LIST OF FIGURES

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1 GENERAL INFORMATION

The description and evaluation of the Model 2000 Shipping Package configuration presented in this request are based on the Model 2000 Radioactive Material Transport Package Safety Analysis Report (SAR), NEDO-32318 [*1*] and the Nuclear Regulatory Commission (NRC) Certificate of Compliance USA/9228/B(U)F-96, Rev 26, Docket Number 71-9228 [*2*]. Sections of these documents are reproduced below for the convenience of the reviewer.

1.1 *Introduction*

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The following describes the specific contents and configuration, and provides appropriate analyses demonstrating safety and compliance. The information is provided following the format guidance found in Regulatory Guide 7.9 [*4*]. Sections of the two SARs, [*1*] and [*5*], have been included as a reference for the text provided. They are identified by the appropriate document number (i.e., NEDO-31581 or NEDO-32318) in brackets.

1.2 *Package Description*

The Model 2000 Shipping Package, shown in Figure 1-3 may be transported either in the upright or horizontal position. The approximate overall packaging dimensions are 131.5 inches in height and 72 inches in diameter. The approximate total weight of the package (packaging plus the contents) is 33,550 lb. [*2*]. Table 2-2 shows the breakdown of the component weights for the GE Model 2000 Shipping Package.

The Model 2000 Shipping Package and requested special authorization contents consist of the following components, which are described below, and is requested for transport only in the upright position.

Packaging

- Overpack
- Cask

Contents

- High Performance Insert (HPI)
- HPI Material Basket

- Radioactive contents in the form of Co-60 rod segments

1.2.1. Packaging

1.2.1.1. Cask

[NEDO-32318 §1.2.1]
The cask body, shown in Figure 1-1, is constructed of two concentric 1 inch thick Stainless Steel (SS) SS-304 cylindrical shells [ASTM A240]. The shells are joined at the bottom end to a 6 inch thick type SS-304 forging [ASTM A182]. The annulus between the two shells is approximately 4 inches and is filled with lead. The cask body is approximately 71 inches high and has an outer diameter of 38.5 inches. The cavity is approximately 26.5 inches in diameter and 54 inches deep.

The cask lid is made of SS-304 and lead. It has a stepped design and is fully recessed into the cask top flange. The lid is secured to the cask body by fifteen (15) 1¼ inch diameter socket head screws. The cask will include a new seal option. The same 6061-T6 aluminum retainer is used but it has a high temperature perfluro-compound bonded to it. See section 1.3.2.1 for seal material specification. The cask has a seal test port in the side of the cask body, a vent port in the cask lid, and a drain port near the bottom of the cask. The port seals will include "O" rings made of the same high temperature perfluro-compound. See section 1.3.2.1 for the "O" ring material specification. The cask body has attachment plates for lifting devices that are detached during transport.

1.2.1.2. Overpack

[NEDO-32318 §1.2.1]
The cask is positioned inside a protective overpack for transport, which is shown in Figure 1-2. The overpack is constructed of two 0.5 inch thick SS-304 concentric cylindrical shells [ASTM A240], which are separated radially by eight equally spaced tubes along the length of the shells, and by two tube sections around the perimeter of the shells. A toroidal shell impact limiter made of SS-304 is attached to each end of the overpack shells. The overpack opens just above the lower impact limiter for access to the cask. The top section of the overpack is joined to the base by fifteen (15) $1^{3}/_{8}$ inch diameter shoulder screws. Gussets on the top and bottom impact limiters provide tie-down points for the package.

[NEDO-32318 §2.1.1]
The external shell has a 48.5 inch outer diameter (OD) and is approximately 83 inches long. The internal cylindrical shell has a 40.5 inch inner diameter (ID). A 24 inch diameter toroidal shell impact limiter made of SS-304 is attached at each end. Additional impact protection is provided by aluminum honeycomb impact absorbers permanently positioned on the inside of the overpack at the top and bottom ends of the cask.

The cask sits on a 0.5 inch thick, 42 inch diameter plate, called the Cask Support Plate. It features 8 square cross-section prongs welded to the plate perimeter to ensure cask concentricity within the overpack. The Cask Support Plate material of construction is SS-304.

The cask lifting devices are detached during transport.

1.2.2. Contents

1.2.2.1. High Performance Insert

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1.2.2.2. HPI Material Basket

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1.2.2.3. Radioactive Material Contents

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The following compares what is currently authorized in the CoC [*2*] for Co-60 rod transport with what is being requested:

- 5.(b)(1)(ii) Byproduct, source, or special nuclear material in solid form. Gamma emitting nuclides are limited to the following isotopes … Co-60.

Co-60 source rods make up the contents.

- 5.(b)(2) Maximum quantity of material per package not to exceed 5,450 lb., including fuel baskets, carrier racks, shoring, and secondary containers.

The maximum quantity of material per package will not exceed 5,450 lb, including the new HPI, HPI Material Basket, shoring, and rod segments.

- 5.(b)(2)(ii) 2000 watts decay heat

This application requests that the maximum decay be increased to 3000 watts.

- 5.(b)(2)(ii) A single package shall not mix nuclides except as allowed below.

No mixing nuclides. Co-60 is the only nuclide.

- 5.(b)(2)(ii) 7,000 curies, with an allowed concurrent maximum of 100 curies Zr/Nb-95.

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The separators, basket filler, Material Basket, barrel rack, and basket support, described in sections

5(a)(3)(ix), 5(a)(3)(vi), 5(a)(3)(v), and 5(a)(3)(x), will not be used. A new HPI with HPI Material Basket will be used.

1.2.3. Special Requirements for Plutonium

Plutonium is not an authorized content.

1.2.4. Operational Features

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Once the package is loaded onto the transport vehicle, external temperature measurements are taken of the loaded overpack. If any temperature exceeds 185°F a protective personnel barrier will be installed around the package to block access. This is discussed in Section 3.3.1.

The containment boundary for this shipment is unchanged from the Model 2000 Radioactive Material Shipping Package SAR, Section 4 [*5*], with the exception of the new cask seal and port O-ring options as discussed in Section 4.

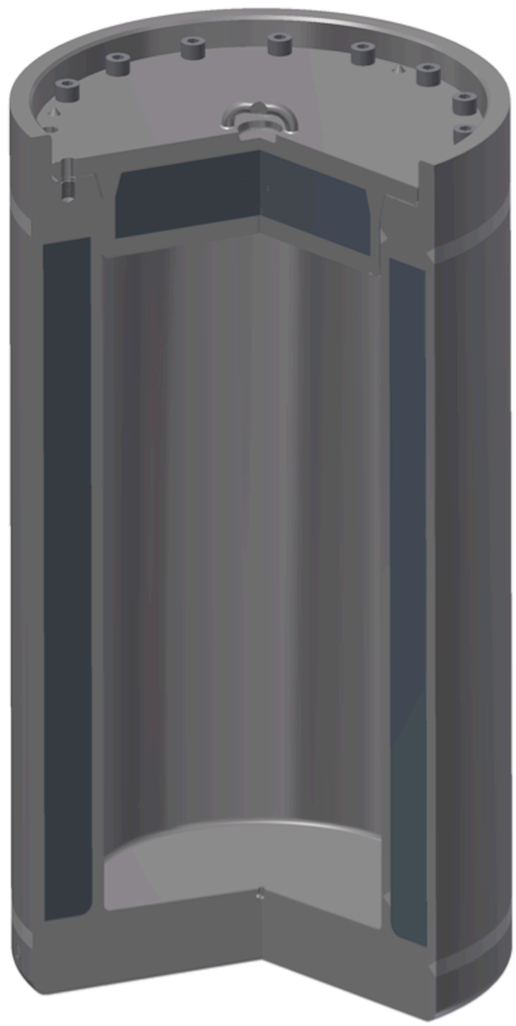

Figure 1-1. Model 2000 Cask

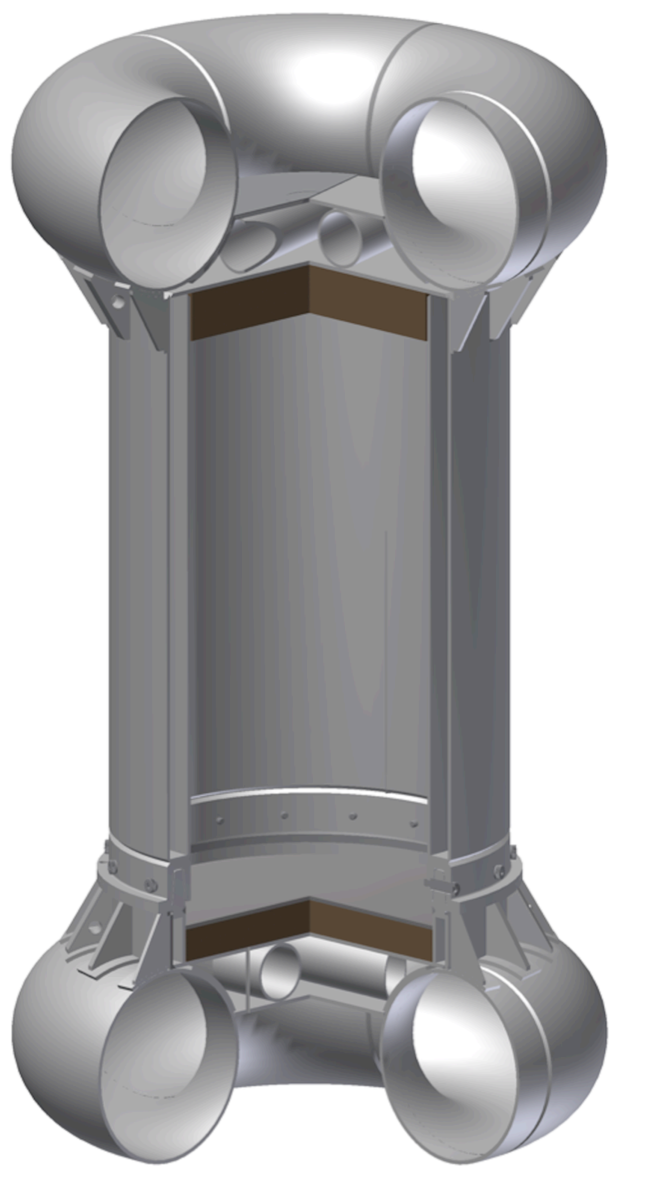

Figure 1-2. Model 2000 Overpack

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Figure 1-3. Model 2000 Packaging with High Performance Insert (HPI)

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Figure 1-4. Model 2000 High Performance Insert (HPI)

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Figure 1-5. Material Basket and Rod Segment Holder

1.3 *Appendix*

1.3.1. Drawings

This section contains the licensing drawings and bill of materials supporting the High Performance Insert, Material Basket, and Cask modifications.

Parts List 001N84SSG001

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Drawing Number 001N8422

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PARTS LIST 001N8423G001

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DRAWING NUMBER 001N8423

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PARTS LIST 001N8424G001

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DRAWING NUMBER 01N8424

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PARTS LIST 001N8425G001

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PARTS LIST 001N8427G001

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DRAWING NUMBER 001N8427

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PARTS LIST 001N8428G001

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DRAWING NUMBER 001N8428

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DRAWING NUMBER 101E8718

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DRAWING NUMBER 105E9520

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1.3.2. Material Specifications

1.3.2.1. Seal Specification

Section 2.2.10 of the subsequent excerpt contains the material specification for the new cask seal and three port "O" rings.

2.2.10 Perfluoroelastomer (FFKM)

Perfluoroelastomer (FFKM) currently offers the highest operating temperature range, the most comprehensive chemical compatibility, and the lowest off-gassing and extractable levels of any rubber material. Parker's proprietary formulations deliver an extreme performance spectrum that make them ideal for use in critical applications like semiconductor chip manufacturing, jet engines and chemical processing equipment.

Heat resistance
- Up to 320°C (608°F).

Cold flexibility
- -18°C to -26°C (0°F to -15°F).

Chemical resistance
- Aliphatic and aromatic hydrocarbons.
- Chlorinated hydrocarbons.
- Polar solvents (ketones, esters, ethers).
- Inorganic and organic acids.
- Water and steam.
- High vacuum with minimal loss in weight.

Not compatible with:
- Fluorinated refrigerants (R11, 12, 13, 113, 114, etc.)
- Perfluorinated lubricants (PFPE)

2.2.11 Polyacrylate (ACM)

ACM (acrylic rubber) has good resistance to mineral oil, oxygen and ozone. Water compatibility and cold flexibility of ACM are significantly worse than with nitrile.

Heat resistance
- Up to approximately 177°C (350°F).

Cold flexibility
- Down to approximately -21°C (-5°F).

Chemical resistance
- Mineral oil (engine, gear box, ATF oil).
- Ozone, weather and aging.

Not compatible with:
- Glycol based brake fluid (Dot 3 and 4).
- Aromatics and chlorinated hydrocarbons.
- Hot water, steam.
- Acids, alkalis, amines.

2.2.12 Polyurethane (AU, EU)

Polyurethane elastomers, as a class, have excellent wear resistance, high tensile strength and high elasticity in comparison with any other elastomers. Permeability is good and comparable with butyl.

Heat resistance
- Up to approximately 82°C (180°F).

Cold flexibility
- Down to approximately -40°C (-40°F).

Chemical resistance
- Pure aliphatic hydrocarbons (propane, butane).
- Mineral oil and grease.
- Silicone oil and grease.
- Water up to 50°C (125°F).

Not compatible with:
- Ketones, esters, ethers, alcohols, glycols.
- Hot water, steam, alkalis, amines, acids.

2.2.13 Silicone Rubber (Q, MQ, VMQ, PVMQ)

Silicones have good ozone and weather resistance as well as good insulating and physiologically neutral properties. However, silicone elastomers as a group, have relatively low tensile strength, poor tear strength and little wear resistance.

Heat resistance
- Up to approximately 204°C (400°F) special compounds up to 260°C (500°F).

Cold flexibility
- Down to approximately -54°C (-65°F) special compounds down to -115°C (-175°F).

Chemical resistance
- Animal and vegetable oil and grease.
- High molecular weight chlorinated aromatic hydrocarbons (including flame-resistant insulators, and coolant for transformers).
- Moderate water resistance.
- Diluted salt solutions.
- Ozone, aging and weather.

Not compatible with:
- Superheated water steam over 121°C (250°F).
- Acids and alkalis.
- Low molecular weight chlorinated hydrocarbons (trichloroethylene).
- Hydrocarbon based fuels.
- Aromatic hydrocarbons (benzene, toluene).
- Low molecular weight silicone oils.

2.2.14 Tetrafluoroethylene-Propylene (AFLAS)

This elastomer is a copolymer of tetrafluoroethylene (TFE) and propylene. Its chemical resistance is excellent across a wide range of aggressive media.

Heat resistance
- Up to approximately 232°C (450°F).

Cold flexibility
- Down to approximately -9°C (15°F).

Compatible with
- Bases.
- Phosphate Esters.
- Amines.
- Engine Oils.
- Steam and hot water.
- Pulp and paper liquors.

Not compatible with:
- Aromatic Fuels.
- Ketones.
- Chlorinated hydrocarbons.

Parker Hannifin Corporation • O-Ring Division
2360 Palumbo Drive, Lexington, KY 40509
Phone: (859) 269-2351 • Fax: (859) 335-5128
www.parkerorings.com

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2 STRUCTURAL ANALYSIS

This section addresses the structural analysis of the High Performance Insert (HPI) and Material Basket within the Model 2000 Shipping Package. The HPI is a shielded insert designed to ship large quantities of Co-60. The cask and overpack are described in Section 1.2.1.1 and 1.2.1.2, respectively.

The structural design of the HPI is based on the following critical characteristics:

- Ensure the maximum content weight does not exceed 5,450 pounds.
- Maintain integrity of [[depleted uranium shielding]]boundary during NCT and HAC to support Section 5.
- Limit the design to 3000 watts decay heat (194,400 curies of Co-60).

2.1 *Description of Structural Design*

2.1.1. Discussion

[NEDO-31581 §2.1.1]
The Model 2000 Shipping Package consists of a welded overpack structure containing a steel-encased, lead cask structure. The cask structure is a lead-filled SS-304 weldment, cylindrical in shape, and measuring approximately 38.5 inches outside diameter (OD) by 71.0 inches high. The inner cavity is 26.5 inches inside diameter (ID) by 54.0 inches high. The lead shielding provided is approximately 4.0 inches of lead on the sides.

The cask body shell is made in of 1.0 inch thick SS-304 plate. At the bottom, the shells are welded to a 6.0 inch thick SS-304 forging. At the upper section, the containment shell joins a 9.0 inch thick SS-304 forging. This forging provides support and sealing surface to the cask seal. Also, it contains 15 equally spaced, internally threaded holes on a 32.25 inch diameter bolt circle. Fifteen 1¼ inch diameter ASTM A540 socket head screws attach the lid to the cask body during operation. The cask lid is a 1.0 inch thick SS-304 forging encasing a lead cylinder 5.38 inches high. A 1¾ inch thick flat plate is attached to the lid steel forging at the top. The plate thickness is reduced to 1.5 inch on the outer edge to accommodate the seal. At the bottom, a 1.5 inch thick plate is attached. The top plate is 34.75 inches OD, and the bottom one is 24.38 inches OD. The lid has a lifting lug for handling.

There are three penetrations into the cask cavity. One serves as a drain for the cask cavity and another one as a vent. The drain hole goes from the center of the cavity bottom to the side of the outer surface. The vent line spirals through the cask lid around the center. These penetrations provide means to eliminate water from the cask cavity collected during underwater operations. A ½ NPT socket head pipe plug followed by a 1¾ - ½ UN cap closes both penetrations. The cap O-ring provides backup sealant to the pipe plug. The third penetration is used as a testing port for the cask seal joint. It is located in the upper forging on the side surface of the cask.

As described in Section 1.2.1.1, there are two cask seal and port O-ring material options. For content heat loads up to 2000 watts, the cask seal is composed of four rings of contoured elastomeric material bounded two in each surface, top and bottom, of a 0.125 inch-thick 6061-T6 aluminum retainer. The seal ring has a 34.0 inch OD and 28.0 inch ID. For content heat loads up to 3000 watts, the cask seal has a [[high temperature rated perfluoro-compound material]]. Similarly, the port O-rings are manufactured from the [[high temperature material]]if heat load temperatures exceed 3000 watts

The welded SS-304 overpack structure is composed of two concentric cylinders, separated vertically by eight equally spaced tubes and horizontally by two tube sections. The external cylinder has a 48.5 inch OD and is approximately 83 inches long. The internal cylindrical shell is 40.5 inch ID. A 24 inch tube diameter toroidal shell is attached at both ends of the external cylinder, and a circular plate is welded across the inner region of the torus. The internal cylinder is closed at each end by circular plates. All materials are 0.5 inches thick with the exception of the space tubes and toroidal shells. The vertical tubes are 3 inches OD, 0.25 inches thick, and the horizontal tube sections are 7.25 inches OD, 0.375 inches thick.

The toroidal shells may be fabricated using four 90° elbows (or two 180° returns). However, the Model 2000 toroidal shell wall thickness range is limited to 0.5 inches min. to 0.76 inches max. The overpack structure separates near the bottom end to allow access to the lead cask. A collar 0.75 inches thick and 4 inches wide is attached in this area to provide bearing surface for the connecting bolts. A total of 15 1-$^{3}/_{8}$ inches diameter ASTM A540 shoulder screws join both portions of the overpack structure. The toroidal shell of the overpack structure acts as an energy-absorbing device during the postulated drop conditions. In addition, the overpack structure provides thermal shielding for the lead cask in the event of a fire.

