06	1.31E-01	7.08E-04	7.08E-04
8	Crud	General		Co-60	1.55E+06		Co-60	① 1.39E+11	② 1.18E+07	1.11E-05		1.11E-05
9	Crud	General		Cs-137	9.88E+05		Cs-137	① 2.58E+12	② 2.56E+08	3.83E-07		3.83E-07

Sum: 4.23E-01

Since the sum is less than 0.95, the container is an acceptable payload if the container and 100 g item are shored such that the 100g item is located at the centroid of the cask cavity.

Example 5 – Contaminated Soil

**Problem:** Determine the acceptability of a 100 ft<sup>3</sup> steel secondary container containing a contaminated soil mixture. The activity is not uniformly distributed. The measured weight of the filled container is 10,100 lbs; the weight of the empty container is 1,100 lbs. 5% of the payload mass is made up of small bits of grout used to immobilize contamination. The size of the grout chunks ranges from 0.1 cm to 10 cm. The grout contains <sup>137</sup>Cs at a maximum concentration of 350 Ci/ft<sup>3</sup>. The remaining 95% of the material is soil with a activity of 10 Ci/ft<sup>3</sup> of <sup>137</sup>Cs. The density of the soil and grout are both 100 lb/ft<sup>3</sup>. Activities were determined by analysis of samples of the most active representative waste.

**Step 1:** Characterize Source

Given in the problem statement.

**Step 2:** Convert Beta Source to Equivalent Gamma Source

Not applicable (Cs-137 is not a pure beta emitter).

**Step 3:** Calculate Gamma Source Strengths and Source Strength Densities

We will evaluate the payload two ways: one treating the entire payload as a single item with a bounding source strength ( $\gamma/\text{sec}$ ) and source strength density ( $\gamma/\text{sec}\cdot\text{g}$ ), and the second assuming we will treat the payload as two separate items: grout and soil.

If there is a potential for the contamination to redistribute, then it would be appropriate to qualify the source using only the  $\gamma/\text{sec}$  limits. For this example, the grout physically prevents its contamination from redistribution, and for simplicity we assume that the soil, which has a much lower source strength density, also physically binds its contaminants. For both payload items, we will therefore perform the qualification using both source strength ( $\gamma/\text{sec}$ ) and source strength density ( $\gamma/\text{sec}\cdot\text{g}$ ). Note that this example does account for the possibility that the grout will redistribute (or concentrate) itself within the soil, since the single payload approach will use the higher source strength density ( $\gamma/\text{sec}\cdot\text{g}$ ) of the grout in the qualification.

Grout Payload Item

The grout gamma source strength is  $(350 \text{ Ci/ft}^3)(1 \text{ ft}^3/100 \text{ lb})(9,000 \text{ lb}\cdot 0.05)$   
 $(3.7\text{E}+10 \text{ d/sec-Ci})(0.85 \text{ } \gamma/\text{d}) = 4.95\text{E}+13 \text{ } \gamma/\text{sec}$ . Dividing by the mass (450 lb, or  
 $2.04\text{E}+05 \text{ g}$ ), the source strength density would be  $2.43\text{E}+08 \text{ } \gamma/\text{sec}\cdot\text{g}$ .

Payload Source Term	
$\gamma/\text{sec}$	$\gamma/\text{sec}\cdot\text{g}$
4.95E+13	2.43E+08

Soil Payload Item

The soil gamma source strength is  $(10 \text{ i/ft}^3)(1 \text{ ft}^3/100 \text{ lb})(9,000 \text{ lb} \cdot 0.95)(3.7\text{E}+10 \text{ d/sec-Ci})(0.85 \text{ } \gamma/\text{d}) = 2.69\text{E}+13 \text{ } \gamma/\text{sec}$ . Dividing by the mass (8550 lb, or  $3.88\text{E}+06 \text{ g}$ ), the source strength density would be  $6.93\text{E}+06 \text{ } \gamma/\text{sec} \cdot \text{g}$ .

