ENERGY*SOLUTIONS*

20 July 2012
EL&P-022-12

Mr. Pierre Saverot
Licensing Branch
Division of Spent Fuel Storage and Transportation
Office of Nuclear Material Safety and Safeguards
U.S. Nuclear Regulatory Commission
Washington, DC 20555

SUBJECT: Amendment Request for Certificate of Compliance No. 9204 for the Model 10-160B Package
Docket No. 71-9204

Dear Mr. Saverot:

Energy*Solutions* requests an amendment to Certificate of Compliance No. 9204 for the Model 10-160B Package allowing addition of a Thermal Shield as a component of the package. Energy*Solutions* provides the attached revision of the Safety Analysis Report (SAR), Consolidated Revision 4, and drawings as supporting information to our amendment request. The revision and drawings address the thermal issues that have been the subject of several recent discussions. Only those parts of the SAR affected by addition of the thermal shield have been revised. The included Revision Control Sheet identifies the specific sections of the SAR that have been revised. Please replace the identified sections with those in this submittal.

Since this package provides unique capabilities in support of both commercial and governmental nuclear facilities, we request completion of the review of this submittal as soon as possible with issue of the revised certificate by August 15, 2012.

Should you or members of your staff have questions about this request, please contact me at mswhittaker@energysolutions.com or Mirza Baig at mibaig@energysolutions.com.

Sincerely,

Mark Whittaker
Sr. Health Physicist, Radiological Services

Attachments:

- SAR Revisions, i.e., Cover Page, Table of Contents, Chapters 1, 2, 3, 5, 7, and Source Insert Addendum
- Drawings
    - C-110-D-29003-010, Rev.16 – Cask Assembly (Non-Public)
    - C-119-B-0018, Rev. 2 – Optional Shield Insert
    - C-038-145083-004, Rev. 0 – Source Insert Assembly
    - C-038-145083-005, Rev.0, Source Insert Steel Cribbing

NMSS01

  - DWG-CSK-12CV01-EG-0002 – 10-160B Cask Secondary Lid Thermal-Shield
- References
  - ST-0001 Rev0 and Data
  - TH-0001 Rev0 and Data
  - TH-0002 Rev2 and Data

SECURITY-RELATED INFORMATION WITHHOLD UNDER 10CFR 2.390

Figure Withheld Under 10 CFR 2.390

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ENERGYSOLUTIONS

CASK ASSEMBLY
GENERAL NOTES/PARTS LIST
10-160B

SIZE	DRAWING NUMBER	REV.
D	C-110-D-29003-010	16

SECURITY-RELATED INFORMATION WITHHOLD UNDER 10CFR 2.390

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ENERGYSOLUTIONS

CASK ASSEMBLY
GENERAL NOTES/PARTS LIST
10-160B

D C-110-D-29003-010 16

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SECURITY-RELATED INFORMATION
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	R.T. ANDERSON	4/11/88	

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CASK ASSEMBLY
GENERAL NOTES/PARTS LIST
10-160B

Size	Drawing No.	Rev.
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Figure Withheld Under 10 CFR 2.390

B

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ITEM	QTY	DESCRIPTION	SPEC. AND / OR PART No.
1	A/R	PLATE 1/2", 1", 1 1/2" AS REQUIRED C/S	ASTM-A36

BILL OF MATERIALS

☐ PROPRIETARY ☒ NON-PROPRIETARY	DO NOT SCALE PRINT DIMENSIONS ARE IN INCHES UNLESS NOTED	CHEM-NUCLEAR SYSTEMS
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FSCM No. 54643	REVIEWERS OF ORIGINAL (REV. 0)	10-160B SHIELD INSERT
	DRAWN BY JEREMY MURPHY 8/7/98	
	CHECKED BY MIKE AHEARN 8/7/98	SIZE B / DRAWING NUMBER C-119-B-0018 / REV. 2
	ENGINEER CHARLES WITT 8/7/98	SCALE 1 : 24 / WT. N/A / SHEET 1 OF 1

Figure Withheld Under 10 CFR 2.390

☐ PROPRIETARY	FSCM No. 54843	ENERGYSOLUTIONS
☒ NON-PROPRIETARY	DO NOT SCALE PRINT	SOURCE INSERT ASSEMBLY AND DETAILS
	P. PREVATTE	D C-038-145083-004 0

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PROPRIETARY / [X] NON-PROPRIETARY	FSCM No. 54843	ENERGYSOLUTIONS
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	ENGINEER [signature] 10/28/11	SCALE 1 : 12 WT. N / A SHEET 4 OF 4

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QL1	☒ PROPRIETARY ☐ NON-PROPRIETARY	ENERGYSOLUTIONS PROJECT NO. 12CV01.1001-01
	P. PREVATTE — 03/13/2013	10-160B CASK SECONDARY LID THERMAL-SHIELD DETAILS
	M. BAIG — 03/17/2013	
	P. DANESHVAR — 03/17/2013	
	M. BAIG — 03/17/2013	
	NOT REQUIRED	SCALE 1:4 — DWG. NO. DWG-CSK-12CV01-EG-0002-01 — REV 1

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CONSOLIDATED SAFETY ANALYSIS REPORT

FOR

MODEL 10-160B

TYPE B RADWASTE SHIPPING CASK

REVISION 4

July 2012

Energy*Solutions*
140 STONERIDGE DRIVE
COLUMBIA, SOUTH CAROLINA 29210

REVISION CONTROL SHEET

TITLE: Consolidated Safety Analysis Report for 10-160B Shipping Cask

AFFECTED PAGE(S)	DOC. REV.	HEADER DATE	REMARKS
Entire Document	0	December 2007	Consolidate Revision 0 Incorporates all previous changes to the SAR
Cover Page i 1-1 – 1-6 5-1 – 5-15 7-1 – 7-9	1 " " " "	April 2010 " " " "	A vertical line in the margin indicates changed text. The date in the page header reflects the date of the change. The revision status of a particular page is noted by the revision number and header date.
Cover Page i 1-1 – 1-6 5-1 – 5-18 7-1 – 7-12	2 " " " "	September 2010 " " " "	A vertical line in the margin indicates changed text. The date in the page header reflects the date of the change. The revision status of a particular page is noted by the revision number and header date.
Cover Page i ii-xxi 1-1 – 1-6 5-1 – 5-18 7-1 – 7-12 8-1 – 8-9	3 " " " " " "	January 2011 " " " " " "	A vertical line in the margin indicates changed text. The date in the page header reflects the date of the change. The revision status of a particular page is noted by the revision number and header date.
Cover Page i ii-xxi 1-1 – 1-6 2-1 – 2-59 2-80 – 2-102 2-205 – 2-217 3-1 – 3-24 5-1 – 5-19 7-1 – 7-12 Insert Addendum	4 " " " " " " " " "	July 2012 " " " " " " " " " "	A vertical line in the margin indicates changed text. The date in the page header reflects the date of the change. The revision status of a particular page is noted by the revision number and header date.

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FIGURE NO. DESCRIPTION

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FIGURE NO. DESCRIPTION

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FIGURE NO. DESCRIPTION

ACRONYMS AND ABBREVIATIONS

CSI ..	Criticality Safety Index
HAC	Hypothetical Accident Conditions
ID	Inside Diameter
MCNP	Monte Carlo N-Particle (computer code)
NCT.	Normal Conditions ofTransport
OD...	Outside Diameter
SAR.	Safety Analysis Report (for packaging)
SS	Stainless Steel

1.0 GENERAL INFORMATION

1.1 Introduction

This Safety Analysis Report describes a reusable shipping package designed to protect radioactive material from both normal conditions of transport and hypothetical accident conditions as required by 10CFR71. The package is designated the Model 10-160B package.

1.2 Package Description

1.2.1 Packaging

The package consists of a steel and lead cylindrical shipping cask with a pair of cylindrical foam-filled impact limiters installed on each end. The package configuration is shown in Figure 1-1. Cask assembly drawings are included in Section 1.3. The internal cavity dimensions are 68 inches in diameter and 77 inches high. The cylindrical cask body is comprised of a 2 inch thick external steel shell and a 1 1/8 inch internal steel shell. The annular space between the shells is filled with 1 7/8 inch thickness of lead. The base of the cask consists of a 5½ inch thickness of flat circular steel plates (2½ and 3 inches) which are welded together. The cask primary lid also consists of a 5½ inch thickness flat circular steel plates (2½ and 3 inches) which are welded together. The primary lid is fastened to the cask body with twenty-four, 1 3/4 - 8 UNC bolts. There is a secondary lid in the middle of the primary lid. This secondary lid is attached to the primary lid with twelve, 1 3/4 – 8" UNC bolts. A thermal shield protects the secondary lid. The thermal-shield consists of two polished stainless-steel plates that are separated by a thin air gap with stand-offs which provide an additional air gap above the secondary lid. The thermal-shield assembly is attached to the secondary lid lifting lugs with hitch-pins. A 12 gauge stainless steel liner (0.105 inches) welded to the cask cavity and lid surface protects all accessible areas from contamination. Also, a steel thermal shield is welded to the exterior barrel of the cask and serves as protection during the fire accident.

The impact limiters are 102 inches in the outside diameter and extend about 12 inches beyond the outside wall of the cask. There is a 47½ inch diameter void at each end. Each limited has an external shell, fabricated from stainless steel which cans the foam and allows it to withstand large plastic deformation without fracturing. The volume inside the shell is filled with a crushable, shock and thermal insulating polyurethane foam. The polyurethane is sprayed into the shell and allowed to expand until the void is completely filled. The foam bonds to the shell, which creates a unitized construction for the impact limiters. The upper and lower impact limiters are held together with eight circumferentially located ratchet binders which secure the limiters to the cask. A general arrangement drawing of the package is included in Appendix 1.3. It shows the package dimensions as well as all materials of construction.

1.2.1.1 Containment Vessel

The containment vessel is defined as the inner steel shell of the cask body together with closure features comprised of the lower surface of the cask lid and the primary and secondary lid bolts.

1.2.1.2 Neutron Absorbers

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

1.2.1.3 Package Weight

Maximum gross weight for the package is 72,000 lbs. including a maximum payload weight of 14,250 lbs.

1.2.1.4 Receptacles

There are no receptacles on this package.

1.2.1.5 Vent, Drain, Test Ports and Pressure Relief Systems

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

The drain and vent ports are provided with same venting features for venting pressures within the containment cavity, which may be generated during transport, prior to lid removal. Each port is sealed with an elastomer gasket. Specification information for all seals and gaskets is contained in Chapter 3.

1.2.1.6 Lifting Devices

Lifting devices are a structural part of the package. The General Arrangement Drawing in Appendix 1.3 shows two lifting lugs provided for removal and handling of the cask. Three lid lifting lugs are used for removal and handling of the secondary and primary lid. Refer to Section 2.4.3 for a detailed analysis of the structural integrity of the lifting devices.

1.2.1.7 Tie-downs

From the General Arrangement Drawing shown in Appendix 1.3, it can be seen that the tie-down arms are an integral part of the external cask shell. Consequently, tie-down arms are considered a structural part of the package. Refer to Section 2.4.4 for a detailed analysis of the structural integrity of the tie-down arms.

1.2.1.8 Heat Dissipation

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

1.2.1.9 Coolants

There are no coolants involved.

1.2.1.10 Protrusions

There are no outer or inner protrusions except for the tie-down arms described above.

1.2.1.11 Shielding

Cask walls provide a shield thickness of 1 7/8 inches of lead and 3 inches of steel. Cask ends provide a minimum of 5 inches of steel. The contents will be limited such that the radiological

shielding provided (nominally 3¼ inches lead equivalent based on Co-60) will assure compliance with DOT and IAEA regulatory requirements.

An optional, removable steel insert may be installed inside the cask to provide additional shoring and shielding for the cask contents. The insert fits closely to the inside walls of the cask, but is not attached to the cask nor the contents. It may vary in thickness between ½ inch and 1½ inch on the sides, and is open on the top and bottom. It is approximately ½ inch shorter than the cask cavity.

1.2.2 Operational Features

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

1.2.3 Contents of Packaging

1.2.3.1 Cask Contents

The contents of the cask will consist of:

1) Radioactive material in secondary containers.

2) Radioactive material which does not generate more than 200 thermal watts of radioactive decay heat.

3) The weight of the contents in the cask cavity will be limited to 14,250 lbs. If an insert is installed in the cavity, the maximum payload is reduced by the weight of the insert.

4) Transuranic Waste (TRU) with not more than 325 fissile gram equivalents (FGE) of fissile radioactive material.

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

1.2.3.2 Waste Forms

The type and form of waste material will include:

1) By-product, source, or special nuclear material consisting of process solids or resins, either dewatered, solid, or solidified in secondary containers. (See Section 4.2.1 for specific limitations). Contents containing greater than 20 Ci of plutonium must be in solid form.

2) Neutron activated metals or metal oxides in solid form in secondary containers.

3) Miscellaneous radioactive solid waste materials, including special form materials and powdered solids in secondary containers. Powdered solids shipments shall be performed only when the most recent periodic leak test meets the requirements of Chapter 4, Section 4.9. Powdered solid radioactive material shall not include radioactive forms of combustible metal hydrides, combustible elemental metals, i.e., magnesium, titanium, sodium, potassium, lithium, zirconium, hafnium, calcium, zinc, plutonium, uranium, and thorium, or combustible non-metals, i.e., phosphorus.

4) TRU wastes are limited as described in Appendix 4.10.2, Transuranic (TRU) Waste Compliance Methodology for Hydrogen Gas Generation. TRU exceeding the fissile limits of 10 CFR 71.15 must not be machine compacted and must have no more than 1% by weight of special reflectors and no more than 25% by volume of hydrogenous material.

5) Explosives, corrosives, non-radioactive pyrophorics, and compressed gases are prohibited. Pyrophoric radionuclides may be present only in residual amounts less than 1 weight percent. The total amount of potentially volatile organic compounds present in the headspace of a secondary container is restricted to 500 parts per million.

10-160B GENERAL ARRANGEMENT

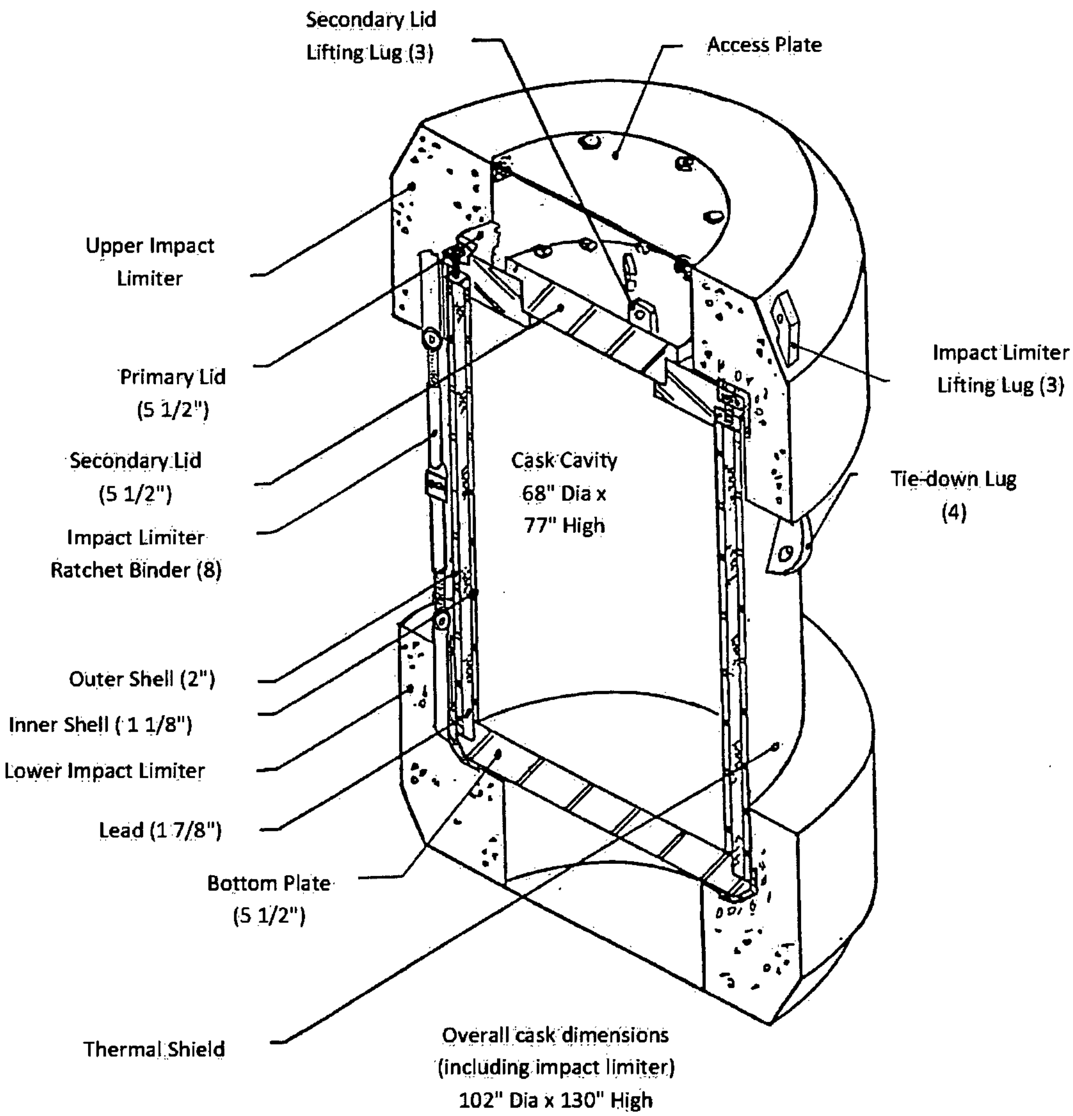


Figure 1-1

1.3 Appendix

10-160B Shipping Cask Drawing

(withheld as security-related sensitive information)

2.0 STRUCTURAL EVALUATION

This Chapter identifies and describes the structural design of the CNS 10-160B packaging, components, and safety systems for compliance with performance requirements of 10 CFR 71 (Ref. 1).

2.1 Structural Design

2.1.1 Discussion

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

The CNS 10-160B assembly is designed to protect the payload from the following conditions: Transport environment, 30 Foot drop test, 40 inch puncture test, 1475°F thermal exposure, and transfer of dissipation of any internally generated heat. The design of the package satisfies these requirements.

Principal structural elements of the system consist of:

- Containment Vessel
- Lead Shielding
- Impact Limiters

These components are identified on the drawing as noted in Appendix 1.3. Their design and function in meeting the requirements of 10 CFR 71 are discussed below.

2.1.1.1 Containment Vessel

The cask is comprised of carbon steel (SA-516 Gr. 70 or SA-537 Class 2) shells, which envelop a lead shield, a steel base, and lids. The inner shell serves as the package containment boundary. The primary lid is attached to the cask with 24 1¾" - 8UN bolts. A secondary lid is attached to the primary lid with 12 equally spaced 1¾" - 8UN bolts. The lid-to-cask body and lid-to-lid interfaces each employ a pair of high temperature, solid elastomer o-rings. All transport environment conditions as well as accident conditions (i.e., 30-foot drop, 40-inch puncture test requirements, etc.) are met with impact limiters installed as discussed in Section 2.1.1.3 below. All thermal loading and dissipation requirements are met as discussed in Section 3.0.

2.1.1.2 Shielding

The area between the two shells discussed in Section 2.1.1.1 is filled with lead. This lead shielding is subjected to a Gamma Scan inspection to assure lead integrity. The designed thickness assures that no biological hazard is presented by the package and all shielding requirements of 10 CFR 71 are met.

2.1.1.3 Impact Limiters

The impact limiters are designed to protect the package from damage during the 30 foot drop and to provide thermal protection during the hypothetical fire accident condition.

They are constructed of fully welded steel shells filled with foamed-in-place rigid structural polyurethane foam. The foam deforms and provides energy absorption during impact. Eight circumferentially located ratchet binders attached to the upper and lower impact limiters secures the limiters to the cask.

2.1.1.4 Summary

Detailed discussions of all components and materials utilized in the 10-160B Package including stress, thermal, and pressure calculations are contained in the applicable sections of this SAR. A drawing of the individual subassemblies and the 10-160B package can be found in Appendix 1.3.

2.1.2 Design Criteria

2.1.2.1 Normal and Accident Conditions of Transport

Regulatory Guide 7.6, "Design Criteria for the Structural Analysis of Shipping Cask Containment Vessels" (Ref. 2) was used in conjunction with Regulatory Guide 7.8, "Load Combinations for the Structural Analysis of Shipping Casks" (Ref. 3) to evaluate the package according to the requirements of 10 CFR 71.71 and 10 CFR 71.73. Table 2-1 summarizes the normal and accident conditions load cases.

1) Containment Vessel & Cask

The containment vessel is defined to be the inside steel shell and its closures. Regulatory guide 7.6 was used for the evaluation of the

Table 2-1

SUMMARY OF NORMAL AND ACCIDENT CONDITION LOADING[1]

Loading Condition	Ambient Temperature (°F)	Heat Load (watts)	Pressure (psia)		Stress Table[2]
			Internal	External	
NORMAL CONDITIONS					
Hot Environment	100	200	8.4	0	A2-31 & 32
Cold Environment	-40	0	11.2[3]	0	A2-29 & 30
Increased External Pressure	-20	0	0	20	A2-33 & 23
Minimum External Pressure	100	200	23.1	3.5	A2-35 & 36
Free Drop + Increased External Pressure	-20	0	0	20	A2-23 A2-25 A2-27
Free Drop + Minimum External Pressure	100	200	11.2[3]	0	A2-23 A2-25 A2-27
ACCIDENT CONDITIONS					
Free Drop + Increased External Pressure	-20	0	0	20	A2-13 A2-17 A2-21
Free Drop + Minimum External Pressure	100	200	11.2(3)	0	A2-13 A2-17 A2-21
Puncture + Increased External Pressure	-20	0	0	20	Page 2-74.3
Puncture + Minimum External Pressure	100	200	11.2(3)	0	Page 2-74.3
Fire	1475	200	31.2	0	A2-41 & 42

[1] These loading combinations are derived from the NRC Regulatory Guide 7.8, March 1989.

[2] See these tables for the stress analysis results of the corresponding loading conditions.

[3] Corresponds to the pressure differential between the atmospheric pressure (14.7 psi) and reduced external pressure (3.5 psi). This pressure is conservatively used in the load combinations instead of the maximum cask internal pressure of 8.4 psi.

containment vessel and the cask for both the normal conditions of transport and the hypothetical accident conditions. The yield and ultimate stress values of all materials of construction are obtained from Section II, American Society of Mechanical Engineers, Boiler and Pressure Vessel Code (BPVC). The design stress intensity value S_m, is the lesser of 2/3 yield or 1/3 ultimate strength. Table 2-4 summarizes primary limits for normal and accident conditions.

(2) **Impact Limiter Foam Strain**

The impact limiter is designed to absorb energy through inelastic deformation during the hypothetical accident conditions. Strain, rather than stress, is used as the limiting parameter to assure that the material does not bottom out. The maximum limiting strain was established as 70% since the stress and corresponding forces applied to the cask become large, and the "stiffness" of the impact system becomes large.

(3) **Brittle Fracture**

The primary structural components of the cask are fabricated with ASME SA 516, Grade 70, or ASME SA 537, Class 2 carbon steel with supplemental nil ductility temperature (NDT)
requirements. Fracture toughness requirements specified in NUREG/CR-1815, "Recommendations for Protection Against Failure by Brittle Fracture in Ferritic Steel Shipping Containers up to Four Inches Thick", (Ref. 4) are complied with. Section 2.6.2 evaluates the critical components of the cask.

Buckling

Buckling, per Regulatory Guide 7.6, is an unacceptable failure mode for the containment vessel. The intent of this provision is to preclude large deformations which would comprise the validity of linear analysis assumptions and quasi-linear stress allowables as given in paragraph C.5 of NRC Regulatory Guide 7.6.

Cask drop calculations show that the critical buckling stresses of the containment vessel and exterior shell are very high. Under service conditions, internal pressure would induce membrane biaxial tensile stress components in the containment vessel. These tensile stresses would tend to reduce compressive stresses due to hypothetical accident impact induced internal forces. Thus, under these conditions, the package would be less susceptible to buckling failure than under the conditions analyzed. Since no incipient buckling was predicted by the analysis, it may be safely concluded that buckling is not a probable failure mechanism for the 10-160B package.

The remainder of this subsection defines techniques and criteria used in subsequent section of this safety analysis report to demonstrate that containment vessel buckling does not occur.

Euler Column Buckling

Reference is made to "Formulas for Stress and Strain" by R.J. Roark, 5th Edition; (Ref. 5) Page 415. The critical buckling load, P_{cr} is calculated by:

$$\frac{Pcr}{A} = \frac{C\ \pi^2 E}{(L/r)^2}$$

Where:

C is the coefficient of constraint
C=1 for simply supported ends.
E is the modulus of elasticity.
L is the length of the cylinder.
r is the radius of gyration.
$I = Ar^2$ = moment of inertia.