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

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

The HPI and Material Basket are described in Section 1.2.2.1 and Section 1.2.2.2, respectively.

2.1.2. Design Criteria

This section defines the stress allowables for all the stresses resulting from the regulatory load combinations given in NRC Regulatory Guide 7.8 [*7*].

The cask is evaluated per ASME service Levels A and D, normal and accident conditions, respectively. The analyses methods and stress criterion allowed by the ASME Code, Section III-Subsection NB is employed. Allowable stresses are presented in NEDO-31581 §2.1.2.

The HPI is evaluated per ASME service Levels A and D, normal and accident conditions, respectively. The analyses methods and stress criterion allowed by the ASME Code, Section III-Subsection NF are employed. Allowable stresses are based on section NF-3200. For normal conditions (Service Level A), design limits are defined in paragraph NF-3221.1. For accident conditions (Service Level D), design limits are defined in Appendix F of ASME Code, Section III [*8*]. Note the evaluation of thermal stresses is not required per ASME Code III-NF (NF-3121.11). Stress intensities caused by mechanical loads are combined before comparing to ASME code stress allowables, which are listed in Table 2-1.

Table 2-1. Structural Design Criteria for HPI and Material Basket

ASME SERVICE LEVEL	STRESS CRITERIA
Normal conditions: Service Level A (NF-3221.1)	$P_m \leq S_m$ $P_m + P_b \leq 1.5\ S_m$
Accident conditions: Service Level D (Appendix F, F-1332)	$P_m > 1.2\ S_y$ and $1.5\ S_m < 0.7\ S_u$ $P_m + P_b <$ 150% of the limit for general primary stress intensity P_m

2.1.3. Weights and Centers of Gravity

Weights and centers of gravity of the Model 2000 Shipping Package with HPI and Material Basket are bounded by the values provided in CoC 9228 Rev 26 and the Model 2000 SAR (NEDO-31581 §2.2).

The maximum weights of the packaging and detailed contents are presented in Table 2-2. The packaging center of gravity (CG) is consistent with Figure 2.2.1 of NEDO-31581.

Table 2-2. Summary of Weights

Description	Drawing Number	Weight (lb)
Total Packaging Weight	—	**28,100**
Cask Overpack	—	10,200
Cask Body	—	16,000
Closure Lid	—	1,900
Allowed Contents Weight	—	**5,450**
HPI Assembly	[[001N8423	5,133]]
[[• HPI Body	001N8425	4,410
• Top Plug	001N8427	270
• Bottom Plug	001N8428	453
Material Basket	001N8424	114
Co-60 Rods plus shoring	—	203]]
Total Package Weight		**33,550**

2.1.4. Identification of Codes and Standards for Package Design

Codes and standards for the Model 2000 cask and overpack are provided in Model 2000 SAR (NEDO-31581 §2.1.2).

[[

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- Section 5.3.3 defines dunnage as follows: “Dunnage is a packing material that is placed between the packaging and the contents to prevent movement of the contents during normal and sometimes accident transport conditions. Dunnage may be required to provide energy absorption and reduce the impact load. If the dunnage in a package is required to reduce impact loading on the containment boundary, it is a higher category item.”

The Material Basket is considered dunnage, and is not required to reduce impact loading on the containment boundary. However, it is required to maintain geometry during NCT to support the shielding analysis assumptions. Therefore, it is considered a Category B item. In addition, for fabrication, [[full-length groove welds]]are Safety Category B. See the Parts List, Section 1.3.1[[, Drawing 001N8424, for the Material Basket]] assembly parts classification.

2.2 *Materials*

The mechanical properties of materials used to evaluate the Model 2000 cask and overpack for this application are.found in Appendix 2.12.1.7.

Materials of construction for [[

]], are found in Section 1.3.1, in the Parts Lists that accompany the drawings.

2.2.1. Material Properties and Specifications

The material properties used in the structural analysis of the HPI and Material Basket are presented in Tables 2-3 through 2-5.

Table 2-3. [[**Mechanical Properties of ASME Type 316 Stainless Steel (16Cr–12Ni–2Mo)**]]

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Table 2-4. Mechanical Properties of ASME Type [[ ]]Stainless Steel (22Cr–13Ni–5Mn)

Temperature (°F)	-20	70	200	300	400	500	600	700	800	900	1000
Ultimate Tensile Strength S_u (ksi)	100.0	100.0	99.4	94.2	91.1	89.1	87.7	86.4	84.8	83.8	79.7
Yield Strength S_y (ksi)	55.0	55.0	47.1	43.3	40.7	38.8	37.4	36.3	35.3	34.5	33.7
Design Stress Intensity S_m (ksi)	33.3	33.3	33.1	31.4	30.4	29.7	29.2	28.8	28.3	—	—
Modulus of Elasticity (E+3, ksi)	28.9	28.3	27.5	27.0	26.4	25.9	25.3	24.8	24.1	23.5	22.8
Coefficient of Thermal Expansion α (E-6, in/in/°F)	—	8.5	8.9	9.2	9.5	9.7	9.9	10.0	10.1	10.2	11.5
Poisson's Ratio	← 0.31 →										
Density (lbm/in^3)	← 0.282 →										

References:
[*11*] Ultimate Tensile Strength: Table U, Page 503, Lines 17-23.
[*11*] Yield Strength: Table Y-1, Page 634, Lines 11-15.
[*11*] Design Stress Intensity: Table 2A, Page 318, Lines 39-45.
[*11*] Modulus of Elasticity: Table TM-1, Material Group G, Page 738.
[*11*] Coefficients of Thermal Expansion: Table TE-1, Group 3, Page 711.
[*11*] Poisson's Ratio: Table PRD, Page 744.
[*11*] Density: Table PRD, 200 Series (S20910), Page 744.

Table 2-5. Mechanical Properties of Shielding Material

Properties of Depleted Uranium											
Temperature (°F)	-20	70	200	300	400	500	600	700	800	900	1000
Ultimate Tensile Strength S_u (ksi)	99.	91.1	88.2	78.4	70.8	66.4	58.3	46.3	32.3	21.3	13.2
Yield Strength S_y (ksi)	—	47.2	43.8	40.2	36.3	33.3	30.5	23.9	15.3	9.3	5.8
Modulus of Elasticity (E+3, ksi)	—	23.6	—	—	—	—	—	—	—	—	—
Poisson's Ratio	← 0.335 →										
Density (lbm/in^3)	← 0.690 →										

References:
[*12*] Ultimate Tensile Strength: Figure 1, Page 671.
[*12*] Yield Strength: Figure 1, Page 671.
[*12*] Density: Page 670.
[*13*] Modulus of Elasticity: Table 7.
[*13*] Poisson's Ratio: Table 7.

2.2.2. Chemical, Galvanic, or Other Reactions

[NEDO-31581 §2.4.4]
The Model 2000 cask is fabricated from SS-304 and pig lead. The lead is completely encased in the stainless steel. This construction excludes moisture at the stainless boundary, thus assuring no galvanic or deleterious reactions could occur. The cask contents contact the stainless cavity surface. The radioactive material contents are in solid form and typically are placed in an inner container. GE's experiences in operating other transport packages with similar arrangements show that chemical, galvanic or other reactions between the cask cavity surface and the radioactive material containers, or between these containers and their solid contents, do not occur.

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2.2.3. Effects of Radiation on Materials

Gamma radiation has no significant effect on metal and therefore, the radiation produced by the contained radioactivity does not cause any measurable damage to the packaging metallic components (stainless steel, depleted uranium, and lead). Seals are inspected prior to each use. Leakage testing of the cask closure seal, vent, and drain are performed prior to each shipment. Seals incapable of passing the leakage test are replaced.

2.3 *Fabrication and Examination*

Requirements for fabrication and examination of the Model 2000 Packaging (i.e., overpack and cask) remain unchanged. Components of the HPI Assembly and Material Basket Assembly that are Category B items are fabricated in accordance with ASME Section III, Subsection NF. All will be fabricated and examined in accordance with an NRC approved Quality Assurance Program.

2.4 *General Requirements for All Packages*

No change to this section as the Model 2000 Shipping Package remains unchanged. The HPI and Material Basket design falls within the bounds identified in CoC 9228 Rev 26 and the Model 2000 SAR (NEDO-31581 §2.4).

2.4.1. Minimum Package Size

[NEDO-31581 §2.4.1]
The smallest overall dimension of the Model 2000 Shipping Package is 131.5 inches. The cask overall dimensions are 71.0 inches high and 38.5 inches OD.

2.4.2. Tamper-Indicating Feature

[NEDO-31581 §2.4.2]
A lock wire and seal of the type that must be broken is installed across the overpack joint section. This seal while intact, would be evidence that unauthorized persons have not opened the package.

2.4.3. Positive Closure

[NEDO-31581 §2.4.3]

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

Review of the SAR documents [*1*] and [*5*] for the 600 and 2000 watt analyses show that the bolt preload does not change as a result of the increase in thermal load. The closure bolt calculation shows that the controlling loads for the bolt preload are the internal pressure and the pin puncture loads. Further review of the temperatures presented in Section 3, show that because of the thermal modeling methodology, the heat load is concentrated in the HPI and Material Basket. As a result, the temperature distribution in the closure bolt and flange are more uniform resulting in a smaller temperature delta and lower thermal stresses. Therefore, the existing bolt preload of 690 ft-lb remains bounding.

2.5 *Lifting and Tie-Down Standards for All Packages*

[NEDO-32318, and NEDO-31581]
The regulations require that lifting devices which are a structural part of the package shall be capable of supporting three times the weight of the loaded package without generating stress in any material of the package in excess of its yield stress. The existing cask lifting devices and tie-downs have been fully analyzed in NEDO-31581 §2.5, and increased contents thermal loading do not affect the lifting and tie-down devices.

2.5.1. Lifting Devices

No change to the lifting device evaluation of the Model 2000 Shipping Package for this special authorization request. The HPI and Material Basket design falls within the bounds identified in CoC 9228 Rev 26 and the Model 2000 SAR (NEDO-31581 §2.5.1).

2.5.2. Tie-Down Devices

No change to the tie-down device evaluation of the Model 2000 Shipping Package for this special authorization request. The HPI and Material Basket design falls within the bounds identified in CoC 9228 Rev 26 and the Model 2000 SAR (NEDO-31581 §2.5.2).

2.6 *Normal Conditions of Transport*

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2.6.1. Heat

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

2.6.1.1. Summary of Pressures and Temperatures

Table 2-6 provides a summary of temperatures for the Model 2000 with HPI and Material Basket thermal evaluation presented in Section 3, Table 3-13, of this application. Table 2-7 compares the summary of temperatures for the 2000 watt and 3000 watt cases. As the table shows, the temperatures in the cask and overpack for the 3000 W cases are consistent with previous analyses in the SAR. Additionally, internal gasses in the cask and HPI are explicitly modeled in Section 3. Evaluation of the maximum pressure at the calculated average gas temperatures shows that the Model 2000 with HPI and Material Basktet does not exceed the design pressure of 30 psia.

2.6.1.2. Differential Thermal Expansion

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Where, the initial diameter, d_0, is multiplied by the product of the coefficient of thermal expansion, α, and change in temperature, ΔT, plus one. Table 2-8 shows the results of the evaluation. The minimum difference in diameters is calculated to be [[ ]]inches between the [[ ]]alignment disks, which results no radial interference. Therefore, the HPI and Material Basket can be removed from the cask following shipment.

<u>*Axial Thermal Expansion*</u>

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

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

Where, the initial length, L_0, is multiplied by the product of the coefficient of thermal expansion, α, and change in temperature, ΔT. Table 2-9 shows the results of the evaluation. The minimum difference in lengths is calculated to be [[0.23]]inches between the Material Basket and HPI inner cavity, which results in no axial interference.

2.6.1.3. Stress Calculations

Thermal stresses for the cask loaded with 3000 watt decay heat are scaled from (NEDO-32318 Table 2.9). Table 2-10 provides the thermal stresses scaled for the 3000 watts. This method is considered bounding since the thermal analysis for the GE 2000 cask with HPI applies the heat flux to the walls of the Material Basket. Even though total power is increased, thermal energy is focused in the HPI and Material Basket, which produces more uniform temperature distribution in the cask body. Regulatory Guide 7.8 stress combination results are presented in Section 2.6.7. For the HPI and Material Basket, the evaluation of thermal stresses is not required per ASME Code III-NF (NF-3121.11).

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Figure 2-1. HPI Support Disk Details

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FIGURE 2-2. MATERIAL BASKET DETAILS

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FIGURE 2-3. HPI INSIDE DIAMETER

Table 2-6. Temperature Results, NCT (in Shade and with Insolation).

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(Note: Data taken from Table 3-13)

Table 2-7. Comparison of 2000 W and 3000 W Temperatures

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Table 2-8. [[**Radial Thermal Expansion Evaluation for HPI and Material Basket**]]

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Table 2-9. [[**Axial Thermal Expansion Evaluation for HPI and Material Basket**]]

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Table 2-10. Scaled Thermal Stresses for 3000 W Case

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2.6.2. Cold

No change to this section as the Model 2000 Shipping Package remains unchanged. Cold conditions for the Model 2000 cask and overpack fall within the bounds identified in CoC 9228 Rev 26 and the Model 2000 SAR (NEDO-31581 and NEDO-32318) Section 2.6.2.

2.6.3. Reduced External Pressure

No change to this section as the Model 2000 Shipping Package remains unchanged. Reduced external pressure for the Model 2000 cask and overpack fall within the bounds identified in CoC 9228 Rev 26 and the Model 2000 SAR (NEDO-31581 and NEDO-32318) Section 2.6.3.

2.6.4. Increased External Pressure

No change to this section as the Model 2000 Shipping Package remains unchanged. Increased external pressure for the Model 2000 cask and overpack fall within the bounds identified in CoC 9228 Rev 26 and the Model 2000 SAR (NEDO-31581 and NEDO-32318) Section 2.6.4.

2.6.5. Vibration

No change to this section as the Model 2000 Shipping Package remains unchanged. Vibrations for the Model 2000 cask and overpack fall within the bounds identified in CoC 9228 Rev 26 and the Model 2000 SAR (NEDO-31581 and NEDO-32318) Section 2.6.5.

2.6.6. Water Spray

[NEDO-32318 §2.6.6]
The containment capabilities of the Model 2000 Shipping Package are not compromised by water spray since all external surfaces are of stainless steel, and the closure seal is impervious to water.

2.6.7. Free Drop

[NEDO-32318 §2.6.7]
The evaluation of the Model 2000 cask and overpack is provided in the Model 2000 SAR (NEDO-31581 and NEDO-32318) Section 2.6.7. Stress combination for the cask body analysis and scaled thermal stresses from Section 2.6.1.3 of this document are provided in Table 2-13 and discussed in Section 2.6.7.1 below. Sections 2.6.7.2-2.6.7.8 provide the structural evaluation of the HPI and Material Basket during free drop conditions. The HPI structural analysis is performed using the finite element program ANSYS [*16*] and the Material Basket is analyzed using classic methods.

2.6.7.1. Cask Body Stress Comparison for 600, 2000 and 3000 watt Cases

To evaluate the effects of increased content decay heat from 2000 to 3000 watts on the cask, the thermal stresses (Q) are linearly scaled based on the increased wattage, as previously discussed in Section 2.6.1.3. These thermal stresses are then combined with stresses previously calculated in the Model 2000 SAR (NEDO-32318 Section 2.6.7).

Tables 2-11 through 2-13 provide the stress combinations for the cask under the 3000 watt case at the peak component temperature for NCT. In all cases, the margin of safety is positive. To bound hot and cold NCT thermal conditions, in some cases the cold initial temperature is used and compared to the hot allowable stress.

[[**Table 2-11. NCT Cask Primary Membrane Stresses**

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Table 2-12. Combined NCT Cask Primary Membrane + Bending Stresses

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Table 2-13. Combined NCT Cask Primary and Secondary (Q) Stresses

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2.6.7.2. HPI Finite Element Model

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2.6.7.3. HPI Side Drop Model

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2.6.7.4. HPI End Drop Model

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FIGURE 2-4. HPI SOLID MODEL

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Figure 2-5. HPI Side Drop Finite Element Model

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FIGURE 2-6. CONTACT ELEMENTS BETWEEN HPI AND CASK INNER SHELL

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FIGURE 2-7. SOLID MODEL OF HPI BOTTOM PLUG

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FIGURE 2-8. FINITE ELEMENT MODEL OF HPI BOTTOM PLUG

2.6.7.5. Boundary Conditions

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

Inertial load

To evaluate the impact performance of the HPI, an LS-DYNA analysis was performed (Appendix 2.12.1) to determine the maximum acceleration during hot/cold and heavy/light environmental conditions and varying impact limiter shell thicknesses. Table 2-14 provides a summary of the maximum accelerations that occur during cold conditions. With the exception of corner drop case, the accelerations listed in Table 2-14 are applied to the HPI model using the ANSYS ACEL command equivalent to NCT accelerations corresponding to the 0.3 meter drop case. The applied accelerations are represented by equivalent static forces, in accordance with D'Alembert's principle.

Pressure loading contents—side drop

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Table 2-14. LS-DYNA NCT Impact Results Summary

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Figure 2-9. Cosine Pressure Distribution used to Represent the Material Basket

2.6.7.6. HPI NCT Side Drop Results

Stress results for the NCT side drop discussed previously are documented in Table 2-15. The table presents the primary membrane (P_m) and primary membrane plus primary bending (P_m+P_b) in accordance with the criteria presented in ASME Section III-NF [*8*].

As shown in the table, the margins of safety when compared to the stress intensity for each category are positive. The most critically stressed component in the system is the [[HPI outer shell]], which is at the [[support disk location]]. The minimum margin of safety is found to be +0.8 for primary membrane stress intensity. Figure 2-10 through Figure 2-13 shows the stress intensity results for the HPI assembly and components. The location of the critical section corresponding to the maximum stress location is shown in Figure 2-11.

Table 2-15. NCT Side Drop Stress Summary

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2.6.7.7. HPI NCT End Drop Results

Stress results for the NCT end drop discussed previously are documented in Table 2-16. The table presents the primary membrane (P_m) and primary membrane plus primary bending (P_m+P_b) in accordance with the criteria presented in ASME Section III-NF [*8*].

As shown in the table, the margins of safety when compared to the stress intensity for each category are positive. The most critically stressed component in the system is the interface between [[ ]]. The minimum margin of safety is found to be large. The locations of the critical sections correspond to the maximum stress location and axial displacement is shown in Figure 2-14.

Table 2-16. NCT End Drop Stress Summary

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Figure 2-10. HPI NCT Side Drop Results (Shell Assembly) – Peak Stress Intensity (psi)

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Figure 2-11. HPI NCT Side Drop Results (Support Disk) – Peak Stress Intensity (psi)

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Figure 2-12. HPI NCT Side Drop Results (Outer Shell) – Peak Stress Intensity (psi)

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Figure 2-13. HPI NCT Side Drop Results (Inner Shell) – Peak Stress Intensity (psi)

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Figure 2-14. HPI NCT End Drop Results – Peak Stress Intensity (psi) and Displacement (in)

2.6.7.8. Material Basket Evaluation

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2.6.8. Corner Drop

As can be seen in Table 2-14, the end drop and side drop NCT accelerations bound the corner drop. Therefore, a stress analysis of the corner drop scenario is not required.