Energy (MeV), or Nuclide	Payload Source Term	
	$\gamma/\text{sec}$	$\gamma/\text{sec} \cdot \text{g}$
Cs-137	2.69E+13	6.93E+06

Combined Grout/Soil Payload Item

If the payload is treated as a single item, the  $\gamma/\text{sec}$  is set equal to the sum of the  $\gamma/\text{sec}$  for both the grout and soil components. The  $\gamma/\text{sec} \cdot \text{g}$  is set equal to that of the “hottest” component (i.e., the grout). Thus, the gamma source strength would be  $5.66\text{E}+13 \text{ } \gamma/\text{sec}$  ( $4.95\text{E}+13 + 2.69\text{E}+13$ ). The  $\gamma/\text{sec} \cdot \text{g}$  equals the  $2.43\text{E}+08$  value that applies for the grout.

Payload Source Term	
$\gamma/\text{sec}$	$\gamma/\text{sec} \cdot \text{g}$
7.64E+13	2.43E+08

Step 4: Select the Limits

Since none of these payload items meets the definition of either of the two discrete shored configurations ( $2.5 \text{ ft}^3$  or 55 gal), they are “general” type payload items. The limits in columns ❶ and ❷ apply for  $\gamma/\text{sec}$  and  $\gamma/\text{sec} \cdot \text{g}$ , respectively.

Steps 5-7 Sum the Fractions

As a first try, we attempt to qualify the payload as being two components: the grout and soil.

ID	Payload Item	Type	Shape (Discrete Only)	Energy (MeV), or Nuclide	Payload Source Term		Limits			Fractions, F		F <sub>min</sub>
					$\gamma/\text{sec}$	$\gamma/\text{sec} \cdot \text{g}$	Energy	$\gamma/\text{sec}$	$\gamma/\text{sec} \cdot \text{g}$	$\gamma/\text{sec}$	$\gamma/\text{sec} \cdot \text{g}$	
1	Grout	General		Cs-137	4.95E+13	2.43E+08	Cs-137	❶ 2.58E+12	❷ 2.56E+08	1.92E+01	9.50E-01	9.50E-01
2	Soil	General		Cs-137	2.69E+13	6.93E+06	Cs-137	❶ 2.58E+12	❷ 2.56E+08	1.04E+01	2.71E-02	2.71E-02
											Sum: 9.77E-01	

Since the sum is greater than 0.95, the container is not an acceptable payload.

It is acceptable, however, to treat the payload as a single (combined) item, with a  $\gamma/\text{sec}$  equal to the sum of the component (grout and soil)  $\gamma/\text{sec}$  values, and a  $\gamma/\text{sec} \cdot \text{g}$  equal to that of the “hottest” component (i.e., the grout).

Line	Payload Item	Type	Shape (Discrete Only)	Energy (MeV), or Nuclide	Payload Source Term		Limits			Fractions, F		F <sub>min</sub>
					γ/sec	γ/sec·g	Energy	γ/sec	γ/sec·g	γ/sec	γ/sec·g	
1	All-grout	General		Cs-137	7.64E+13	2.43E+08	Cs-137	● 2.58E+12	● 2.56E+08	2.96E+01	9.50E-01	9.50E-01
Sum: 9.50E-01												

Since the sum is less than 0.95, the container is an acceptable payload.

This example illustrates that there is no benefit from dividing a payload into multiple payload items if all of the items qualify under the  $\gamma/\text{sec}\cdot\text{g}$  limit. If the payload is divided, one of the ( $\gamma/\text{sec}\cdot\text{g}$ ) fractions will be that which applies for the grout (i.e., 0.950). If the single payload approach is used, the  $\gamma/\text{sec}\cdot\text{g}$  value is set to that which applies for the “hottest” item (the grout), so the total fraction for the entire payload would be 0.950. Separating small, high source strength density items from the overall payload only helps if those small (low mass) items are qualified under the  $\gamma/\text{sec}$  limit, and not the  $\gamma/\text{sec}\cdot\text{g}$  limit.

**Attachment 2**  
**Determination of Hydrogen Concentration**

1. Determine the radionuclide concentration in the contents.

For any package containing dry or dewatered materials with radioactivity concentration not exceeding that for LSA, ensure the shipment occurs within 10 days of preparation, or within 10 days of venting the secondary container.

For packages which satisfy the previous conditions, go to step 11, otherwise continue with step 2.

2. Determine the void volume within the secondary container(s) and within the cask cavity void volume.

For contents with interstitial void spaces (e.g., dewatered or grossly dewatered resins), the secondary container void volume includes the ullage volume plus the interstitial void volume.