The above equation could be written as follows:

$$Pcr = \frac{\pi^2 E I}{L^2}$$

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

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

Where R = cylinder radius
t = cylinder thickness

Inner Shell

$$I_i = \pi (34.5)^3 (1) = 129{,}005 \text{ in}^4$$

$$Pcr_i = 5.97 \text{ X } 10^9 \text{ lbs}$$

Outer Shell

I_o = $\pi\,(37.625)^3(2)$ = 334,664 in^4

Pcr_o = 1.51×10^{10} lbs

Axial Stress Limits

Refer to Baker, Kovalesvky, Rish, Structural Analysis of Shells. 1981 Ed., (Ref. 6) page 230.

A thin-wall cylinder is considered "moderately long" if: $\gamma z > \dfrac{\pi^2 K_{co}}{2\sqrt{3}}$

Where γ is the correction factor dependent on R/t.

$$z = \frac{L^2}{Rt}\sqrt{1-\nu^2}$$

K_{co} = 1, for simply supported edges. (Conservative)

L = cylinder length

R = cylinder mean radius

t = cylinder mean thickness

ν = Poisson's ratio

The following two sets of properties correspond to the inner and outer shells of the cask side wall:

Inner Shell			Outer Shell		
t_i	=	1 in	t_o	=	2 in
R_i	=	34.5 in	R_o	=	37.625 in
L_i	=	77 in	L_o	=	78 in
ν	=	.3	ν	=	.3 in
z_i	=	163.94	z_o	=	77.13

Check value of $\frac{\pi^2 K_{co}}{2\sqrt{3}} = 2.85$

Figure 10-9, Page 230 (Ref. 6)

$R_i/t_i = 34.50$ yields $\gamma_i = .74$

$R_o/t_o = 18.81$ yields $\gamma_o = .8$

$$\left.\begin{matrix} \gamma_i z_i = 121.32 \\ \gamma_o z_o = 61.70 \end{matrix}\right\} \rangle\ 2.85$$

Both shells will be treated as moderately long cylinders.

From (ref. 6) Page 229

$$\sigma_e = \sigma_{cr} / \eta = K_c \frac{\pi^2 E}{12(1 - \nu^2)} \left(\frac{t}{L}\right)^2$$

$$K_c = \frac{4\sqrt{3}}{\pi^2} \gamma z$$

$\sigma_{ei} = 360,906$ psi

and

$\sigma_{eo} = 715,482$ psi

HOOP STRESS LIMIT

(Ref. 6) PAGE 236

$$\sigma_h = \sigma_{cr}/\eta = k_p \pi \frac{2_E}{12(1-\nu^2)} \left(\frac{t}{L}\right)^2$$

where K_p is a function of z. (Page 237)

then

z_i	=	163.94	→	K_{pi}	=	10.5
z_o	=	77.13	→	K_{po}	=	8

σ_{hi} = 44,497 psi

and

σ_{ho} = 132,155 psi

Critical Buckling Stress

Critical buckling stress (σ_{cr}) for each of the above cases, can be found by solving the following equation (Ref. 6, page 265)

$$\sigma_e = \sigma_{cr}/\eta \qquad (1)$$

Where η is the plasticity coefficient. For moderately long cylinders under uniform axial and hoop compressions this coefficient can be defined as follows:

For axial stresses

$$\eta = \sqrt{\frac{E_t E_s}{E}} \qquad (2)$$

Where:

E_t = tangent modulus = $\frac{d\sigma}{d\epsilon}$

E_S = secant modulus = $\frac{\sigma}{\epsilon}$

σ_{cr} = critical stress

ϵ = strain

The stress-strain relationship of A516 GR.70, (σ_y = 38,000 psi) between the proportional limit ($0.7\sigma_y$) and the yield point (σ_y) can be expressed by the following quadratic equation:

$$\sigma = A\ \varepsilon^2 + B\ \varepsilon\ + C \qquad \text{.....(3)}$$

Where,

$$A = -1.6948 \text{ X } 10^{10}$$

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

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

Figure 2.1.1 shows a plot of stress-strain curve thus constituted. Substitution of eqn. (3) into eqn. (2) yields the following expression for the plasticity coefficient,

$$\eta = \frac{\sqrt{(2A\varepsilon + B)(A\varepsilon + B + c/\varepsilon)}}{E}$$

Using equations (1) and (4), inelastic buckling stress for any elastically calculated buckling stress can be calculated for 10-160B Cask, these stresses are calculated as follows:

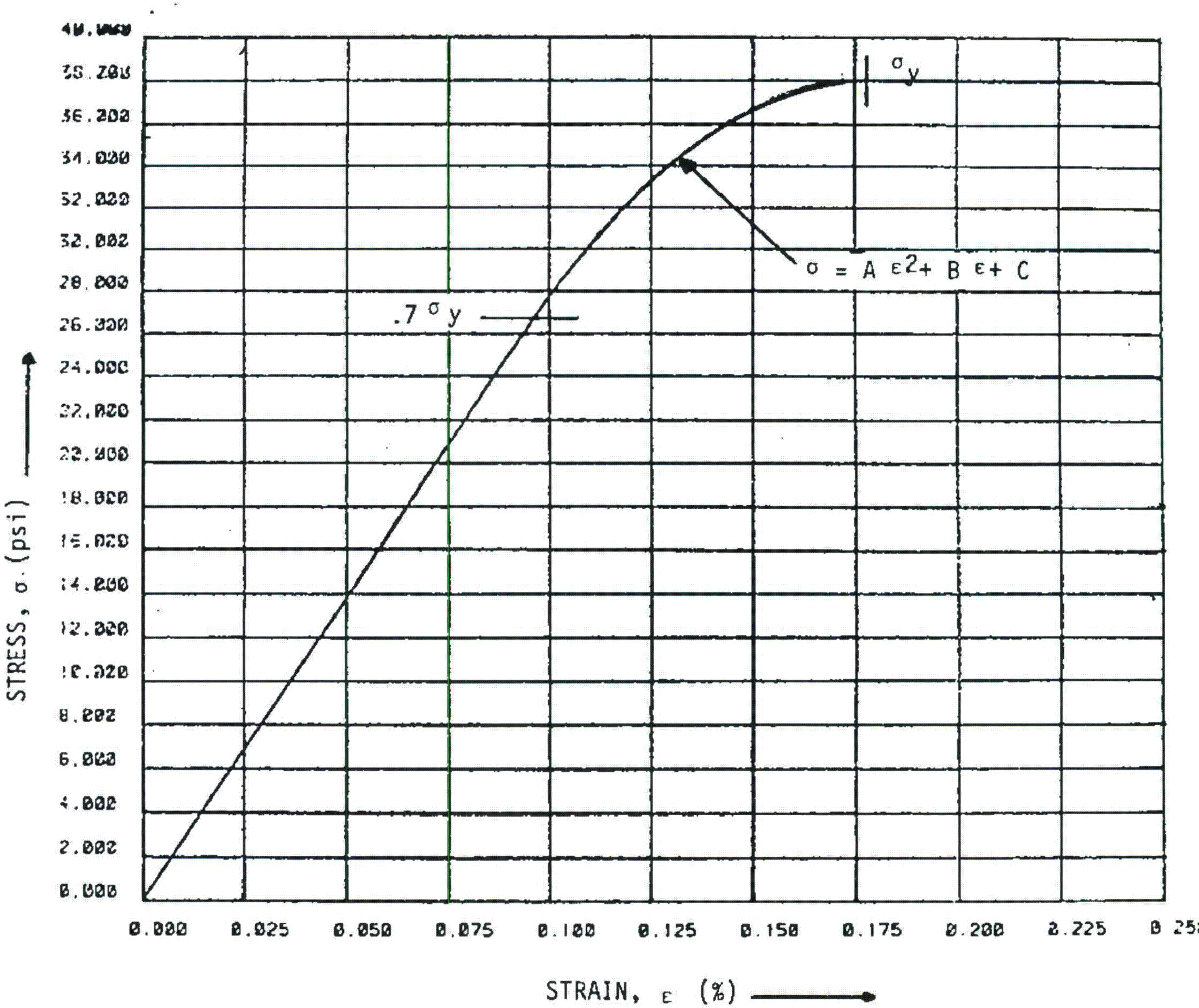


Figure 2.1.1
Constituted Stress-Strain Curve
For A516 GR.70

Axial

	Inner	Outer
σ_e, psi	360,906	715,482
ϵ_{cr}	1.7653×10^{-3}	1.774×10^{-3}
η	0.1051	0.0539
σ_{cr}, psi	37,921	37,948

Hoop

	Inner	Outer
σ_h, psi	44,497	132,155
ϵ_{cr}	1.165×10^{-3}	1.6928×10^{-3}
η	0.854	0.2875
σ_{cr}, psi	37,999	37,989

The buckling stress limits are summarized in the following table:

	Inner Shell	Outer Shell
Axial Membrane	37,921 psi	37,948 psi
Hoop Membrane	37,999 psi	37,989 psi

Buckling evaluation of the cylindrical shells, for combined loading, is done using the technique described in (Ref. 6), Page 275 accordingly.

$\sigma_{cr} - \eta\sigma_i \quad = \quad o$

Where σ_{cr} is the combined load critical buckling stress intensity.

η is the plasticity correction Factor $\sqrt{\frac{E_s.E_t}{E}}$

σ_i is elastic buckling stress intensity

$\sigma_i = \sqrt{(\sigma_e)^2 + (\sigma_h)^2 - (\sigma_e\sigma_h)}$

$\sigma_{ii} \quad = \quad 340{,}843$ psi

$\sigma_{io} \quad = \quad 659{,}413$ psi

Values for both shells are as follows:

	Inner	Outer
σ_e psi	360,906	715,482
σ_H psi	44,497	132,155
σ_i psi	340,843	659,413
ϵ_{cr}	1.7639×10^{-3}	1.77347×10^{-3}
η	0.1112	0.0576
σ_{cr} (Combined Load), psi	37,911	37,949

The largest stress intensity under the hypothetical accident condition in the outer shell is 16,880 psi (see Table 2-11) and in the inner shell is 21, 120 psi (See Table 2-20) which are clearly well below the corresponding critical buckling stresses. Hence, buckling of shells in the 10-160B cask is not a possible mode of failure.

2.1.2.2 Tie-downs and Lifting Devices

(1) Cask and Lid Lifting Devices

10 CFR 71.45 (a) requires that the cask lifting devices be capable of supporting three times the weight of the loaded package without generating any stress in the cask in excess of the yield strength. No stresses shall be generated in any material in excess of yield strength.

Maximum stresses and safety factors are computed in Section 2.4.3.

(2) Tie-downs

10 CFR 71, 7.45 (b) paragraph (1) requires that the tie-downs be designed such that no stresses exist in any material of the package in excess of yield strength for the specified 10-5-2G loading condition. Maximum package stresses and factors or safety are computed in Section 2.4.4.

(3) Failure of the Tie-down and Lifting Devices

Any tie-down, cask lifting or lid lifting device must be designed such that failure of the device under excessive loads will not impair the ability of the package to meet the other requirements specified in 10 CFR 71.45.

Sections 2.4.3 and 2.4.4 demonstrate that the failure load for tiedown and lifting components, the shielding and containment requirements are met.

Failure is predicted for an equivalent state of stress which produces a maximum shear stress of:

$$\sigma \text{ failure} = \frac{1}{\sqrt{3}} S_u = 0.577 S_u$$

Where S_u = Material ultimate tensile strength

2.2 Weights and Center of Gravity

The weight breakdown of the package is as follows:

Cask Body		47,250 lbs
Outer Shell	10,600	
Inner Shell	6,000	
Lead Shell	13,800	
Base Plate	7,200	
Upper Ring	1,050	
Primary Lid	5,300	
Secondary Lid	2,150	
Tie-Down Lugs (4)	200	
Lifting Lug Pads	350	
Thermal Shield	350	
Thermal Shield (lid)	250	
Impact Limiters		10,500 lbs
Upper	5,300	
Lower	5,200	
Net Package Payload		14,250 lbs (See Note)
	Total Package Weight	72,000
	GROSS PACKAGE WEIGHT	72,000

The center of gravity of the package is located at the geometric center of the package.

Note. If an optional insert is installed in the cavity, the maximum payload is reduced by the weight of the insert.

2.3 Mechanical Properties of Materials

All major cask body components are fabricated of carbon steel, including the shells and lids; and are included in Section II of the ASME BPVC. The basic material properties of the lid and shell components are shown in Table 2-2. The temperature variation of these properties can be obtained from Appendix I of Section III, ASME BPVC. The basic properties of the other steel components are shown in Table 2-3 as a function of temperature. The allowable stress intensity, S_m, is the lesser of one third ultimate or two-thirds of yield at a given temperature. The primary stress allowables are tabulated in Table 2-4.

The impact limiters are constructed of rigid, self-extinguishing, polyurethane foam, foamed in-place. Figure 2-1 represents the stress-strain curve for the foam used for this package. The tolerance limits (10%) are shown along the nominal curve. The specification for the foam is located in Appendix 8.3.1.

2.4 General Standards for All Packages

This section demonstrates that the general standards and loading conditions for all packages are met.

2.4.1 Chemical and Galvanic Reactions

The materials from which the packaging is fabricated (steel, lead, and polyurethane foam) along with the contents of the package will not cause significant chemical, galvanic, or other reaction in air, nitrogen, or water atmospheres.

2.4.2 Positive Closure

The positive closure system has been previously described in Section 1.2.1.

Table 2-2

MECHANICAL PROPERTIES OF MATERIALS USED IN FABRICATION OF 10-160B CASK

MATERIAL	TYPE, CLASS OR GRADE	S_y (psi)	S_u (psi)	S_m (psi)	E (psi)	α in/in °F
SA-516	70	38,000	70,000	23,300	29.5×10^6	6.41×10^{-6}
SA-537(1)	2	55,000	85,000(2)	28,300	29.5×10^6	5.42×10^{-6}
SA-517	F	100,000	115,000	38,300	29.5×10^6	6.20×10^{-6}
A-354	BD	130,000	150,000	-	29.9×10^6	6.50×10^{-6}
A-540(3)	B21, Class 1	150,000	165,000	-	29.7×10^6	5.42×10^{-6}

Nomenclature: S_y = Yield Stress of the Material
S_u = Ultimate Stress of the Material
S_m = Allowable Membrane Stress Intensity of the Material
E = Modulus of Elasticity of the Material
α = Mean Coefficient of thermal Expansion

NOTES:

(1) Alternate material for inner shell and bolting ring. This material has a higher allowable than SA-516 Gr. 70 for all loading conditions. Therefore, the allowable values for SA-516 are used throughout in the SAR.

(2) SA-537 Class 2 has S_u in the range of 75,000 to 95,000 psi. A minimum S_u of 85,000 psi has been specified for the CNS10-160B cask.

(3) Alternate material for primary and secondary lid bolts. This material has a higher allowable than A-354 Gr. BD for all loading conditions. Therefore, the allowable values for A-354 are used throughout in the SAR.

TABLE 2-3
MATERIAL PROPERTIES VERSUS TEMPERATURE

Material	Type Class or Grade	Temp. F	Sy (psi)	Su (psi)	Sm (Psi)	E (psi) (5)	α in/in F (4)
SA-516	70	70	38,000	70,000	23,300	29.5E6	6.50E-6
(2)		100	38,000	70,000	23,000	29.5E6	6.50E-6
		200	34,600	70,000	23,100	28.8E6	6.67E-6
		300	33,700	70,000	22,500	28.3E6	6.87E-6
		400	37,600	70,000	21,700	27.7E6	7.07E-6
		500	30,900	70,000	20,500	27.3E6	7.25E-6
SA-517	F	70	100,000	115,000	38,300	29.5E5	6.27E-6
(1)		100	100,000	115,000	38,300	29.5E6	6.27E-6
		200	95,500	115,000	38,300	28.8E6	6.54E-6
		300	92,500	115,000	38,300	28.3E6	6.78E-6
		400	89,800	115,000	38,300	27.7E6	6.98E-6
		500	87,600	115,000	38,300	27.3E6	7.16E-6
A-354	BD	100	130,000	150,000	-------	29.9E6	6.20E-6
(3)							
LEAD	Chemical	-40	-	-	-	2.46E6	15.56E-6
B-29		-20	-	-	-	2.43E6	15.65E-6
(6)		70	-	-	-	2.27E6	16.06E-6
		100	-	-	-	2.21E6	16.22E-6
		200	-	-	-	2.01E6	16.70E-6
		300	-	-	-	1.85E6	17.33E-6
		400	-	-	-	1.70E6	18.16E-6
		500	-	-	-	1.52E6	19.12E-6

NOTES:
(1) From Code Case N-71-11
(2) From Section VIII, Division II, ASME B&PVC
(3) From ASTM Specification
(4) From Table 1-5.0, Section III, ASME B&PVC
(5) From Table 1-6.0, Section III, ASME B&PVC
(6) From NUREG/CR-0481 (Ref. 25)

TABLE 2-4
PRIMARY STRESS INTENSITY ALLOWABLES

Material	Type Class or Grade	Sm (psi)	Su (psi)	Normal Condition		Accident Condition	
				Membrane (psi)	Membrane + Bending (psi)	Membrane (psi)	Membrane + Bending (psi)
SA-516	70	23,300	70,000	23,300	34,950	49,000	70,000
SA-517	F	38,300	115,000	38,300	57,400	80,500	115,000
A-354	BD	-	150,000	-	-	-	-

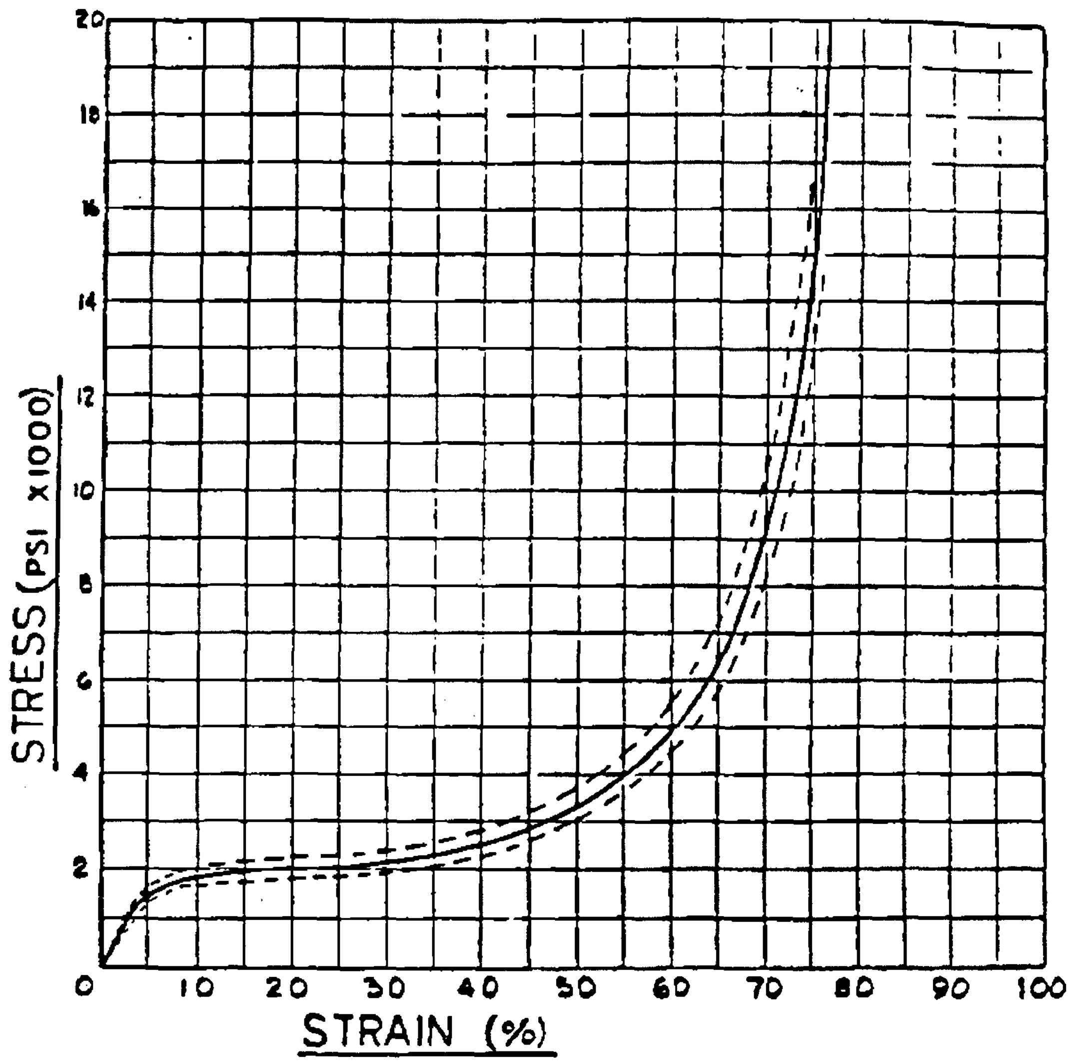


Figure 2-1

Compressive Stress-Strain Curve for Foam

2.4.3 Lifting Devices

The 10-160B cask is provided with two (2) removable lifting lugs (Figure 2-2) attached to a 2 inch plate welded to the outer shell of the cask by which the cask and payload can be lifted. The lid is provided with three (3) lifting lugs by which the lid may be removed from the cask. The lid lifting lugs are covered by the impact limiter and the cask lifting lugs are removed during the transportation. Hence, neither lugs can be inadvertently used for the tie-down. A stress summary of the lifting devices is tabulated in Table 2-5.

The load requirements for lifting devices are defined in 10 CFR 71, paragraph 71.45 subpart "a" as, "... must be designed with a minimum safety factor of three against yielding when used to lift the package in the intended manner."

Cask Lifting Lugs

The lugs can be used only with impact limiters removed; for conservatism, the weight of the impact limiters will be included in the following analysis. Therefore, the total lifted weight is:

W = 72,000 lbs.

The lug load is:

$$P = \frac{72{,}000}{2 \text{ Lugs}} = 36{,}000 \text{ lbs/lug.}$$

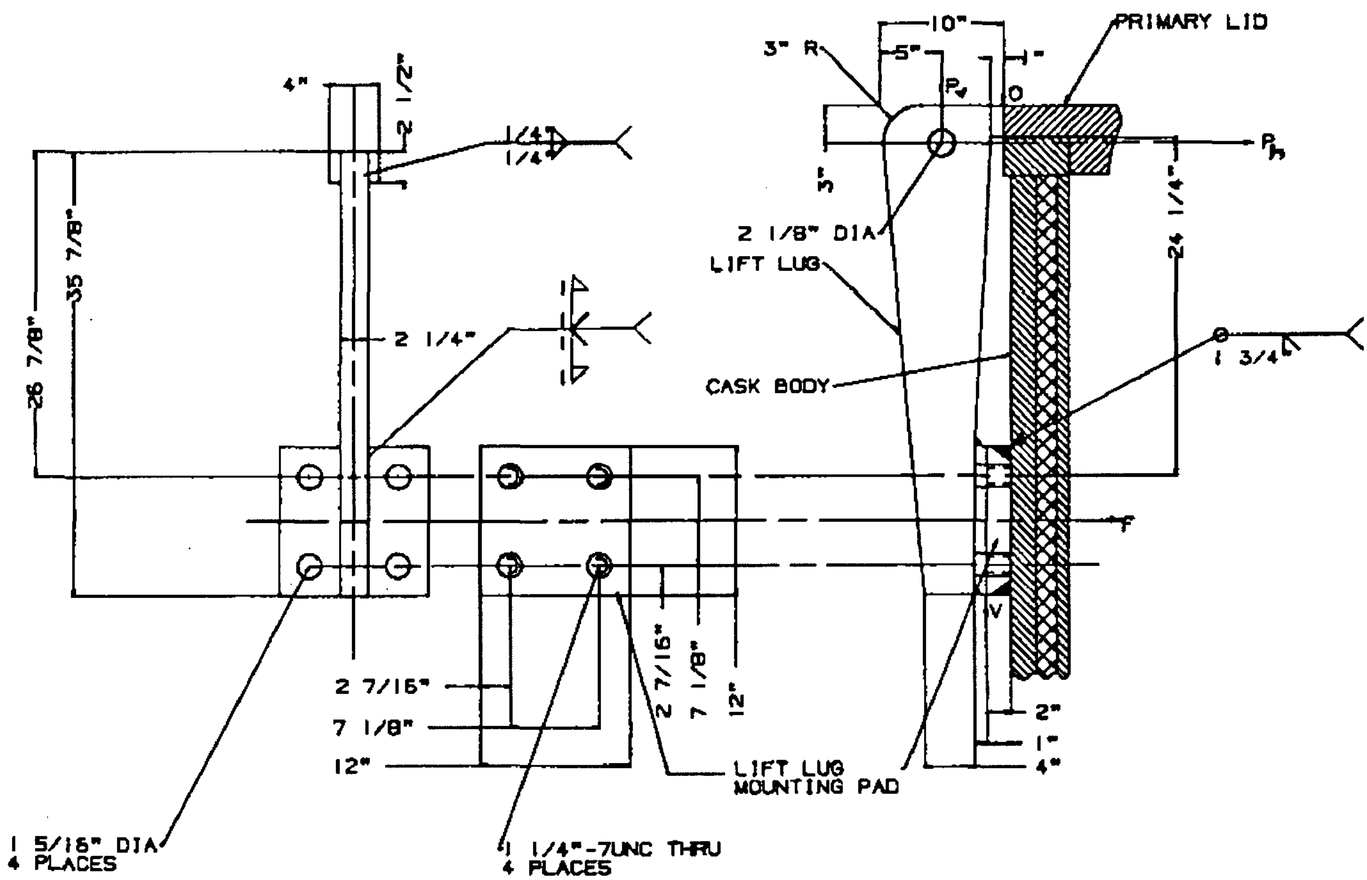


Figure 2-2
Cask Lift Lug

TABLE 2-5

STRESS SUMMARY OF LIFT LUGS AND WELDS

Material	Shear Stress (psi)	Direct Stress (psi)	Stress Intensity (psi)	Stress Allowable (psi)	Safety Factor (1)
Steel of Cask Lug	---	3,027	3,027	12,667	4.20
	4,129	---	---	7,309	1.77
Weld	1,819	---	3,638	7,309	3.48
	1,819	---	---	7,309	4.02
Steel of Lid Lug	870	2,004	2,654	12,667	4.77
	870	---	---	7,309	8.40
Weld	159	000	000	7,309	45.97
Bolts	37,152	1,161	37,737	75,010	1.99
Bolt Holes (Threads)	1,515	---	---	7,309	4.83

A – Shear in weld of mounting plate to cask body

Each mounting plate is attached to the outer shell of the cask with a 1.75" full penetration weld all around. The weld properties are as follows:

Weld length, $L_w = 4 \times 12 = 48"$

Weld throat thickness, $t_w = 1\ 3/4 \times .707 = 1.24"$

Weld area, $A_w = 48 \times 1.24 = 59.39\ in^2$

The weld shear stress, $\tau_w = \frac{P}{A_w}$

$$\tau_w = \frac{36,000}{59.39} = 606 \text{ psi}$$

Allowable stress in pure shear is $1/3 \times .577 \times S_y =$
$1/3 \times .577 \times 38,000 = 7,309$ psi

$$\text{S.F.} = \frac{7,309}{606} = 12.06$$

Stress Intensity of Weld

2 x 606 = 1,212 psi

$$\text{S.F.} = \frac{1/3 \times 38,000}{1,212} = 10.45$$

Shear in weld of lift lug

Each lift lug is attached to a base plate by a 1-inch weld. The weld properties are as follows:

Weld length, L_w = $(2 \times 12) + (2 \times 2) = 28"$

Weld throat thickness, $t_w = .707 \times 1 = .707"$

Weld area, $A_w = 28 \times .707 = 19.8 \text{ in}^2$

The weld shear stress, $\tau_w = P/A_w$

$\tau_w = 36{,}000/19.8 = 1{,}819$ psi

Allowable stress in pure shear is
1/3 x .577 x 38,000 = 7.309 psi

S.F. = 7,309/1,819 = 4.02

Stress intensity of weld = 2 x 1,819 = 3,638 psi

S.F. = (1/3 x 38,000)/3,638 = 3.48

B – Bolt stresses

Each lifting ear is attached to the cask mounting plate, as shown in Figure 2-2 using four (4) 1-1/4-7 UNC –2A, 2 –3/4-inch-long ASTM 354 grade BD Hex head bolts. The stress area for each bolt is 0.969 in^2.