2.6.9. Compression

[NEDO-32318 §2.6.8]
This test does not apply to the Model 2000 Shipping Package, since the package weight is in excess of 5,000 kg (11,000 lbs).

2.6.10. Penetration

[NEDO-31581]
The regulations for normal conditions of transport stipulate that the package must be capable of withstanding the impact of the hemispherical end of a vertical steel cylinder that weighs 13 pounds, has a 1¼ inch diameter, and is dropped from a height of 40 inches, normally onto the exposed surface of the package that is expected to be the most vulnerable to puncture. The outer shell of the cask is 1.0 inch thick steel. Tests conducted on 1.0 in thick stainless steel have shown that the damage produced by the 13 pound steel cylinder being dropped through a distance of 40 inches will be negligible and the effectiveness of the cask will not be reduced. In addition, the cask is enclosed by the overpack structure. The overpack structure is constructed of two 0.5 inch thick concentric shells. These shells will have to be penetrated by the dropped cylinder before it can reach the cask containment boundary.

2.7 *Hypothetical Accident Conditions*

[NEDO-32318 §2.7]
The Model 2000 Shipping Package has been demonstrated to meet the performance requirements specified in Subpart E of 10 CFR 71, when subjected to hypothetical accident conditions as specified in 10 CFR 71.73. According to the Regulatory Guide 7.6 [*17*], for the hypothetical accident conditions the stress intensities resulting from primary membrane and primary bending stresses are to be investigated. The stress intensities from the thermal stresses are presented in this section.

2.7.1. Free Drop

The performance and structural integrity of the package evaluated for the drop orientation that causes the most severe damage in the following sections. Section 2.6.7.1 provides the cask body stresses evaluated at the 3000 watt case NCT temperatures. Table 2-17 provides a summary of the HAC accelerations predicted by the LS-DYNA analysis presented in Appendix 2.12.1 and Table 2-23. A Lead Slump analysis is provided in Appendix 2.12.2.

Table 2-17. HAC LS-DYNA Results

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2.7.1.1. End Drop

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

As shown in Table 2-18, the margins of safety when compared to the stress intensity for each category are positive. The most critically stressed component in the system is the interface between the [[bottom cover ring and bottom plug cover plate that surrounds and supports the depleted uranium shield]]. The minimum margin of safety is +8.0 for primary membrane stress intensity. The locations of the critical sections correspond to the maximum stress location and axial displacement is shown in Figure 2-14.

Table 2-18. HAC End Drop Stress Summary

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2.7.1.2. Side Drop

The HPI is evaluated using the ANSYS finite element model presented in Section 2.6.7. Table 2-17 provides a summary of the HAC accelerations predicted by the LS-DYNA analysis presented in Appendix 2.12.1. Stress results for the HAC side drop discussed previously are documented in Table 2-19. The table presents the primary membrane (P_m) and primary membrane plus primary bending (P_m+P_b) in accordance with the criteria presented in ASME Section III, Appendix F [*18*].

As Table 2-19 shows, the margins of safety when compared to the stress intensity for each category are positive. The most critically stressed component in the system is the [[

]]. The minimum margin of safety is found to be +0.3 for primary membrane stress intensity. Figure 2-16 through Figure 2-18 show the stress intensity results for the HPI assembly and components. The locations of the critical sections correspond to the maximum stress location is shown in Figure 2-16.

Table 2-19. HAC Side Drop Stress Summary

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Figure 2-15. HPI HAC End Drop Results – Peak Stress Intensity (psi) and Displacement (in)

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Figure 2-16. HPI HAC Side Drop Results (Support Disk) – Stress Intensity (psi)

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Figure 2-17. HPI HAC Side Drop Results (Outer Shell) – Peak Stress Intensity (psi)

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Figure 2-18. HPI HAC Side Drop Results (Inner Shell) – Peak Stress Intensity (psi)

2.7.1.3. Corner Drop

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

2.7.1.4. Oblique Drops

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

2.7.1.5. Summary of Results

The above sections show that the HPI meets the HAC stress criteria. Reference [*5*] describes the condition or damage of the package after each orientation drop. Appendix 2.12.1 provides detailed results of the LS-DYNA impact analyses. Additionally, Tables 2-20 and 2-21 provide the stress combinations for the Model 2000 cask components with allowable stresses calculated at the peak component temperature. In all cases the margin of safety is positive. Note "Bottom" means "Bottom Drop," and "CGOC" means "Center of Gravity Over Corner."

Table 2-20. Cask HAC Primary Membrane Stresses Compared to Allowable at Temperature

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Table 2-21. Cask HAC Primary Membrane + Bending Stresses Compared to Allowables

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2.7.2. Crush

In accordance with the requirements of 10 CFR 71.73(c)(2), the Model 2000 Shipping Package is to be subjected to a dynamic crush test by evaluating the package on essentially unyielding horizontal surface so as to suffer maximum damage by the drop of a 1100 pound mass from 30 feet onto the package. The mass must consist of a solid mild steel plate 40 inches× 40 inches and must fall in a horizontal attitude. The crush test is required only when the specimen has a mass not greater than 1100 lb., and overall density not greater than 1000 kg/m^3 (62.4 lb/ft^3) based on external dimension. The crush condition is not applicable since the Model 2000 Shipping Package weighs more than 500 kg (1100 lb.) and overall density is greater than 62.4 lb/ft^3.

2.7.3. Puncture

[NEDO-32318, and NEDO-31581 §2.7.2]
This section addresses the second event in the accident design sequence outlined in 10 CFR 71.73(c)(3), the 40 inch drop of the Model 2000 Shipping Package onto a mild steel cylindrical punch. The evaluation of this condition is conducted for the cask structure and the containment vessel. The demonstration of the puncture capability of the package is presented in NEDO-31581 §2.7.2 Since the increased heat loading does not affect the puncture strength of the Model 2000 Shipping Package, results are not presented here.

Additional puncture analyses are provided in Appendix 2.12.1 to predict the accumulated damage in support of the thermal analysis. The maximum strain in the outer shell of the cask is 31% and limited to the puncture area. Therefore, no gross deformations of the cask are predicted.

2.7.4. Thermal

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

2.7.4.1. Summary of Pressures and Temperatures

Table 2-22 provides summary temperatures for the GE Model 2000 for HAC. During HAC, the average temperature of the cask fill gas (including the gas within the HPI) peaks at 591°F 11 hours after the end of the 30-minute fire. Using the ideal gas law, the cask internal pressure from gas expansion is 29.2 psia, which is less than the design pressure of 30 psia.

Table 2-22. Summary Temperatures for HAC

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2.7.4.2. Differential Thermal Expansion

[NEDO-32318 §2.7.3.2]
Differential thermal expansion resulting from the fire transient has minimum consequence to the Model 2000 Shipping Package. All stresses are classified as secondary displacement-limited stresses. Because the thermal load is focused in the Material Basket, the temperature in the cask wall is more uniform, which results in lower thermal differentials than those presented in NEDO-32318, Section 2.7.3.2. Therefore the stress evaluation presented in NEDO-32318 is bounding.

2.7.4.3. Stress Calculations

[NEDO-32318 §2.7.3.3]
The stress evaluation is provided in NEDO-32318, Section 2.7.3.3.

2.7.4.4. Comparison with Allowable Stresses

[NEDO-32318 §2.7.3.4]
The stress evaluation is provided in NEDO-32318, Section 2.7.3.4.

2.7.5. Immersion — Fissile Material

This is not applicable because no fissile material is being transported.

2.7.6. Immersion — All Packages

[NEDO-31581 §2.7.5]
The effect of a 22 psig external pressure when the package is immersed under 50 feet of water is of negligible consequence. The analysis presented in NEDO-31581 shows that the maximum stresses that result from external water pressure 50-feet poses no threat to the Model 2000 Shipping Package containment.

2.7.7. Deep Water Immersion Test (for Type B Packages Containing More than 10^5 A_2)

The contents specified for this special authorization request is less than 10^5 A_2. Therefore, this is not applicable for the Model 2000 Shipping Package with HPI and Material Basket.

2.7.8. Summary of Damage

For the cask, the effects of increasing power rating from 2000 to 3000 watts are evaluated by recalculating the allowable stresses at the peak temperature. Refer to Tables 2-20 and 2-21. Also, for the cask and overpack, the extent to which safety systems and components can be found in Appendix 2.12.1. For the HPI, an ANSYS analysis was performed using the inertial loads from the LS-DYNA analysis presented in Appendix 2.12.1 and allowable temperatures for the 3000 watt thermal analysis. In all cases, the margin of safety is positive.

2.8 *Accident Conditions for Air Transport of Plutonium*

This section does not apply for the Model 2000 Shipping Package with HPI and Material Basket.

2.9 *Accident Conditions for Fissile Material Packages for Air Transport*

This section does not apply for the Model 2000 Shipping Package with HPI and Material Basket.

2.10 *Special Form*

This section does not apply for the Model 2000 Shipping Package with HPI and Material Basket.

2.11 *Fuel Rods*

This section does not apply for the Model 2000 Shipping Package with HPI and Material Basket.

2.12 *Appendix*

2.12.1. LS-DYNA Evaluation of the Model 2000 Package

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2.12.1.1. Introduction

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Table 2-23. Summary of Drop Cases

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Figure 2-19. Model 2000 Solid Model

The three drop orientations are shown in Figure 2-20 below.

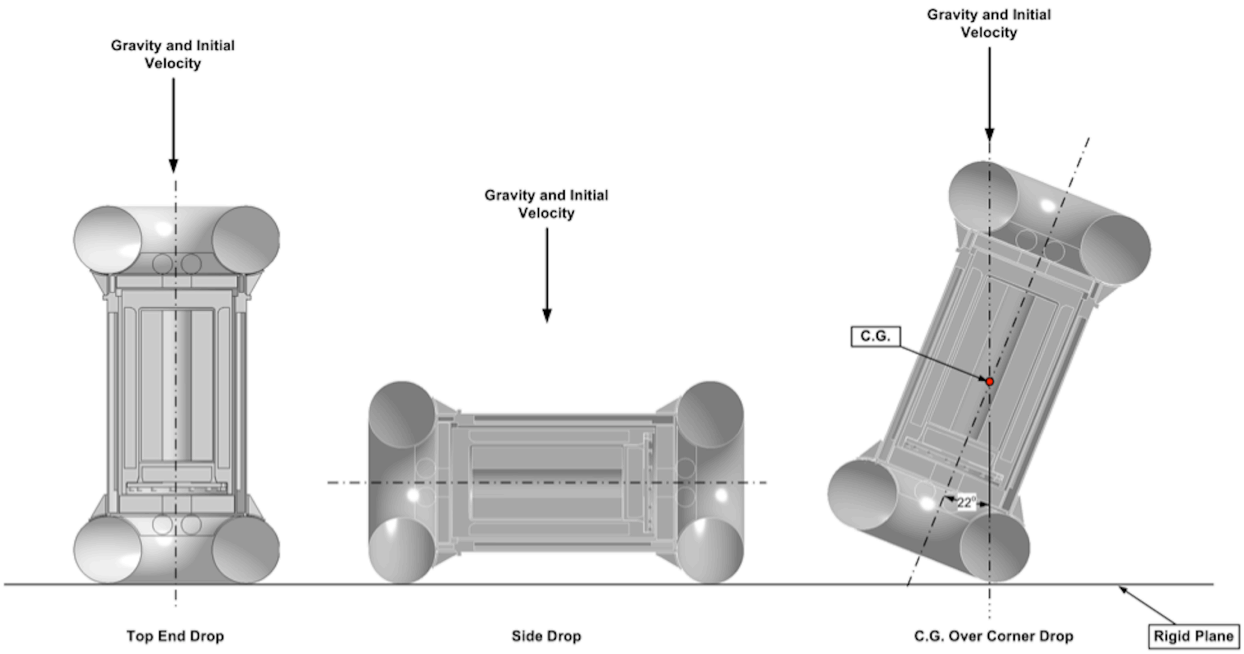

Figure 2-20. Drop Orientations

2.12.1.2. Benchmarking Runs

The selection of the drop cases are described in this section. Section 2.12.1.12.1 contains the Benchmark results. Benchmarks of the analysis methodology are performed using the 3 drop orientations shown in Figure 2-20 above to compare with the actual drop tests performed on a quarter-scale model. The benchmark runs are designated as drop cases 1 through 3. The actual drop tests were performed under ambient condition at room temperature. The nominal payload weight is 5450 pounds. The thickness in the toroidal shell is 0.76 inches. The drop height is 30 ft. The parameters of the benchmarking runs are listed in Table 2-24 below.

Table 2-24. Benchmark Runs and the Drop Parameters

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2.12.1.3. Normal Condition of Transport

The purpose of the drop simulation is to determine the peak acceleration of the payload and contents during the drop. The bounding acceleration occurs when the toroidal shell is thick so a stiffer response will result. At cold temperature, the material properties have greater elasticity and yield strength, therefore results in a stiffer response. Finally, a lighter payload will result in lower total cask weight, which in turn causes greater acceleration during impact. The bounding three drops are simulated with thick toroidal shell, reduced-weight payload, and material properties at cold temperature. The drop cases are designated as Drop Case No 4 through Drop Case No. 6, as listed in Table 2-25 below.

Table 2-25. Normal Condition of Transport Runs and the Drop Parameters

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2.12.1.4. Hypothetical Accident Condition

The purpose of the drop simulation is to determine the peak acceleration of the payload and/or the maximum damage during the drop.

The bounding acceleration occurs when the toroidal shell is thick so a stiffer response will result. At cold temperatures, the material properties have greater elasticity and yield strength, which results in a stiffer response. Finally, a lighter payload will result in lowered total cask weight, which in turn causes greater acceleration during impact. The three drops with bounding accelerations are simulated with thick toroidal shell, reduced payload, and material properties at cold temperature. For the end drop, the maximum force on the closure lid bolts occurs when the container lid in oriented towards to the rigid plane. The drop cases are designated as Drop Case No 7, 9, and 11 for the end drop, side drop and C.G. over Corner drop, respectively.

The maximum damage of the cask occurs when the toroidal shell is thin and has less structural strength. At warmer temperature, comparing with the material strength at room temperature, the material has lower elasticity and yield strength therefore resulted in greater damage to the cask. The heavier payload will also result in greater deformation of the toroidal shell. The drop cases with the bounding damage are designated as Drop Case No 8, 10 and 12 for the end drop, side drop and C.G. over Corner drop, respectively. The six bounding drop cases for the HAC are listed in Table 2-26 below.

Table 2-26. Hypothetical Accident Condition of Transport Runs and the Drop Parameters

[[Case No.										
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2.12.1.5. Shallow Angle Drops

Two shallow angle drops (5° and 10° from horizontal) with the drop configuration shown in Figure 2-21 below are performed to compare the acceleration with the result of the side drop benchmark run. With the same material parameters as the benchmark run, the shallow angle drop parameters consist of the nominal payload weight, material properties at room temperature, and thick toroidal shell thickness. The drop cases are designated as Drop Case No 13 and No.14 as listed in Table 2-27 below.

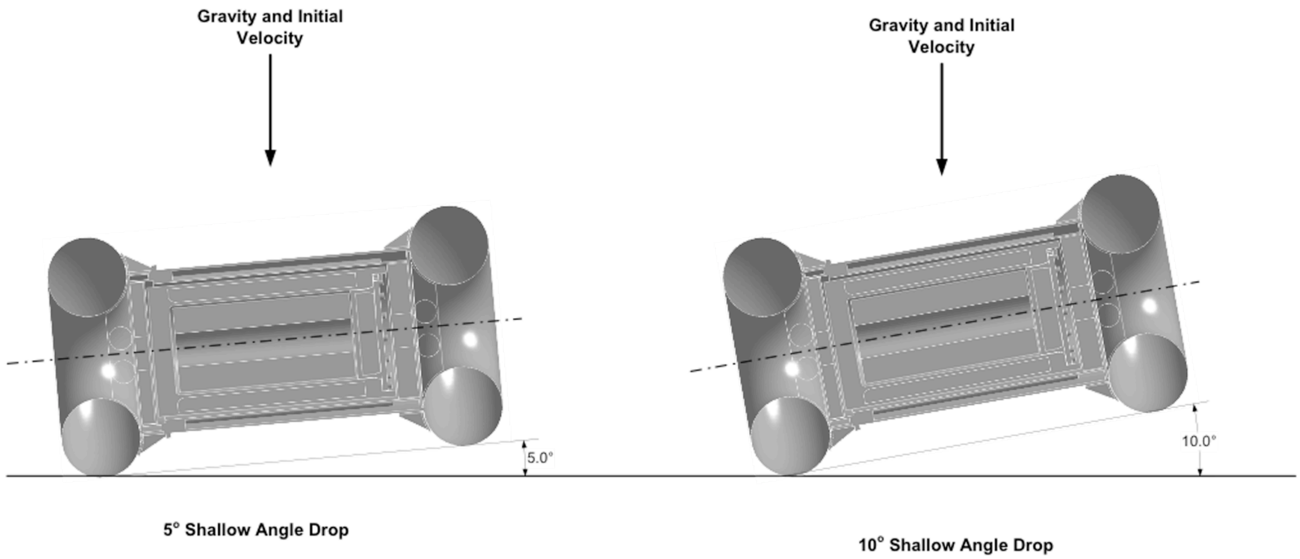

Figure 2-21. Shallow Angle Drops

Table 2-27. Shallow Angle Drop Runs and the Drop Parameters

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2.12.1.6. Pin Puncture

10 CFR Part 71.73 requires that a free drop of the specimen through a distance of 1 m (40 in) in a position for which maximum damage is expected, onto the upper end of a solid, vertical, cylindrical, mild steel bar mounted on an essentially unyielding, horizontal surface. The bar must be 15 cm (6 in) in diameter, with the top horizontal and its edge rounded to a radius of not more than 6 mm (0.25 in), and of a length as to cause maximum damage to the package, but not less than 20 cm (8 in) long. The long axis of the bar must be vertical.

To simulate the sequential drops, a rigid plane and a rigid pin of 6 in diameter with 8 in long are created, for the End Drop and Side Drop respectively. During the pin puncture, the model is allowed to pass through the rigid plane; therefore the puncture is independent of the pin length. Two drop configurations are selected, that will be subjected to maximum damage. The drop configurations selected for the pin puncture drop are listed in the table below. The drop cases are designated as Drop Case No. 15 and No. 16 as listed in Table 2-28 below.

Table 2-28. HAC Drop Cases with Pin Puncture

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2.12.1.7. Material Properties

2.12.1.7.1. 304 Stainless Steel

This material is used in the cask inner shell, over pack outer shell, gussets, and toroidal shell (impact limiter). The mechanical properties of the 304 SS at three different temperatures of interest in this calculation are tabulated in Table 2-29 below.

Table 2-29. Mechanical Properties of SS-304 at Temperature of Interest

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The stress strain curves for 304 stainless steel, taken from references [*11*] and [*21*], and are presented in Tables 2-30 through 2-32. The graphical representations of the stress strain curves of the SS-304 are displayed in Figures 2-22 through 2-24.