- a. If the interstitial void volume can be characterized, then add it to the ullage volume to obtain the secondary container void volume.
  - b. If the interstitial void volume cannot be readily determined, then assume a value of zero (i.e., use only the ullage volume as the secondary container void volume).
3. Identify the secondary container vent path(s), if applicable. Establish the hydrogen permeability of the vent path. Assume zero if there is no vent path, or the permeability cannot be determined.
  4. Determine the quantity of hydrogenous contents.
  5. Determine the G value of the hydrogenous contents per NUREG/CR-6673<sup>8</sup>, Section 3.  
For contents with interstitial void spaces (e.g., dewatered or grossly dewatered resins):
    - a. When the amount of free standing water can be characterized, use the relative volumes of the resin and free standing water to calculate the effective G value.
    - b. When the amount of free standing water cannot be readily determined, use the volumes of the resin and the minimum known amount of free standing water to calculate the effective G value. This is because the G value for resin is generally higher than the G value for water.
  6. Determine the energy deposition rate in the hydrogenous contents.
  7. Determine the hydrogen generation rate per NUREG/CR-6673, Section 4.2.

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<sup>8</sup> B. L. Anderson et al. *Hydrogen Generation in TRU Waste Transportation Packages*, NUREG/CR-6673, Lawrence Livermore National Laboratory, Livermore, CA, February 2000

8. Determine the effective hydrogen transport rate due to diffusion for the vent path; see NUREG/CR-6673, Section 4.1.
9. Determine the shipping time to reach a hydrogen concentration of 5% in the package; see NUREG/CR-6673, Section 4.2.2.1 and Appendix F, Example #4.
10. If the time to reach 5% concentration is more than double the expected shipping time, the shipment meets the hydrogen concentration requirement.
11. Authorize the shipment.

## **8.0 ACCEPTANCE TESTS AND MAINTENANCE PROGRAM**

Acceptance tests for Configurations 1 and 2 have different weld examination and leak tests than Configuration 3. Maintenance is the same for all configurations. Any reference to drawings, either in general or by specific number, means the drawings listed in the CoC.

### **8.1 ACCEPTANCE TESTS – CONFIGURATIONS 1 AND 2 (CASKS FABRICATED BEFORE APRIL 1, 1999)**

Prior to the first use of the 8-120B package fabricated to Configuration 1 or 2, the following tests and evaluations will be performed.

#### **8.1.1 VISUAL EXAMINATION**

The package will be examined visually for any adverse conditions in materials or fabrication. Welds shall be examined for compliance to the drawings. Weld integrity shall be verified by visual examination and magnetic particle or dye penetrant. NDE examinations shall be performed by an ASME Certified inspector. Acceptance criteria for NDE shall be according to ASME Code Section III, Div. 1-Section NB5342 or NB5352 as applicable.

#### **8.1.2 STRUCTURAL TESTS**

No structural testing is required.

#### **8.1.3 LEAK TESTS**

For Configurations 1 and 2 (built before April 1, 1999), fabrication leakage testing was performed in as described in Section 8.1.3.1. As part of an upgrade to “leaktight” status, the Configurations 1 and 2 as-built cask body assemblies must pass the confirmatory leakage test described in Section 8.1.3.2 because they were not required to be tested to the leaktight acceptance criterion during original manufacturing. Note that the drawings in Appendix 1.3 require all 8-120B configurations to operate with Configuration 3 primary and secondary lids. All 8-120B lids authorized for use are therefore leakage tested to the applicable requirements of Section 8.2.

##### **8.1.3.1 Leak Test Performed During Fabrication**

This test shall be performed prior to acceptance and operation of a newly fabricated package in accordance with ASTM E-427 using a leak detector capable of detecting the applicable leak rates. Calibration of the leak detector shall be performed using a leak rate standard traceable to NIST. The standard’s setting shall correspond to the approved leak rates.

All four containment boundary penetrations must be tested.

- The volume above the vent port seal
- The volume between the drain line plug and interior of the cask
- The annulus between the o-ring seals of the primary lid

- The annulus between the o-ring seals of the secondary lid

All four of these volumes must be evacuated to a minimum vacuum of 20” Hg, and then be pressurized to a minimum pressure of 25 psig with pure dichlorodifluoromethane (R-12) or 1,1,1,2 – tetrafluoroethane (R-134a). Use the detector probe to “sniff” the following areas:

- The vent port penetration on the underside of the primary lid
- Around the outer plug of the drain line
- Interior side of the inner o-ring for the primary lid
- Interior side of the inner o-ring for the secondary lid

Leak detection shall be in accordance with the specifications of ASTM E-427.