The shear force, V, will be carried by four bolts, so the shear force acting on the bolts is, V = 36,000 x 3 = 108,000 lbs.

Nominal shear stress, $\tau_b = \dfrac{108{,}000}{4\,(.969)} =$

τ_b nom. = 27,864 psi

Maximum shear stress in the bolts will be 4/3 (four-thirds) the nominal shear stress, so $\tau_b = \dfrac{4 \times 27864}{3}$

$\tau_b = 37{,}152$ psi

The tensile force, F, will be carried by all four bolts.

The horizontal component of the force acting on the cask lifting lug is,

108,000/tan 60° = 62,354

Summation of moments about point 0.

$30.4375\ F + 3P_h - 5\ P_v + 2\ V = 0$

$$F = \frac{5\,(108{,}000 - 2\,(108{,}000) - 3\,(62{,}354)}{30.4375}$$

F = 4,499 lbs

Therefore, tensile stress, $\sigma_b = F/A_b$

σ_b = 4,499/4 (.969) = 1,161 psi

Maximum principal stresses in the bolt are found by

$$\sigma_p = \sigma_b/2 \pm \sqrt{(\sigma_b/2)^2 + (\tau_b)}^2$$

$$\sigma_p = 1{,}161/2 \pm \sqrt{(1{,}161/2)^2 + (37{,}152)^2}$$

σ_p = 37,737 psi

S.F. = (.577 x 130,000)/37,737 = 1.99

c – Threads – Cask Metal

Because the cask material is weaker than the bolt material, failure will occur at the root of the cask material threads. From Bickford, John H., an introduction to the design and behavior of bolted joints, Marcel Bekker, Inc. 1981, pp. 272-273, the equations for shear area and the length of thread engagement required to develop full strength of the threads are:

$A_{TS} = (\pi)(n)(L_e)(D_{min})[\ 1/2n + 0.57735\ (D_{min}\text{-}E_{nmax})]$

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

Where:

D_{min}	=	Min. O.D. of bolt, in
	=	1.25 in.
E_{nmax}	=	Max. P.D. of cask threads, in.
	=	1.157 in.
S_{st}	=	Tensile strength of bolt material, psi
	=	150,000 psi
n	=	Threads per inch
	=	7.0 threads/in
As	=	Stress area of bolt threads, in^2
	=	0.969 in^2
S_{nt}	=	Tensile strength of cask material, psi
	=	70,000 psi
A_{TS}	=	Shear area at root of cask threads, $in.^2$
L_e	=	Length of thread engagement required to develop full strength, in.

L_e = $[(150{,}000)(2)(0.969)]/[\pi(70{,}000)(7)(1.25)[1/14+0.57735(1.25 - 1.157)]]$

L_e = 1.21 in. deep

A_{TS} = $(\pi)(n)(L_e)(D_{min})[1/2n + 0.57735(D_{min} - E_{nmax})]$

A_{TS} = 2.97 $in.^2$

A_{TS} = 2.97 $in.^2$

The bolt tension was determined as 6.257 lbs resulting in shear stress at the threads of:

$$\tau \text{ thread shear} = F_{bolt}/A_{TS} = \frac{4.499}{2.97}$$

$$\tau = 1{,}515 \text{ psi}$$

The allowable shear stress is (1/3)(.577)(S_y), where the yield stress for the cask body material is 38,000 psi.

$$\tau_{allowable} = (1/3)(.577)(38{,}000) = 7{,}309 \text{ psi}$$

The associated safety factor is:

$$S.F. = \frac{7{,}309}{1{,}515} = 4.83$$

d – Lug Stresses

Lug Thickness, t = 2 ¼"
Effective lug width, W = 5.29" at weld location

Tension

$$\sigma_t = \frac{P}{EffectiveArea} = \frac{36{,}000}{21/4(5.29)} = 3{,}027 \text{ psi}$$

$$S.F. = \frac{38{,}000}{3x3{,}027} = 4.20$$

Shear out of lug

V = 36,000 lbs.
Plate thickness, t = 2 ¼"
Hole radius, r_i = 1,0625"
L = 3 – 1.0625 = 1.9375"
No. of shear faces, N=2
A_s=N . L . b = 2 ¼ x 1.9375 x 2 = 8.72 in^2

$$\text{Shear stress, } \tau = \frac{V}{A_s} = \frac{36,000}{8.72} = 4,129 \text{ psi}$$

$$\text{F.S.} = \frac{.577 \times 38,000}{3 \times 4,129} = 1.77$$

e – Lid Lift Lug stresses

Lug thickness, t = 1"
Lid weight, W = 4,550 + 1,650 = 6,200 lbs.
Lug width, w = 5.25"
Lug height, h = 4.25"
No. of lugs = 3

Tension

σ_t = W/(Effective Area) = 6,200/(3 x (5.25 – 1.125)) = 501 psi
Apply a stress concentration factor of 4.
σ = 501 x 4 = 2,004 psi
S.F. = 38,000/(3 x 2,004) = 6.32

<u>Shear out of lug</u>

L = $1.75 - \frac{1.125}{2} = 1.1875"$

V = Lid weight/No. of lugs = 6,200/3

N = 2

t = 1"

A_s = N.L.t = 2 x 1.1875 x 1 = 2.375 in^2

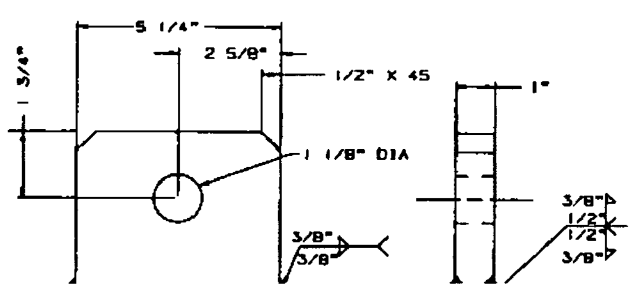
τ = $V/A_s = \frac{6{,}200/3}{2.375} = 870$ psi

S.F. = $\frac{38000 \times .577}{870 \times 3} = 8.4$

Stress intensity, S.I. = $2\sqrt{\tau^2 + (\sigma/2)^2}$

$2\sqrt{(870)^2 + \frac{2{,}004^2}{2}} = 2{,}654$ psi

S.F. = $\frac{38{,}000}{3 \times 2{,}654}$ = 4.77



<u>Shear in weld</u>

Weld length, L = (5.25 x 2) = 10.5"
Weld thickness, t = (2 x .5 x .707) + (2 x .375 x .707) = 1.237"
Weld area, A_w = 10.5 x 1.237 = 12.99 in^2
τ_w = 6,200/(3 x 12.99) = 159 psi
S.F. = (38,000 x .577)/(3 x 159) = 45.97

2.4.4 Tie-Down Devices

The tie-down system for transporting the package is designed to load conditions defined in 10 CFR 71, paragraph 71.45(b). This load condition is defined as follows: "The system must be capable of withstanding, without generating stress in any material of the package in excess of its yield strength, a static force applied to the center of gravity of the package having a vertical component of two times the weight of the package and its contents, a horizontal component along the direction in which the vehicle travels of 10 times the weight of the package with its contents and a horizontal component in the transverse direction of five times the weight of a the package with its contents."

The 10-160B cask has been provided with 4 tie-down lugs welded to the cask's outer shell. The tie-down force is calculated by considering the equilibrium of forces and moments acting on the impact limiter and the cask as one rigid body. This approach is more conservative than that of considering the equilibrium of forces on the cask without the impact limiter. The impact limiter increases the moment arms of the overturning moment, thereby resulting in larger cable loads.

Each component used in the tie-down arrangement is designed and evaluated for the loading conditions described in 10 CFR 71.45 (b). For the purpose of this analysis, the package is assumed to weigh 72,000 lbs.

The results of the analysis verify that the tie-down system is capable of withstanding the above mentioned forces, without generating stress in any part of the packaging in excess of its yield strength. The analysis is subdivided into individual sections dealing with: Loads acting on the lugs, and lug stresses. A stress summary of the tie-down devices is tabulated in Table 2-7.

Table 2-5.1

Stress Summary of Tie-Downs

Component	Shear Stress (psi)	Direct Stress (psi)	Bending Stress (psi)	Stress Intensity (psi)	Allow Stress (psi)	Safety Factor (psi)
Tie-Down	45,252.7	---------	-----------	------------	57,700	1.28
Lug	10,414.6	16,313	8900.31	32,704.24	100,000	3.06
Weld Stress	21,195.1	------------	-----------	-------------	57,700	2.72

2.4.4.1 Tie-down Load Evaluation

The tie-down arrangement of the 10-160B cask to the vehicle is as shown in Figure 2-3. The loads in the tie-down cables are obtained by statically applying the required 10W, 5W and 2W loads on the cask center of gravity along X, Z, and Y-directions respectively. The total load in the cables is obtained as the sum of the cable loads under each of these load conditions.

Cable Load Under X-Direction Loading

Due to negative X-direction loading, two of the four cables, namely cables 1 and 2, will be slack and the remaining two will carry the load. Due to symmetry, both cables 3 and 4 will carry equal loads. The magnitude of the load in each cable, T_x, can be calculated by moment balance about point A and by summing forces in the X-direction.

$\Sigma F_x = -10W + 2S_x + 2T_xB_x = 0, \rightarrow S_x = 5W - T_xB_x$ ....(Eq. A)

$\Sigma M_a = 10Wc - 2B_xT_xh - 2B_yT_xa - WR_o - 2S_xb = 0$ ....(Eq. B)

Eq. A into Eq. B yields the following:

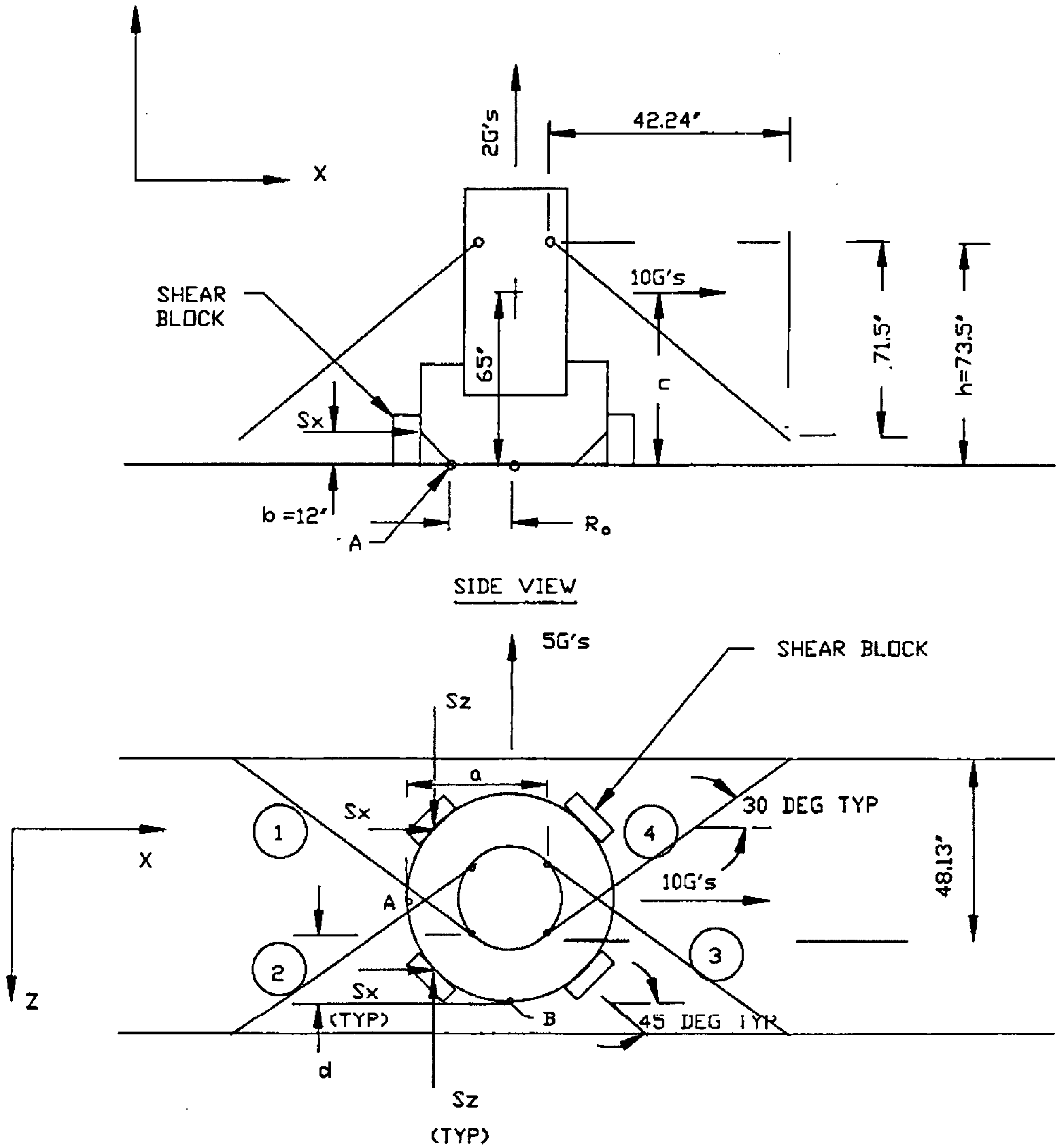
$$Tx = \frac{-10Wc + WR_o + 10Wb}{-2B_xh - 2B_ya + 2B_xb}$$

Where

$B_x = L_x / \sqrt{L_x^2 + L_y^2 + L_z^2}$

L_x = X-component of cable length
L_y = Y-component of cable length
L_z = Z-component of cable length

S_x = X-component of shear block force
S_z = Z-component of shear block force



Top View
Figure 2-3
Tie-Down Arrangement

W = 72,000 lbs.

B_x = $42.24/\sqrt{(42.24)^2 + (71.5)^2 + (48.13)^2}$

B_x = .4401

B_y = $L_y/\sqrt{L_x{}^2 + L_y{}^2 + L_z{}^2}$

B_y = $71.5/\sqrt{(42.24)^2 + (71.5)^2 + (48.13)^2}$

B_y = .7449

h = 73.5"

b = 12"

a = $R_o + R_L \cos 30°$

c = 65"

R_o = Impact limiter radius

R_o = 45"

R_L = Radium extended to the tie-down lug

R_L = 41.625"

a = 45 + 41.625 cos 30° = 81.05"

h = 73.5"

$$T_x = \frac{-10(72{,}000)(65) + 72{,}000(45) + 10(72{,}000)(12)}{-2(.4401)(73.5) - 2(.7449)(81.05) + 2(.4401)(12)}$$

T_x = 199,679.78 lbs.

We thus have:

T_{1x} = T_{2x} = 0, T_{3x} = T_{4x} = 199,679.78 lbs.

Eq. A. yields the following:

S_x = 5(72,000) - (199,67.78)(.4401) = 272,120.93 lbs.

We thus have:

S_{1x} = S_{2x} = S_{1z} = S_{2z} = 272,120.931 lbs.

Cable Load under Z-Direction Loading

Due to negative Z-direction loading, two of the four cables, namely cables 2 and 3, will be slack and the remaining two cables will carry equal loads. The magnitude of the load in each cable, T_z, can be calculated by moment balance about point B and by summing the Forces in the Z-direction.

$$\Sigma F_z = 5W - 2T_zB_z - 2S_z = 0 \rightarrow S_z = \frac{5W}{2} - T_zB_z \quad \text{.......(Eq. C)}$$

$$\Sigma M_B = 5Wc - 2B_zT_zh - 2B_yT_zd - WR_o - 2S_zb = 0 \quad \text{.......(Eq. D)}$$

Eq. C into Eq. D yields the following:

$$T_z = \frac{-5Wc + WR_o + 5bW}{-2B_zh - 2B_yd + 2bB_z}$$

$$d = R_o - R_L \sin 30°$$

$$d = 45 - 41.625 \sin 30° = 24.19''$$

$$B_z = L_z / \sqrt{L_x^2 + L_y^2 + L_z^2}$$

$$B_z = 48.13 / \sqrt{(42.24)^2 + (71.5)^2 + (48.13)^2}$$

$$B_z = .5014$$

$$T_z = \frac{-5(72{,}000)(65) + (72{,}000)(45) + 5(12)(72{,}000)}{-2(.5014)(73.5) - 2(.7449)(24.19) + 2(12)(.5014)}$$

T_z = 162,116.6 lbs.

We thus have:

$T_{2z} = T_{3z} = 0$, $\quad T_{1z} = T_{4z}$ = 162,116.6 lbs.

$$S_z = \frac{5}{2}(72{,}000) - (162{,}116.6)(.5014)$$

S_z = 98,717.24 lbs.

We thus have:

$S_{2z} = S_{3z} = S_{2x} = S_{3x}$ = 98,717.24 lbs.

Maximum load per shear block = $\sqrt{S_{2x}^2 + S_{2y}^2 + S_{2z}^2}$

Maximum load per shear block = 139,607.26 lbs.

Cable Load Under Y-Direction Loading

Due to negative Y-direction loading, all of the four cables are effective and because of symmetry, they carry equal loading. The magnitude of the loading, T_y, can be calculated by force balance along the Y-direction.

$\Sigma F_y = 2W - 4B_yT_y = 0$

$T_y = W/2B_y$

$T_y = 72{,}000/(2 \times .7449)$

$T_y = 48{,}329$ lbs.

We thus have,

$T_{1y} = T_{2y} = T_{3y} = T_{4y} = 48{,}329$ lbs.

Cable Load Under Combined Loading

To obtain the load under the combined loading of 10G, 5G, and 2G along X, Z, and Y-directions, respectively, the loads in a particular cable under these loadings can be added together which yields the following:

$T_1 = T_{1x} + T_{1y} + T_{1z} = 0 + 48{,}329 + 162{,}116.6 = 210{,}445.6$ lbs.

$T_2 = T_{2x} + T_{2y} + T_{2z} = 0 + 48{,}329 + 0 = 48{,}329$ lbs.

$T_3 = T_{3x} + T_{3y} + T_{3z} = 199{,}679.78 + 48{,}329 + 0 = 248{,}008.78$ lbs.

$T_4 = T_{4x} + T_{4y} + T_{4z} = 199{,}679.78 + 48{,}329 + 162{,}116.6$

$T_4 = 410{,}125.38$ lbs.

The largest tension under the combined loading occurs in cable 4 and is equal to 410,125.38 lbs. (5.7 times the weight of the cask). The Tie-down arrangement is designed to withstand this loading without generating stress in excess of its yield strength.

2.4.4.2 Tie-Down Stress Evaluation

Tie-Down Lug Stresses

Four tie-down lugs are constructed from 2.5" thick A517 grade F, the tie-down lug (Figure 2-4 is analyzed for shear-out, tension, and bending and it is shown that under these conditions, stresses nowhere in the lug exceed the yield strength of the material.

Shear Out of Lug

The maximum shear stress in the lug is calculated as follows:

Shear force, V = 410,125.38 lbs

Lug thickness, t = 2.5"

Shear out length, L = 2.75 - .9375 = 1.813"

No. of surfaces, N = 2

Shear area, A_{ES} = N.L.t + 2 x 1.813 x 2.5 = 9.063 in^2

Shear stress, $\tau = V/A_{ES}$ = 410,125.38/9.063

τ = 45,252.71

$$S.F. = \frac{.577\ (100{,}000)}{45{,}252.71} = 1.28$$

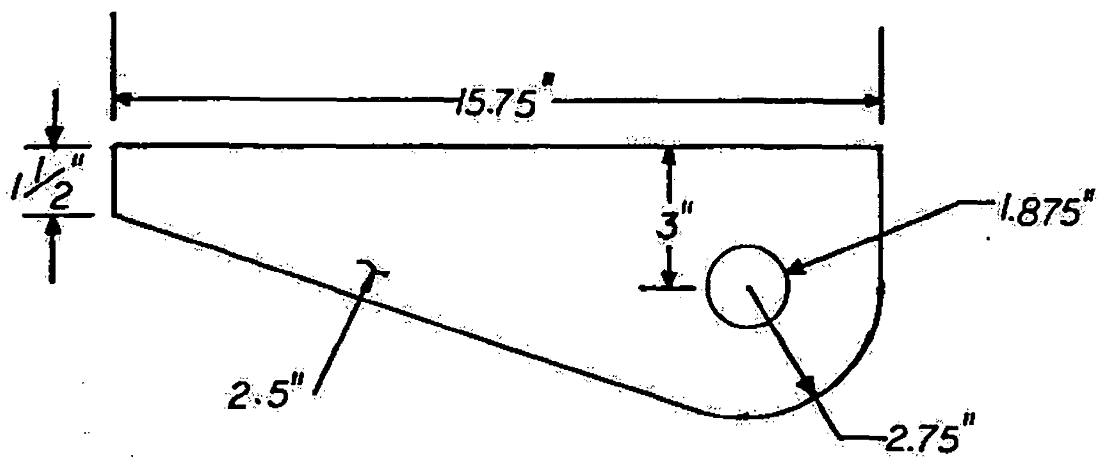


FIGURE – 2-4
TIE-DOWN LUG DETAIL

Tension Stress

Force, F = 410,125.38 lbs.

Horizontal component, $F_H = F\,(B_x^2 + B_z^2)^{1/2}\sin 12.27°$

$F_H = 410{,}125.38\,[(.4401)^2 + (.5014)^2]^{1/2}\sin 12.27°$

F_H = 58,148.41 lbs.