Table 2-30. Stress Strain Curve of SS-304 at -40°F

Strain	Stress, psi
0.0020	27,000
0.0034	30,000
0.0074	34,868
0.0182	39,736
0.0395	44,604
0.0625	49,472
0.0816	54,340
0.0998	59,208
0.1189	64,076
0.1398	68,944
0.1624	73,812
0.1870	78,680
0.2134	83,548
0.2418	88,416
0.2722	93,284
0.3045	98,152
0.3389	103,020
0.3753	107,888
0.4137	112,755
0.4542	117,623
0.5542	117,623
0.6542	117,623
0.7542	117,623

Table 2-31. Stress Strain Curve of SS-304 at Room Temperature

Strain	Stress, psi
0.0020	27,000
0.0035	30,000
0.0075	34,868
0.0183	39,736
0.0396	44,604
0.0626	49,472
0.0817	54,340
0.0999	59,208
0.1191	64,076
0.1399	68,944
0.1626	73,812
0.1871	78,680
0.2136	83,548
0.2420	88,416
0.2723	93,284
0.3047	98,152
0.3391	103,020
0.3755	107,888
0.4139	112,755
0.4544	117,623
0.5544	117,623
0.6544	117,623
0.7544	117,623

Table 2-32. Stress Strain Curve of SS-304 at 300°F

Strain	Stress, psi
0.0022	22,500
0.0033	25,000
0.0076	29,477
0.0198	33,953
0.0431	38,430
0.0659	42,906
0.0849	47,383
0.1036	51,859
0.1236	56,336
0.1454	60,812
0.1691	65,289
0.1947	69,765
0.2223	74,242
0.2518	78,719
0.2832	83,195
0.3167	87,672
0.3522	92,148
0.3896	96,625
0.4291	101,101
0.4707	105,578
0.5707	105,578
0.6707	105,578

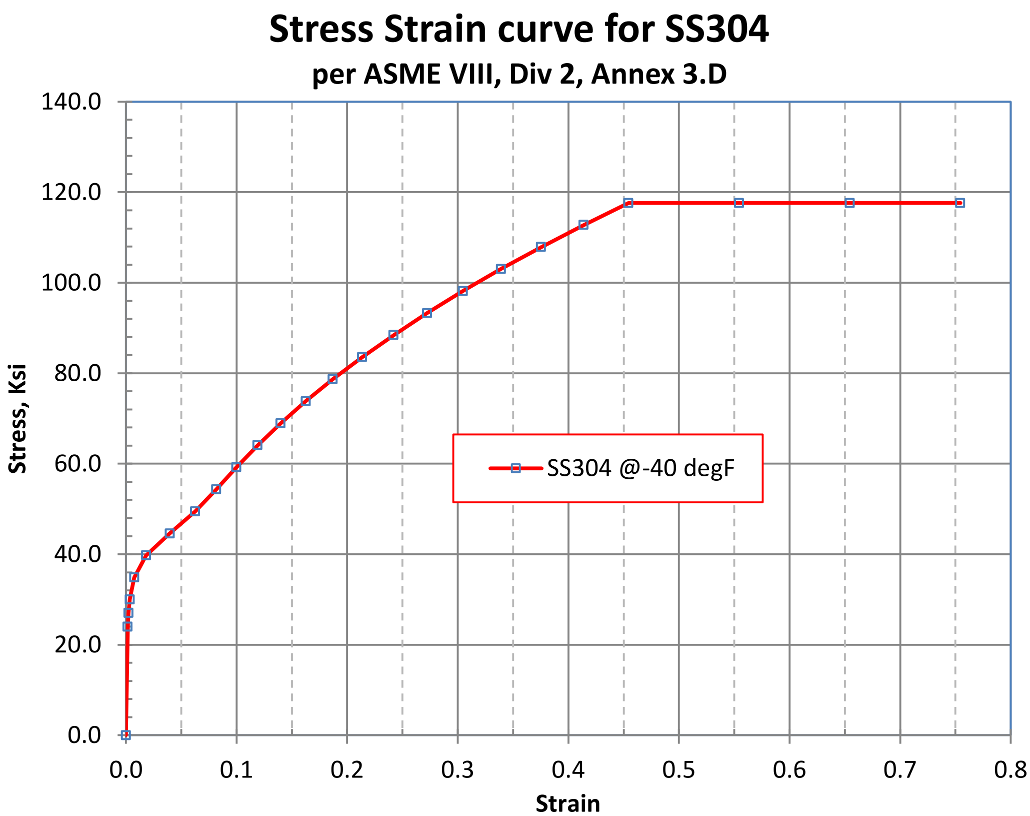

Figure 2-22. Stress-Strain Curve of SS-304 at -40°F

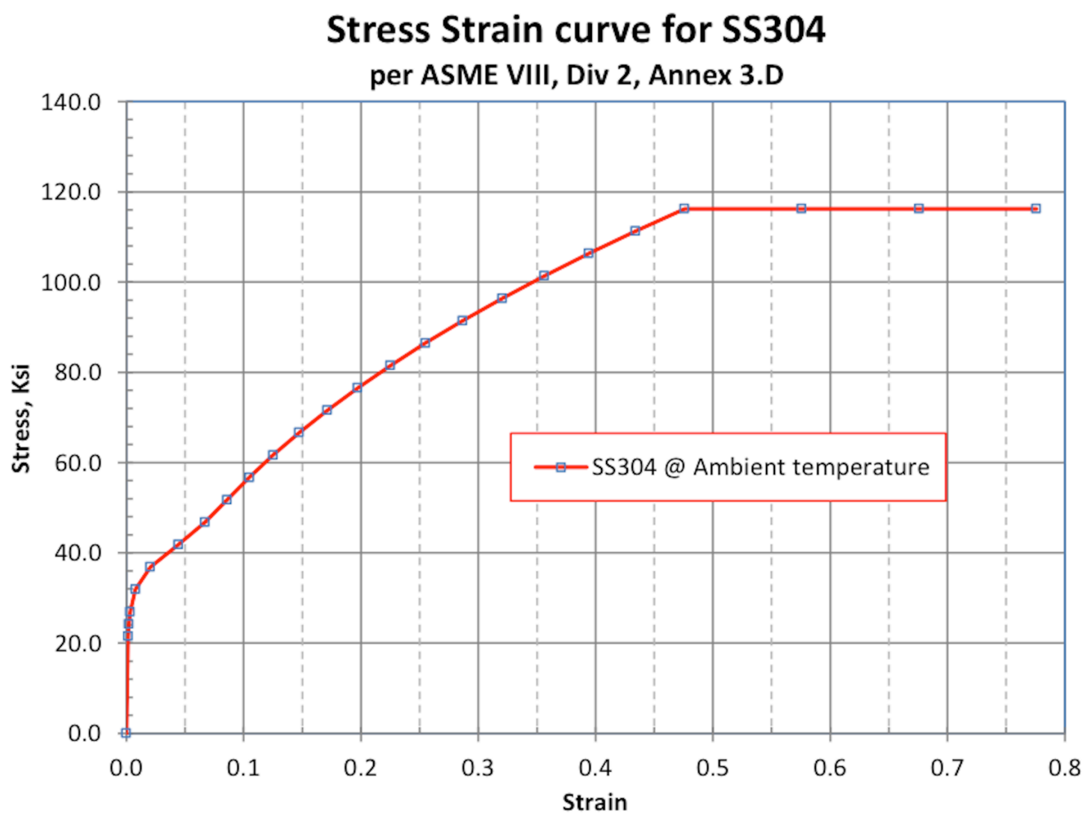

Figure 2-23. Stress-Strain Curve of SS-304 at Room Temperature

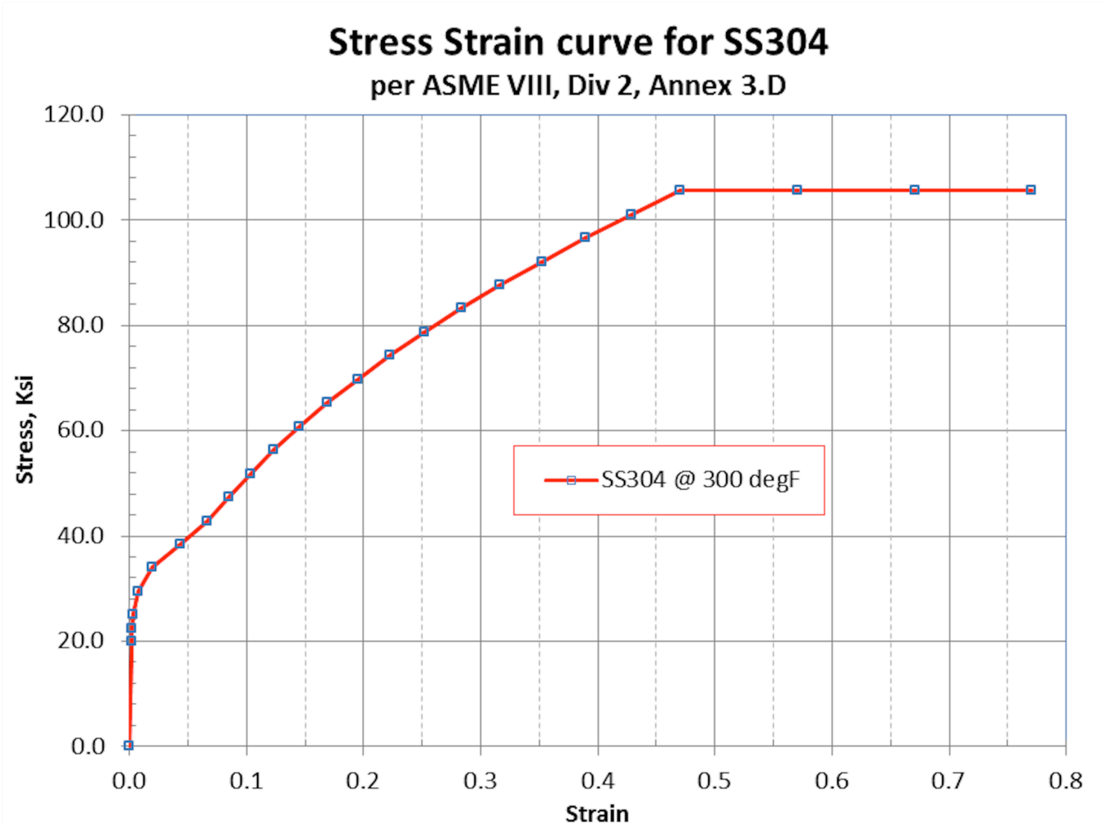

Figure 2-24. Stress-Strain Curve of SS-304 at 300°F

2.12.1.7.2. Lead

Chemical lead is used in the cask as shielding material. The mechanical property of the chemical lead is taken from Reference [*1*] and presented in Table 2-33 below.

Table 2-33. Lead Temperature Dependent Properties

Temperature, (°F)	Modulus of Elasticity, $\times 10^6$ (psi)	Density (lb_m/in^3)	Yield Strength, (psi)
-40	2.58	0.41	795
75	2.41	0.41	620
100	2.38	0.41	580
150	2.30	0.41	550
300	2.04	0.41	390

2.12.1.7.3. Strain-Rate Sensitive Material Properties of SS-304

The factors that elevate true stress-strain curves for SS304 at various strain rates and temperatures were generated by Reference [*22*] (pp. 84-87) and reproduced in Table 2-34 below.

Table 2-34. Strain-Rate Factors that elevated the Stress-Strain Curves of SS-304

Strain Rate (in/in/sec)	-20°F	70°F	300°F	600°F
5	1.333	1.235	1.166	1.043
10	1.361	1.278	1.210	1.094
22	1.428	1.381	1.316	1.217
25	1.445	1.407	1.342	1.247

The data from the above table are used to generate the strain-rate multiplication factors for the current analyses at temperatures of -40°F, room temperature and 300°F.

2.12.1.7.4. Honeycomb Material Property

The crush strength of the honeycomb material is 750 psi that is taken from Reference [*1*], page 2-16. The material property at temperature of -20°F is assigned a value of 10% greater to account for the increase of rigidity due to cold temperature. Based on the HPI thermal analyses presented in Section 3, the temperature of the Honeycomb material is bounded by 400°F. For the crush strength of Honeycomb material at 400°F, a reduction of the crush strength of 40% is conservatively assigned. This is based on the thermal tests from Reference [*23*], p. 9. The temperature test result is presented in Figure 2-25 below.

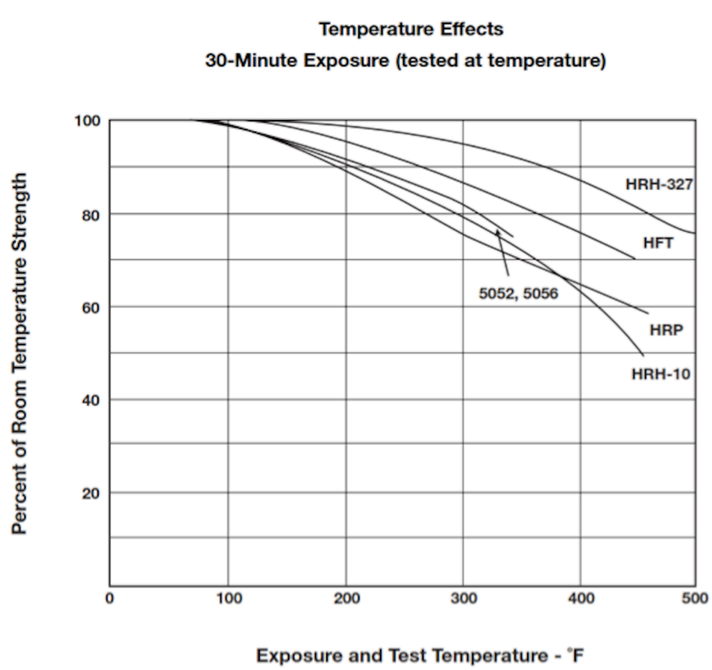

Figure 2-25. Temperature Effect of Honeycomb Material

2.12.1.7.5. Temperature Range for Material Properties

The component temperature range and justification for the applied temperature is discussed in Table 2-35 below.

Table 2-35. Component Temperature Range and Justification

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2.12.1.8. LS-DYNA Model Description

2.12.1.8.1. Finite Element Model

In accordance with the Model 2000 SAR and licensing drawings, an LS-DYNA finite element model was generated to evaluate the structural performance of the cask when loaded with the maximum content weight. The model includes the overpack and the Model 2000 cask body with lead shield and lid. The contents of the cask are modeled as a rigid body.

The solid model of the Model 2000 cask and overpack shown in Figure 2-19, was generated from the provided drawings and design input. The 3D (half-symmetry) solid model was generated using Autodesk Inventor, which was imported into ANSYS Workbench Design Modeler [*16*]. The finite element mesh was generated using the ANSYS Workbench Mechanical interface. The completed FEA model was then saved as a text input file to perform the analyses. Figure 2-26 shows the finite element model.

The finite element model is comprised of 3D brick elements (fully integrated selective-reduced solid) that represent the main body of cask components. Contact between components is modeled as surfaces using contact pairs. Boundary conditions such as symmetry are applied to the symmetry plane of the model. The final model includes 790,526 elements and 1,355,593 nodes.

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Figure 2-26. Model 2000 Overpack and Cask Finite Element Model

2.12.1.8.2. Pin Puncture Analysis Methodology

The accident sequence presented in 10 CFR 71.73 requires that the cask, after a 30 ft drop, to be dropped onto a pin with 6 in diameter with a modeled length of 8 inches To simulate the sequential drops, a rigid plane and a rigid pin of 6 in diameter with 8 in length are created as shown in the Figures 2-27 and 2-28 below for the End Drop and Side Drop, respectively.

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Figure 2-27. Rigid Plane and Pin Model for the End Drop Configuration

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Figure 2-28. Rigid Plane and Pin Model for the Side Drop Configuration

The dynamic simulation for this 30 ft drop onto an unyielding surface followed by a 40 in drop onto a pin is performed using a two steps drop sequence. For the first sequence, the impact velocity of the 30 ft drop is 527.5 in/sec. For the second sequence, the initial velocity for a 40 in drop is 175.8 in/sec.

During the first drop sequence at the beginning of the 30-ft drop accident, the cask travels in the downward direction with an initial velocity of 703.3 in/sec (=527.5+175.8). The rigid plane and the pin travel at an initial velocity of 175.8 in/sec and the contact interface is activated between the cask and the rigid plane while the contact interface between the cask and the pin is not activated. Therefore, the relative velocity between the cask and the rigid plane is 527.5 in/sec, which is equivalent to a drop height of 30 ft. During this sequence, the distance between the cask the pin is reduced as time progresses. The kinetic energy of the cask dissipates to zero at time = 35 milliseconds. This is the time at which the puncture impact starts.

At the beginning of the second sequence, the distance between the pin and the cask is reduces to a minimum gap but not touching. At this point, the absolute velocity of the cask and pin is 175.8 in/sec. At this time, the contact interface between the pin and the cask is activated while the contact interface between the rigid plane and the cask is deactivated, which allows the damaged impact limiters to pass through the rigid plane. Additionally, the velocity of the pin is set to zero, which results in relative velocity between the cask and the pin of 175.8 in/sec. Figure 2-29 shows the cumulative damage following the 30 ft top end drop and 40 in pin puncture.

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Figure 2-29**. Deformed Geometry of the Overpack after a 30 ft End Drop**

Figure 2-30 shows the cumulative damage for the side drop and pin puncture sequence. For the side drop, the depth of the unexposed cavity below the toroidal shell is less than 2.3 in (taken from the result of Drop Case No. 10). Therefore, the modeled pin length of 8 in is sufficient to sustain maximum damage.

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Figure 2-30. Deformed Geometry of the Overpack after a 30 ft Side Drop

2.12.1.9. Weight

The Model 2000 components consist of the closure lid, cask body and overpack. The dimensions used in the calculations are taken from the Transport Package fabrication drawings. The total weight of the 2000 package empty is found to be 28,100 lb. per Reference [*5*], Section 2.10.1. From the finite element model, the center of gravity is located 1.5 inches below the centerline of the overpack, 64.25 inches from the bottom line. Table 2-36 presents the breakdown of the components weights used for the dynamic analyses.

Table 2-36. Weights of the Model 2000 Cask used in the Analysis

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2.12.1.9.1. Material Model

The LS-DYNA material models used in the analyses are described below:

- The stainless steel shells are modeled using *MAT_PIECEWISE_LINEAR_PLASTICITY
- The honeycomb impact limiters are modeled using *MAT_CRUSHABLE_FOAM.
- The payload is modeled as *MAT_RIGID.
- The closure lid bolts of the inner shell are modeled as *MAT_ELASTIC.

2.12.1.9.2. Contact Interfaces

The control card *CONTACT_TIED_SURFACE_TO_SURFACE is used to fasten the welded components. For the components within the cask and the overpack, the control card *CONTACT_AUTOMATIC_SINGLE_SURFACE is used to provide global contact control. The honeycomb material has significant stiffness difference between the adjacent part, therefore the control card *CONTACT_AUTOMATIC_SURFACE_TO_SURFACE is used to control and prevent penetration between parts.

2.12.1.10. Boundary Conditions

2.12.1.10.1. Symmetry Plane

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2.12.1.10.2. Initial Velocity

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2.12.1.10.3. Gravity

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2.12.1.11. Dynamic Analysis Results HAC 30 ft Drops

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Accelerations – Accelerations are extracted from the LS-DYNA MATSUM file. Using the MATSUM data allows for the reporting of the maximum acceleration in any part and at any point in the model.