Any condition, which results in leakage in excess of the applicable values shall be corrected.

#### 8.1.3.2 Qualification Leak Test Performed After Fabrication

Because the containment boundaries of Configuration 1 and 2 units (fabricated prior to 1999) were not required to be leak tested to a leaktight criterion at the time of fabrication, each “as-built” Configuration 1 or 2 body assembly<sup>9</sup> must pass a confirmatory leak test to demonstrate its ability to meet the “leaktight” criterion specified in Chapter 4.

Confirmatory leakage rate tests shall be performed on each Configuration 1 and 2 “as-built” body assembly to a leaktight acceptance criterion with sensitivity requirements per ANSI N14.5 [8-1]. The testing of may be performed on the body assembly separately, or together with its associated primary and secondary lids.

The test shall be performed as described in ASME Section V, Article 10, Mandatory Appendix IX, Helium Mass Spectrometer Test (hood technique). This test is a gas filled envelope technique (helium in a hood bag surrounding the evacuated “as-built” cask body). The dwell testing time shall be selected to detect leakage via a torturous path across the multiple layers of the “as built” cask body. This test shall be performed in accordance with written procedures approved by ASNT NDT Level III in Leak Testing personnel. Leakage rate testing shall be performed by personnel that are qualified and certified in accordance with the American Society of Non Destructive Testing, Recommended Practice No. SNT-TC-1A [8-3].

#### 8.1.4 COMPONENT TESTS

Gaskets and seals will be procured and examined in accordance with the Energy Solutions Quality Assurance Program.

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<sup>9</sup> Due to the multiple layer construction of the 8-120B cask body (i.e. a carbon steel containment boundary sandwiched between a welded stainless steel inner liner, cast lead shielding, and a welded carbon steel outer vessel), it is not possible to directly access the containment shell in the as-built condition.

### 8.1.5 TEST FOR SHIELDING INTEGRITY

Shielding integrity of the package will be verified by gamma scan or gamma probe methods to assure the package is free of significant voids in the poured lead shield annulus. All gamma scanning will be performed on a 4-inch square or less grid system. The acceptance criteria will be that voids resulting in shield loss in excess of 10 % of the normal lead thickness in the direction measured shall not be acceptable. Remedy for an unacceptable gamma scan include actions such as controlled re-heating of the cask body to melt the lead to remove any voids or streaming paths. This process may be used as long as average metal temperatures are kept below ~800°F. If the remedy could affect more than just the unacceptable area, e.g., re-heating of the cask body, all affected portions will be re-scanned.

### 8.1.6 THERMAL ACCEPTANCE TESTS

No thermal acceptance testing will be performed on the 8-120B package. Refer to the Thermal Evaluation, Chapter 3.0 of the report.

## 8.2 ACCEPTANCE TESTS – CONFIGURATION 3 (CASKS FABRICATED AFTER APRIL 1, 1999)

Prior to the first use of an 8-120B package fabricated to Configuration 3, the following tests and evaluations will be performed:

### 8.2.1 VISUAL INSPECTIONS AND MEASUREMENTS

Throughout the fabrication process, confirmation by visual examination and measurement are required to be performed to verify that the 8-120B packaging dimensionally conforms to the drawing referenced in the current Certificate of Compliance for the 8-120B.

The packaging is also required to be visually examined for any adverse conditions in materials or fabrication that would not allow the packaging to be assembled and operated per Section 7.0 or tested in accordance with the requirements of Section 8.0.

Throughout the fabrication process, the fabricator shall request approval from *EnergySolutions* prior to implementation of any options allowed in the drawing.

### 8.2.2 WELD EXAMINATIONS

8.2.2.1 All welding of the Containment Boundary identified on drawing C-110-E-0007 will be done in accordance with ASME Code, Section III, Division I, Subsection ND, except as follows:

- a. Due to the geometry of the joint configuration, between Item 17 and 18, NDE of the  $\frac{3}{4}$ " bevel groove weld and the 1" bevel groove weld may be done by progressive surface examination utilizing the MT method in lieu of RT or UT.
- b. Due to the geometry of the joint configuration, between Item 3 and 5A, NDE of the  $\frac{3}{4}$ " v groove weld may be done by progressive surface examination utilizing the MT method in lieu of RT or UT.