Vertical component, $F_V = (F^2 - F_H^2)^{1/2}$

$F_V = [(410{,}125.38)^2 - 58{,}148.41)^2]^{1/2} = 405{,}982.25$ lbs.

$$\sigma_{th} = F_H/A = \frac{58{,}148.41}{2.5(5.75 - 1.875)} = 6002.42 \text{ psi.}$$

$$\sigma_{tv} = Fv/A = \frac{405{,}982.25}{15.75 \times 2.5} = 10{,}310.66 \text{ psi}$$

$\sigma_t = \sigma_{th} + \sigma_{tv} = 16{,}313.08$ psi

Bending Stress

The bending moment about the center of the lug base is:

$$M = 405{,}982.25(3) - 58148.41\,(\frac{15.75}{2} - 2.75)$$

M = 919,936.15 in-lbs

$$\text{Section modulus, } S = bh^2/6 = \frac{2.5(15.75)^2}{6}$$

$S = 103.36 \text{ in}^3$

$\sigma_b = 919{,}936.15/103.36 = 8900.31$ psi

Direct stress is $\sigma_t + \sigma_b = 25{,}213.39$ psi

Shear Stress

Use v = 410,125.38 lbs (conservative)

Shear area, A_{ES} = 15.75(2.5) = 39.38 in^2

$\tau = V/A_{ES}$ = 410,125.38/39.38 = 10,414.56 psi

Stress Intensity, S.I. = $2\sqrt{\tau^2 + (\sigma/2)^2}$

S.I. = $2\sqrt{(10{,}414.56)^2 + (25{,}213.39/2)^2}$

S.I. = 32,704.24 psi

$$S.F. = \frac{100{,}000}{25{,}213.39} = 3.06$$

2.4.4.3 Stresses in the Welds

Length of weld, L_W = (15.75 x 2 + 2.5 x 2)

L_W = 36.5"

Width of weld, W_W = .707 x ¾ = .53"
Area of weld, A_W = 36.5 x .53 = 19.35 in^2

Conservatively assume the force acting on weld:

F = 410,125.38 lbs

$$\tau_W = \frac{410{,}125.38}{19.35} = 21{,}195.11 \text{ psi}$$

$$S.F. = \frac{57{,}700}{21{,}195.11} = 2.72$$

2.5 Standards for Type B and Larger Quantity Packaging

This section is not applicable.

2.6 Normal Condition of Transport

The package has been designed, constructed and the contents limited such that the performance requirements specified in 10CFR 71.71 will be met when the package is subjected to the normal condition of transport specified in 10CFR 71.71. The ability of the package to satisfactorily withstand the normal condition of transport has been assessed as described in the following paragraphs.

2.6.1 Heat

10CFR 71.71 (c) (1) specifies an ambient temperature of 100°F in still air, and insolation requirements as normal condition of transport. The pressure, shown in Table 3.1-1, and the thermal gradients corresponding to this case are small. The stresses resulting from internal pressure are very low in comparison to the allowable stresses summarized in Table 2-40. Therefore, this normal heat condition will not affect cask performance.

2.6.2 Cold

The materials of construction for the packaging, including the lead, carbon steel, overpack and seals are not significantly affected by an ambient temperature of -40°F.

The cask must be able to resist brittle fracture failure under normal conditions of transport and hypothetical conditions at temperatures as low as -20°F per NRC Regulatory Guide 7.8. Fracture-critical parts of the cask include the 2-inch thick outer shell, the 3-inch and 2½-inch plates in the lids and bottom end plate, the 1 1/8-inch thick steel inner shell and welds jointing these components. Note that according to NUREG/CR-1875, the bolts are not fracture-critical because they are part of a redundant system.

These critical components are shown in Figure 2-9. For compliance with Category II, fracture toughness requirements of NUREG/CR-1875, the nil ductility transition temperature (TNDT) of this steel must be less than the value determined by the equation:

$$T_{NDT} = L_{ST} - A$$

Where L_{ST} = Lowest service temperature (= - 20°F)

A = Value from Figure 2-9A
(from NUREG/CR 1815)

Table 2-5A tabulates the T_{NDT} required for critical components.

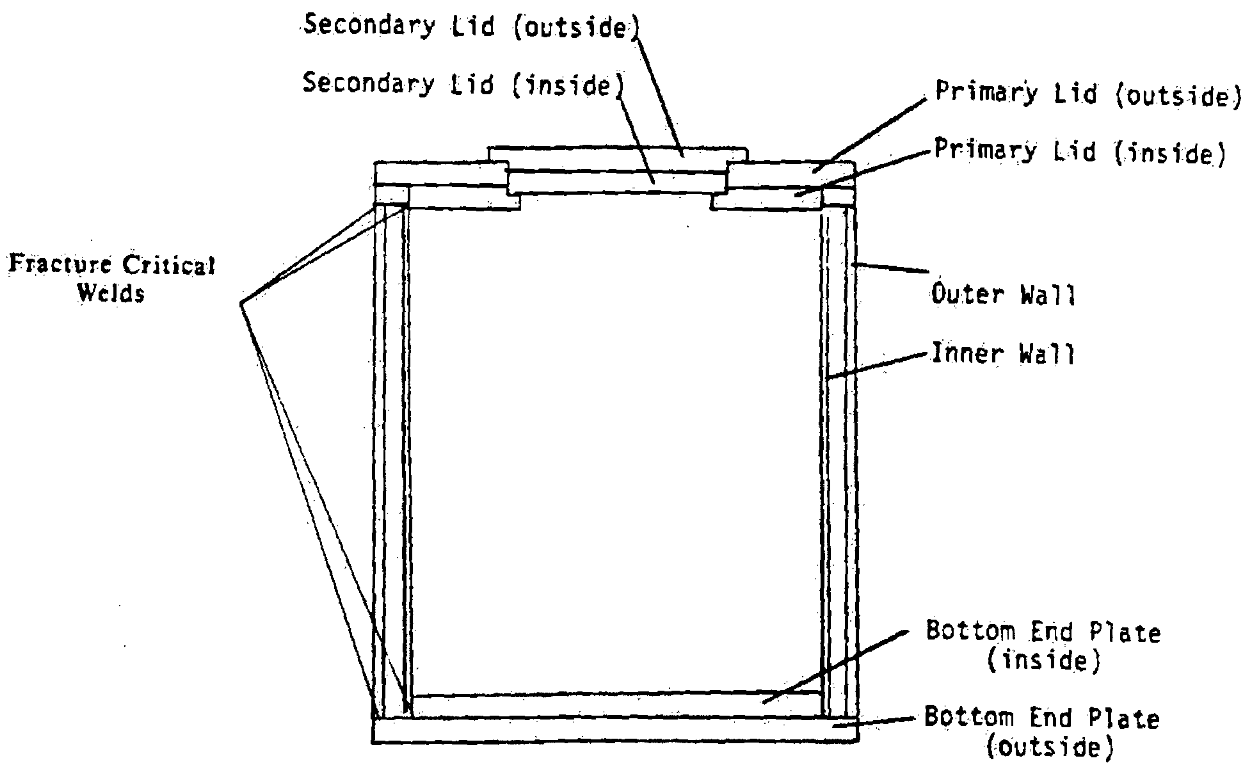


Figure 2-9

Fracture Critical Components

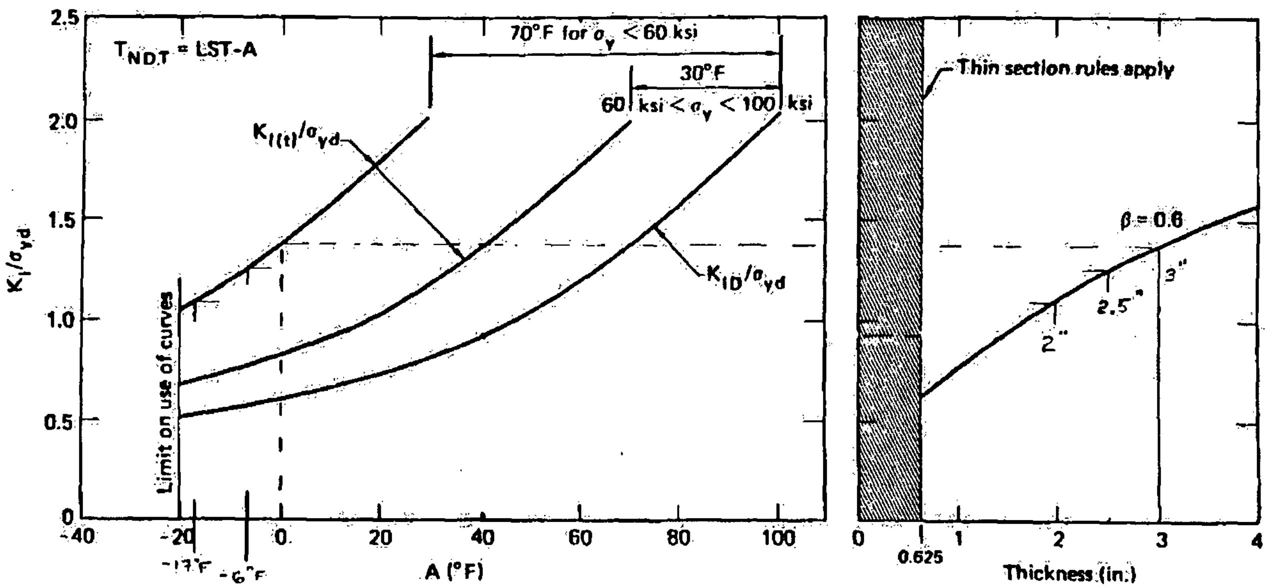


Figure 2-9A

Design Chart for Category 11 Fracture Critical mponentsCo

TABLE 2-5A

NIL DUCTILITY TEMPERATURE REQUIREMENTS FOR FRACTURE CRITICAL COMPONENTS OF THE 10-160B CASK

Component	Thickness (inches)	A(2)	TNDT req(3) (°F)
Bottom End Plate (outside)	2 1/2	-6	-14
Bottom End Plate (inside)	3	0	-20
Inner Wall	1 1/8	-20	0
Outer Wall	2	-17	-3
Primary Lid (inside)	3	0	-20
Primary Lid (outside)	2 1/2	-6	-14
Secondary Lid (inside)	3	0	-20
Secondary Lid (outside)	2 1/2	-6	-14
Welds Joining bottom end plates and the upper ring to the shells.	2	-17	-3

Notes:

1) Material number from drawing
2) Calculated according to Figure 2-9A
3) T_{NDT} determined according to ASTM Standard E208-81

2.6.3 **Pressure**

10CFR 71.71 (c)(3) and (4) require a reduced external and external pressure cases as to be evaluated as a normal condition of transport. The reduced external pressure of 3.5 psi absolute and the maximum internal pressure of 8.4 psig (see Section 3.4.4) under normal conditions results in a net pressure differential of, ΔP, = 8.4 + 14.7 – 3.5 = 19.6 psi.

Review of Tables A2-35 and A2-36, which provides cask stresses for internal pressure cases, shows that 19.6 psi would have no significant effect on the cask. The 20 psi external pressure will also have an insignificant effect on the cask (See Tables A2-39 and A2-40).

2.6.4 **Vibration**

The package is similar to many other proven casks with many years operational use in a transport environment. This experience demonstrates that vibration normally incident to transport will have an effect upon the package.

2.6.5 **Water Spray**

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

2.6.6 **Free Drop**

The gross package weight of 72,000 pounds establishes the normal handling condition drop height to be one foot. The package must survive a one-foot free fall onto a flat, unyielding surface without reducing its effectiveness in withstanding subsequent accident conditions. Using techniques described in Appendix 2.10.1, the maximum accelerations experienced by the package for a one-foot drop have been calculated to be:

Condition	Acceleration (G's)
End	54.3
Side	29.0
Corner	9.4

A portion of the CASKDROP computer output for these cases are shown in Figures 2-10 and 2-12. The stresses resulting from these loads have been found as a percentage of those calculated for the 30-foot drop conditions based on the ratios of peak accelerations. These stresses are summarized in the following sections.

```
05-22-1985 13:12:27
C A S K   G E O M E T R Y
   End Drop Analysis
Cask:SOROWT   SOR OVERWEIGHT                                    G= 386.4  in/sec^2>>>>>>>>>> Package          uses correction factor table:standard
Weight               (lb) W       72000
Outer diamter        (in) POD     78.5
Length               (in) LC      88
Drop height          (ft) H       1
CG (cask btm)        (in) LCG     56.257
Moment of Inertia         ICG     0                    (LB SEC^2 INCHES)
Ovp materials: Top:    Bottom: FR6725H
Upper      Lower  (All values in inches)
Inner diameter  (in) OID                    47.5       47.5
Outer diameter  (in) OOD                    102.001    102.001
Inner thickness (in) LI                     21.012     21.012
Outer thickness (in) LO                     44.01      44.01
05-22-1985 13:12:28
C A S K   D R O P   R E S U L T S
   End Drop Analysis
METHOD  2
Cask:SOROWT   SOR OVERWEIGHT       Overpack:FR6725H  lower
   ============iteration   Time      Deflection  Acc      Force      E(abs)
Projection           3     .008         0.4     -54.3   2517598.     909386.
Overpack             0     .000         0.0      0.0    1467462.          0.
Correction factors
 1 : 1    2 : 1    3 : 1    4 : 1    5 : 1    6 : 1    7 : 1    8 : 1    9 : 1    10 : 1    11 : 1    12 : 1    13 : 1    14 : 1    15 : 1
```

Figure 2-10

1-Foot End Drop CASKDROP

```
05-22-1985 13:19:58
C A S K   G E O M E T R Y
   Side Drop Analysis
Cask:50ROVT   50R OVERWEIGHT                                  G= 386.4  in/sec^2>>>>>>>>> Package          uses correction factor table:standard
Weight              (lb) W      72000
Outer diamter       (in) POD    78.5
Length              (in) LC     88
Drop height         (ft) H      1
CG (cask btm)       (in) LCG    44
Moment of Inertia        ICG    0                (LB SEC^2 INCHES)
Ovp materials: Top: FR6725H   Bottom: FR6725H
Upper     Lower  (All values in inches)
Inner diameter  (in) OID                  47.5      47.5
Outer diameter  (in) OOD                  102.001   102.001
Inner thickness (in) LI                   21.012    21.012
Outer thickness (in) LO                   44.01     44.01
05-22-1985 13:19:59
C A S K   D R O P   R E S U L T S
   Side Drop Analysis
METHOD  2
C--k:50ROVT   50R OVERWEIGHT      Overpacks:FR6725H  & FR6725H

        Iteration     Time   Deflection   Acc      Force      E(abs)
 Top        9       0.0155    0.9822     -29.0    1081765.    470072.
 Bottom                       0.9822     -29.0    1081765.    470072.
 Combined                                -29.0    2163530.    940143.
Correction factors
 1 : 1   2 : 1   3 : 1   4 : 1   5 : 1   6 : 1   7 : 1   8 : 1   9 : 1   10 : 1   11 : 1   12 : 1   13 : 1   14 : 1   15 : 1
```

Figure 2-11

1-Foot Side Drop CASKDROP Print-out

```
05-22-1985 13:17:44
C A S K   G E O M E T R Y
 Corner Drop Analysis
Cask:SOROUT   SOR OVERWEIGHT                              G= 386.4  in/sec^2>>>>>>>>>> Package          uses correction factor table:standard
Weight                 (lb) W     72000
Outer diameter         (in) POD   78.5
Length                 (in) LC    88
Drop height            (ft) H     1
CG (cask btm)          (in) LCG   56.257
Moment of inertia           ICG   0                (LB SEC^2 INCHES)
Ovp materials: Top: FR6725    Bottom: fr6725h
Upper      Lower  (All values in inches)
Inner diameter  (in) OID                  47.5      47.5
Outer diameter  (in) OOD                  102.001   102.001
Inner thickness (in) LI                   21.012    21.012
Outer thickness (in) LO                   44.01     44.01
Press space bar to proceed05-22-1985 13:17:45
C A S K   D R O P   R E S U L T S
 Corner Drop Analysis
METHOD  2
Cask:SOROUT   SOR OVERWEIGHT      Overpack:fr6725h
       =============
  ALPHA:  33.42634
             Iteration   Time     Deflection  Acc      Force      E(abs)
 BOTTOM DOWN       20    0.0700    4.7770     -9.4     747115.    1227023.
Correction factors
 1 : 1    2 : 1    3 : 1    4 : 1    5 : 1    6 : 1    7 : 1    8 : 1    9 : 1    10 : 1    11 : 1    12 : 1    13 : 1    14 : 1    15 : 1
```

Figure 2-12
1-Foot Corner Drop CASKDROP Print-out

2.6.6.1 End Drop

The ratio of stresses for the one foot drop compared to the thirty-foot drop is 54.3/175.6 = 0.3092. Maximum stress intensities are summarized in Table 2-6. Stress intensities throughout the package are well below allowables. The maximum stress intensity, 9,433 psi, occurs in the inner shell at the section shown in Figure A2-40. The results in a minimum factor of safety of:

$$S.F. = \frac{35{,}000}{9{,}433} = 3.71$$

2.6.6.2 Side Drop

The ratio of stresses for the one-foot drop compared to the thirty-foot drop is 29./120.6 = 0.2405. Maximum stress intensities are summarized in Table 2-7. Stress intensities throughout the cask remain well below allowables during the side drop. The highest stress intensity is 13,618 psi in the inner shell at the section shown in Figure A2-41. The minimum factor of safety is then:

$$S.F. = \frac{23{,}300}{13{,}618} = 1.71$$

2.6.6.3 Corner Drop

The ratio of stresses for the one foot compared to the thirty-foot drop is 9.4/71.13 = 0.1322. Maximum stress intensities are summarized in Table 2-8. Stress intensities are well below allowables throughout the cask. The highest stress intensity, 7,435 psi occurs in the inner shell at the section shown in Figure A2-43. The corresponding minimum safety factor is:

$$S.F. = \frac{23{,}300}{7{,}435} = 3.13$$

2.6.7 (Successive) Corner Drop

Not applicable since this is not a wooden package.

Table 2-6
Maximum Stress Intensities in Cask Components
Hypothetical Accident – 1-Ft End Drop[1]

Cask Component	Stress Classification	S.I.[2] (PSI)	Allowable (PSI)	Safety Factor
Baseplate	Membrane	269.82	23,300	86.4
	Membrane Plus Bending	5,142.04	35,000	6.81
Outer Shell	Membrane	4,142.86	23,300	5.62
	Membrane Plus Bending	9,427.74	35,000	3.71
Inner Shell	Membrane	6,431.72	23,300	3.62
	Membrane Plus Bending	9,433.3	35,000	3.71
Bolting Ring	Membrane	4,051.69	23,300	5.75
	Membrane Plus Bending	4,380.27	35,000	7.99
Primary Lid	Membrane	2,006.49	23,300	11.61
	Membrane Plus Bending	6,798.35	35,000	5.15
Secondary Lid	Membrane	81.56	23,300	286.0
	Membrane Plus Bending	7,764.57	35,000	4.51

[1] See Table 2-1 for accident condition load combination
[2] See Table A2-23 for the load combination per Regulatory Guide 7.8.

Table 2-7
Maximum Stress Intensities in Cask Components
Hypothetical Accident – 1-Ft Side Drop[1]

Cask Component	Stress Classification	S.I.[2] (PSI)	Allowable (PSI)	Safety Factor
Baseplate	Membrane	3,422	23,300	6.81
	Membrane Plus Bending	8,614.94	35,000	4.06
Outer Shell	Membrane	10,244.61	23,300	2.27
	Membrane Plus Bending	14,625.95	35,000	2.39
Inner Shell	Membrane	13,618.43	23,300	1.71
	Membrane Plus Bending	18,343.48	35,000	1.91
Bolting Ring	Membrane	12,311.74	23,300	1.89
	Membrane Plus Bending	13,408.91	35,000	2.61
Primary Lid	Membrane	3,480.92	23,300	6.69
	Membrane Plus Bending	9,166.15	35,000	3.82
Secondary Lid	Membrane	3,332.02	23,300	6.99
	Membrane Plus Bending	9,422.1	35,000	3.71

[1] See Table 2-1 for accident condition load combination
[2] See Table A2-25 for the load combination per Regulatory Guide 7.8.

Table 2-8
Maximum Stress Intensities in Cask Components
Hypothetical Accident – 1-Ft Corner Drop[1]

Cask Component	Stress Classification	S.I.[2] (PSI)	Allowable (PSI)	Safety Factor
Baseplate	Membrane	1,489.03	23,300	15.65
	Membrane Plus Bending	3,306.04	35,000	10.59
Outer Shell	Membrane	4,191.65	23,300	5.65
	Membrane Plus Bending	7,561.5	35,000	4.63
Inner Shell	Membrane	7,434.98	23,300	3.13
	Membrane Plus Bending	8,952.06	35,000	3.91
Bolting Ring	Membrane	4,278.36	23,300	5.45
	Membrane Plus Bending	5,507.76	35,000	6.35
Primary Lid	Membrane	3,422.5	23,300	6.81
	Membrane Plus Bending	5,025.03	35,000	6.97
Secondary Lid	Membrane	1,472.72	23,300	15.82
	Membrane Plus Bending	3,165.2	35,000	11.06

[1] See Table 2-1 for accident condition load combination
[2] See Table A2-27 for the load combination per Regulatory Guide 7.8.

2.6.8 Penetration

Impact energies resulting from a 13-pound rod dropping from a height of 40 inches will have no significant effect on the package. The impact limiter fully protects both ends of the cask leaving only the central body exposed. The cask body is manufactured from 2-inch thick steel plate and backed with 1 7/8 inches of lead. The ends are 5 ½ inches of thick steel. No valves, valve covers or fragile protrusions exist.

2.7 Hypothetical Accident Conditions

The package has been designed and the contents limited such that the performance requirements specified in 10 CFR 71.51 will be met if the package is subjected to the hypothetical accident conditions specified in Section 71.73 of 10 CFR 71.

To demonstrate the structural integrity of the cask and its ability to withstand accident conditions, a set of comprehensive loading, stress and deflection analyses have been made addressing each of the specified accident conditions. For the thirty-foot drop analyses, loads were derived by computing energy absorption of the foam impact limiters and the distribution of stresses over the outer cask surface due to the impact limiters. For the fire accident conditions, temperatures through the cask walls were computed using a one-dimensional ANSYS thermal finite element model. Transient analysis over a period of 90 minutes was performed to evaluate the temperature gradient and average temperature of the cask walls (see section 3.5 for details of the analysis). A conservative estimate of temperature distribution in the entire cask was established based upon the results of this analysis. These temperatures were used in hand calculations in order to find stresses in the cask. Descriptions of these calculations are contained in Appendix 2.10.1.

2.7.1 Free Drop

Section 71.73 of 10 CFR 71 requires that the package survive a thirty-foot drop onto a flat unyielding surface. Analytical methods were used to demonstrate the capability to withstand the effects of this accident. These analytical techniques are described in Appendix Section 2.10.1.

As described in Section 1.2, the package features cylindrical energy absorbing impact limiters surrounding each end of the cask body. These impact limiters are designed to minimize damage to the cask body from thirty-foot drops at any orientation onto an unyielding surface. The analyses described in this section demonstrate that these impact limiters function as designed; the cask body experiences no damage and incurs no stresses in excess of allowable levels. This behavior, under thirty-foot drop conditions, assures the complete effectiveness of the cask closure features essential for preservation of packager containment integrity.

Using the methods described in Appendix 2.10.1.1, three drop conditions for the package have been evaluated, i.e. end, side and corner. Analytical values of stress and deflection are combined with appropriate values due to temperature and pressure. These combined results are then compared with applicable criteria to demonstrate compliance of the package with the requirements for the hypothetical accident conditions.

2.7.1.1 Free Drop Impact – End Drop

The end drop produces the largest deceleration forces in the package of all the potential drop orientations. This produces the worst case loading for lead slump or deformation (see Sections 5.4.3).

For a thirty-foot end impact drop, deformation of the impact limiters amounted to 5.7 inches. This prediction employed the end drop analysis described in Appendix 2.10.1.1 and the energy absorbing foam properties of Figure 2-1. In order to predict maximum deflection, the curve of stress vs. strain for the lower bound was used and only the regions of the impact limiter that are directly backed by the cask are considered effective. Results of the analysis are shown in Table 2-9. A second analysis, using the upper bound of foam stiffness, and all regions of the impact limiter was used to predict the maximum bounding deceleration experienced by the cask upon impact. This maximum deceleration was found to be 176 G's. The results of this analysis are shown in Table 2-10.