Kinetic Energy - The kinetic energy time history is used to confirm that the kinetic energy of the cask assembly is completely dissipated during the impact and the acceleration has peaked. For a normal and completed drop impact scenario, the kinetic energy must be decreasing to a minimum value as close to zero as possible and starts to increase (due to gravity loading). At the moment of minimum kinetic energy, the primary impact event is over.

Internal Energy - The internal energy plot is a measure of how much of the kinetic energy is converted into strain energy, either elastic or inelastic. Most likely, the internal energy is a measure of inelastic strain energy corresponding to the permanent deformation of the energy absorber material. The accumulated internal energy is a measure of how well the impact limiter is working as designed. Internal energy that is significantly smaller than the initial kinetic energy is an indication that the impact limiter is not dissipating the impact energy.

Hourglass Energy - The hour glass energy and the sliding energy are numerical terms that is produced by the mathematic solver but not derived from kinetic energy. The hourglass energy is strain energy numerically produced and proportional to the energy used to control the distortion of brick finite elements (solid element). As recommended by the LS-DYNA user manual, the brick elements perform best during the solution when the hourglass energy is limited to less than 10% of the internal energy.

Sliding Energy - The sliding energy plots represent the efficiency of the contact interface and the level of penetration between adjacent parts. A negative sliding energy indicates that the contact interface is not working well with a high degree of part penetrations. The contact interface control parameters must be revised to allow the use of different contact algorithms to prevent parts penetrations and pass-through. A positive sliding energy indicates the contact interface is working well and no penetrations are present.

2.12.1.11.1. Case 1 End Drop Benchmark

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Figure 2-31. Case 1 Deformed Over Pack Shape (Effective Plastic Strain)

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Figure 2-32. Case 1 Payload Acceleration Time History

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Figure 2-33. Case 1 Impact Energy Plot

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Figure 2-34. Case 1 Interface Sliding Energy Time History

2.12.1.11.2. Case 2 Side Drop Benchmark

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Figure 2-35. Case 2 Deformed Over Pack Shape (Effective Plastic Strain)

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Figure 2-36. Case 2 Payload Acceleration Time History

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Figure 2-37. Case 2 Impact Energy Plot

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Figure 2-38. Case 2 Interface Sliding Energy Time History

2.12.1.11.3. Case 3 C.G. over Corner Drop Benchmark

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Figure 2-39. Case 3 Deformed Over Pack Shape (Effective Plastic Strain)

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Figure 2-40. Case 3 Payload Acceleration Time History

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Figure 2-41. Case 3 Impact Energy Plot

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Figure 2-42. Case 3 Interface Sliding Energy Time History

2.12.1.11.4. Case 4 NCT End Drop with Thick Shell, Cold Condition and Light Payload

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Figure 2-43. Case 4 Deformed Over Pack Shape (Effective Plastic Strain)

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Figure 2-44. Case 4 Payload Acceleration Time History

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Figure 2-45. Case 4 Impact Energy Plot

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Figure 2-46. Case 4 Interface Sliding Energy Time History

2.12.1.11.5. Case 5 NCT Side Drop with Thick Shell, Cold Condition and Light Payload

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Figure 2-47. Case 5 Deformed Over Pack Shape (Effective Plastic Strain)

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Figure 2-48. Case 5 Payload Acceleration Time History

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Figure 2-49. Case 5 Impact Energy Plot

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Figure 2-50. Case 5 Interface Sliding Energy Time History

2.12.1.11.6. Case 6 NCT Corner Drop with Thick Shell, Cold Condition and Light Payload

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Figure 2-51. Case 6 Deformed Over Pack Shape (Effective Plastic Strain)

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Figure 2-52. Case 6 Payload Acceleration Time History

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Figure 2-53. Case 6 Impact Energy Plot

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Figure 2-54. Case 6 Interface Sliding Energy Time History

2.12.1.11.7. Case 7 HAC End Drop with Thick Shell, Cold Condition and Light Payload

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Figure 2-55. Case 7 Deformed Over Pack Shape (Effective Plastic Strain)

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Figure 2-56. Case 7 Payload Acceleration Time History

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Figure 2-57. Case 7 Impact Energy Plot

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Figure 2-58. Case 7 Interface Sliding Energy Time History

2.12.1.11.8. Case 8 HAC End Drop with Thick Shell, Hot Condition and Heavy Payload

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Figure 2-59. Case 8 Deformed Over Pack Shape (Effective Plastic Strain)

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Figure 2-60. Case 8 Payload Acceleration Time History

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Figure 2-61. Case 8 Impact Energy Plot

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Figure 2-62. Case 8 Interface Sliding Energy Time History

2.12.1.11.9. Case 9 Side Drop with Thick Shell, Cold Condition and Light Payload

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Figure 2-63. Case 9 Deformed Over Pack Shape (Effective Plastic Strain)

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Figure 2-64. Case 9 Payload Acceleration Time History

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Figure 2-65. Case 9 Impact Energy Plot

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Figure 2-66. Case 9 Interface Sliding Energy Time History

2.12.1.11.10. Case 10 Side Drop with Thin Shell, Hot Condition and Heavy Payload

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Figure 2-67. Case 10 Deformed Over Pack Shape (Effective Plastic Strain)

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Figure 2-68. Case 10 Payload Acceleration Time History

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Figure 2-69. Case 10 Impact Energy Plot

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Figure 2-70. Case 10 Interface Sliding Energy Time History

2.12.1.11.11. Case 11 Corner Drop with Thick Shell, Cold Condition and Light Payload

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Figure 2-71. Case 11 Deformed Over Pack Shape (Effective Plastic Strain)

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Figure 2-72. Case 11 Payload Acceleration Time History

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Figure 2-73. Case 11 Impact Energy Plot

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Figure 2-74. Case 11 Interface Sliding Energy Time History

2.12.1.11.12. Case 12 Corner Drop with Thin Shell, Hot Condition and Heavy Payload

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Figure 2-75. Case 12 Deformed Over Pack Shape (Effective Plastic Strain)

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Figure 2-76. Case 12 Payload Acceleration Time History

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Figure 2-77. Case 12 Impact Energy Plot

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Figure 2-78. Case 12 Interface Sliding Energy Time History

2.12.1.11.13. Case 13 Slapdown Drop (5°), Thick Shell, Ambient Condition and Nominal Payload

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Figure 2-79. Case 13 Deformed Over Pack Shape (Effective Plastic Strain)

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Figure 2-80. Case 13 Payload Acceleration Time History

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Figure 2-81. Case 13 Impact Energy Plot

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Figure 2-82. Case 13 Interface Sliding Energy Time History

2.12.1.11.14. Case 14 Slapdown Drop (10°), Thick Shell, Ambient Condition and Nominal Payload

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Figure 2-83. Case 14 Deformed Over Pack Shape (Effective Plastic Strain)

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Figure 2-84. Case 14 Payload Acceleration Time History

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Figure 2-85. Case 14 Impact Energy Plot

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Figure 2-86. Case 14 Interface Sliding Energy Time History

2.12.1.11.15. Results for 30 ft Drop Followed and 40 in Pin Puncture Drop Sequence

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Figure 2-87. Strain Contour of Package after 30 ft End Drop and Pin Puncture Sequence

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Figure 2-88. Strain Contour of Package after 30 ft Side Drop and Pin Puncture Sequence

2.12.1.12. Summary of Impact Analysis Results

Conservative impact analyses of the Model 2000 cask during the NCT and HAC impact events were performed to evaluate the performance of impact limiter design. This report summarizes the results of structural analyses of the Model 2000 Shipping Package during NCT per 10 CFR 71.71 and HAC per 10 CFR 71.73. The summary of results for the bounding drop cases are presented in Table 2-23.

The worst case HAC accelerations occur during the cold/thick/light side drop and the hot/thin/heavy bottom end drop. For the bottom end drop, the acceleration trend showed that the accelerations dropped until the honeycomb temperature was increased to 400°F and the honeycomb fully compresses. Since the average temperature of the honeycomb is less than 350°F, the honeycomb has sufficient capacity to protect the package during hot conditions.

The results of the evaluations presented in this appendix shows that the Model 2000 overpack provides sufficient protection of the cask and contents.

2.12.1.12.1. Benchmark Tests

The peak accelerations of the benchmark analysis results from Drop Cases 1 through 3 are compared with the drop test results from Reference [*5*] in Table 2-37 below.

Table 2-37. Comparison of Benchmark Simulations and Drop Tests Acceleration

Drop Case No.	Drop Configuration	LS-DYNA Analysis	Drop Test[1] Measurements	Notes
1	30-ft End Drop	130.0 G	408/4 = 102 G	Quarter-scale model
2	30-ft Side Drop	157.0 G	Not available	Instrument failure, No result
3	30-ft Corner Drop	70.9 G	156/4 = 39 G	Quarter-scale model

Notes: 1. Reference [*5*], Table 2.10.8.1.

The comparison of ¼-scale drop test deformation results and the LS-DYNA benchmark simulation is provided in Table 2-38.

Table 2-38. Comparison of Benchmark Simulations and Drop Tests Deformations

Drop Case No.	Drop Configuration	LS-DYNA Analysis	Drop Test[1] Measurements
1	30-ft End Drop	3.5 in	2.255×4 = 9.0 in
2	30-ft Side Drop	9.4 in	3.18×4 = 12.7 in
3	30-ft Corner Drop	11.8 in	5.3×4 = 21.2 in

Notes: 1. Reference [*5*], pp. 2-270 through 2-287.

The comparison of measured accelerations and deformations with LS-DYNA analysis results for each drop orientation shows that the LS-DYNA model is stiffer, which results in higher accelerations.

2.12.1.12.2. Shallow Angle Drops—Slap Down

Two shallow angle drop simulations are also performed. The drop configurations include nominal payload at ambient room temperature with thick toroidal shell thickness (t=0.76 inches) to compare with the side-drop test performed for the benchmarking test. The results for the two shallow angle drop cases are presented in Table 2-23. The two shallow angles are 5° and 10° slapdown drops that are designated as Drop Case 13 and 14. The results of shallow angle drops for the 0° (Drop Case 2, side drop), 5° (Drop Case 13) and 10° (Drop Case 14) conclude that the side drop (Drop Case 2) bounds the shallow angle cases with and acceleration of 157 G. Table 2-39 provides a summary of results for the shallow angle analyses.

Table 2-39. Comparison of Shallow Angle Drop Analyses

Drop Case No.	Shallow Angle Drop Angle	Peak Acceleration
2	0°	157.0 G
13	5°	115.0 G
14	10°	118.0 G

2.12.1.12.3. Pin Puncture

Besides the 30 ft drop configurations, two HAC drop configurations (side drop and end drop) are selected to perform the code-required pin puncture test, where the cask is dropped 30 ft and then followed by a drop height of 40 in onto a rigid pin of 6 in diameter. Evaluation of the pin puncture results shows that the maximum strain is limited to local area and will not result in the degradation of the containment boundary.

As the figures show the maximum strain is 39%. However review of results show the maximum strain is limited to local deformation of the overpack. The maximum strain in the outer shell of the cask is 31% and limited to the puncture area. Therefore, no gross deformations of the cask are predicted. Additionally, results for the combined 30 ft impact and pin puncture are used as input for the HAC thermal evaluation.

2.12.1.12.4. Containment Integrity

Based on the analyses presented in the calculation, there are no gross structural deformations of the cask body or containment boundary. Therefore, the containment integrity of the cask is maintained.

2.12.2. Lead Slump Calculation

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2.12.2.1. Thermal Expansion

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2.12.2.2. Compressive Stress in Lead during Bottom End Drop

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2.12.2.3. Elastic Deformation during Bottom Impact

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Table 2-40. Compressive Stress in Lead Shield

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2.12.3. References

All references are found in Section 1.3.3.

3 THERMAL EVALUATION

This section presents the thermal evaluation of the Model 2000 Shipping Package and High Performance Insert (HPI), with a contents thermal loading of 3000 watts, under Normal Conditions of Transport (NCT) and Hypothetical Accident Conditions (HAC) as prescribed by 10 CFR 71 [*19*].

Specifically, the following requirements of 10 CFR 71 are addressed:

1) General standards for all packages, 10 CFR 71.43(g)

A package must be designed, constructed, and prepared for transport so that in still air at 100°F and in the shade, no accessible surface of a package would have a temperature exceeding 122°F in a nonexclusive use shipment, or 185°F in an exclusive use shipment.

2) Normal Conditions of Transport—heat, 10 CFR 71.71(c)(1)

Evaluation of the package design for exposure to an ambient temperature in still air and insolation according to Table 3-1.

Table 3-1. Insolation Data per 10 CFR 71.71

Form and Location of Surface	Total Insolation for a 12-Hour Period (g cal/cm²)
Flat surfaces transported horizontally;	
Base	None
Other surface	800
Flat surfaces not transported horizontally	200
Curved surfaces	400

3) Hypothetical Accident Conditions—thermal, 10 CFR 71.73(c)(4)

Exposure of the package fully engulfed in a hydrocarbon fuel/air fire of sufficient extent, and in sufficiently quiescent ambient conditions, to provide an average emissivity coefficient of at least 0.9, with an average flame temperature of at least 1475°F for a period of 30 minutes, or any other thermal test that provides the equivalent total heat input to the package and which provides a time averaged environmental temperature of 1475°F.

For purposes of calculation, the surface absorptivity coefficient must be either that value which the package may be expected to possess if exposed to the fire specified or 0.8, whichever is greater; and the convective coefficient must be that value which may be demonstrated to exist if the package were exposed to the fire specified. Artificial cooling may not be applied after cessation of external heat input, and any combustion of materials of construction, must be allowed to proceed until it terminates naturally.

§71.73(b) With respect to the initial test conditions, the ambient air temperature before and after the test must remain constant at that value between -20°F and 100°F which is most unfavorable for the feature under consideration.

To demonstrate that the Model 2000, shown in]]

Figure 3-1, meets these requirements, a three-dimensional finite element model of the package was developed and analyzed using the general-purpose finite element analysis (FEA) code ANSYS, Release 14.0 [*16*]. Multiple ANSYS thermal calculations were performed simulating NCT and HAC using the finite element representation of the Model 2000 Shipping Package with HPI.

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Figure 3-1. Model 2000 Shipping Package (High Performance Insert and Basket Not Shown)

3.1 *Description of Thermal Design*

3.1.1. Design Features

[NEDO-32318 §3.1]
The Model 2000 Shipping Package, described in Section 1.2.1, is designed with a thermally passive system. The cask is enclosed in an overpack that serves as a fire shield. The overpack is designed to reduce heat flow from the fire environment into the cask structure by the use of enclosed air spaces. It is composed of two concentric cylindrical SS-304 shells approximately 83 inches long with an OD of 48.5 inches and an ID of 40.5 inches. The shells are separated radially by eight equally spaced tubes along the length of the shells, and horizontally by two tube sections to provide closed air spaces. A 24 inch diameter toroidal shell is attached at both ends of the outer shell with a circular plate enclosing the inner regions of the torus. The internal shell is also closed at each end by a circular plate. All materials are SS-304. The vertical tubes have a 3 inch OD and are 0.25 inches thick. The horizontal tube sections have a 7.25 inch OD and are 0.375 inches thick. Attached at both ends of the overpack inner surface are aluminum honeycomb pads.

The cask is designed with lead shielding on 3 sides and a 6 inch thick stainless steel forging at the base that functions as a heat sink that allows the heat to flow through the bottom of the package. When the cask is placed in the overpack during assembly, air gaps of 1.0 inch radially and 1.5 inches at the top separate the cask from the overpack inner surfaces.

The cask seal and test port O-ring designs are unchanged with the exception of use of [[

]]withstand the increased temperatures [*27*]. See Section 1.3.2.

The HPI is described in Section 1.2.2.1.

3.1.2. Content's Decay Heat

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3.1.2.1. Heat Generation by Contents

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The actual heat flux applied to the Basket tubes is shown in]]

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Figure 3-2. Contents Heat Flux Applied to Basket Tubes

3.1.3. Summary Tables of Temperatures

Thermal design criteria are specified for regions throughout the cask, cask cavity, and the outside overpack wall. The seal material is limited to 600°F and this serves as the thermal criteria for the region associated with the seal area. The maximum allowable internal pressure is 30 psia, which corresponds to air of 100% humidity heated to 600°F at constant volume.

Table 3-2 presents the maximum design temperatures of the components or materials that affect structural integrity, containment, and shielding under both NCT and HAC for the Model 2000 with the HPI. Where available, temperature limits for the Model 2000 Shipping Package components are obtained from manufacturers' literature. Otherwise, component temperature limits are defined as the melting temperature of the material of construction.

Table 3-2. Temperature Limits

Component or Material	Temperature Limit (°F)
Stainless Steel Components	2546
Lead Shielding[a]	622
[[Depleted Uranium Shielding[a]	2071]]
Aluminum Honeycomb[b]	350
Cask Seal	-15 to 600[c]
Cask Port O-Rings	-15 to 600[c]
Accessible Surfaces Of Package	< 185°F[d]

Notes:

a. Temperature limit is melting temperature *[*28*]*.
b. Maximum operating temperature *[*23*]*.
c. [[Parker O-Ring Handbook *[27]*]]
d. Exclusive use requirement per 10 CFR 71.43(g).

3.1.3.1. NCT Temperature Summary

Per the requirements of 10 CFR 71.71(c)(1) [*19*], the Model 2000 Shipping Package with HPI is evaluated for Normal Conditions of Transport. Specifically, a steady-state thermal analysis is performed simulating exposure of the package to a 100°F ambient temperature in still air and insolation as specified in Table 3-1. The results of the analysis are presented in Section 3.3. The temperatures of several key package components are summarized and compared with their allowable temperatures in Table 3-3.

Table 3-3. NCT Temperature Summary and Comparison with Allowable Temperatures

Item	NCT Temperatures (°F)	Allowable Temperature (°F)
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		]]

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The Model 2000 Shipping Package components remain below their allowable temperatures for NCT with insolation. Therefore, when exposed to NCT with insolation, the Model 2000 with HPI will maintain containment of the contents, as neither the shielding nor the impact limiting materials exceed temperatures that would adversely affect their performance.

3.1.3.2. HAC Temperature Summary

When exposed to the HAC fire prescribed in the regulations, the Model 2000 Shipping Package with HPI must maintain containment of its contents and maintain it shielding capabilities. The results of the HAC thermal evaluation are presented in Section 3.4. As shown in Table 3-4, the maximum temperatures of the different package components are below the allowable temperatures. Therefore, the HAC fire does not adversely affect the package's ability to provide containment and shielding for its contents. Note that the maximum average fill gas temperatures in the HPI and cask are 744°F and 576°F respectively. The maximum average combined fill gas temperature (HPI + cask) is 591°F.

Table 3-4. HAC Maximum Temperature Summary and Comparison with Allowable Temperatures

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3.1.4. Summary Tables of Maximum Pressures

Table 3-5 shows the maximum normal operating pressure and the maximum pressure under hypothetical accident conditions.

Table 3-5. Maximum Pressures

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		]]

3.2 *Material Properties and Component Specifications*

3.2.1. Material Properties

The thermal properties of the materials of construction used in the analyses for the thermal evaluation are presented in Table 3-6. When available from the open literature, temperature-dependent properties are used in the analyses. Additionally, the thermal properties of the HPI and cask fill gas (Helium) and Overpack gas (air) are presented in Table 3-7 [*28*].