- c. Due to the geometry of the joint configuration, between Item 3 and 4, NDE of the  $\frac{3}{4}$ " v groove weld may be done by utilizing the UT + MT methods in lieu of RT.

8.2.2.2 All welding of Non-Containment Boundary items identified on drawing C-110-E-0007 will be done in accordance with ASME Code, Section III, Division I, Subsection NF (Class 3), except as follows:

- a. The Root Pass and the Final Pass of the v groove weld between Item 5A, Cask Bottom Plate and Item 5B, Cask Bottom Plate Outer Ring, shall be done in accordance with ASME Code, Section III, Division I, Subsection NF-5230 by magnetic particle examination (MT) with acceptance requirements of ASME Code, Section III, Division I, Subsection NF, Article NF-5340.
- b. The Root Pass and the Final Pass of the bevel groove weld between Item 5B, Cask Bottom Plate and Item 1, Outer Cask Shell, shall be done in accordance with ASME Code, Section III, Division I, Subsection NF-5230 by magnetic particle examination (MT) with acceptance requirements of ASME Code, Section III, Division I, Subsection NF, Article NF-5340.

8.2.2.3 Welding on lifting and tiedown lugs identified on drawing C-110-E-0007 will be done in accordance with ASME Code, Section III, Division I, Subsection NF (Class 3) and shall be inspected by magnetic particle examination (MT) with acceptance requirements of ASME Code, Section III, Division I, Subsection ND, Article ND-5340 or NF, Article NF-5340. Inspection shall be before and after 150% load test.

### 8.2.3 STRUCTURAL AND PRESSURE TESTS

A pressure test of the containment system will be performed as required by 10CFR71.85. As determined in Section 3.4.4, the maximum normal operating pressure for the cask cavity is 35 psig; therefore the minimum test pressure will be  $1.5 \times 35 = 52.5$  psig. The hydrostatic test pressure will be held for a minimum of 10 minutes prior to initiation of any examinations. Following the 10 minute hold time, the cask body, lid and lid/body closure shall be examined for leakage. Any leaks, except from temporary connections, will be remedied and the test and inspection will be repeated. After depressurization and draining, the cask cavity and seal areas will be visually inspected for cracks and deformation. Any cracks or deformation will be remedied and the test and inspection will be repeated.

### 8.2.4 LEAKAGE TESTS

Testing of the entire containment boundary described in Section 4.1 will be performed prior to lead pour to allow access to all containment welds.

The ANSI N14.5 requirements for fabrication leakage test shall be met including requirements for qualification and certification of the leakage rate testing personnel, test procedure sensitivity and procedure qualification.

- a) Testing method – Gas filled envelope as defined in ANSI N14.5 Appendix A.

- b) Acceptance Criteria – The acceptance criteria shall be equivalent to  $10^{-7}$  ref-cm<sup>3</sup>/s air (leaktight).
- c) The Test Procedure Sensitivity - The test shall be sensitive to the equivalent of  $5 \times 10^{-8}$  ref-cm<sup>3</sup>/s air or more sensitive (a smaller numerical value represents greater test sensitivity).
- d) Certification of the Leakage Rate Testing Procedure – Leakage rate testing shall be performed in accordance with written procedures. Leakage rate testing procedures shall be approved by personnel whose qualifications and certification on the nondestructive method of leakage testing includes certification by a nationally recognized society at a level appropriate to the writing and/or review of leakage rate testing procedure (such as ASNT NDT Level III in Leak Testing).
- e) Qualification of the Leakage Rate Testing Procedures – Leakage rate testing procedures shall be qualified and their qualification shall be documented.
- f) Leakage Rate Testing Personnel – Leakage rate testing shall be performed by personnel that are qualified and certified in accordance with the American Society of Non Destructive Testing, Recommended Practice No. SNT-TC-1A [8-3]. Any containment boundary component that do not satisfy the fabrication leakage rate test acceptance criteria shall be reworked, replaced, or repaired, as required, and retested.