Detailed cask stress calculations were made using the cask finite element model discussed in Section 2.10.1. The constraints and loads placed on the cask for the end drop analysis are shown in Appendix 2.10.2 with the resulting reaction forces to show moment and force equilibrium. The stresses associated with an end impact deceleration of 175.6 G's were combined with maximum normal temperature and pressure stresses as outlined in NRC Regulatory Guide 7.8. Maximum stress intensities are summarized in Table 2-11.

```
FILE: END17C   OUT  4-17-85   8:47a                    PRINTS VERSION: 12-28-84   9:14a                PAGE NO.   1
-------------------------------------------------------------------------------------------------------------------------

04-17-1985 08:46:57
C A S K   G E O M E T R Y
  End Drop Analysis
Cask:5ORONT   50r cask over wt                         G= 386.4  in/sec^2))))))))) Package        uses correction factor tabl
Weight              (lb) W      72000
Outer diamter       (in) POD    78
Length              (in) LC     88
Drop height         (ft) H      30
CG (cask btm)       (in) LCG    100
Moment of Inertia        ICG    0                 (LB SEC^2 INCHES)
Ovp materials: Top:   Bottom: fr6725s
Upper     Lower  (All values in inches)
Inner diameter  (in) DID              47.5      47.5
Outer diameter  (in) DOD              102.001   102.001
Inner thickness (in) LI               21.012    21.012
Outer thickness (in) LO               44.01     44.01
04-17-1985 08:46:58
C A S K   D R O P   R E S U L T S
  End Drop Analysis
METHOD  1
Cask:5ORONT   50r cask over wt    Overpack:fr6725s  lower
   ============Iteration   Time     Deflection  Acc      Force      E(abs)
Projection          28      .020       5.7    -78.3   5711553.   26343602.
Overpack             0      .000       0.0      0.0         0.          0.
Correction factors
 1 : 0    2 : 0    3 : 1    4 : 1    5 : 0    6 : 1    7 : 0    8 : 0    9 : 1    10 : 1    11 : 0    12 : 1    13 : 0
```

Table 2-9
Caskdrop Program Output for End Drop (Soft Foam)

```
FILE: EWC17B   OUT  4-17-85   8:45a                    PRINTS VERSION: 12-28-84   9:14a                    PAGE NO.    1
------------------------------------------------------------------------------------------------------------------------

04-17-1985 08:45:43
C A S K   G E O M E T R Y
   End Drop Analysis
Cask:50RDWT   50r cask over wt                        G= 386.4  in/sec^2>>>>>>>>> Package          uses correction factor tabl
Weight              (lb) W      72000
Outer diamter       (in) POD    78
Length              (in) LC     88
Drop height         (ft) H      30
CG (cask btm)       (in) LCG    100
Moment of Inertia        ICG    0                    (LB SEC^2 INCHES)
Ovp materials: Top:   Bottom: fr6725h
Upper      Lower  (All values in inches)
Inner diameter  (in) DIB                47.5      47.5
Outer diameter  (in) DOD                102.001   102.001
Inner thickness (in) LI                 21.012    21.012
Outer thickness (in) LO                 44.01     44.01
04-17-1985 08:45:44
C A S K   D R O P   R E S U L T S
   End Drop Analysis
METHOD  2
Cask:50RDWT   50r cask over wt     Overpack:fr6725h  lower
   ============Iteration   Time      Deflection  Acc      Force      E(abs)
Projection            15     .010          3.0   1-175.7   6305201.   26146930.
Overpack               0     .000          0.0      0.0  6414935.          0.
Correction factors
 1 : 1    2 : 1    3 : 1    4 : 1    5 : 1    6 : 1    7 : 1    8 : 1    9 : 1    10 : 1    11 : 1    12 : 1    13 : 1
```

Table 2-10

Caskdrop Program Output for End Drop (Hard Foam)

Corner Drop Secondary Lid Bolt Forces

The load required to hold the secondary lid in place was computed using the ANSYS stress analysis model. The forces on the bolts were computed in the axial (tensile), radial (shear), and tangential (shear) directions. The lids and bolts are designed so that radial "compressive" forces are reacted by bearing between the primary lid and the cask body and between the secondary lid and the primary lid. Because of this, only radial "tensile" forces are used in computing bolt stresses. Radial "compressive" forces are those that tend to drive the bolted parts together in the radial directions, while radial "tensile" forces are those which tend to separate the parts in the radial direction. The resulting stress intensities (for 1 ¾" Bolts), as a function of angular position of the bolts, are shown in Table 2-21(a) for the secondary bolts. The angular position is measured around the circumference of the cask with zero degree corresponding to the vertical downward direction. The highest stress intensity was found to be 113,204 psi, and the corresponding safety factor, based on yield is:

$$S.F. = \frac{130,000}{113,204} = 1.15$$

Corner Drop Primary Lid Bolt Forces

The loads required to hold the primary lid in place under the corner drop conditions were obtained from the results of ANSYS finite element model. The forces on the bolts were computed in the axial (tensile), radial (shear) and tangential (shear) directions. The resulting stress intensities (for 1 ¾" 8UN bolts), as a function of angular position of the bolts are shown in Table 2-21(b) for the primary lid bolts. The angular position is measured around the circumference of the cask with zero degree corresponding to the vertical downward direction. The highest stress intensity was found to be 81,461 psi and the corresponding safety factor, based on yield, is:

$$S.F. = \frac{130,000}{81,461} = 1.60$$

2.7.1.4 Oblique Drop

An analysis of similar dimensioned packages (Ref. 10) indicates that for a package with the diameter approximately equal to its length, there is no slapdown effect. That is, the impact is not more severe than a side drop.

Table 2-21(a)

10-160B Cask – Corner Drop Analysis
Secondary-Lid Bolt Loading

Location[5] (Degrees)	FEM Node No	FX[1] (lbs.)	FY[1] (lbs)	FZ[1] (lbs)	Axial (lbs.)	Shear (lbs)	S.I.[4] (psi)
0	114	92,079[2]	-[3]	-28,086	28,086	-[2]	13,508
30	116	33,055[2]	-12,767	-34,910	34,910	35,435	37,996
60	118	-56,361	29,781	-31,004	31,004	63,745	63,103
90	120	-98,594	63,468	-20,136	20,136	117,256	113,204
120	122	-99,751	68,728	-24,959	24,959	121,135	117,137
150	124	-79,318	44,284	-33,064	33,064	91,107	89,067
180	126	67,905[2]	-[3]	-36,539	36,539	67,905	67,641

NOTES: (1) FX is force on the node in radial, FY in tangential and FZ in axial directions.

(2) The 'compressive' loads in radial and axial directions do not go through the bolts. See section 2.6.6.2.

(2) Tangential loads at the plane of symmetry do not go through the bolts.

(3) For 1 ¾" – 8UN bolts (stress area 2.0792 in^2).

Table 2-21(b)

10-160B Cask – Corner Drop Analysis
Primary-Lid Bolt Loading

Location[5] (Degrees)	FEM Node No.	FX[1] (lbs.)	FY[1] (lbs.)	FZ[1] (lbs.)	Axial (lbs.)	Shear (lbs.)	S.I[4] (psi)
0	433	-6,241	-[3]	29,430	-[2]	6,241	6,003
30	438	-11,909	15,505	53,840	-[2]	19,551	18,798
60	443	-32,424	78,213	51,263	-[2]	84,687	81,461
90	464	-16,427	63,464	6,410	-[2]	65,556	63,059
120	222	9,953	79,753	-50,820	50,820	80,372	81,082
150	224	18,205	43,416	-56,574	56,574	47,078	52,830
180	226	3,645	-[3]	-56,569	56,569	3,645	27,432

NOTES: (1) FX is force on the node in radial, FY in tangential and FZ in axial directions.

(2) The 'compressive' loads in radial and axial directions do not go through the bolts. See section 2.6.6.2.

(3) Tangential loads at the plane of symmetry do not go through the bolts.

(4) For 1¾" – 8UN bolts (stress area 2.0792 in^2).

2.7.1.5 Impact Limiter Attachment Forces

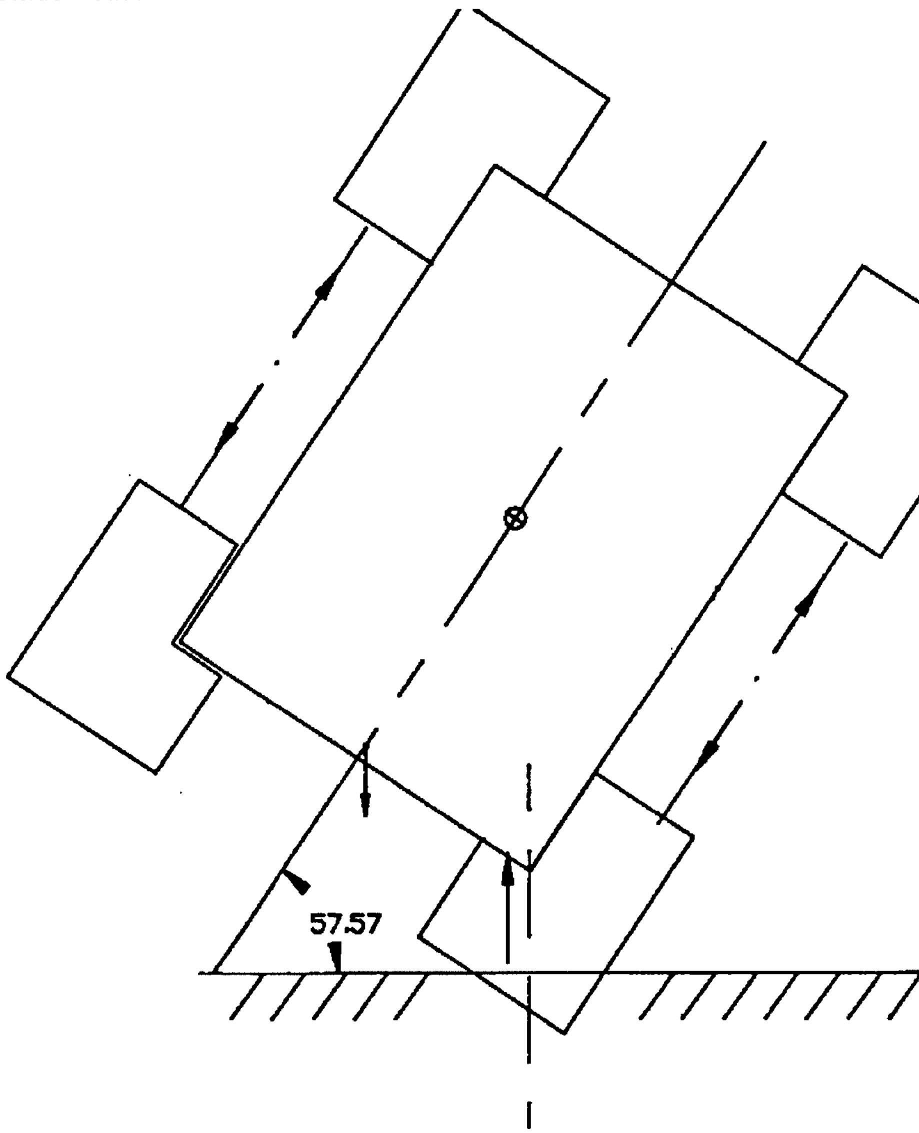
The purpose of this section is to demonstrate that during an oblique 30-foot drop, the impact limiter will remain attached to the cask body.

For most oblique angle orientations and crush depths, the impact limiter reaction is transmitted to the cask body in direct compression. Therefore, the forces transmitted to the impact limiter ratchet binders are near zero. This is not true for near vertical (90°) and near horizontal (0°) orientations of the package, at modest crush deformations and crush forces. In these very limited situations, the center of pressure of the crush force lies beyond the outer extremities of the cask

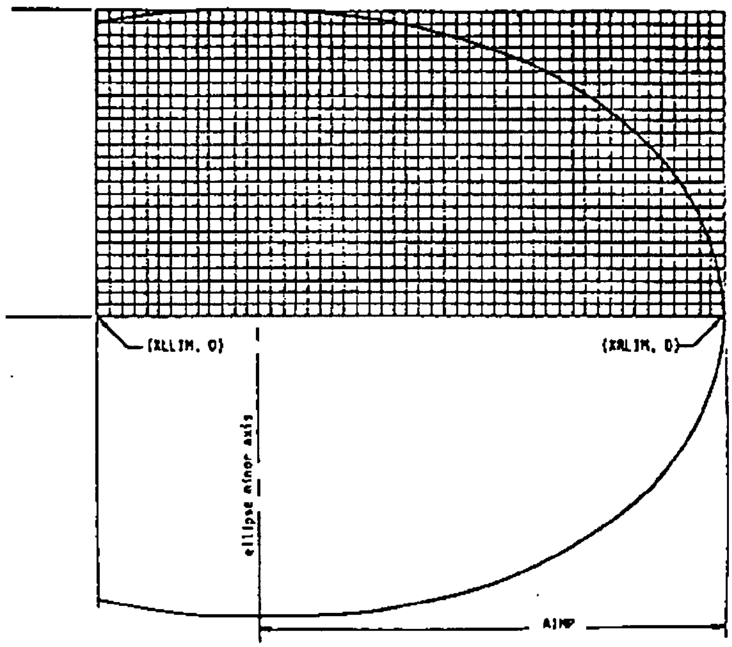
body and loads the impact limiter ratchet binders. These ratchet binders loads exist only for modest crush deformations and crush forces. At maximum crush depth and maximum crush force, for all angles of orientations, there are no loads acting on the ratchet binders because the impact limiter interface forces are all direct compression.

There are 3 cases to consider for the oblique drop. The first case covers a range of angles between 0° (side drop) and 13° with respect to the horizontal. This range of angles is small enough to cause the cask to fall on its side without bouncing. The ratchet binders will not be affected in this case sine the acting load is minimal for this drop condition. The second case will be discussed and illustrated after case 3. The third case covers a range of angles between 61° and 90° (end drop). The 10-160B has a length to diameter (aspect) ratio equal to 1.13. This shape will have the tendency to tip and lands the cask on its base (end). No bouncing will occur for this case, since the cask will tip on its end. The impact limiter will remain attached to the cask body. Case two covers the largest range of angles (from 13° to 61°). In this situation, the center of pressure of the crush force can lie within the outer extremities of the cask body. The corner drop (C.G. over struck corner) is in this case 2 range of angles and is to demonstrate how the forces and moments will reactor on the cask.

The free body diagram of the impact limiter under the corner drop loading conditions is show in the following sketch. Since the impact limiter is more flexible than the cask body, a separation between the cask body and the impact limiter as shown in the sketch can load the ratchet binder on the opposite side of the impact in tension. For a conservative estimate of this tensile load, it can be assumed that the parallax between the line of action of the impact limiter reaction force and the impact limiter inertia force will cause a moment which will be resisted by the ratchet binder load.



For a 30-foot corner-over-C.G. drop, a maximum deceleration of 71.13 g's is obtained (see Attachment 1).



The foot print area of the impact limiter crush plane as shown below. The line of action of the reaction force is close to the centeroid of this foot print area, but for conservativeness, assume that the line of action passes through the lower corner of the cask. The C.G. of the impact limiter is 21.2576" above its base, but again for conservativeness assume that this distance is 21".

Impact limiter inertia force = 4,200 x 71.13
= 298,746 lbs.

Moment arm = 39.25 x Sin 56.57° (see sketch)
= 32.76 inch

Moment due to I/L inertia force about the I/L reaction point,

M = 298,746 x 32.76
= 9.77×10^6 in-lb.

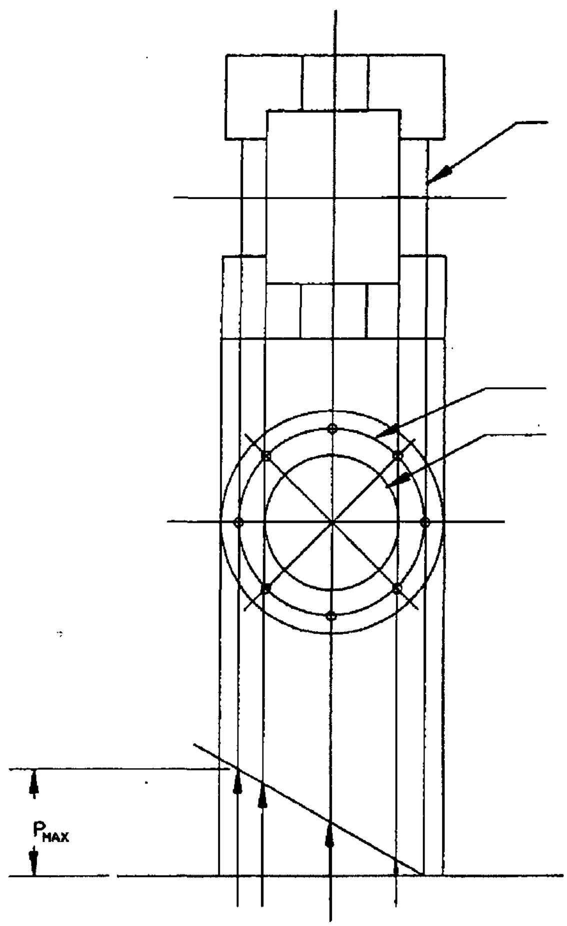
This moment will be resisted by the ratchet binder load and the cask shell-impact limiter interface load. Since the moment arising due to cask shell impact limiter load helps reduce the ratchet binder load, it has been neglected.

Referring to the sketch, the moment resisted by the impact limiter attachments (ratchet binders) is:

$$M = \sum_{i=1}^{8} P_i \times d_i$$

Where,

M	=	Resisted Movement	
P_i	=	Axial load in i-th ratchet-binder	
	=	$P_{max} \times \sin(\theta_i/2)$	
θ_i	=	Angular location if i-th ratchet binder from pivot point	
d_I	=	Distance of the i-th ratchet binder from pivot point	
	=	$R \times (1-\cos\theta_i)$	
R	=	Ratchet binder circle radius =	42 inches



RATCHET BINDER LOAD

DISTRIBUTION

Thus,

$$
\begin{aligned}
M &= 2 \times P_{max} \times R\ [\sin 22.5° \times (1\text{-}\cos 45°) + \text{Sin } 45° \times (1\text{-}\cos 90°) \\
&+ \text{Sin } 67.5° \times (1\text{-}\cos 135°) + 0.5 \times \text{Sin } 90° \times (1\text{-}\cos 180°)] \\
&= 285.3P_{max}
\end{aligned}
$$

Therefore,

$$P_{max} = 9.77 \times 10^6/285.3 = 34{,}245 \text{ lbs.}$$

The ratchet binders used in the 10-160B cask have 1" diameter shank (See Figure 1.1 and 1.2). The load carrying capacity of these ratchet binders is 45,000 lbs (per manufacturer's catalog). Thus, a factor of safety of 45,000/34,245 = 1.31 exists. The quick release pins attaching the ratchet binders to the impact limiter lugs have a 7/8" diameter (0.6013 in^2 cross-section area) and are made of 17.4 PH steel (S_y = 160,000 ksi). The average shear stress in the pin will be 34,245/(2 x 0.6013) = 28,476 psi giving a large factor of safety against the pin shear. The average shear in the attachment lug (made of SA 516 Gr 70 steel) will be 34,245/[2 x 0.5 x (2 – 15/32)] = 22,364 psi. The allowable shear stress is 0.42 S_u = 0.42 x 70,000 = 29,400 psi, giving a factor of safety of 29,400/22,364 = 1.31. It should be noted that these calculations have been performed with the most conservative assumptions and are applicable to the most stressed ratchet binder. The other ratchet binders experience a much smaller loading, and hence, have a larger factor of safety. It can, therefore, be concluded that under the corner drop loading conditions, the impact limiters will remain attached to the cask.

2.7.1.6 Thermal-Shield Attachment Evaluation

The thermal-shield is attached to the secondary lid lifting lugs by three hitch pins. These pins have 7/8" diameter and are made of ASTM A-276 Gr. 304 stainless steel. In this section an evaluation is performed to show that the pins will provide enough strength to support the inertia of the thermal-shield during all the postulated hypothetical free drop tests.

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

Mass of Item #1	$= 0.28 \times \pi/4 \times 46^2 \times 0.25$	= 116 lb
Mass of Item #2	$= 0.28 \times \pi/4 \times 46^2 \times 0.12$	= 56 lb
Mass of Item #3	$= 7 \times 0.28 \times 5.58 \times 1.75$	= 17 lb
Misc (10% of above)		= 19 lb
Total		= 208 lb => Use 250 lb

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

$$A = 3\times 2\times(\pi/4)\times 0.875^2 = 3.608 \text{ in}^2$$

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

$$V = 3.608\times 45{,}000 = 162{,}360 \text{ lb}$$

Deceleration acceptable = 162,360/250 = 649 g's

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

2.7.2 Puncture

10 CFR 71.73 c (2) requires package free fall 40 inches onto a 6" diameter mild steel bar without significant damage. The most critical regions are the sides of the cask and the ends of the cask.

2.7.2.1 Sides

Steel-lead casks dropped onto their sides were studied by Nelms (Structural Analysis of Shipping Casks, Vol. 3 Effects of Jacket Physical Properties and Curvature on Puncture Resistance, June 1968).

The equation developed empirically by Nelms is:

$$t_{req} = (W/S_u)\ 0.71$$

Where t = outer shell thickness required

W = weight of the cask (lbs)

S_u = tensile strength of the outer shell

For the 10-160B cask

t = 2"
W = 72,000 lbs
S_u = 70,000 psi

$$t_{req} = \left(\frac{72{,}000}{70{,}000}\right) .71 = 1.02 \text{ in}$$

The outer shell thickness of this cask is 2" which is sufficient to satisfy the Nelms express.

In addition to the empirical Nelms equation the stresses resulting from the drop are estimated as follows:

The maximum load a 6" diameter mild steel bar can exert on the package is

$$F_{max} = Ak_s$$
$$K_s = \text{plastic flow stress of mild steel (45000 psi assumed)}$$
$$A = \text{area of steel bar}$$
$$F_{max} = 45000 \frac{(6)^2}{4} = 1.26 \times 10^6 \text{ lbs}$$

The static G load is $\frac{1.26 \times 10^6}{72{,}000} = 17.67$ G's

The maximum bending moment in the cask, assuming the cask acts as a beam, is:

$$M = \frac{WL^2}{8}$$

$$W = \text{uniform load} = \frac{72{,}000\ (17.67)}{88} = 14{,}457 \text{ lb/in}$$

at 17.67 G's

$$M = \frac{14{,}457\ (88)^2}{8} = 13.99 \times 10^6 \text{ lb-in}$$

The section modulus of the outer shell of the cask is:

$$Z = \pi(R_o^{\ 4} - R_I^{\ 4})/4\ (R_o)$$
$$R_o = \text{outer radius (in)}$$
$$R_I = \text{inner radius (in)}$$

$$Z = \pi \frac{x(38.625^4 - 36.625^4)}{4x38.625} = 8{,}671 \text{ in}^3$$

$$S_{max} = \frac{13.99 \times 10^6}{8{,}671} = 1{,}613 \quad <48{,}000 \text{ psi}$$

2.7.2.2 Ends

The end plate and the lids of the cask have a total thickness of 5½ inches each, made-up of two plates: one of 3 inch thickness and the other of 2 ½ inch thickness. An analysis of these plates for a direct hit at the worst possible location is performed to show that the stresses in the plates are within the allowable values and the lids remain closed during the puncture accident. This is performed by idealizing the closure plates to circular plates of uniform thickness, loaded by a concentrated pressure over a circular area of 6-inch diameter. Closed-form solution from Reference 24 is used to estimate the displacement and the strain energy of the plates under this loading conditions. The largest bending moment, and hence the largest bending stress, in such a plate occurs if the loading is applied to the farthest distance from the support. Therefore, the analysis has been performed for the puncture bar hitting the secondary lid of the cask. The strike at the base plate and the primary lid is enveloped by the analysis presented herein. Since the two constitutive plates should have identical deflections, the total drop energy will be allocated to each plate in the ratio of their thicknesses.

Reference page 24 page 415 gives the following equation for the deflection of a centrally loaded circular plate:

$$\frac{y}{h} + A\left(\frac{y}{h}\right)^3 = B\,\frac{Pa^2}{Eh^4}$$

where,

	y	=	deflection at the center of the plate
	h	=	plate thickness
	P	=	central load
	E	=	Young's Modulus
	a	=	plate radius
	A	=	0.272 (simply supported plate, Ref. 24 page 416)
	B	=	0.552 (simply supported plate, Ref. 24 page 416)

Solving for P,

$$P = \frac{Eh^4}{Ba^2}\left[\frac{y}{h} + A\left(\frac{y}{h}\right)^3\right]$$

The strain energy can be estimated from

$$
\begin{aligned}
U &= \int_0^{\delta} P \quad dy \\
&= \int_o^{\delta} \frac{Eh^4}{Ba^2}\left[\frac{y}{h} + A\left(\frac{y}{h}\right)^3\right]dy \\
&= \frac{Eh^4}{Ba^2}\left[\frac{\delta^2}{2h} + \frac{A\delta^4}{4h^3}\right]
\end{aligned}
$$

The energy absorbed by the 3 inch thick plate, can be equated to the strain energy as follows:

$$
WHx\frac{3}{5.5} = \frac{Eh^4}{Ba^2}\left[\frac{\delta^2}{2h} + \frac{A\delta^4}{4h^3}\right]
$$

where,	W	=	weight of the cask, 72,000 lb_f
	H	=	drop height, 40 inches
	H	=	3 inches
	a	=	bolt circle radius, 36.8125 inch
	E	=	29×10^6 psi

Rearranging,

$$
\frac{A\delta^4}{4h^3} + \frac{\delta^2}{2h} = \frac{WH}{1.833}\,\frac{Ba^2}{Eh^4}
$$

$$
\delta^4 + \left(\frac{2h^2}{A}\right)\delta^2 - \frac{2.1818WHBa^2}{EhA} = 0
$$

$$
\delta^2 = \frac{-\left(\frac{2h^2}{A}\right) \pm \sqrt{\left(\frac{2h^2}{A}\right)^2 + \frac{4x2.1818WHBa^2}{Eha}}}{2}
$$

$$
\delta^2 = \frac{h^2}{A}\left[-1 \pm \sqrt{1 + \frac{2.1818WHBAa^2}{Eh^5}}\right]
$$

Then, δ = 1.6957 inch

Solving for the force required to produce this deflection,

P = $1.9292 \text{ X } 10^6$ lbs.