Table 3-6. Thermal Properties of Solid Regions in the Model 2000 Finite Element Thermal Model

Material	Temperature (°F)	Density (lbm/in^3)	Thermal Conductivity (Btu/h-in-°F)	Specific Heat (Btu/lbm-°F)	Emissivity
[[					
					]]

Material	**Temperature (°F)**	**Density (lbm/in^3)**	**Thermal Conductivity (Btu/h-in-°F)**	**Specific Heat (Btu/lbm-°F)**	**Emissivity**
[[					
					]]

Notes:
a. Reference *[*28*]* Table A.1 (density, thermal conductivity, and specific heat) and Table A.11 (emissivity).
b. Reference *[*29*]*
c. Density and thermal conductivity *[*23*]*. Specific heat of Aluminum 2024-T6 *[*28*]*, Table A.1. Emissivity of heavily oxidized aluminum *[*30*]*, Appendix D

Table 3-7. Thermal Properties of Gaseous Regions in the Finite Element Thermal Model

Material	**Temperature (°F)**	**Density (lbm/in^3)**	**Thermal Conductivity (Btu/h-in-°F)**	**Specific Heat (Btu/lbm-°F)**	**Emissivity**
[[					

Material	**Temperature (°F)**	**Density (lbm/in^3)**	**Thermal Conductivity (Btu/h-in-°F)**	**Specific Heat (Btu/lbm-°F)**	**Emissivity**
					]]

3.2.2. Component Specifications

The Model 2000 packaging component materials are primarily stainless steel, lead, and aluminum. The melting points (i.e., maximum design temperatures) of these materials are given in Table 3-2. The temperatures resulting from normal and accident thermal conditions fall within these temperatures.

The only component material that is temperature sensitive is the [[

]].

3.3 *Thermal Evaluation under Normal Conditions of Transport*

The thermal performance of the Model 2000 Shipping Package with HPI is analyzed for NCT (with and without insolation) by performing steady-state heat transfer analyses on a finite element representation of the package. Specifically, the general-purpose finite element code ANSYS, release 14.0 [*16*], is used to model and analyze the Model 2000 with a content heat load of 3000 W for NCT. Several ANSYS macros are created in order to build the model, apply boundary conditions, and perform the steady-state analyses.

Assumptions made for this evaluation are given below.

- The Model 2000 Shipping Package is assumed to be in an upright (vertical) orientation during NCT.
- The Cask and HPI are backfilled with Helium at 70°F and 14.7 psia.
- Natural convection within the package cavities is neglected.
- The contents of the HPI are assumed to generate a maximum of 3000 W that is uniformly distributed among the [[nineteen Basket tubes]].
- During NCT, the package is assumed to have an emissivity consistent with the material of construction at temperature.

NCT Summary Temperatures

As mentioned above, for the NCT analysis, a steady-state thermal analysis was performed simulating exposure of the package to a 100°F ambient temperature in still air and insolation as specified in Table 3-1. The results of the analysis are presented below. The temperatures of the key package components are summarized and compared with their allowable temperatures in Table 3-3.

Model Description

The general-purpose finite element code ANSYS, release 14.0 [*16*], is used to model and analyze the Model 2000 with a content heat load of 3000 watts for NCT. Several ANSYS macros are created in order to build the model, apply boundary conditions, and perform the steady-state analyses.

The model, shown in **Figure 3-3** through Figure 3-5, represents a half-symmetry of the package. A half-symmetry model is used so that damage from the HAC drop/puncture test may be incorporated using the same model.

In the model, the decay heat of the contents, applied as a heat flux to the basket tubes, is transferred through the solid and gaseous regions via conduction heat transfer, across gaseous regions separating solids via thermal radiation, and then rejected to the surroundings via natural convection and thermal radiation. Heat transfer via convection within the package is not considered. In addition to the decay heat of the contents, other heat sources—insolation (heat flux) and/or fire (convection/thermal radiation)—are also included as boundary conditions where appropriate.

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Figure 3-3. Finite Element Model of the Model 2000

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Figure 3-4. Finite Element Model of the Model 2000 - Air and He not Shown

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Figure 3-5. Finite Element Model of the Model 2000 - Exploded View

Thermal Contact Resistance/Conductance

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Figure 3-6. Heat Transfer Through the Contact Plane Between Two Solid Surfaces

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Table 3-8. Typical Thermal Contact Conductance Values from Open Literature

Material (Both Surfaces)	Surface Roughness (μ in)	Interfacial Gas	Pressure (psi)	TCC (Btu/h-in²-°F)	Source
[[					
					]]

Table 3-9. TCC Values Used in the Thermal Analyses

Thermal Contact Resistance ID	Thermal Contact Resistance Level	TCC (Btu/h-in²-°F)
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		]]

Notes:

a. [[

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Table 3-10. Thermal Contact Resistance Levels Assigned to the Modeled Contact Elements

Contact ID (Real Constant)	Surface 1 (CONTA173)	Surface 2 (TARGE170)	Thermal Contact Resistance ID (See Table 3-9)
			]]

Table 3-10. Thermal Contact Resistance Levels Assigned to the Modeled Contact Elements

Contact ID (Real Constant)	Surface 1 (CONTA173)	Surface 2 (TARGE170)	Thermal Contact Resistance ID (See Table 3-9)
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			]]

[[			
			]]

Note: [[ ]]

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Figure 3-7. Thermal Contact Pair Locations In the Finite Element Model

Boundary Conditions

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Natural Convection and Thermal Radiation to the Environment

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Horizontal Cylinder—natural convection to environment

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Horizontal Plate—natural convection environment

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Vertical Flat Plate—natural convection to environment

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Table 3-11. Thermophysical Properties of Dry Air [*28*]

Temperature (°F)	Density (lbm/in^3)	Thermal Conductivity (Btu/h-in-°F)	Specific Heat (Btu/lbm-°F)	Viscosity (in²/h)	Thermal Diffusivity (in²/h)	Prandtl Number
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Thermal Radiation to Environment

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Normal Conditions Convection Coefficients

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Figure 3-8. Natural Convection Boundary Conditions for NCT

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Figure 3-9. Natural Convection and Thermal Radiation Coefficients for NCT

(Note data for NCT in shade and with insolation)

NCT Solar Heat Flux (Insolation)

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Figure 3-10. Solar Heat Flux Boundary Conditions for NCT

Detailed NCT Results

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Table 3-12. Temperature Results, NCT (in Shade and With Insolation)

Component	100°F Ambient Temperature, in Shade			100°F Ambient Temperature, with Insolation		
	Max	Min	Avg	Max	Min	Avg
[[						
						]]

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Figure 3-11. Steady-State Temperature Distribution—Normal Conditions of Transport.

3.3.1. Heat and Cold

Maximum Surface Temperature ResultsThe Model 2000 Shipping Package with HPI is also evaluated to the requirements of 10 CFR 71.43(g) [*19*], which requires that no accessible surface of the package exceed 185°F in an exclusive use shipment when exposed to a 100°F ambient temperature in still air and shade. As shown in Figure 3-12, the overpack in the region of the bolting ring exceeds the allowable temperature of 185°F. Therefore, a personnel barrier not part of the packaging will be used to block access to this region when readied for transport.

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Figure 3-12. Overpack Steady-State Temperature Distribution, 100°F

(Note: Assumes ambient temperature in shade)

3.3.2. Maximum Normal Operating Pressure

3.3.2.1. NCT Pressure Evaluation

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3.4 *Thermal Evaluation under Hypothetical Accident Conditions*

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3.4.1. Initial Conditions

When evaluating the package for the HAC 30-minute fire, the package must include damage from a 30 foot drop onto an unyielding surface and a 40 inch drop onto a 6 inch diameter pin [*19*]. The structural evaluation of the Model 2000 Shipping Package considers several drop orientations for HAC; however the side-drop orientation is chosen as the worst-case from a thermal standpoint. The reason for this is due primarily to the damage to the overpack side from the 40 inch drop onto the 6 inch diameter pin. The drop onto the pin causes the overpack outer and inner shells to come in contact—thus, creating a path for the heat from the fire to more easily reach the cask (and cask shielding). Although the damage from the drop onto the pin is not modeled in the deformed geometry, its effect is included by using LINK34 elements to model the contact of the two shells.

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Figure 3-13. Three-Dimensional Finite Element Model of the Model 2000 (Half Symmetry)

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3.4.1.1. Additional Thermal Contact for the Hypothetical Accident Condition

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When oriented on its side, the contact between the Basket disks and HPI inner shell, between the HPI disks and cask cavity shell, and between the cask shell and overpack inner shell are modeled with a "Low/Moderate" thermal contact resistance (thermal contact conductance of 15.0 Btu/h-in²-°F) and 2° of contact as shown in **]]**

Figure 3-14. Additionally, the puncture damage is simulated by adding LINK34 elements (20° contact area) between the overpack inner and outer shells as shown in **]]**

Figure 3-14. The "Low/Moderate" thermal contact resistance is chosen for these contact elements in order to maximize the heat from the contents and the HAC fire into the cask shield at the puncture location.

3.4.1.2. Hypothetical Accident Conditions Convection Coefficients

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Figure 3-14. LINK34 Incorporated to Simulate HAC Side Contact and Puncture Damage

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Figure 3-15. Natural Convection Boundary Conditions for HAC

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Figure 3-16. Natural Convection and Thermal Radiation Coefficients for HAC

(Note: Coefficients are for HAC Pre-Fire, Fire, and Post-Fire)

3.4.2. Fire Test Conditions

3.4.2.1. HAC Solar Heat Flux (Insolation)

Previous versions of 10 CFR 71.73 (i.e., prior to ~1997), stated that insolation need not be considered before, during, or after the 30 minute hypothetical accident fire. However, the current regulations do not specifically address whether insolation should be included prior to, during, or after the HAC fire. The HAC thermal analysis presented in this report does not include insolation during the HAC fire; however, insolation is applied to the package surfaces during steady-state conditions prior to the fire and during the transient post-fire cool-down. Since the side drop and side puncture damage is simulated for the HAC thermal evaluation, the Model 2000 Shipping Package is assumed to be in a horizontal orientation. Therefore, prior to the fire and during the post-fire cool-down, a heat flux of 0.427 Btu/h-in² is applied to the toroidal shells and overpack sides, and a heat flux of 0.214 Btu/h-in² is applied to the overpack top and bottom end plates as shown in **Figure 3-17**.

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Figure 3-17. Solar Heat Flux Boundary Conditions for HAC (Post-Fire Cool-Down)

3.4.3. Maximum Temperatures and Pressure

When exposed to the HAC fire prescribed in 10 CFR 73(c)(4) [*19*], the Model 2000 Shipping Package with HPI must maintain containment of its contents and maintain it shielding capabilities. The results of the HAC thermal evaluation are presented in Table 3-13. Comparing with Table 3-2, it can be seen that the maximum temperatures of the different components are below the allowable temperatures. Therefore, the HAC fire will not adversely affect the package's ability to provide containment and shielding for its contents.

3.4.3.1. HAC Temperature Results

A transient thermal analysis was performed on the model. This transient analysis simulates exposure of the Model 2000 package to a 30 minute hypothetical accident fire followed by a 36 hour cool-down period in which the package is exposed to a 100°F ambient temperature and insolation (solar heat flux). The 36 hour cool-down period is of sufficient length to allow the package temperatures to reach their peak values.

The results of the transient HAC thermal analysis are presented in Table 3-13.

Table 3-13. Temperature Results, Hypothetical Accident Conditions

Item	Peak Temperature (°F)	Time at Which Peak Temperature Occurs (Hours)
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Additionally, temperature-history plots of several package components are presented in **Figure 3-18** through **]]Figure 3-20**. As shown in these figures, the cool-down period of 36 hours is sufficient to allow all package temperatures to achieve their peak values.

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Figure 3-18. Temperature-History of the Basket and Overpack for HAC

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Figure 3-19. Temperature-History of the HPI Cask for HAC

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Figure 3-20. Temperature-History of the HPI and Cask Fill Gases

(Note: Volumetric Average Temperature)

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Figure 3-21. Temperature Contours During HAC 30-Minute Fire and Cool-Down

3.4.3.2. HAC Maximum Pressure Calculation

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3.4.4. Maximum Thermal Stresses

Section 2.7.4.3 discusses thermal stresses.

3.4.5. Accident Conditions for Fissile Material Packages for Air Transport

This package will not be transported by air.

3.5 *Appendix*

3.5.1. References

References can be found in Section 1.3.3.

4 CONTAINMENT ANALYSIS

This section demonstrates the ability of the Model 2000 Shipping Package to meet the containment requirements of 10 CFR 71. The containment system for the Shipping Package consists of the cask alone. The other components (i.e., overpack, HPI, etc.) are not part of the containment system.

4.1 *Description of Containment System*

The cask design has been modified to support the 3000 watt decay heat upgrade. Specifically, the cask features [[

]]. There are no other design changes to the containment system.

4.1.1. *Containment Vessel*

[NEDO-31581 §4.1.1]
Figure 1-2 shows the containment vessel (cask) for the Model 2000 Shipping Package. The cask is constructed of a steel-clad lead cylinder with a stainless steel forging at each end. The cask lid is placed within the upper forging to protect the seal area during the accident conditions. The materials of construction of the cask meet the requirements of Federal Specification QQ-L-171e pig lead for the lead and ASTM A240 and ASTM A182 Type 304 stainless steel for the steels.

4.1.2. *Closure*

[NEDO-31581 §4.1.4]
The cask lid connects to the cask body by fifteen 1.25 inch diameter ASTM A540, Grade B22 socket head screws. The screws are equally spaced on a 32.25 inch diameter bolt circle. Each screw is tightened to 690 ft-lb torque. The closure evaluation is presented in Section 2.4.3. The stress analysis of these screws is given in Reference [*5*], Section 2. The screw analysis shows that positive closure is maintained during all conditions.

4.1.3. *Containment Penetrations*

[NEDO-31581 §4.1.2 revised]
The Model 2000 cask has three penetrations or ports. One port, located two inches from the bottom of the cask, serves as a drain for the cask cavity. This port is made by a series of offset ½ inch drilled holes through the 6 inch thick steel forging. The second penetration is located approximately in the center of the cask lid. It is made of 3/8 inch diameter tubing spiraled through the lead and welded at both ends to the steel flanges that make up the lid. A combined use of these two ports provides means to eliminate water from the cask cavity collected during underwater operations.

The third penetration or port is used to test the adequacy of the cask closure seal after each loading operation. A ½ NPT socket head pipe plug followed by 1¾-12 UNC cap close each of these penetrations. An [[ ]]attached to the cap provides positive seal to these penetrations. This closure of pipe plug/cap with O-ring combination is designed for leaktightness as defined in ANSI 14.5-1993, Section 3.7 [*33*]. The seal is designed to operate in a range of -15 to 600°F. A performance test of this material at -40°F and 600°F will be performed to demonstrate that the material maintains leaktightness under these temperature and pressure conditions.

4.1.3.1. Seals and Welds

[NEDO-31581 §4.1.3 revised]
The cask includes a modified seal design between the lid and the cask body. The cask seal is composed [[of [[ ]]bounded in a grooved metal retainer, two cross sections at each face. [[ ]]. The retainer ring is 1/8 inch thick 6061-T6 aluminum. Under the pressure of assembly, the [[ ]]deform to occupy the pre-established free volume of the groove. Tests conducted on a prototype seal will be performed to demonstrate leaktightness under hot (600°F) and cold (-40°F) environments.

All cask welds are full penetration groove welds to ensure structural and containment integrity. Each weld is penetrant tested on the root and final passes. In addition, the welds are Helium leak tested.

4.2 *Containment under Normal Conditions of Transport*

[NEDO-31581 §4.2]
The Model 2000 cask containment is designed so that no release of radioactive materials will occur under the Normal Conditions of Transport (NCT), and there will not be any significant increase in external radiation or reduction in package effectiveness. This conclusion is supported by the analyses in Sections 2 and 3 and the various component qualification tests.

The cask will withstand pressures and temperatures in excess of those encountered in routine transport and normal conditions of transport. The maximum pressure encountered under NCT is 26.4 psia. This pressure corresponds to the maximum average fill gas temperature of 492°F given in Section 3.3.3. This pressure value is based on Helium occupying the entire cavity volume. The structural evaluation presented in Section 2 shows low stress values throughout the cask structure, especially in the seal area under NCT. In addition, the maximum average fill gas temperatures are below the operational limits of 600°F for the seal material so containment integrity is maintained.

4.3 *Containment under Hypothetical Accident Conditions*

[NEDO-31581 §4.3]
As seen in Section 3.4.3.2, the maximum average fill gas temperature in the cask cavity for HAC is 591°F with a corresponding pressure of 29.2 psia. As stated above, this pressure is based on Helium occupying the entire cavity volume. This pressure does not exceed the design pressure of 30 psia. Temperatures at the seal region and penetration or port areas are below the 600°F design temperature of the seal material. Figure 3-20 shows the volumetric average fill gas temperature versus time for the cask and HPI under HAC. Figure 3-19 similarly shows temperature versus time for the cask seal area. The analytical evaluations under accident conditions presented in Section 2 show that the stresses throughout the cask structure are below the failure criteria for the material.

4.4 *Leakage Rate Tests for Type B Packages*

The maximum temperature at the seal region is not greater than 600°F and those of penetrations or port areas are below 600°F. The internal pressure in the cask cavity may increase to 29.2 psia due to rise in the temperature. The Model 2000 cask is loaded dry or underwater. If loaded underwater the cavity must be vacuum dried to remove any residual moisture.

Regardless of how the cask is loaded, a leak test is performed after it is loaded. To perform the leak test Helium (He) is introduced into the cavity to a pressure of 15 psig. At the conclusion of the test, the pressure is released. Therefore it can be assumed that He remains inside the cavity. The peak average fill gas temperature under hypothetical accident conditions is 591°F. The seal will be prototype tested at 600°F. The pressure of 29.2 psia is less than the design pressure of 30 psia. Therefore, the Model 2000 design pressure is a conservative design basis for the shipment of the desired Co-60 rod segments.

4.5 *Appendix*

4.5.1. Cask Penetration Leaktightness test procedure and results.

4.5.2. References

References can be found in Section 1.3.3.

5 SHIELDING EVALUATION

The objective of this analysis is to demonstrate that the special authorization shipping configuration meets the external radiation requirements of 10 CFR 71 [*19*] summarized in Table 5-1. This shielding evaluation was performed to demonstrate that the Model 2000 Shipping Package with the High Performance Insert (HPI) provide sufficient shielding, such that the external radiation limits are satisfied under Normal Conditions of Transport (NCT) and Hypothetical Accident Conditions (HAC).

Table 5-1. Regulatory Limits

Dose Location (Case)		Regulatory Limit (mrem/hr)	10 CFR 71	Regulation
Package Surface (NCT)	Top	200	47(b)(1)	"**2 mSv/h (200 mrem/h)** on the external surface of the package …"
	Side	200		
	Bottom	200		
2-meter (NCT)	Side	10	47(b)(3)	"**0.1 mSv/h (10 mrem/h)** at any point 2 m (6.6 feet) from the outer lateral surfaces of the vehicle (excluding the top and underside of the vehicle); or in the case of a flat-bed style vehicle, at any point 2 m (6.6 feet) from the vertical planes projected by the outer edges of the vehicle (excluding the top and underside of the vehicle)"
Cab (NCT)	Side	2	47(b)(4)	"**0.02 mSv/h (2mrem/h)** in any normally occupied space…"
1-meter (HAC)	Top	1000	51(a)(2)	"…no external radiation dose rate exceeding **10 mSv/h (1 rem/h) at 1 m** (40 in) from the external surface of the package."
	Side			
	Bottom			

5.1 *Description of Shielding Design*

5.1.1. Design Features

The radiation shielding design features of the Model 2000 with the HPI Liner are the lead and stainless steel (SS) in the Model 2000 cask and the [[ ]]and stainless steel in the HPI. Narrative descriptions of the cask and HPI are given in Section 1.2. Table 5-2 provides dimensions, materials of construction, and densities of material for the components that provide gamma shielding.