## 8.2.5 COMPONENT AND MATERIAL TESTS

EnergySolutions will apply its USNRC approved 10CFR71 Subpart H Quality Assurance Program, which implements a graded approach to quality based on a component's or material's importance to safety to assure all materials used to fabricate and maintain the 8-120B are procured with appropriate documentation which meet the appropriate tests and acceptance criteria for packaging materials.

### 8.2.5.1 Steel Materials

ASTM steel material used for shells, lids, bolts, etc. will comply with and meet ASTM manufacturing requirements.

### 8.2.5.2 Elastomeric Seals

Containment O-rings will be made from an elastomeric compound that has been qualified based on elastomer type (e.g., ethylene propylene or butyl), temperature compatibility, permeability, and material compatibility. The elastomer type shall comply with the elastomer type(s) specified in Appendix 1.3. Qualified compounds for the primary lid and secondary lid containment seals shall be suitable for low-temperature service down to -40 °F, continuous service up to the maximum allowable NCT seal temperature of 180 °F (Table 3-1), and short-term service to the maximum allowable HAC seal temperature of 340 °F (Table 3-2). The vent port seal shall likewise be suitable for low-temperature service down to -40 °F, continuous service up to the

maximum allowable NCT seal temperature of 180 °F, and short-term service to the maximum allowable HAC seal temperature of 235 °F.

Although elastomer permeability is not a safety function of the containment seals, the periodic maintenance leakage rate testing is performed using helium; therefore only elastomer types with helium permeability suitable for helium leak testing shall be used for the containment and test seals. Qualified compounds shall be made from an elastomer type that is compatible with steel, water, steam, silicone-based lubricants, and high-vapor solvent cleaning agents (e.g., acetone). Radiation resistance is not a critical characteristic for the 8-120B seal materials because the radiation exposure is estimated to be below  $1 \times 10^{-6}$  rads, which is below the level of degradation for elastomers as described in Section 4.1.

Fabricated seals are acceptable for use provided that they are traceable to a batch of material manufactured under the same process and having the same chemical composition as a qualified elastomeric compound. Each batch of elastomeric material will be subjected to hardness and temperature resistance testing acceptance testing in accordance with applicable nationally recognized testing standards (e.g., ASTM D2240, ASTM D2137, and ASTM E1069) to assure the material meets the hardness and temperature resistance requirements in Appendix 1.3. Additionally, each batch of elastomeric material shall be tested by the manufacturer for tensile strength, elongation, and compression set to assure compliance with the manufacturer's specifications for the qualified elastomer compound. Finally, procured seals will be subjected to visual inspection and dimensional acceptance testing prior to use.

#### 8.2.5.3 Impact Limiter Foam

The impact limiters will be filled with General Plastics Manufacturing Company Last-A-Foam® FR 3700 or FR 6700 with a nominal density of 25 pounds per cubic foot (pcf). Samples from each batch of foam shall be tested for material density, static crush strength, and flame retardancy.

- The average density of the foam is required to be within  $\pm 1$  pcf of the nominal density.
- The average static compressive crush strength of the foam samples, when tested at room temperature in the direction perpendicular to rise, shall be within  $\pm 10\%$  of nominal static crush strength values of 1,870 psi at 10% strain, 2,170 psi at 30% strain, 3,160 psi at 50% strain, and 4,700 psi at 60% strain.
- The foam shall not sustain a flame for more than 15 seconds following the removal of a flame that is applied for at least 60 seconds and the average burn length shall not exceed 6 inches.

Foam that does not to meet the acceptance criteria shall be rejected.

#### 8.2.6 SHIELDING TESTS

Shielding integrity of the package will be verified by gamma scan to assure the package lead layer meets or exceeds the minimum thickness specified on the cask drawing. All gamma scanning will be performed on a 4-inch square or less grid system. The acceptance criteria (maximum dose rate value) will be determined by: Option 1) measurement of the maximum

dose rate value using a test block, which has shield layers that replicate the cask geometry per the drawing, using the gamma scan source and reproducing the source/shield/detector geometry that will be used during the scan of the cask, or Option 2) calculation of the maximum dose rate value using detailed modeling software (MCNP or equivalent) incorporating the specific cask dimensions from the drawing and the source/shield/detector geometry applicable to the gamma scan. Any location on the cask which shows a gamma scan dose rate value greater than the maximum dose rate value will be identified as unacceptable. All unacceptable areas will be remedied and re-scanned. Remedy for an unacceptable gamma scan include actions such as controlled re-heating of the cask body to melt the lead to remove any voids or streaming paths. This process may be used as long as average metal temperatures are kept below ~800°F. If the remedy could affect more than just the unacceptable area, e.g., re-heating of the cask body, all affected portions will be re-scanned.