This will result in a pressure of $1.9292 \times 10^6 / (\pi \times 3^2) = 68{,}231$ psi over the area of cross section of the puncture bar.

Reference 24, page 415, gives the following equations for the maximum membrane and membrane-plus-bending stresses:

$\sigma_{membrane} = \alpha E \delta^2 / a^2$

α = 0.407 (Ref. 24 page 416)

$\sigma_{membrane}$ = 25,044 psi

Allowable membrane stress = 49,000 psi

Factor of safety = 49,000 / 25,044 = 1.96

$\sigma_{membrane+bending} = \beta E \delta h / a^2$

β = 0.606 (Ref. 24 page 416)

$\sigma_{membrane+bending}$ = 65,971 psi

The largest membrane-plus-bending stress in the base plate, the primary lid or the secondary lid during the increased external pressure is 750 psi (see Table A2-34) and during the minimum external pressure is 927 psi (see Table A2-36). Therefore, membrane-plus-bending stress in the end-plates due to combined conditions are:

Puncture + Increased External Pressure = 65,971 + 750
= 66,721 psi

Puncture + Minimum External Pressure = 65,971 + 927
= 66,898 psi

Allowable membrane + bending stress = 70,000 psi

Factor of Safety = 70,000 / 66,898 = 1.05

To obtain the bolt loads due to the puncture accident, a simple 2-dimensional model of the primary and secondary lids was made using ANSYS finite element program. The lids were modeled using axisymmetric isoparametric solid elements and the bolts were modeled using two dimensional beam elements having appropriate area and the moment of inertia. The interfaces between the bolting ring and the primary lid, between the secondary lid and the primary lid and between the plates themselves were modeled using the 2-dimensional interface elements. The results of the analysis for a 68,231 psi loading at the contact area of the puncture bar showed that

due to the puncture accident, the secondary lid transferred the load to the primary lid by the contact

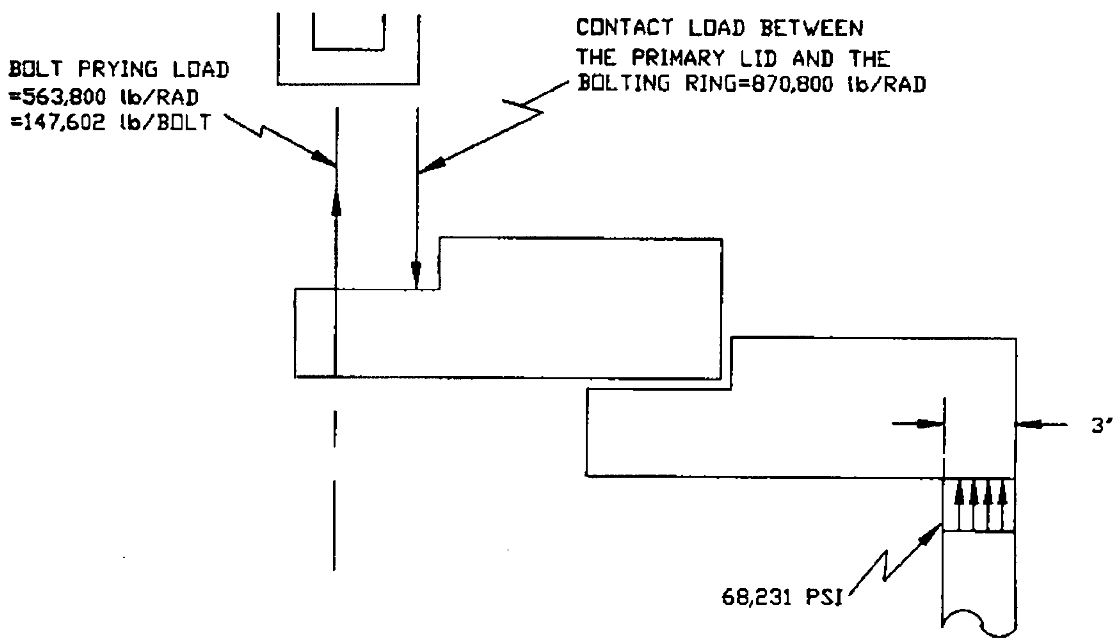


Figure 2-18.1

Load Distribution During the Puncture Accident

Pressure and not through the bolting. However, the primary lid transferred the load to the bolting ring by a prying action, resulting in a bolt load of 147,602 lbs. per bolt.

The bolt stress area = 2.0792 in^2

Therefore,

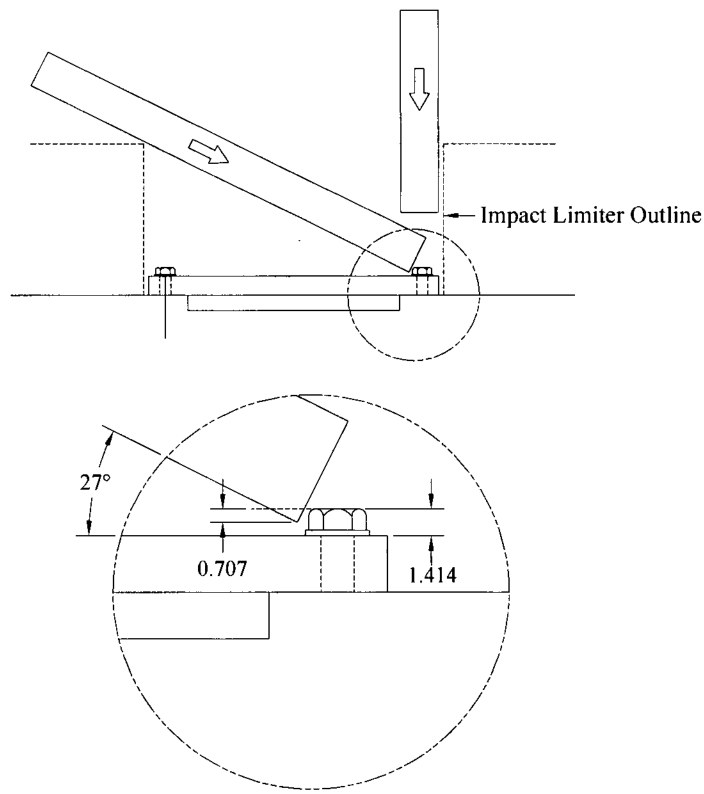
The bolt tensile stress = 147,602 lbs / 2.0792 in^2
= 70,990 psi

Allowable bolt stress = smaller of (.7S_u or S_y)
= 105,000 psi

Factor of Safety = 105,000 / 70,990 = 1.48

In the scenario of the puncture bar piercing through the top hollow portion of the impact limiter sheet-metal cover, it is also postulated that the puncture bar may contact the thermal shield and possibly the secondary lid bolts. Structural evaluation of the thermal-shield has been performed in Reference 2-26. Evaluation of the deformation and/or damage to the thermal-shield in this scenario has been performed using a 3-dimensional ANSYS inelastic finite element model. It has been shown that the puncture bar may cause minor damage to the shield near the central portion. Near the edge of the assembly the puncture bar may cause the shield-plates to deform all the way to the lid with only minor damage. The two stainless-steel plates will remain intact over most of the area, providing thermal resistance during the fire test.

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



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

Based on the geometry of the impact limiter hollow section, the rod will have to be inclined at an angle of 27° from the lid surface to make contact with the bolthead in an orientation that may cause the maximum shear load on the bolthead. The bolts are specified to be 1¾" heavy head cap screws with flat washers.

Maximum head thickness of 1¾" heavy head cap screws	= 1.134"
Maximum thickness of 1¾" washers	= 0.28"
Maximum projection above the lid surface	= 1.134 + 0.28 = 1.414"

Assuming that the rod makes contact at approximately the mid-height of the projection, the height of the shear-plane on the rod is located at 0.707" as shown in the sketch.

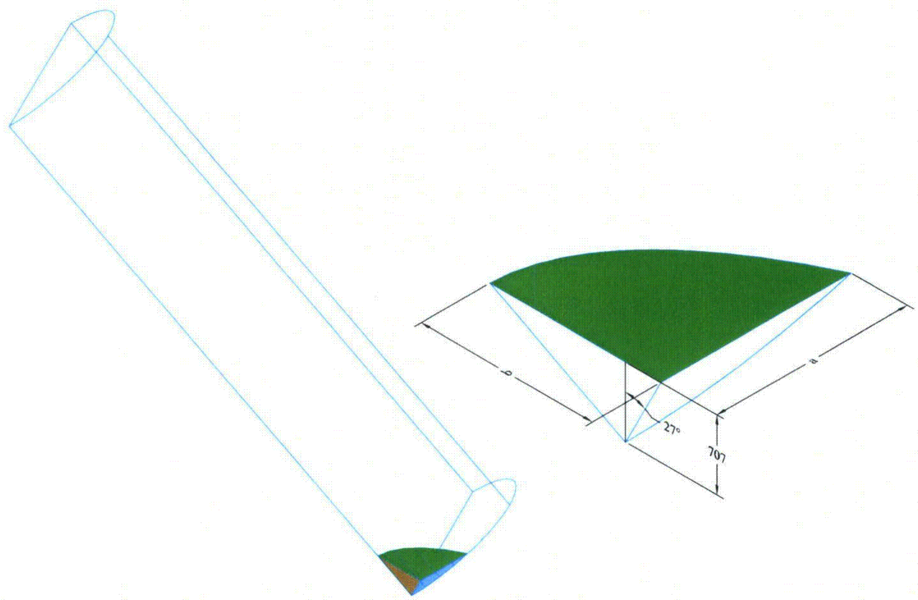
The rod, according to the regulations (Reference 2-1) is specified to be mild steel. Typical value of the ultimate tensile strength of mild steel is 45,000 to 55,000 psi (e.g. A-675 Gr. 45). The bolt has been specified as ASTM-354 Gr. BD for which the ultimate tensile strength is 150,000 psi. Taking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

Rod material shear strength = 0.6×55,000 = 33,000 psi

Bolt material shear strength = 0.6×150,000 = 90,000 psi

The bolt shear area is $(\pi/4)\times1.75^2 = 2.405$ in^2. The rod shear area is calculated as follows.

Consider the following sketch that shows half of the rod:



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

$a = [3^2 - (3 - 0.707/\cos 27°)^2]^{1/2} \quad = 2.033"$

$b = 0.707\times(\tan 27° + \cot 27°) \quad = 1.748"$

Area of the parabola:

$$A = (2/3)\times 2a\times b = (2/3)\times 2\times 2.033\times 1.748 = 4.74 \text{ in}^2$$

Thus,

Rod shear strength = 4.74×33,000 = 156,420 lb

Bolt shear strength = 2.405×90,000 = 216,450 lb

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

2.7.3 Thermal

2.7.3.1 Summary of Pressures and Temperatures

The maximum temperatures resulting from the hypothetical accident conditions, presented in Sections 3.5.3 and 3.5.4 are summarized as follows:

(1) Maximum containment vessel pressure = 3.12 psig

(2) Temperatures:

Structural shell	352°F
Lead	335°F
Seal Area	352°F

2.7.3.2 Differential Thermal Expansion

Differential thermal expansion between the two shells of the cask and the lead shield along with temperature gradients in the cask has been used in analyzing the stresses in the cask body. Results from various loading conditions, per Reg. Guide 7.8, are presented in Section 2.10.3.2 (Tables A2-29 through A2-32).

2.7.3.3 Stress Calculation

Table 2-25 summarizes the thermal and pressure stresses calculated in Section 2.10.1.5.

Table 2-25

Summary of Largest Secondary Stress Intensity

In 10-160B Cask Under Fire Accident[1]

Cask Component	Stress Classification	S.I. (psi)	Allowable[2] (psi)	Safety Factor
Baseplate	Membrane	1,499	66,300	44.23
	Membrane + Bending	9,992	66,300	6.64
Outer Shell	Membrane	28,565	66,300	2.32
	Membrane + Bending	42,453	66,300	1.56
Inner Shell	Membrane	38,309	66,300	1.73
	Membrane + Bending	49,404	66,300	1.34
Bolting Ring	Membrane	25,231	66,300	2.63
	Membrane + Bending	31,353	66,300	2.11
Primary Lid	Membrane	10,709	66,300	6.19
	Membrane + Bending	29,285	66,300	2.26
Secondary Lid	Membrane	7,588	66,300	8.74
	Membrane + Bending	20,540	66,300	3.23

Notes:

(1) These values are calculated using the most conservative assumptions.

See Attachment 5 for the basis of these numbers.

(2) Allowable values for secondary stresses, per ASME Section III, is $3S_m$ at actual
temperature.

2.7.4 Water Immersion

10 CFR 71.73 (c) (4) is not applicable, since no fissile materials are to be carried in the cask.

10 CFR 71.73 (c) (5) requires an immersion in water with a pressure of 21. psig for eight hours. Review of the stresses summarized in Table A2-16 for a 25 psig pressure indicates the stresses are low, and this test will have no significant effect on the package.

2.7.5 Summary of Damage

The structural integrity of the CNSI 10-160B package has been demonstrated, by analytical models, to be maintained during the hypothetical accident conditions. The condition of the package after the hypothetical accident is:

(1) Impact limiters are crushed during the 30 foot drop condition. Cask stresses are less than those prescribed by NRC Regulatory Guide 7.6.

(2) Small local deformations to the external shell may result from the 40 inch puncture condition. There will be no loss of shielding and the containment vessel will not be deformed.

Table 2-6 summarizes the maximum Primary Stresses during the hypothetical accident conditions.

2.8 Special Form

Not applicable since no special form is claimed.

Table 2-26
Summary of Largest Primary Stress Intensity in 10-160B Cask
Under Hypothetical Condition[1]

Cask Component	Stress Classification	S.I (PSI)	Allowable (PSI)	Safety Factor	Reference Table
Baseplate	Membrane	13,919	49,000	3.52	2-15
	Membrane Plus Bending	32,897	70,000	2.13	2-15
Outer Shell	Membrane	33,494	49,000	1.46	2-15
	Membrane Plus Bending	41,711	70,000	1.68	2-15
Inner Shell	Membrane	43,055	49,000	1.14	2-15
	Membrane Plus Bending	58,589	70,000	1.19	2-15
Bolting Ring	Membrane	47,220	49,000	1.04	2-15
	Membrane Plus Bending	51,410	70,000	1.36	2-15
Primary Lid	Membrane	23,505	49,000	2.08	2-20
	Membrane Plus Bending	35,750	70,000	1.96	2-15
Secondary Lid	Membrane	13,801	49,000	3.55	2-15
	Membrane Plus Bending	37,396	70,000	1.87	2-15

2.9 Fuel Rods

Not applicable, since fuel rods will not be part of package contents.

[1] See Table 2-1 for accident condition load combination

TABLE A2-35

MEMBRANE STRESSES IN VARIOUS COMPONENTS OF THE CASK

MINIMUM EXTERNAL PRESSURE(1)

Cask Component	Location(2)	Stress Components, (psi)(3)				Principal Stresses (psi)(3)			S.I.(3) (psi)	S.I.(4) (psi)
		Normal Radial	Normal Axial	Normal Hoop	In-Plane Shear	S_1	S_2	S_3		
Base Plate	A	89.25	-9.535	89.25	0	89.25	89.25	-9.535	98.79	149
Outer Shell	B	2599	147	965.4	759.4	2815	965.4	-69.2	2884	3,145
Inner Shell	C	-2358	1486	-736.9	-962.8	1714	-736.9	-2586	4299	4,606
Bolting Ring	D	217.6	10.68	1258	-53.43	1258	230.6	-2.305	1260	1,375
Primary Lid	E	62.42	-146.5	205.4	-52.78	205.4	74.99	-159.1	364.5	449
Secondary Lid	F	-13.57	-6.44	-13.57	0	-6.44	-13.57	-13.57	7.131	16

GENERAL NOTES:

(1) See Table 2-1 for load combinations.
(2) See Figure A2-45 for locations indicated in this table.
(3) These stresses were calculated with 11.2 psi internal pressure in the cask.
(4) Conservatively the stress intensities corresponding to 19.6 psi cask internal pressure have been added to the stress intensities of the previous column. The stress intensities for 19.6 psi internal pressure are obtained by multiplying the stress intensities of Table A2-37 by a factor of 19.6/10 = 1.96.

TABLE A2-36

MEMBRANE PLUS BENDING STRESSES IN VARIOUS COMPONENTS OF THE CASK
MINIMUM EXTERNAL PRESSURE(1)

Cask Component	Location(2)	Stress Components, (psi)(3)				Principal Stresses (psi)(3)			S.I.(3)	S.I.(4)
		Normal Radial	Normal Axial	Normal Hoop	In-Plane Shear	S_1	S_2	S_3	(psi)	(psi)
Base Plate	a	-727.5	2.208	-727.5	0	2.208	-727.5	-727.5	729.7	1,393
	b	906	-21.28	906	0	906	906	-21.28	927.3	1,691
Outer Shell	c	-3143	2714	1804	759.4	2811	1804	-3240	6051	6,561
	d	1958	-2375	126.8	759.4	2087	126.8	-2504	4592	5,380
Inner Shell	e	-2350	61.87	-1143	-962.8	399.1	-1143	-2687	3086	3,651
	f	-2366	2895	-331	-962.8	3065	-331	-2537	5602	6,295
Bolting Ring	g	-42.39	-152.4	1204	-53.43	1204	-20.71	-174.1	1378	1,574
	h	834.4	166.5	1311	-53.43	1311	838.6	162.2	1149	1,321
Primary Lid	i	-416.2	-218.3	-172.8	-102.2	-172.8	-175	-459.5	286.7	1,128
	j	541	-74.7	583.5	-3.362	583.5	541.1	-74.72	658.3	1,509
Secondary Lid	k	-484.1	1.724	-484.1	0	1.724	-484.1	-484.1	485.8	1,180
	l	457	-14.6	457	0	457	457	-14.6	471.6	1,148

GENERAL NOTES:

(1) See Table 2-1 for load combinations.
(2) See Figure A2-45 for locations indicated in this table.
(3) These stresses were calculated with 11.2 psi internal pressure in the cask.
(4) Conservatively the stress intensities corresponding to 19.6 psi cask internal pressure have been added to the stress intensities of the previous column. The stress intensities for 19.6 psi internal pressure are obtained by multiplying the stress intensities of Table A2-38 by a factor of 19.6/10 = 1.96.

TABLE A2-37

MEMBRANE STRESSES IN VARIOUS COMPONENTS OF THE CASK

INTERNAL PRESSURE OF 10 PSIG(1)

COMPONENT	LOCATION(2)	STRESS COMPONENTS				PRINCIPAL STRESSES			
		NORMAL RADIAL psi	NORMAL AXIAL psi	NORM HOOP psi	IN-PLANE psi	S1 psi	S2 psi	S3 psi	S.I. psi
BASE PLATE	A	19.27	-6.349	19.27	0	19.27	19.27	-6.349	25.62
OUTER SHELL	B	101.2	-32.6	-25.72	-0.2057	101.2	-25.72	-32.6	133.1
INNER SHELL	C	71.04	-5.432	-85.15	6.848	71.64	-6.041	-85.15	156.8
BOLTING RING	D	-9.053	0.1235	48.52	-2.927	48.52	0.9774	-9.907	58.43
PRIMARY LID	E	-12.18	-9.497	-7.057	-21.63	10.83	-7.057	-35.51	43.34
SECONDARY LID	F	-9.96	-5.588	-9.96	0	-5.588	-9.96	-9.96	4.373

GENERAL NOTES: (1) See Table 2-1 for load combinations.
(2) See Figure A2-46 for locations indicated in this table.

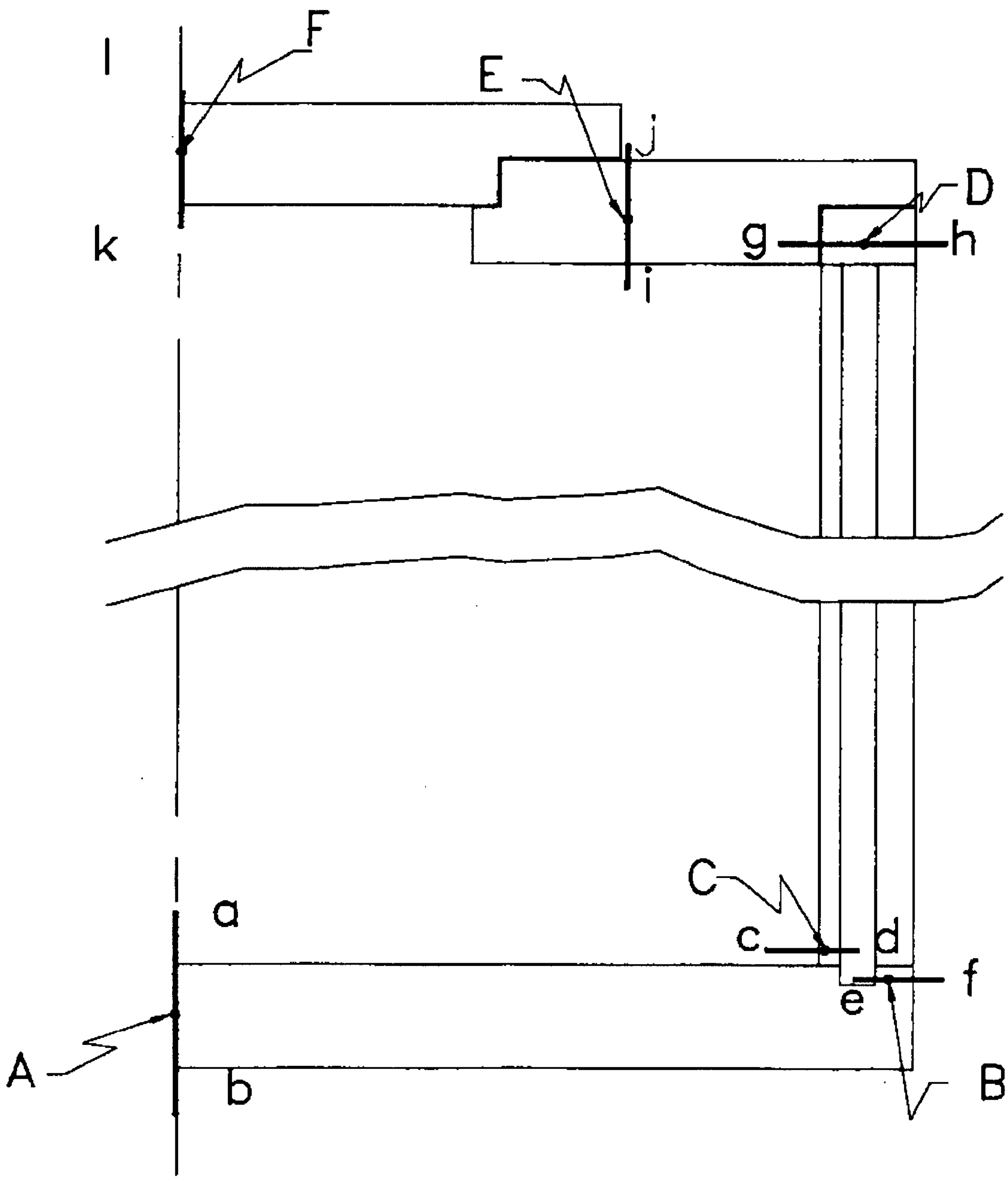


FIGURE A2-46
LOCATIONS OF STRESSES INDICATED
IN TABLES A2-37 THROUGH A2-40

TABLE A2-38

MEMBRANE PLUS BENDING STRESSES IN VARIOUS COMPONENTS OF THE CASK

INTERNAL PRESSURE OF 10 PSIG[1]

COMPONENT	LOCATION[2]	STRESS COMPONENTS				PRINCIPAL STRESSES			
		NORMAL RADIAL psi	NORMAL AXIAL psi	NORM HOOP psi	IN-PLANE psi	S1 psi	S2 psi	S3 psi	S.I. psi
BASE PLATE	a	-339.5	-0.9632	-339.5	0	-0.9632	-339.5	-339.5	338.5
	b	378	-1174	378	0	378	378	-11.74	389.7
OUTER SHELL	c	-5.568	254.8	62.3	-0.2057	254.8	62.3	-5.568	260.4
	d	87.26	-315	-113.7	-0.2057	87.26	-113.7	-315	402.2
INNER SHELL	e	95.42	299	11.1	6.848	299.2	95.19	11.1	288.1
	f	46.65	-306.6	-181.4	6.848	46.78	-181.4	-306.7	353.5
BOLTING RING	g	-27.66	65.85	72.28	-2.927	72.28	65.94	-27.76	100
	h	-22.65	-62.67	24.77	-2.927	24.77	-22.44	-62.88	87.65
PRIMARY LID	i	-235.7	-13.86	-441.1	-21.62	-11.77	-237.8	-441.1	429.3
	j	211.4	-5.134	427	-21.64	427	213.5	-7.275	434.2
SECONDARY LID	k	-354.3	-0.08722	-354.3	0	0.08722	-354.3	-354.3	354.2
	l	334.3	-11.09	334.3	0	334.3	334.3	-11.09	345.1

GENERAL NOTES: (1) See Table 2-1 for load combinations.
(2) See Figure A2-46 for locations indicated in this table.