Table 5-2. Model 2000 Shipping Package Shielding Design Features

Model 2000 Component	Part	Component	Thickness (in)	Thickness (cm)	Material of Construction	Material Density (lb/in^3)	Material Density (g/cm^3)
Cask	Cask Lid	Top Shell	1.75	4.45	SS-304	0.29	8.02
		Lead	5.37	13.64	Lead	0.41	11.34
		Bottom Shell	1.50	3.81	SS-304	0.29	8.02
	Cask Side	Cask Outer Shell	1.00	2.54	SS-304	0.29	8.02
		Lead	4.00	10.16	Lead	0.41	11.34
		Cask Inner Shell	1.00	2.54	SS-304	0.29	8.02
	Cask Bottom	Bottom Plate	6.00	15.24	SS-304	0.29	8.02
[[							
							]]

[[ ]]

5.1.2. Summary Table of Maximum Radiation Levels

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Table 5-3. Maximum Dose Rates for Normal Conditions of Transport

Normal Conditions of Transport	Package Surface mSv/hr (mrem/hr)			2 Meter from Edge of Vehicle mSv/hr (mrem/hr)	Vehicle Occupied Position mSv/hr (mrem/hr)
Radiation	**Top**	**Side**	**Bottom**	**Side**	**Side**
Gamma	0.70 (69.93)	1.59 (159.28)	1.58 (157.80)	0.07 (6.59)	0.01 (1.40)
10 CFR 71.47 (b)(2) Limit	2 (200)	2 (200)	2 (200)	0.1 (10)	0.02 (2)

Table 5-4. Maximum Dose Rates for Hypothetical Accident Conditions

Hypothetical Accident Conditions	1-meter from Package Surface mSv/hr (mrem/hr)		
Radiation	**Top**	**Side**	**Bottom**
Gamma	0.70 (70.01)	0.31 (30.95)	0.39 (39.49)
10 CFR 71.51 (a)(2) Limit	10 (1000)	10 (1000)	10 (1000)

5.2 *Source Specification*

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Figure 5-1. One Co-60 Isotope [[ ]] **(Left) and a Full Isotope Rod (Right)**

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Figure 5-2. [[ ]] **Types**

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Figure 5-3. Source Rod Segments as Defined in the Loading Plan

5.2.1. Gamma Source

5.2.1.1. Gamma Source Strength

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Table 5-5. Gamma Source Strength

Energy (MeV)	Emission Probability	Source Strength (photons/sec)
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5.2.1.2. Source Distribution

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Figure 5-4. Estimated Axial Activity Distribution for One Isotope Rod

5.2.2. Neutron Source

Not applicable because the proposed contents does not include neutron emitters.

5.3 *Shielding Model*

5.3.1. Configuration of Source and Shielding

5.3.1.1. MCNP Source Configuration

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Figure 5-5. Predicted Activity Plot Values

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Figure 5-6. Generated Axial Specific Activity Plot

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Figure 5-7. Side by Side Rod Segment Activity Summation

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Figure 5-8. Activity Distribution Comparison

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Table 5-6. Summary of Cases Run

Transport Condition	Location (Relevant Tallies)	Case[1]	MCNP Input	Source Geometry Description	Source Length (in)
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					.]]

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5.3.1.2. MCNP Shielding Model Geometry

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Table 5-7. Relevant Shielding Model Dimensions

Model 2000 Component	Part	Dimension	MCNP Surface(s)	Value (cm)	Value (in)
Cask	Cask Lid	t_{SS1}	51 / 63	3.81	1.50
		t_{Pb}	63 / 60	13.64	5.37
		t_{SS2}	60 / 45	4.45	1.75
	Cask Side	r_{cavity}	48	33.66	13.25
		t_{SS1}	64 / 48	2.54	1.00
		t_{Pb}	66 / 64	10.16	4.00
		t_{SS2}	9 / 66	2.54	1.00
	Cask Bottom	t_{SS}	47 / 10	15.24	6.00
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NCT Model

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Figure 5-9. NCT Case MCNP Model

HAC Model

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Figure 5-10. HAC Case MCNP Model

5.3.1.3. MCNP Tallies

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Table 5-8. Relevant Tally Locations

Transport Condition	Dose Rate Location	MCNP Tally Type (Tally Number)	Tally Location Description
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			]]

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Table 5-9. Dimensions for Tally Locations

Relevant MCNP Dimensions		Top	Side	Bottom
		inches (cm)	inches (cm)	inches (cm)
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Figure 5-11. Tally Offset Provided by Overpack (Left – Package Top; Right – Package Bottom)

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Figure 5-12. All Tally Locations

5.3.2. Material Properties

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Table 5-10. SS-316 Composition

Element	Weight Fraction (%)
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5.4 *Shielding Evaluation*

5.4.1. Methods

5.4.1.1. Computer Codes

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5.4.1.2. MCNP Variance Reduction

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5.4.1.3. Dose Rate Calculation

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5.4.2. Input and Output Data

5.4.2.1. Input Data

Input data will be submitted separately.

5.4.2.2. Output Data

Output data will be submitted separately.

The MCNP manual states that “A tally is considered to be converged with high confidence only when it passes all ten statistical checks” [*36*]. Table 5-11, provides a summary of the ten statistical checks for each tally included in every MCNP file. A cell in this table that represents a passed test will be highlighted green, and any that fail will be highlighted red. Note that in Table 5-11 all statistical checks are passed for all MCNP calculations used for this analysis.

Table 5-11. Tally Statistical Convergence Summary

MCNP Output	Tally	Mean	Relative Error			Variance of Variance			Figure of Merit		PDF
		Behavior	Value	Decrease	Rate	Value	Decrease	Rate	Value	Behavior	Slope
[[											
											]]

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5.4.3. Flux-to-Dose-Rate Conversion

Consistent with NUREG-1617, section 5.5.4.3 [*39*], the ANSI/ANS-6.1.1 1977 [*38*] flux-to-dose-rate conversion factors are used. The specific values used can be seen in the MCNP input files and are tabulated here in Table 5-12.

Table 5-12. Gamma Flux-to-Dose Rate Conversion Factors (ANSI/ANS-6.1.1 1977)

Gamma Energy (MeV)	Conversion Factor (mrem/hr)(gammas/cm^2-s)
0.01	3.96E-03
0.03	5.82E-04
0.05	2.90E-04
0.07	2.58E-04
0.1	2.83E-04
0.15	3.79E-04
0.2	5.01E-04
0.25	6.31E-04
0.3	7.59E-04
0.35	8.78E-04
0.4	9.85E-04
0.45	1.08E-03
0.5	1.17E-03
0.55	1.27E-03
0.6	1.36E-03
0.65	1.44E-03
0.7	1.52E-03
0.8	1.68E-03
1.0	1.98E-03
1.4	2.51E-03
1.8	2.99E-03
2.2	3.42E-03
2.6	3.82E-03
2.8	4.01E-03
3.25	4.41E-03
3.75	4.83E-03
4.25	5.23E-03
4.75	5.60E-03
5.0	5.80E-03
5.25	6.01E-03
5.75	6.37E-03
6.25	6.74E-03
6.75	7.11E-03
7.5	7.66E-03
9	8.77E-03
11	1.03E-02
13	1.18E-02
15	1.33E-02

5.4.4. External Radiation Levels

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Table 5-13. Tally Results

Tally Location	Case	MCNP Tally Score	MCNP Tally fsd	2σ	Calculated Dose Rate per Ci (mrem/hr/Ci)	Calculated Dose Rate (mrem/hr)
					DR_{perCi}	DR
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5.5 *Appendices*

5.5.1. MCNP Source Configurations

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Figure 5-13. Top NCT Source Locations (Case 1)

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Figure 5-14. Top NCT Source Locations (Case 2)

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Figure 5-15. Top HAC Source Locations

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Figure 5-16. Side NCT Source Locations (Case 1)

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Figure 5-17. Side NCT Source Locations (Case 2)

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Figure 5-18. Side NCT Source Locations (Case 3)

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Figure 5-19. Side HAC Source Locations (Case 1)

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Figure 5-20. Side HAC Source Locations (Case 2)

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Figure 5-21. Bottom NCT Source Locations (Case 1)

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Figure 5-22. Bottom NCT Source Locations (Case 2)

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Figure 5-23. Bottom HAC Source Locations

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5.5.2. Assessment of Potential for Radiation Streaming

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Figure 5-24. Dose Rates Calculated on Cask Lid Surface

5.5.3. References

References can be found in Section 1.3.3.

6 CRITICALITY EVALUATION

The criticality evaluation for the Model 2000 Shipping Package is provided in Section 6 of the Package Safety Analysis Report (SAR), NEDO-31581. The evaluation presented in the SAR identifies, describes, discusses, and analyzes the principle criticality engineering physics design of the packaging and components important to safety and necessary to comply with the requirements of 10 CFR 71 for the transport of fissile materials. Since this special authorization request is only applicable to non-fissile materials, an additional criticality evaluation is not necessary.

7 OPERATING PROCEDURES

Included in this section is a description of the handling operations for loading, unloading, and preparing the empty GE Model 2000 packaging for transport. The information is taken from NEDO-31581 [*5*] and edited to apply specifically to the Co-60 rod campaign.

The major steps are given in the order in which they are performed. The operations described below are contained in detailed site-specific written procedures, which will be followed at each site where the package or packaging is operated.

Note that the package operations are written to maintain occupational radiation exposures as low as reasonably achievable (ALARA) as required by the "Standards for Protection Against Radiation" in 10 CFR 20.1101(b).

7.1 *Package Loading*

Fully trained personnel using approved operating procedures will carry out all loading operations at the facility. The general sequence is as follows:

- Receive the Model 2000 packaging with the HPI and Material Basket already installed,
- Transfer Co-60 rod segments into the empty Material Basket in the cask,
- Close the HPI and cask lid, raise and drain the cask, vacuum dry the cask, and
- Perform pre-shipment leak test.

7.1.1. Preparation for Loading

7.1.1.1. Packaging Receipt and Inspection

a. Position the Model 2000 transport vehicle for packaging inspection upon arrival.

b. Perform a visual inspection for damage.

7.1.1.2. Removal of the Packaging from the Transport Vehicle

a. Position the transport vehicle under an overhead crane.

b. Remove the packaging tie-downs.

c. Position the Spreader Bar and connect the appropriate slings and shackles.

d. Depending on site-specific issues, either

- Lift the overpack top section off the overpack base and place on the overpack stand, or
- Lift the entire packaging free from the transport vehicle and set down. Then lift the overpack top section from the overpack base and place on the overpack stand.

7.1.1.3. Preparing To Load the Cask

a. Perform a visual inspection. Note any damage or unusual conditions. If functionality of the part is impaired, repair or replace as required.

- Install the cask ears. If a forklift is to be used to transport the cask, the standard lifting ears must be used. If the cask is to be lifted by crane, then either the standard or auxiliary ears may be used. If lifted by crane, the lifting slings shall not make an angle of greater than 30° measured from the vertical.

b. Move the cask to the designated prep area at the site.

c. With proper radiological protection and monitoring, remove the cask lid and verify presence of the

HPI.

d. If there is a spacer, remove.

e. Visually inspect the cask and lid sealing surfaces for damage or foreign material. Note any damage and repair or replace as required.

f. Visually inspect the cask seal for damage. Any gouges or cuts in the seal area are cause for replacement.

g. Place the seal over the alignment pins on the top of the cask.

7.1.2. Loading of Contents

7.1.2.1. Loading the Material Basket

a. Remove the HPI top plug and verify presence of the Material Basket. The Material Basket when inside the HPI will have been inspected visually prior to shipping to the site. It will not be removed and inspected at the site.

b. Move the cask to the designated loading area at the site.

c. Remove the rod segments from the site designated storage loacation and place in the Material Basket in the HPI. (Note that the rod segments to be transported may have been pre-positioned in a designated storage loacation at the site.)

d. All rod segments from a particular rod shall be loaded into the Material Basket.

e. After all rod segments are inserted, lower the HPI top plug over the 4 alignment pins with the proper rigging.

f. If spacer was provided, install over HPI top plug.

g. Slowly lower the lid onto the cask over the guide pins with proper rigging. This operation is closely watched to ensure that the lid is properly aligned.

7.1.3. Closing the Cask and Performing Leakage Tests

7.1.3.1. Removing the Cask from the Loading Area

a. Carefully monitor the cask radiation levels while removing the cask from the loading area.

b. Tighten the lid bolts so they are hand tight.

c. If the cask was loaded under water,

- drain by removing the drain plug and the lid vent plug.
- After the water has drained, vacuum-dry the cask cavity until 1 torr pressure is obtained. Maintain the pressure in the cavity at or below 1 torr for at least 30 minutes. Filter the discharged gas of the vacuum pump. Refer to Figure 7.1.7.1 from Reference [*5*] for a typical vacuum drying set up and its equipment. If the vacuum pump used in this procedure is equipped with a "gas ballast" device, this device must be inoperative during the cask vacuum drying operation. The gas ballast device is used to drive off any moisture that may have been trapped in the vacuum pump oil. If needed to remove water vapor from the pump oil during the vacuum drying operation, the system shall be isolated. Turn on the gas ballast device until the oil is cleared up, turn off the gas ballast, and then place the system back on line.

d. Decontaminate the cask to a level consistent with 49 CFR 173.443 and 10 CFR 71.87.

7.1.3.2. Securing the Cask Lid

a. Torque the lid bolts to 690 ft-lb in a crisscross pattern to ensure equal compression of the seal.

b. Install the drain and vent plugs following the drying operation as applicable. Apply pipe thread sealant over thread area on plugs prior to installation.

7.1.3.3. Assembly Verification Leakage Testing

a. Leakage testing of the cask closure seal and vent port and drain port threaded pipe plugs is performed with a thermal conductivity sensing instrument. This type of instrument is sensitive to any gas stream having a thermal conductivity different from the ambient air in which the instrument is being used. Pressurize the cask cavity with 15 psi of Helium at the completion of the vacuum drying procedure. Helium is introduced using the "quick connect" fitting at the vent port.

b. The test instrument is set up and used according to written procedures and the manufacturer's instructions.

c. With the instrument calibrated to a sensitivity of at least 1 x $10^{-3}cm^3$/sec (Helium), check the vent and drain threaded pipe plugs for indications of leakage.

d. With the instrument calibrated to a sensitivity of at least 1 x 10^{-3} cm^3/sec (Helium), check the closure seal for indications of leakage.

e. If leakage is detected during either of the above checks, repair or replace the offending components and then re-test for leakage.

7.1.4. Preparation for Transport

7.1.4.1. Preparing the Cask for Transport

a. Transport the cask to the overpack base and place it on.

b. Remove the cask lifting ears or redundant ears from the cask.

c. Position the Spreader Bar over the overpack and connect the slings and shackles.

d. Slowly lower the overpack over the cask with the locating pins aligned.

e. Install the overpack bolts, securing the top section to the base section. An adhesive/sealant compound is applied to bolt threads prior to installation to prevent vibration loosening of bolts.

f. Position the package on the transport vehicle if required.

g. Remove the shackle and slings and tie down the package to the transport vehicle. The Model 2000 does not have any parts or devices that would need to be rendered inoperable pursuant to 10 CFR 71.87(h).

h. Perform the radiological survey of the package and transport vehicle consistent with 10 CFR 71.47, 71.87 and 10 CFR 173.441, 443.

i. Measure the temperature of the overpack paying particular attention to the area around the bolting ring. If any temperature reading exceeds 185°F install the protective personnel barrier around the package, in accordance with 10 CFR 71.43.

j. Apply the security seal to the overpack.

7.2 *Package Unloading*

Operations at the unloading facility (i.e., GE Vallecitos) are largely the reverse of loading operations. The unloading facility must provide fully trained personnel and will be supplied with detailed operating procedures to cover all activities as required by 10 CFR 71.89.

7.2.1. Receipt of Package from Carrier

7.2.1.1. Package Receipt and Inspection

Steps 7.1.1 (a and b) are repeated and a radiological survey is performed in accordance with the requirements of 10 CFR 20.205 or equivalent agreement state regulations.

7.2.1.2. Removal of the Package from the Transport Vehicle

a. Position the transport vehicle under an overhead crane.

b. Remove the packaging tie-downs.

c. Position the Spreader Bar and connect the appropriate slings and shackles.

d. Depending on site-specific issues, either

- Lift the overpack top section off the overpack base and place on the overpack stand, or
- Lift the entire packaging free from the transport vehicle and set down. Then lift the overpack top section from the overpack base and place on the overpack stand.

7.2.1.3. Preparing To Unload Co-60 rod segments

a. Perform a visual inspection. Note any damage or unusual conditions. If functionality of the part is impaired, repair or replace as required.

b. Perform a radiological survey of the cask.

c. Install the cask lifting ears or auxiliary ears (if applicable). Transport the cask to the unloading area.

d. With radiological monitoring and controlled ventilation in place, remove the vent plug and drain plugs.

e. Remove the lid bolts for unloading in either a storage basin or hot cell.

f. Remove the lid following the placing of the cask within a hot cell or storage basin.

g. Remove the spacer if present.

h. Remove the HPI top plug.

7.2.2. Removal of Contents

7.2.2.1. Unloading Co-60 Rod Segments from the Cask

a. Obtain the list identifying rod segments to be unloaded.

b. Verify the Isotope Rod identification and location in the cask.

c. Transfer the rod segments one at a time in accordance with the site's transfer procedure.

7.2.2.2. Installing the Cask Closure Lid

a. With proper rigging, slowly lower the HPI top plug over the alignment pins.

b. Install the spacer, if one came with the packaging.

c. With proper rigging, slowly lower the lid onto the cask over the guide pins. This operation is closely watched to assure that the lid is properly aligned .

7.2.2.3. Removing the Cask from the Unloading Area

a. Tighten the lid bolts hand-tight.

b. Remove the cask to the storage area.

7.2.2.4. Securing the Cask Lid

Repeat Section 7.1.3.2.

7.3 *Preparation of Empty Packaging for Transport*

The following operations are typically performed after transport of radioactive material.

7.3.1. Cask Cavity Inspection

a. Remove the lid from the empty cask.

b. Perform a radiological survey of the cavity to determine extent of any contamination.

c. Decontaminate the cavity to the limits of 49 CFR 173.427 if the cask is shipped as an empty container as defined in the regulation.

d. Visually inspect the cask and contents to ensure that moisture has been removed.

7.3.2. Installation of the Cask Closure Lid

a. With proper rigging, slowly lower the lid onto the cask over the guide pins. This operation is closely watched to assure that the lid is properly aligned.

b. Install the head bolts and torque to 690 ft-lb in a crisscross pattern to ensure equal compression of the seal.

c. Inspect the cask to verify that all drain and vent plugs are properly installed.

7.3.3. Assembly Verification Leakage Testing

Leakage testing is not performed on the empty container.

7.3.4. Preparing the Empty Cask for Transport

Decontaminate the external surfaces of the cask to a level consistent with 49 CFR 173.427, "Empty Radioactive Materials Packaging".