### 8.2.7 THERMAL TESTS

No thermal acceptance testing will be performed on the 8-120B packaging. Refer to the Thermal Evaluation, Section 3.0 of this report.

### 8.2.8 MISCELLANEOUS TESTS

No miscellaneous testing will be performed on the 8-120B packaging.

## 8.3 MAINTENANCE PROGRAM

EnergySolutions operates an ongoing preventative maintenance program for all shipping packages. The 8-120B package will be subjected to routine and periodic inspection and tests as outlined in this section and the approved procedure based on these requirements. Defective items are replaced or remedied, including testing, as appropriate.

Examples of inspections performed prior to each use of the cask include:

- Cask Seal Areas: O-rings are inspected for any cracks, tears, cuts, or discontinuities that may prevent the O-ring from sealing properly. O-ring seal seating surfaces are inspected to ensure they are free of scratches, gouges, nicks, cracks, etc. that may prevent the O-ring from sealing properly. Defective items are replaced or remedied, as appropriate and tested in accordance with Section 8.3.2.
- Cask bolts, bolt holes, and washers are inspected for damaged threads, severe rusting or corrosion pitting. Defective items are replaced or remedied, as appropriate.
- Lift Lugs and visible lift lug welds are inspected to verify that no deformation of the lift lug is evident and that no obvious defects are visible. Defective items are replaced or remedied, as appropriate and tested in accordance with Section 8.2.2.3.

### 8.3.1 STRUCTURAL AND PRESSURE TESTS

No routine or periodic structural or pressure testing will be performed on the 8-120B packaging.

## 8.3.2 LEAKAGE TESTS

### 8.3.2.1 Periodic and Maintenance Leak Test

Each Type B radioactive material shipment shall be made with containment seals that have been replaced and have had periodic leakage rate testing performed within the preceding 12-month period. Periodic leakage rate testing shall be performed as required in ANSI N14.5 [8-1].

Maintenance leakage rate testing is required after replacement of containment seals (primary, secondary lid or vent port seals) and after repair or replacement of associated containment sealing surfaces, and shall also be performed as required in ANSI N14.5 [8-1].

The ANSI N14.5 requirements for maintenance and periodic leakage rate testing procedure and technique shall be met including requirements for qualification and certification of the leakage rate testing personnel, test procedure sensitivity and procedure qualification.

- a) Testing method – Gas filled envelope as defined in ANSI N14.5 Appendix A.
- b) Acceptance Criteria – The acceptance criteria shall be equivalent to  $10^{-7}$  ref-cm<sup>3</sup>/s air (leaktight).
- c) The Test Procedure Sensitivity - The test shall be sensitive to the equivalent of  $5 \times 10^{-8}$  ref-cm<sup>3</sup>/s air or more sensitive (a smaller numerical value represents greater test sensitivity).
- d) Qualification of the Leakage Rate Testing Procedures – Leakage rate testing procedures shall be qualified and their qualification shall be documented.
- e) Certification of the Leakage Rate Testing Procedure – Leakage rate testing shall be performed in accordance with written procedures. Leakage rate testing procedures shall be approved by personnel whose qualifications and certification on the nondestructive method of leakage testing includes certification by a nationally recognized society at a level appropriate to the writing and/or review of leakage rate testing procedure (such as ASNT NDT Level III in Leak Testing).
- f) Leakage Rate Testing Personnel- Leakage rate testing shall be performed by personnel that are qualified and certified in accordance with the American Society of Non Destructive Testing, Recommended Practice No. SNT-TC-1A [8-3].

Any containment closure and/or seal that does not satisfy the maintenance and periodic leakage rate test acceptance criteria shall be reworked, replaced, or repaired, as required, and retested prior to returning the package to service.

### 8.3.2.2 Pre-Shipment Leakage Tests

Pre-shipment leakage rate testing of all containment closures of the loaded package (primary lid to the body of the cask, secondary lid to the primary lid, and vent port) is required before each

Type B shipment of a loaded package to verify that the containment system is properly assembled for shipment.