TABLE A2-39

MEMBRANE STRESSES IN VARIOUS COMPONENTS OF THE CASK

EXTERNAL PRESSURE OF 25 PSIG(1)

COMPONENT	LOCATION(2)	STRESS COMPONENTS				PRINCIPAL STRESSES			
		NORMAL RADIAL psi	NORMAL AXIAL psi	NORM HOOP psi	IN-PLANE psi	S1 psi	S2 psi	S3 psi	S.I. psi
BASE PLATE	A	-71.7	-8.906	-71.7	0	-8.906	-71.7	-71.7	62.79
OUTER SHELL	B	-192.1	75.42	57.71	26.85	78.08	57.71	-194.8	272.8
INNER SHELL	C	-268.3	-100.7	101.2	-45.8	101.2	-89.03	-280	381.1
BOLTING RING	D	-76.11	-110.7	-476.2	14.97	-70.53	116.3	-476.2	405.7
PRIMARY LID	E	19.69	-92.16	-23.26	23.25	24.33	-23.26	-96.8	121.1
SECONDARY LID	F	12.54	-11.45	12.54	0	12.54	12.54	-11.45	23.99

GENERAL NOTES: (1) See Table 2-1 for load combinations.
(2) See Figure A2-46 for locations indicated in this table.

TABLE A2-40

MEMBRANE PLUS BENDING STRESSES IN VARIOUS COMPONENTS OF THE CASK

INTERNAL PRESSURE OF 25 PSIG(1)

COMPONENT	LOCATION(2)	STRESS COMPONENTS				PRINCIPAL STRESSES			
		NORMAL RADIAL psi	NORMAL AXIAL psi	NORM HOOP psi	IN-PLANE psi	S1 psi	S2 psi	S3 psi	S.I. psi
BASE PLATE	a	768.8	-21.91	768.8	0	768.8	768.8	-21.91	790.7
	b	-912.2	4.101	-912.2	0	4.101	-912.2	-912.2	916.3
OUTER SHELL	c	-34.21	-509.6	-120.3	26.85	-32.7	-120.3	-511.1	-478.4
	d	-168	650.3	235.8	26.85	651.1	235.8	-168.8	820
INNER SHELL	e	-334.5	-767.7	113.4	-45.8	-113.4	-329.7	-772.5	659.1
	f	-202	559	315.7	-45.8	561.8	315.7	-204.7	766.5
BOLTING RING	g	49.1	-454.4	-615.1	14.97	49.55	-454.9	-615.1	664.7
	h	-5.376	217.7	-337.3	14.97	218.7	-6.376	-337.3	555.9
PRIMARY LID	i	313.6	-7.549	844.8	21.97	844.8	315.1	-9.045	853.8
	j	-274.2	-176.8	-891.3	24.52	-171	-280	-891.3	720.3
SECONDARY LID	k	728.9	-22.5	728.9	0	728.9	728.9	-22.5	751.4
	l	-703.9	-0.4031	-703.9	0	0.4031	-703.9	-703.9	703.4

GENERAL NOTES: (1) See Table 2-1 for load combinations.
(2) See Figure A2-46 for locations indicated in this table.

TABLE A2-41

MEMBRANE STRESSES IN VARIOUS COMPONENTS OF THE CASK

FIRE ACCIDENT(1)

Cask Component	Location(2)	Stress Components, (psi)(3)				Principal Stresses (psi)(3)			S.I.(3)
		Normal Radial	Normal Axial	Normal Hoop	In-Plane Shear	S_1	S_2	S_3	(psi)
Base Plate	A	-1247	9.867	-1247	0	9.867	-1247	-1247	1257
Outer Shell	B	7851	641	26,850	3030	26,850	8955	-462.9	27,310
Inner Shell	C	7979	3739	34,410	-7996	34,410	14,130	-2414	36,830
Bolting Ring	D	11,360	3172	27,590	-1496	27,590	11,630	2907	24,680
Primary Lid	E	-640.0	1622	7537	-3047	7537	3741	-2760	10,300
Secondary Lid	F	-931.2	-1813	5585	-391.9	5585	-782.2	-1962	7547

GENERAL NOTES:

(1) See Table 2-1 for load combinations.
(2) See Figure A2-48 for locations indicated in this table.
(3) These stresses were calculated with 7.3 psi internal pressure in the cask. For a conservative estimate of fire accident stresses with 3.12 psi internal pressure please see Attachment 5 of this SAR.

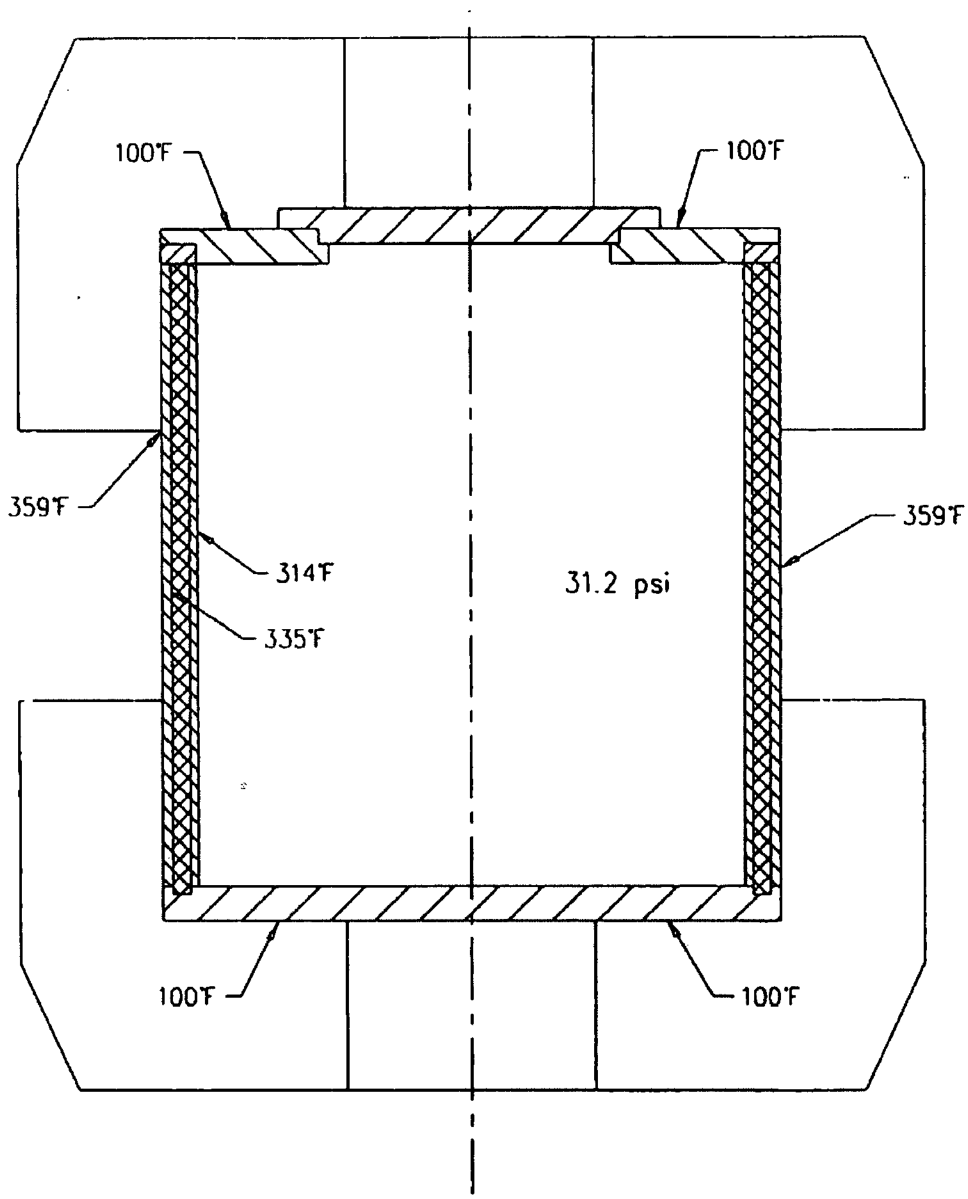


Figure A2-47
Fire Accident Temperature Distribution

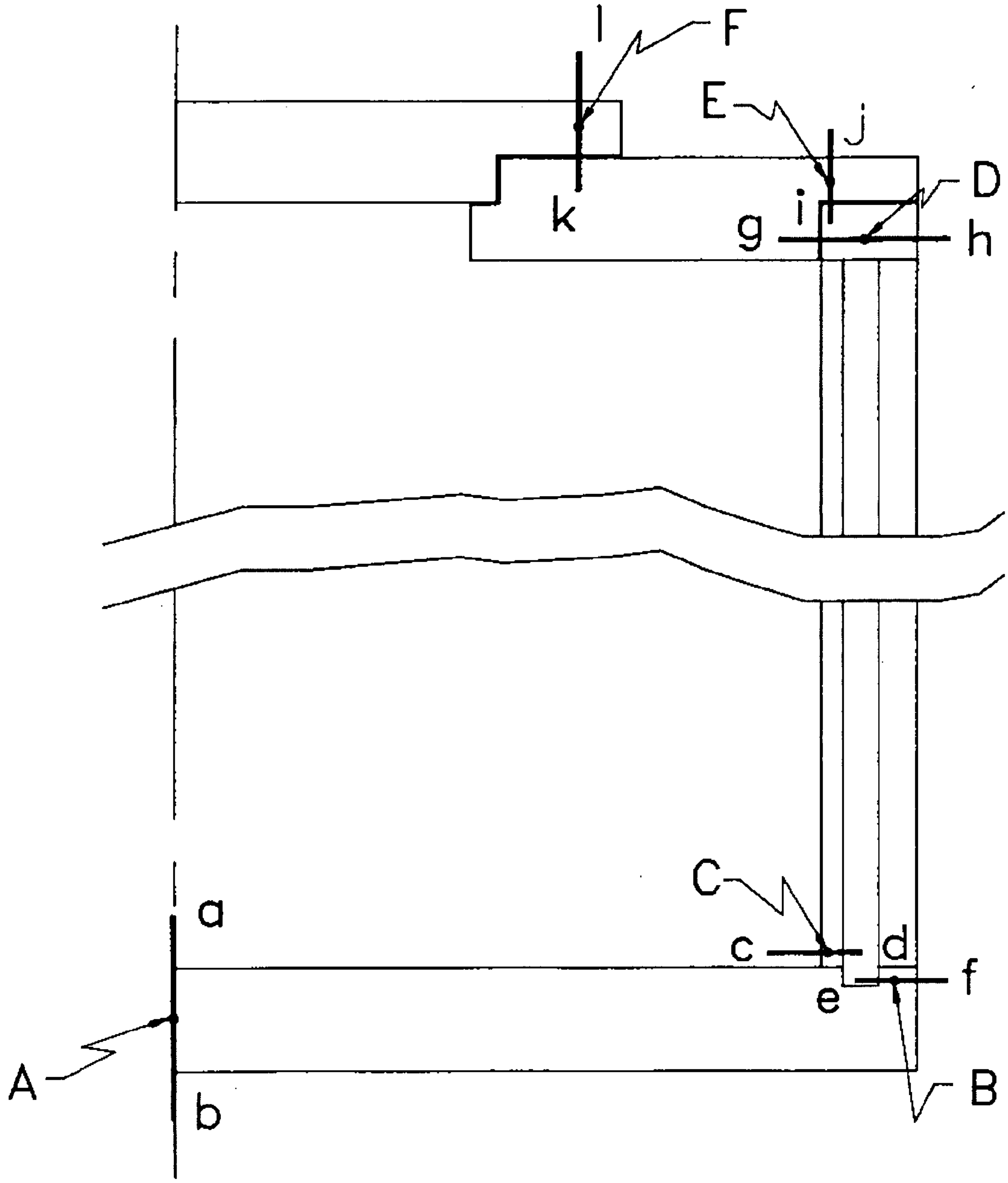


Figure A2-48
Fire Accident
Locations of Stresses Indicated
Tables A2-41 and A2-42

TABLE A2-42
MEMBRANE PLUS BENDING STRESSES IN VARIOUS COMPONENTS OF THE CASK
FIRE ACCIDENT(1)

Cask Component	Location(2)	Stress Components, (psi)(3)				Principal Stresses (psi)(3)			S.I.(3)
		Normal Radial	Normal Axial	Normal Hoop	In-Plane Shear	S_1	S_2	S_3	(psi)
Base Plate	a	-6210	106.9	-6210	0	106.9	-6210	-6210	6317
	b	3715	-87.19	3715	0	3715	3715	-87.19	3802
Outer Shell	c	-4871	18,440	32,250	3030	32,250	18,820	-5258	37,510
	d	7230	-16,840	21,440	3030	21,440	7606	-17,220	38,660
Inner Shell	e	13,450	-18,260	25,900	-7996	25,900	15,350	-20,160	46,070
	f	2511	25,500	42,930	-7996	42,930	28,010	3.147	42,920
Bolting Ring	g	-1907	-2839	26,470	-1496	26,470	-806.1	-3941	30,410
	h	5348	8916	28,710	-1496	28,710	9460	4803	23,900
Primary Lid	i	-13,540	1793	10,690	-3961	10,690	2756	-14,500	25,190
	j	12,260	1451	4384	-2134	12,660	4384	1045	11,620
Secondary Lid	k	-2609	-948	14,470	-468.5	14,470	-825	-2732	17,200
	l	746.6	-2678	-3296	-315.3	775.4	-2707	-3296	4072

GENERAL NOTES:

(1) See Table 2-1 for load combinations.
(2) See Figure A2-48 for locations indicated in this table.
(3) These stresses were calculated with 7.3 psi internal pressure in the cask. For a conservative estimate of fire accident stresses with 3.12 psi internal pressure please see Attachment 5 of this SAR.

2.10.4 References for Chapter 2

1. US NRC Code of Federal Regulations, Title 10, Part 71.

2. US NRC Regulatory Guide 7.6, "Design Criteria for the Structural Analysis of Shipping Cask Containment Vessels.

3. US NRC Regulatory Guide 7.8, "Load Combinations for the Structural Analysis of Shipping Casks."

4. NUREG/CR 1815, "Recommendations for Protecting Against Failure By Brittle Fracture in Ferritic Steel Shipping Containers up to Four Inches Thick."

5. Roark and Young, "Formulas for Stress and Strain," Fifth Edition.

6. Baker, Kovalevsky, Rish, "Structural Analysis of Shells" 1972.

7. None.

8. Swanson Analysis Systems, Inc. "ANSYS Engineering Analysis User's Manual," March 1983.

9. None.

10. Safety Analysis Report for Chem-Nuclear Systems, Inc., Model CNS 8-120B Type B Radwaste Shipping Cask, Revision 2, March 1984.

11. Timoshenko and Goodier, "Theory of Elasticity," Third Edition, 1970.

12. Wichman, Hopper and Mershon, "Local Stresses in Spherical and Cylindrical Shells due to External Loadings," Welding Research Council Bulletin No. 107, March 1979.

13. CASKDROP Users Manual.

14. CASKDROP Technical Manual.

15. CASKDROP Verification Manual.

16. CORNVT Program Documentation

17. PAYLOAD Program Documentation.

18. None

19. Swanson Analysis Systems, Inc., "ANSYS Theoretical Manual."

20. None

21. None.

22. None.

23. ASME Boiler and Pressure Vessel Code, Section III.

24. Timoshenko, S. and Woinowsky-Krieger, S; Theory of Plates & Shells, Second Edition, McGraw Hill Book Company, 1959.

25. An Assessment of Stress-Strain Data Suitable for Finite Element Elastic-Plastic Analysis for Shipping Containers," NUREG/CR-0481, SAND77-1972.

26. Energy*Solutions* Document ST-0001, Revision 0, Structural Evaluation of the Thermal-Shields of the 8-120B & 10-160B Casks under Puncture Drop Conditions.

3. THERMAL EVALUATION

This chapter identifies, describes, discusses, and analyzes the principal thermal engineering design of the 10-160B cask. Compliance with the performance requirements of 10 CFR 71 is demonstrated.

3.1 Discussion

Two components contribute to the thermal protection of the cask body. These components are the impact limiters which provide thermal protection to the top and bottom of the cask and the fire shield which protects the side walls between the impact limiters. The impact limiters are sheet metal enclosures filled with polyurethane foam which acts as an insulation barrier to heat flow. The central portion of both, the top and the bottom, impact limiters contain a hollow region that is covered by sheet-metal. In the puncture drop test, that precedes the fire test, the sheet-metal may rupture and provide a direct path to the secondary lid and the baseplate. In order to protect the seals a thermal-shield is externally attached to the secondary lid. The exposed portion of the cask body is covered with a fire-shield. The fire shield is 0.104 inch thick steel plate with a 0.156 inch thick air gap between it and the outer structural shell of the cask. These components reduce the heat load on the cask body during the hypothetical fire accident. Thus, temperatures of the containment and shielding components of the cask are kept within their service limits. Figure 3.1 shows the location of the components considered in the thermal analysis.

Results of the thermal analysis are summarized in Tables 3.1-1 and 3.1-2. Initial conditions and assumptions are listed in Table 3.2.

The results summarized in Tables 3.1-1 and 3.1-2 are discussed in detail in Sections 3.4 and 3.5. The decay heat load assumed for all analyses is 200 watts.

An optional steel insert being installed in the cask will have very minor effects on the calculations performed in this Chapter.

Table 3.1-1
Summary of Thermal Results
Normal Conditions of Transport (NCT)

Quantity	Calculated(1) Value (1-d Model)	Calculated(2) Value (2-d Model)	Maximum Allowable
Maximum temperature difference across the cask body (°F)	0.16	0.2	(3)
Maximum temperature difference across the outer shell (°F)	0.05	0.0	(3)
Maximum temperature difference across the inner shell (°F)	0.03	0.0	(3)
Maximum average wall temperature (°F)	168	173	(3)
Maximum lead temperature (°F)	168	173	622
Maximum cask body temperature (°F)	168	175	(3)
Maximum seal temperature (°F)	-	174	250(4)
Average bulk air temperature (°F)	-	188	(4)
Maximum internal pressure (PSIG)	12.22		(3)

NOTES:

(1) The values presented in these columns are the results obtained from the analyses presented in this chapter.

(2) The values presented in these columns are the results obtained from the supplemental analysis, using 2-d FEM. See Section 3.5.1.3 and Reference 11.

(3) Set by stress considerations.

(4) See Section 3.4.2

Table 3.1-2
Summary of Thermal Results
Hypothetical Accident Conditions (HAC)

Quantity	Calculated[1] Value (1-d Model)	Calculated[2] Value (2-d Model)	Analyzed[3]	Maximum Allowable
Maximum temperature difference across the cask body (°F)	30.3	39.8	45	[4]
Maximum temperature difference across the outer shell (°F)	15.3	20.2	24	[4]
Maximum temperature difference across the inner shell (°F)	1.7	2.3	2	[4]
Maximum average wall temperature (°F)	243	279	334	[4]
Maximum lead temperature (°F)	243	274	335	622
Maximum cask body temperature (°F)	252	289	352	[4]
Maximum seal temperature (°F)	-	375	375	375[5]
Average bulk air temperature (°F)	-	281	290	290
Maximum internal pressure (PSIG)	15.42		94.3[6]	[4]

NOTES:
(1) The values presented in these columns are the results obtained from the analyses presented in this chapter.
(2) The values presented in these columns are the results obtained from the supplemental analysis, using 2-d FEM. See Section 3.5.1.3 and Reference 11.
(3) The values presented in these columns are obtained by conservatively increasing the results from the analyses presented in this chapter.
(4) Set by stress considerations.
(5) See Section 3.5.3. The calculated maximum temperature of 375°F has been obtained from a conservative analysis. Setting this as the temperature limit has a built-in margin of safety.
(6) See Section 3.5.4

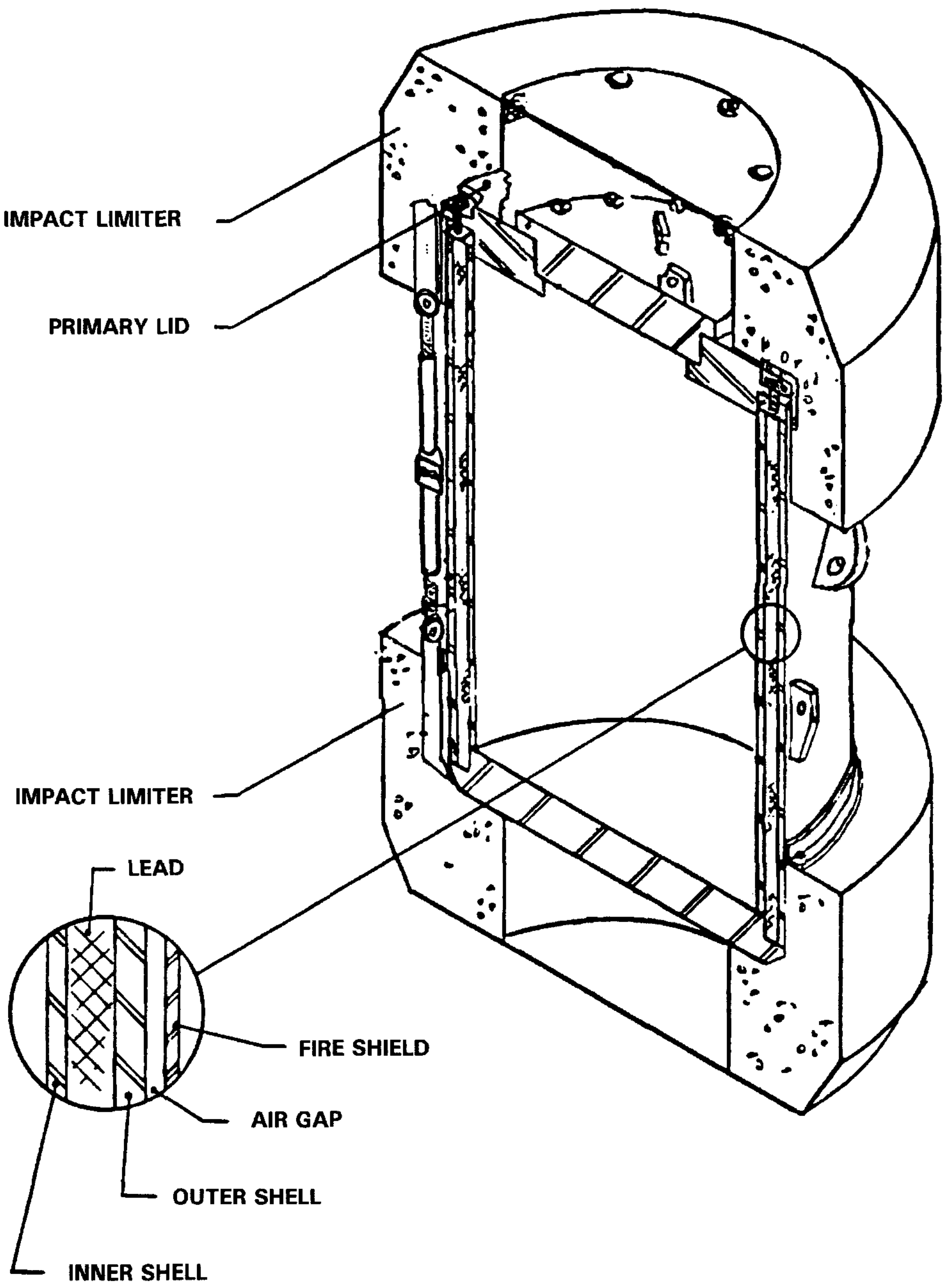


Figure 3.1
Location of Components Analyzed in Thermal Design

Table 3.2

Summary of Initial Conditions and Assumptions

Condition or Assumption	Normal Conditions	Hypothetical Accident
Ambient temperature for radiation (°F)	100	1475 during the fire; 100 thereafter
Ambient temperature for convection (°F)	100	1475 during the fire; 100 thereafter
Insolation (gcal/sq cm)	400	0 during the fire; 400 thereafter
Outside surface emissivity	0.8	0.8
Environment emissivity	0.9	0.9
Gap surfaces emissivity	0.15	0.15

3.2 Summary of Thermal Properties of Materials

Thermal properties of the materials included in the thermal model of the cask are shown in Table 3.3 (a) and 3.3 (b). The properties of the elastomer seals will vary depending on the type of elastomer used. The elastomer chosen for use shall have thermal properties such that the usable temperature range meets or exceeds the range required to meet the Normal Conditions of Transport (minimum= -40°F, maximum= +250°F) and meets the temperature required to meet the Hypothetical Accident Conditions (+375°F for 1 hour). The thermal properties may be determined from manufacturer's recommended temperature ranges or from independent testing. An example of manufacturer's recommendations is found in Reference 6. Elastomers that have been evaluated and have passed the criteria listed above are butyl rubber, ethylene propylene rubber, and silicone rubber.