7.4 *Other Operations*

Not applicable.

7.5 *Appendix*

7.5.1. References

References can be found in Section 1.3.3.

8 ACCEPTANCE TESTS AND MAINTENANCE PROGRAM

[NEDO-32318]
The acceptance tests and maintenance programs for the Model 2000 Shipping Package presented in Safety Analysis Report (SAR), NEDO-31581[*5*], is included here. The programs are also applicable to the 3000 watts of decay heat upgrade presented in this Special Authorization Request.

Non-destructive examinations required during fabrication of the HPI and Material Basket follow the guidance presented in ASME Section III-NF [*8*]. Routine inspection (prior to each loading) consists of visual examination for physical damages of all surfaces and components. Periodic or annual inspection includes visual examination, penetrant inspection of welds, and replacement of all non-safety related components as applicable.

8.1 *ACCEPTANCE TEST*

The inspection and acceptance tests are specified in the fabrication specifications and engineering drawings for the Model 2000 Shipping Package and are governed by GE Quality Assurance Program QAP-1. QAP-1 has been approved by the NRC (Docket Number 71-0170).

8.1.1. Visual Inspections and Measurements

Visual examinations of all dimensions are conducted during fabrication to ensure that the packaging is fabricated and assembled in accordance with manufacturing drawings and specifications. All dimensions and tolerances specified on the drawings are confirmed by measurement.

8.1.2. Weld Examinations

Visual examinations of all welds are conducted during fabrication. In addition, all welds within the cask containment boundary are liquid penetration tested (root and final passes); also, the welds forming the toroidal shell are 100% radiographed. These inspections are performed to ensure no cracks, incomplete fusion or lack of penetration exists. Parts that do not meet the established criteria are repaired or replaced in accordance with written procedures. Nondestructive examination (NDE) procedures and acceptance standards are based on the ASME Code, Section III, Subsection NG. The above criteria applied to the fabrication of packaging serial number (S/N) 2001.

All future fabrication will meet the requirements of the ASME code, Section III as follows:

Cask assembly including ears:

- Materials per NB-2000, Certification NCA-3800
- Fabrication per NB-4000
- Pressure testing per NB-6000

The following components of the cask assembly will be excluded of the above requirements:

- Shielding lead and its installation
- Elastomers
- Seals and test port components
- Electro-polishing
- Miscellaneous equipment like name plate and its screws, honeycomb, and thread inserts.

Overpack assembly per Subsection NF.
HPI and Material Basket per Subsection NF.

8.1.3. Structural and Pressure Tests

The inner and outer cylinder welds of the cask are leak tested with a Helium (He) Mass Spectrometer Leak Detector (MSLD) by surrounding the cask with He and evacuating the plenum or by pressurizing the lead region of the cask and sniff all cask body welds. These test methods have a minimum sensitivity level of 10^{-7} atm cm^3/sec. If any He is detected above the minimum sensitivity, the failed weld area will be located, repaired, and reinspected.

In addition to the above test, the cask cavity is hydrostatically tested, to ensure that it is tight, per the requirements of NB6200, Subsection NG, Section III of the ASME Code. The test pressure is 45 psia.

8.1.4. Leakage Tests

The assembled cask is leak tested by pressurizing the cavity to 15 psig with Helium. Leak testing of the vent and drain plugs as well as the lid seal is performed using a MSLD with a sensitivity of 1×10^{-9} atm cc/sec. The lid seal is tested by connecting the test probe to a test port between the two seal rings of the seal and determining the leak rate. A leak-tightness criterion of 10^{-7} atm cm^3/sec or less based on dry air at 25°C and for a pressure differential of 1 atm is used. If the leak-tightness criterion is not met, a new seal will be tested.

8.1.5. Component and Material Tests

8.1.5.1. Valves, Rupture Discs, and Fluid Transport Devices

Component tests of valves, rupture discs and/or fluid transport devices are not applicable, since these parts do not exist in the Model 2000 packaging design.

8.1.5.2. Seal Testing

The procedure for testing the seals is based on ANSI 14.5-1997, “American National Standard for Radioactive Materials – Leakage Tests on Packages for Shipment”. The seal material is tested under normal, high and low temperature environments; the test temperatures are 70°F, 600°F and -40°F, respectively. The seal material is mounted in a test flange and leak tested with a MSLD. Seal material exceeding the allowable leak rate is rejected. The test seal/flange joint used for the tests is scaled by matching the force per inch on the seal, and the flange stiffness so they are the same as for the actual joint.

8.1.5.3. Honeycomb Testing

The honeycomb energy absorber is tested in accordance with military specification MIL-STD-401B, Sandwich Constructions and Core Materials, General Test Methods. The test procedure determines the compressive properties of the honeycomb material in the direction normal to the plane of facings. The test produces a load deformation curve, and from this curve the compressive stress at proportional limit load is calculated. If the honeycomb material does not meet the required crush strength, the material will be rejected.

8.1.6. Shielding Tests

The shielding material is inspected for integrity. A Cobalt source placed inside the cask is surveying from the outside of the cask with a gamma detection instrument. The cask outside surface is divided by radial lines 12° apart and by equally spaced circumferential lines along the vertical axis. Dose rate readings are taken over each of the 420 rectangular regions (~4 inches square); see Figure 8-1. If an area of void is detected, radiographic film is placed over this area to determine the size and location of the void. The criterion used to evaluate the effect of the void is that the dose rate may not exceed one and one-half times the mean dose rate. Any void area that does not meet the criteria will be re-poured with lead.

The shielding integrity of the HPI is determined using the same process. The Cobalt source will be placed inside the HPI and similar measurements will be taken.

8.1.7. Thermal Tests

A thermal test is performed on the first unit built of the Model 2000 packaging to determine the thermal performance of the system versus what is predicted by the analysis.

8.1.7.1. Discussion of Test Setup

A 600 watt heat source is concentrically installed within the cask cavity. Thermocouples are strategically placed within the cavity and the external portions of the cask and overpack surfaces as schematically shown in Figure 8-2.

8.1.7.2. Test Procedure

The test is conducted with a 600 watt heat source in a controlled ambient environment to simulate normal conditions of transport. The temperature data are recorded every 30 minutes with a data acquisition system, permitting easy analysis and plotting of the results. Data are recorded until temperature remains significantly unchanged for a one-hour period.

8.1.7.3. Acceptance Criteria

The results of the thermal test are evaluated against the predicted thermal performances. If the evaluation shows a discrepancy, the analytical thermal model is corrected based on the test results and a new thermal analysis will be conducted. If the new analysis results indicate deficiency in the thermal characteristics of the packaging, thermal barrier coating could be applied to the inner surface of the overpack structure as a corrective measure.

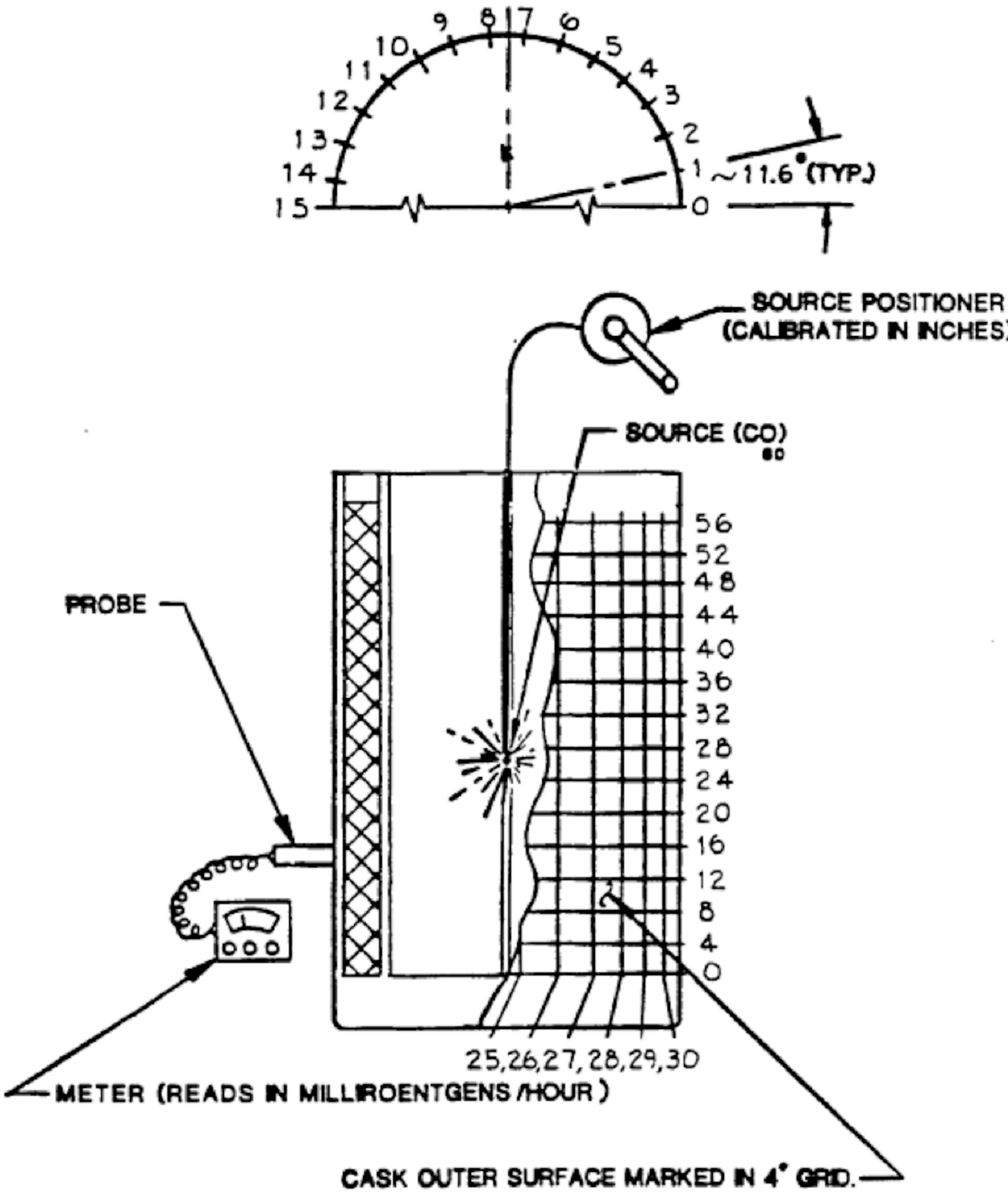

Figure 8-1. Cask Shielding Inspection Points

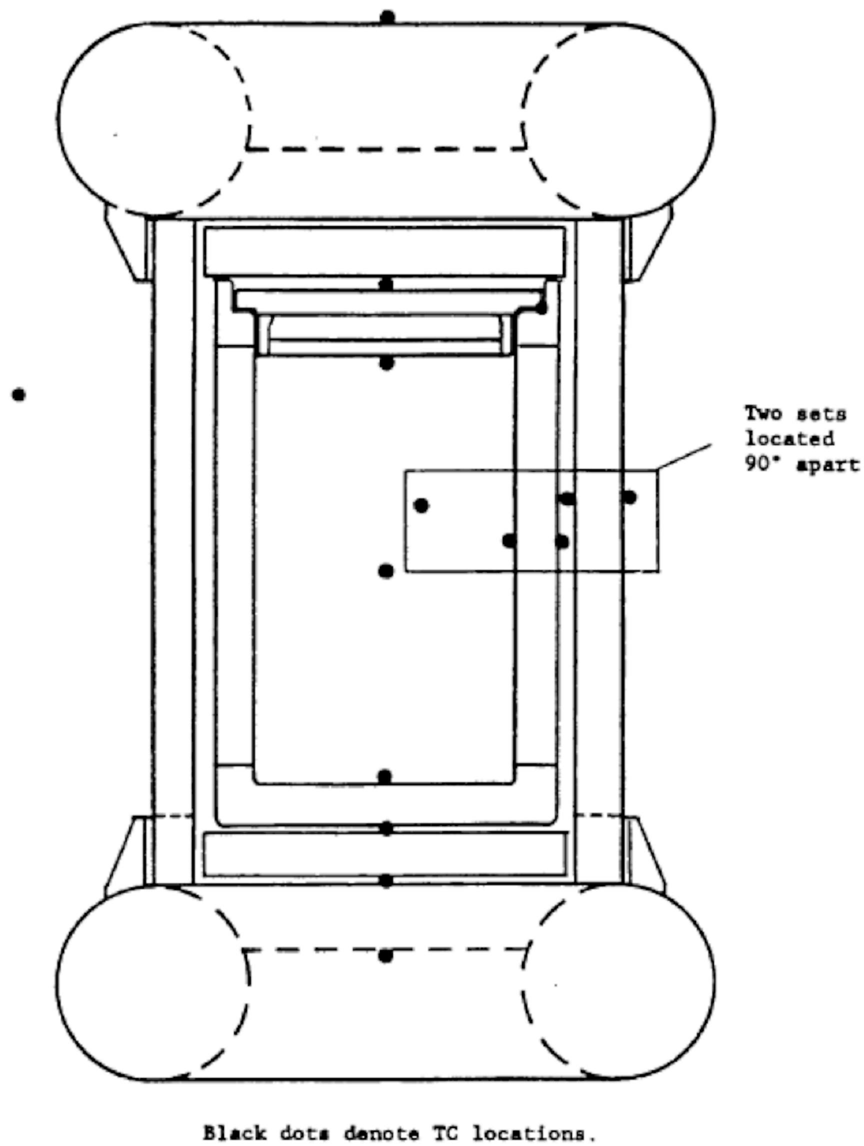

Figure 8-2. Thermocouple Locations

8.2 *MAINTENANCE PROGRAM*

The cask maintenance program is delineated specification 22A9380. Routine inspections are performed prior to each assembly and prior to each shipment. These inspections include visual and dimensional checks of the cask and components and pressurization of the cask cavity. This pressurization is part of the leak check procedure. Additional detailed inspections are also performed every 12 usages or at least once within the 12 month period prior to each use.

8.2.1. Structural and Pressure Tests

8.2.1.1. Routine Inspection

Prior to each loading and assembly operation, the cask and lid are inspected for physical damage, especially the bolt holes, vent ports and sealing surfaces. The lid bolts, port plugs, O-rings, and lid gasket are all inspected visually and for proper dimensions and identification. As part of the leak check, the cask cavity is pressurized to 15 psig with He.

8.2.1.2. Periodic Inspections.

After every 12 usages, the following inspections are made. Any maintenance work required is identified on a maintenance checksheet.

The overpack is inspected for:

- Signs of excessive heat or fire.
- Punctures, holes, or other surface failures.
- Crushed sides or ends indicating a drop or severe impact.
- Defects resulting from normal or abnormal wear.
- Compression or damage to the honeycomb absorber material.
- Cracks or other damage to welds.
- Proper identification and damage to the bolts.

The cask is inspected for:

- Wear, corrosion or damage to the vent and drain port plugs, caps, and O-rings.
- Damage to sealing surfaces on the cask and lid.
- Damage or cracks to welds on the cask and lid.
- Proper identification or damage to the lid and ear bolts.

8.2.2. Leak Tests

8.2.2.1. Routine

Leakage testing of the cask closure seal and vent and drain plugs are performed with a thermal conductivity sensing instrument. The test is performed by pressurizing the cask cavity to 15 psig with He then “sniffing” with the instrument which senses differences in the thermal conductivity of the sampled gas if He is present. The instrument will be calibrated to a sensitivity of 1×10^{-5} atm. cm^3/sec (He). If leakage greater than 1×10^{-3} atm. cm^3/sec is detected, the offending components will be repaired or replaced and then retested for leakage.

8.2.2.2. Periodic

After every 12 usages, the cask closure seal and vent and drain plugs will be leak checked with a He MSLD. This instrument has a sensitivity of $<1 \times 10^{-9}$ atm. cm^3/sec (He). This test is performed by pressurizing the cask cavity to 15 psig and then testing for leaks. If any leaks greater than 1 × 10^{-7} atm cm^3/sec are detected, the offending component will be repaired or replaced and then retested.

8.2.3. Component and Material Tests

There are no auxiliary cooling systems or other subsystems requiring maintenance.

8.2.3.1. Valves, Rupture Disks, and Gaskets on Containment Vessel

The cask closure seal will be used until visual and/or leak test inspections identify the seal as defective. The O-rings on the three penetration caps will be replaced when visual or leak test inspections identify them as defective, or during the periodic inspection, whichever comes first.

8.2.3.2. Shielding

The shielding materials are lead and depleted uranium. The initial tests for voids during fabrication and the required radiological surveys following each loading assure shielding integrity. If the results of surveys exceed the regulatory requirements, the contents are reduced or the shipment is not made.

8.2.4. Thermal

Thermal testing is only performed following initial fabrication of the cask.

8.3 *Appendix*

8.3.1. References

References can be found in Section 1.3.3.

The Following GE 2000 Licensing Drawings Are Redacted in Whole As They Contain GEH Proprietary Information

1. Drawing Number 001N8422r0
2. Drawing Number 001N8423r0
3. Drawing Number 001N8424r0
4. Drawing Number 001N8425r0
5. Drawing Number 001N8427r0
6. Drawing Number 001N8428r0
7. Drawing Number 101E8718r14
8. Drawing Number 105E9520r6

The Following GE 2000 Bill of Material Release Reports Are Redacted in Whole
As They Contain GEH Proprietary Information

1. Bill of Material Release Report 001N8422G001
2. Bill of Material Release Report 001N8423G001
3. Bill of Material Release Report 001N8423P004
4. Bill of Material Release Report 001N8423P005
5. Bill of Material Release Report 001N8423P006
6. Bill of Material Release Report 001N8423P007
7. Bill of Material Release Report 001N8424G001
8. Bill of Material Release Report 001N8424P001
9. Bill of Material Release Report 001N8424P002
10. Bill of Material Release Report 001N8424P003
11. Bill of Material Release Report 001N8424P004
12. Bill of Material Release Report 001N8424P005
13. Bill of Material Release Report 001N8425G001
14. Bill of Material Release Report 001N8425P001
15. Bill of Material Release Report 001N8425P002
16. Bill of Material Release Report 001N8425P003
17. Bill of Material Release Report 001N8425P004
18. Bill of Material Release Report 001N8425P005
19. Bill of Material Release Report 001N8425P006
20. Bill of Material Release Report 001N8425P007
21. Bill of Material Release Report 001N8425P008
22. Bill of Material Release Report 001N8425P009
23. Bill of Material Release Report 001N8425P010
24. Bill of Material Release Report 001N8427G001
25. Bill of Material Release Report 001N8427P001
26. Bill of Material Release Report 001N8427P002
27. Bill of Material Release Report 001N8427P003
28. Bill of Material Release Report 001N8427P004
29. Bill of Material Release Report 001N8427P005
30. Bill of Material Release Report 001N8427P006
31. Bill of Material Release Report 001N8428G001
32. Bill of Material Release Report 001N8428P001
33. Bill of Material Release Report 001N8428P002
34. Bill of Material Release Report 001N8428P003
35. Bill of Material Release Report 001N8428P004
36. Bill of Material Release Report 001N8428P005
37. Bill of Material Release Report 001N8428P006

The Following GE 2000 Computational Files Are Redacted in Whole As They Contain GEH Proprietary Information

1. LS-DYNA Input/Output Files
2. ANSYS Input/Output Files
3. MCNP Input/Output Files