The ANSI N14.5 requirements for pre-shipment leakage rate testing procedure and technique shall be met including requirements for qualification and certification of the leakage rate testing personnel, test procedure sensitivity and procedure qualification.

- a) Testing method – Pressure Change Testing, by either Gas Pressure Drop, or Gas Pressure Rise technique similar to that described in ANSI N14.5 A.5.1 and/or A.5.2.
- b) Acceptance Criteria – There shall be no detected leakage when tested to the required sensitivity below.
- c) Test Procedure Sensitivity – The Test Procedure Sensitivity shall be equal to or more sensitive than  $10^{-3}$  ref-cm<sup>3</sup>/s.
- d) Qualification of Leakage Rate Testing Procedures –Leakage rate testing procedures shall be qualified and their qualification shall be documented.
- e) Certification of the Leakage Rate Testing Procedure – Leakage rate testing shall be performed in accordance with written procedures. Leakage rate test procedures shall be approved by personnel whose qualifications and certification on the nondestructive method of leakage testing includes certification by a nationally recognized society at a level appropriate to the writing and/or review of leakage rate testing procedure (such as ASNT NDT Level III in Leak Testing).
- f) Leakage Rate Testing Personnel- Leakage rate testing shall be performed by personnel that are qualified and certified in accordance with the American Society of Non Destructive Testing, Recommended Practice No. SNT-TC-1A [8-3].

Any containment closure that does not satisfy the pre-shipment leakage rate test acceptance criteria shall be inspected, cleaned (if needed), reassembled, and retested prior to shipment. Any containment seal that does not satisfy the pre-shipment leakage rate test acceptance criteria after repeated attempts, may require replacement of the primary and/or secondary O-ring or/and vent port seal or repair of the affected sealing surface. A maintenance leakage rate test is required for all new/replaced containment seals and for any repaired containment sealing surfaces.

### 8.3.3 COMPONENT AND MATERIAL TESTS

Cask seals (O-rings) are inspected each time the cask lids or vent port cap screw are removed. Inspection and replacement of the seal is discussed in Section 8.3.

New seals are lightly coated with a lightweight lubricant such as Parker Super O-Lube or equivalent prior to installation. The lubricant will minimize deterioration or cracking of the elastomer during usage and tearing if removal from the dovetail groove is necessary for inspection. Coating the exposed surfaces of installed lid seals with the lightweight lubricant

immediately prior to closing the lid can help to minimize deterioration or cracking of the seal during use. Excess lubricant should be wiped off before closing the lid.

Painted surfaces, identification markings, and match marks used for closure orientation shall be visually inspected to ensure that painted surfaces are in good condition, identification markings are legible, and that match marks used for closure orientation remain legible and are easy to identify.

Visible cask external and cavity welds shall be inspected within twelve months prior to use to verify that the welds specified by the applicable cask drawing are present and that no obvious weld defects are visible. If paint is covering these welds, the inspection may be completed without removing the paint.

#### 8.3.4 THERMAL TESTS

No periodic or routine thermal testing will be performed on the 8-120B packaging.

#### 8.3.5 MISCELLANEOUS TESTS

##### 8.3.5.1 Repair of Bolt Holes

Threaded inserts may be used for repair of bolt holes. The following steps shall be performed for each repair using a threaded insert.

- a. Install threaded insert(s), sized per manufacturer's recommendation, per the manufacturer's instructions.
- b. At a minimum, each repaired bolt hole(s) will be tested for proper installation by assembling the joint components where the insert is used and tightening the bolts to their required torque value.

Note: If the repair is to bolt holes for lifting components, then a load test will also be performed to the affected components equal to 150% of maximum service load.

- c. Each threaded insert shall be visually inspected after testing to insure that there is no visible damage or deformation to the insert.

#### 8.4 REFERENCES

- [8-1] ANSI N14.5, “*American National Standard for Radioactive Materials – Leakage Tests on Packages for Shipment*,” 2014.
- [8-2] ASME Boiler and Pressure Vessel Code, Section V, *Nondestructive Examination*, Subsection A, *Nondestructive Methods of Examination*, 2013 Edition, July 1, 2013.
- [8-3] Recommended Practice No. SNT-TC-1A, *Personnel Qualification and Certification in Nondestructive Testing*, American Society of Non Destructive Testing.