Note that the outside surface of the fire shield must be conservatively assumed to have an emissivity, ε, of at least 0.8 during the fire accident according to the Code of Federal Regulations (10CFR71.73). This same emissivity is used in analyzing the normal conditions of transport.

Table 3.3a

Temperature-Independent Thermal Properties

Material	Property	Ref.:Page	Value
Steel	Density	2:536	488 lb/ft^3
	ε (Outside)	3:648	0.8
	ε (Inside)	4:133	0.15
Lead	Density	2:535	710 lb/ft3
	Spec. Heat	2:535	0.0311 Btu/lb-°F
	Melting Point	5:B-29	621.5 °F

3.3 Technical Specifications of Components

Not applicable.

Table 3.3 (b)
Temperature-Dependent Thermal Properties

Temp.	Stainless Steel		Carbon Steel		Lead	Air		
(°F)	Sp. Heat	Cond.	Sp. Heat	Cond.	Cond.	Dens.	Sp. Heat	Cond.
70	0.117	8.6	0.104	35.1	20.1	0.07518	0.2402	0.01490
100	0.117	8.7	0.106	34.7	19.9	0.07105	0.2404	0.01546
150	0.120	9.0	0.109	34.1	19.7	0.06483	0.2408	0.01686
200	0.122	9.3	0.113	33.6	19.4	0.05992	0.2414	0.01804
250	0.125	9.6	0.115	32.9	19.1	0.05592	0.2421	0.01921
300	0.126	9.8	0.118	32.3	18.8	0.05237	0.2429	0.02032
350	0.128	10.1	0.122	31.6	18.5	0.04892	0.2438	0.02141
400	0.129	10.4	0.124	30.9	18.2	0.04619	0.2450	0.02248
450	0.130	10.6	0.126	30.3	17.9	0.04358	0.2461	0.02354
500	0.131	10.9	0.128	29.5	17.7	0.04141	0.2474	0.02457
550	0.132	11.1	0.131	28.8	17.4	0.03936	0.2490	0.02558
600	0.133	11.3	0.133	28.0	17.1	0.03747	0.2511	0.02654
650	0.134	11.6	0.135	27.3	16.8	0.03578	0.2527	0.02749
700	0.135	11.8	0.139	26.6	16.8	0.03422	0.2538	0.02843
750	0.136	12.0	0.142	25.9	16.8	0.03280	0.2552	0.02933
800	0.136	12.2	0.146	25.2	16.8	0.03141	0.2568	0.03022
900	0.138	12.7	0.154	23.8	16.8	0.02920	0.2596	0.03201
1000	0.139	13.2	0.163	22.4	16.8	0.02715	0.2628	0.03371
1100	0.141	13.6	0.172	20.9	16.8	0.02544	0.2659	0.03532
1200	0.141	14.0	0.184	19.5	16.8	0.02393	0.2689	0.03691
1300	0.143	14.5	0.205	18.0	16.8	0.02254	0.2717	0.03844
1400	0.144	14.9	0.411	16.4	16.8	0.02134	0.2742	0.04011
1500	0.145	15.3	0.199	15.7	16.8	0.02023	0.2766	0.04193

Units:		References:	
Specific Heat:	BTU/lbm-F	Stainless Steel Properties:	Reference 1, Page 88
Conductivity:	BTU/hr-ft-F	Carbon Steel	Reference 1, Page 83
Density:	lbm/cu ft	Lead Properties:	Reference 2, Page 535
		Air Properties:	Reference 2, Page 542

3.4 Thermal Evaluation for Normal Conditions of Transport

3.4.1 Thermal Model

3.4.1.1 Analytical Model. Normal conditions of transport are calculated with a steady state ANSYS (Reference 7) finite element thermal model of the cask. The location of the nodes and elements in the ANSYS model are shown in Figure 3.2. The model is a one-dimensional model through the cask axial midplane.

Cask surfaces which are covered by the impact limiters are given insulated boundary conditions. Convection and radiation are modeled on the fire shield outside surfaces. Equation 1 gives the relationship used to model convection (Reference 4, page 135).

(Equation 1)

$$h = C\left(T_s - T_a\right)^{1/3}$$

where:

C = 0.19 (assumes the cask is vertical)
h = Heat transfer coefficient (BTU/hr-sq ft-F)
T_s = cask surface temperature (Degrees F)
T_a = ambient temperature (Degrees F)

Convection is modeled from a 100°F bulk air temperature and radiation is modeled from a 100°F environment. The 200 watt decay heat load is modeled as a constant heat flux over the exposed side wall inner surface of the cask. The heat flow rate across the inner surface of the cask inner shell set equal to the decay heat load. This is a conservative approximation during the fire transient, since, in reality, some of the heat from the fire would be transferred to the waste. Thus, the waste would act as a heat sink lowering the wall temperature.

Equation 2 (Reference 7, Page 4.31.1) gives the radiation heat transfer equation solved by the model.

(Equation 2)

$$q = \sigma\, \varepsilon\, F\, A\left(T_I^4 - T_J^4\right)$$

where:

q = heat flow rate (BTU/hr)
σ = Stefan-Boltzmann Constant
= 1.7136×10^{-9} (BTU/hr-sq ft-R^4)
ε = emissivity
F = geometric form factor
A = area (sq ft)
T = temperature (°R)
I = first node number
J = second node number

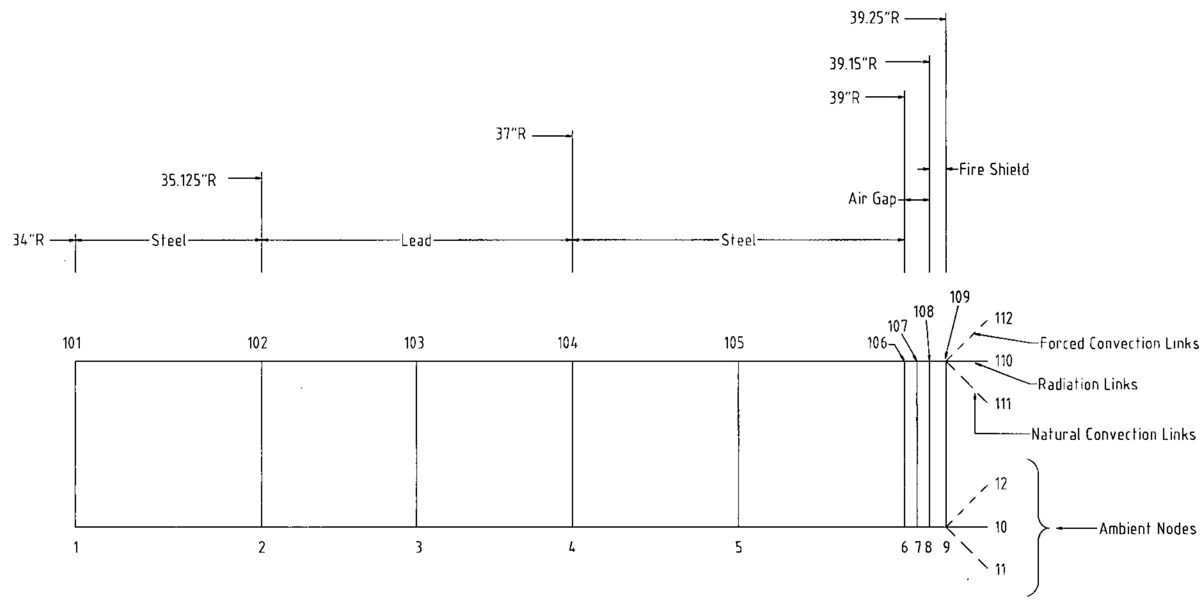


Figure 3.2

Node and Element Locations in the 10-160B Cask Thermal Finite Element Model

Two radiation heat transfer systems are modeled: (1) radiation heat transfer between the fire shield outside surface and the environment, and (2) radiation between the fire shield inside surface and the structural shell outside surface. Emissivity, area, and geometric form factors are defined in both systems.

The overall emissivity for radiation heat transfer between the fire shield and the environment is set equal to the overall emissivity, ε, for heat transfer between two infinite parallel planes as given by equation 3 (Reference 2, page 336).

(Equation 3)

$$\varepsilon = \frac{\varepsilon_1 \varepsilon_2}{\varepsilon_2 + \varepsilon_1 - \varepsilon_1 \varepsilon_2}$$

where:

ε = overall emissivity
ε_1 = surface 1 emissivity
ε_2 = surface 2 emissivity

The emissivity values of the outside of the fire shield and the environment are 0.8 and 0.9, respectively. Thus, the overall emissivity is calculated by equation 3 to be 0.7347. The area of this radiation heat transfer system is set equal to the area of the outside surface of the fire shield and the geometric form factor is set to 1.0.

Radiation heat transfer between the fire shield inside surface and the structural shell outside surface is approximated by the equation for radiation heat transfer between long concentric cylinders as given by equation 4 (Reference 2, page 336).

(Equation 4)

$$q = \frac{\sigma A_1 \left(T_1^4 - T_2^4\right)}{\frac{1}{\varepsilon_1} + \frac{(A_1)(1/\varepsilon_2 - 1)}{A_2}}$$

The parameters in equation 4 are the same as defined previously and subscripts 1 and 2 refer to the inside cylinder and the outside cylinder, respectively. Since $\varepsilon = \varepsilon_1 = \varepsilon_2$, a form factor may be defined by equation 5 to put equation 4 in the same form as equation 2.

(Equation 5)

$$F = \frac{1}{\varepsilon} \frac{1}{\frac{1}{\varepsilon} + \frac{(A_1)(1/\varepsilon - 1)}{A_2}}$$

The area in equation 2 is set equal to the area of the inside cylinder and the emissivity is set equal to the minimum emissivity of the radiating surfaces, 0.15.

The total insolation is required to be 400 gcal/sq cm for a 12-hour period for curved surfaces according to the Code of Federal Regulations (10CFR71.71). The total insolation of 400 gcal/sq cm is divided by 12 hours of assumed sunlight to yield an average insolation rate. The average insolation rate is then multiplied by the surface emissivity specified in Section 3.2 above (0.8) yielding an insolation rate of 1.897E-4 BTU/sq in/sec. This insolation heat load is applied to the outside surface of the fire shield.

Both the ambient air temperature and the environment temperature and the environment temperature are set to 100°F in accordance with the Code of Federal Regulations (10CFR71.71).

3.4.1.2 Test Model. Not applicable.

3.4.2 Maximum Temperatures

The maximum temperature of the cask occurs at the inside surface of the secondary lid, and is calculated to be 175°F (see table 3.1-1). The maximum temperature of the gas mixture within the cask, determined from the 2-d finite element model, is 188°F on the 100°F day. This is well within the service temperature of all materials and components used within the cask. The maximum temperature of the seals, calculated by the 2-d finite element model, is 174°F. The NCT temperature criterion for the seal material is conservatively set at 250°F for continuous use. The maximum temperature of the contents depends on its physical characteristics. Based on the 2-d finite element model analysis, the maximum temperature of the waste liner is calculated to be 236.4°F (see Reference 11). This temperature is well below the value at which deterioration of the waste can be expected.

3.4.3 Minimum Temperature

The waste transported with the cask may not be a heat source, so the minimum temperature the cask can reach is the minimum ambient temperature, -40°F. All components used in the cask are serviceable at this temperature (see Section 3.2).

3.4.4 Maximum Internal Pressures

The maximum internal pressure of the cask is calculated assuming that the gas within the cask, a mixture of air and water vapor, behaves as an ideal gas. The inside surface of the cask is assumed to be dry.

The temperature of the gas mixture within the cask is determined from the 2-d FEM. The maximum temperature of the gas mixture is 188°F on the 100°F day. Assuming that atmospheric pressure, P_2, exists inside the cask at 70°F, the pressure in the cask at 188°F, P_1, may be calculated by the ideal gas relationship given in equation 6.

(Equation 6)

$$P_1 = \frac{T_1}{T_2} * P_2$$

$$P_1 = \frac{(460+188°R)}{(460+70°R)} * 14.70 PSIA$$

$$P_1 = 17.97 PSIA$$

The vapor pressure contributed by water in the cavity at 188°F is 8.95 psia (Reference 10). The gauge pressure in the cask under normal conditions of transport is equal to the absolute pressure of the gas mixture within the cask minus the outside ambient pressure. Equation 7 expresses the maximum gauge pressure for this cask during normal conditions of transport (MNOP).

(Equation 7) 17.97 PSIA + 8.95 PSIA - 14.7 PSIA = 12.22 PSIG

Section 2.6.1 discusses the impact of the internal pressure on cask performance. Pressure calculations for TRU waste transportation are detailed in Appendix 4.10.2.

3.4.5 Maximum Thermal Stresses

The temperature gradient through the side wall under normal conditions of transport is due to the decay heat of 200 watts. The temperature difference between the outside surface of the outer shell and the inside surface of the inner steel shell is only 0.2°F on the 100°F ambient temperature. Stresses resulting from this temperature gradient are insignificant. Section 2.6.1 discusses the effect of thermal stresses in detail.

3.4.6 Evaluation of Package Performance for Normal Conditions of Transport

All temperatures and stresses within the package due to normal conditions of transport are within allowable service ranges for all components and materials used in the cask. Seal temperatures range from -40 to 174°F and are within the required elastomer seal operating region of -40 to 250°F. All structural materials are below their melting points.

The temperature difference between the inside surface of the inner shell and the outside surface of the outer shell is only 0.2°F. Thermal stresses resulting from this thermal gradient are discussed in section 2.6.1. The average temperature at the inside surface of the inner shell and at the outside surface of the outer shell is 168°F. The average wall temperature is also used in the thermal stress calculations of section 2.6.1.

3.5 Hypothetical Accident Thermal Evaluation

3.5.1 Thermal Model

3.5.1.1 Analytical Model. The thermal model used to evaluate the hypothetical accident is identical to the model used to evaluate normal conditions of transport.

Initial conditions for the hypothetical accident are steady state with a 100°F ambient and no convection nor insolation. These initial conditions are consistent with those required by the Code of Federal Regulations for the hypothetical accident (10CRF71.73).

The Code of Federal Regulations (10CFR71.73) requires the use of a fire emissivity coefficient of at least 0.9. Thus, an environment emissivity coefficient of 0.9 was assumed in both the normal conditions of transport and in the hypothetical accident.

The initial steady state solution is followed by a 0.5 hour fire transient in which the 100°F ambient is replaced by a 1475°F fire temperature as required by the Code of Federal Regulations (10CFR71.73). The effect of the fire is represented by radiative and convective heat flux, the average temperature of which is 1475°F and an emissivity of 0.9. Based on the explanatory material for the IAEA regulations in Safety Series No.37 (Reference 9), the pool fire gas velocity is taken to be 10 m/sec (32.8 ft/sec). The forced convection heat transfer coefficient for large casks, according to Reference 9, is:

$$h = 10 \frac{W}{m^2 \, {}^\circ C}$$

1 W = 9.4804×10^{-4} Btu/sec
1 m = 39.37 inch
1°C = 1.8°F

Therefore,

$$h = \frac{10 \times 9.4804 \times 10^{-4}}{39.37^2 \times 1.8} = 3.398 \times 10^{-6} \frac{\text{Btu}}{\text{sec}-\text{in}^2-{}^\circ\text{F}}$$

The convective heat transfer per unit area between the cask and the atmosphere, q, is governed by the equation:

(Equation 8) $$q = hA\left(T_s - T_a\right)$$

where:

h = Heat transfer coefficient (BTU/hr-sq ft-F)
A = Area (sq ft)
T_s = cask surface temperature (Degrees F)
T_a = ambient temperature (Degrees F)

Finally, the fire transient is followed by a 1.0 hour cooldown transient. The 1475°F fire temperature is replaced by a 100°F ambient during the cooldown transient. Also, the forced convection is replaced with the natural convection, as described in section 3.4.1 of this SAR. The solar insolation is included during the cooldown.

The ANSYS time increment size is set at 5 seconds. The ANSYS (Reference 7) computer program observes the second derivative of temperature with respect to time (curvature) for each node and automatically increases the time increment when its default transient thermal optimization criterion is met. A total of 65 time increments were required to analyze the hypothetical accident.

3.5.1.2 Test Model Not applicable.

3.5.1.3 Supplemental Analyses

In order to obtain the temperatures of the waste content, and the primary and secondary lid seals, during the NCT and HAC fire, supplemental analyses, using a 2-dimensional finite element model, have been performed. The details of these analyses are provided in Reference 11. In these analyses, the overall emissivity of 0.9 has been used to model the heat transfer between the cask and the environment due to radiation.
The results of the analyses of the 2-dimensional finite element model are also included in the Summary Tables 3.1-1 and 3.1-2. The more conservative of the 1-d or 2-d model results have been used for the calculation of the design and operating pressures as well as the structural analyses.

3.5.1.4 Thermal-Shield Analyses

The scenario in which the hollow central portion of the impact limiters is breached during the puncture drop test that precedes the fire test has been analyzed in Energy*Solutions* document TH-0002 (Reference 12). In Reference 12 a finite element model of the secondary lid with the thermal shield is analyzed for the HAC fire test. The finite element model is reproduced in Figure 3-6. The temperature

time-history plot of the representative seal locations is shown in Figure 3-7. Figure 3-8 shows the temperature contour plot of the secondary lid with the thermal-shield at the end of the 30 minute fire.

3.5.2 Package Conditions and Environment

Damage to the package caused by free drop and puncture tests will not significantly alter the thermal characteristics of the package. Even after crushing the impact limiters continue to act as thermal barriers.

3.5.3 Package Temperatures

The maximum temperatures in the fire shield, cask structure, and the lead all occur halfway up the cask. Table 3.4 summarizes the location, time of occurrence measured from the start of the fire, and value of the maximum temperature in each cask component. The cask seals are not explicitly modeled in the 1-d finite element model. The maximum temperature of the primary lid seals are obtained from the 2-d finite element model analysis described in Section 3.5.1.3 and documented in Reference 11. The secondary lid seal temperatures are obtained from the thermal-shield analysis, described in Section 3.5.1.4. The secondary lid seal temperatures are much higher than those of the primary lid. Therefore, the maximum temperature of the secondary lid seal is used to establish the seal temperature acceptance criterion. It is shown that the seals attain a maximum temperature of 375°F. The HAC temperature criterion (maximum allowable) for the seal material is set at 375°F with a duration of 1 hour.

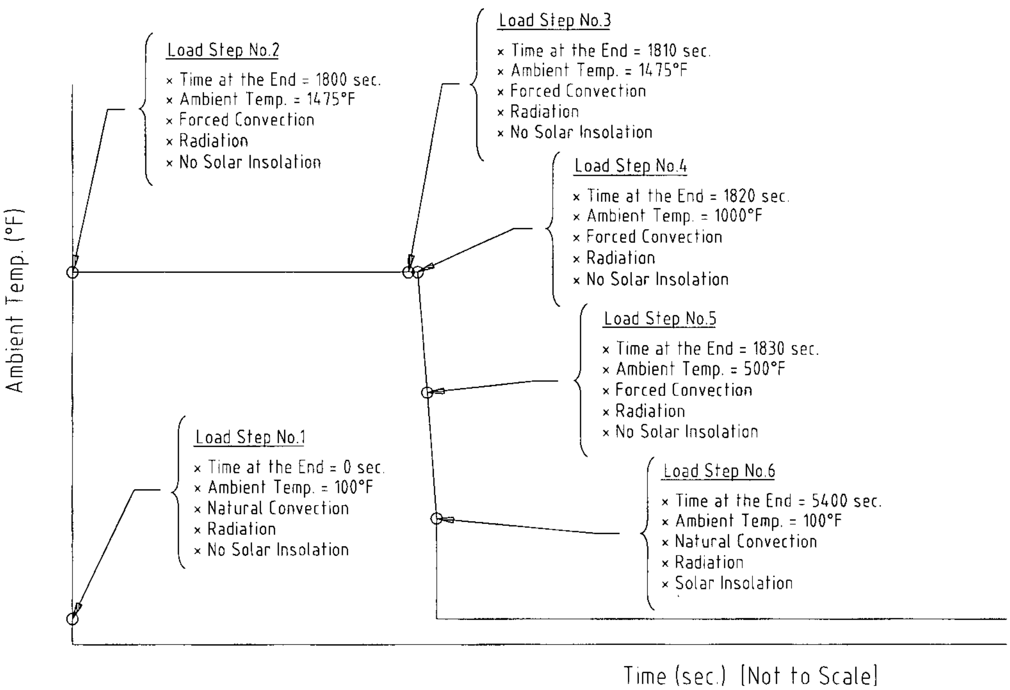


Figure 3.3
Transient Fire Analysis - Load Step and Boundary Conditions Schematic

Table 3.4

Summary of Maximum Hypothetical Accident Temperatures

Component	Maximum Calculated Temp. Location	Time (hrs)	Value (°F)	Maximum Allowable Temperature (°F)
Fire Shield	Mid-Plane	0.5	1361[1]	N.A.
Structural Shell	Mid-Plane	0.5	289[2]	800
Lead	Mid-Plane	0.73	274[2]	622
Seals	N.A.	8.5	164[2]	400

NOTES:
(1) From 1-d finite element model analysis.
(2) From 2-d finite element model analysis (Reference 11)

The maximum calculated temperatures are less than the maximum allowable temperatures for each component. Figure 3.3 plots the temperature during the fire transient of selected points in the model versus time. Figure 3.4 plots the temperature during the subsequent cooldown of the same points.

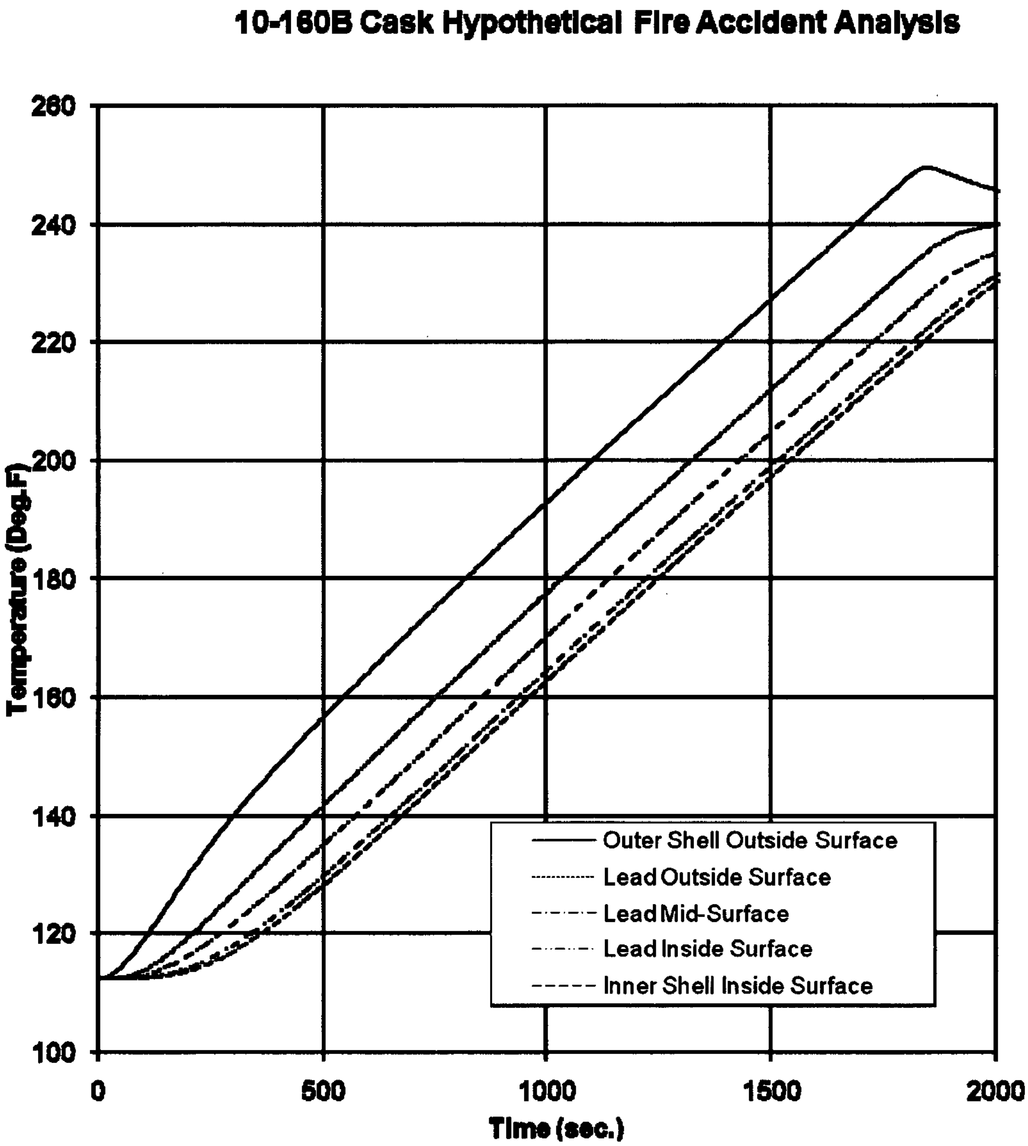


Figure 3.4

Hypothetical Accident - Fire Transient:
Temperature Versus Time

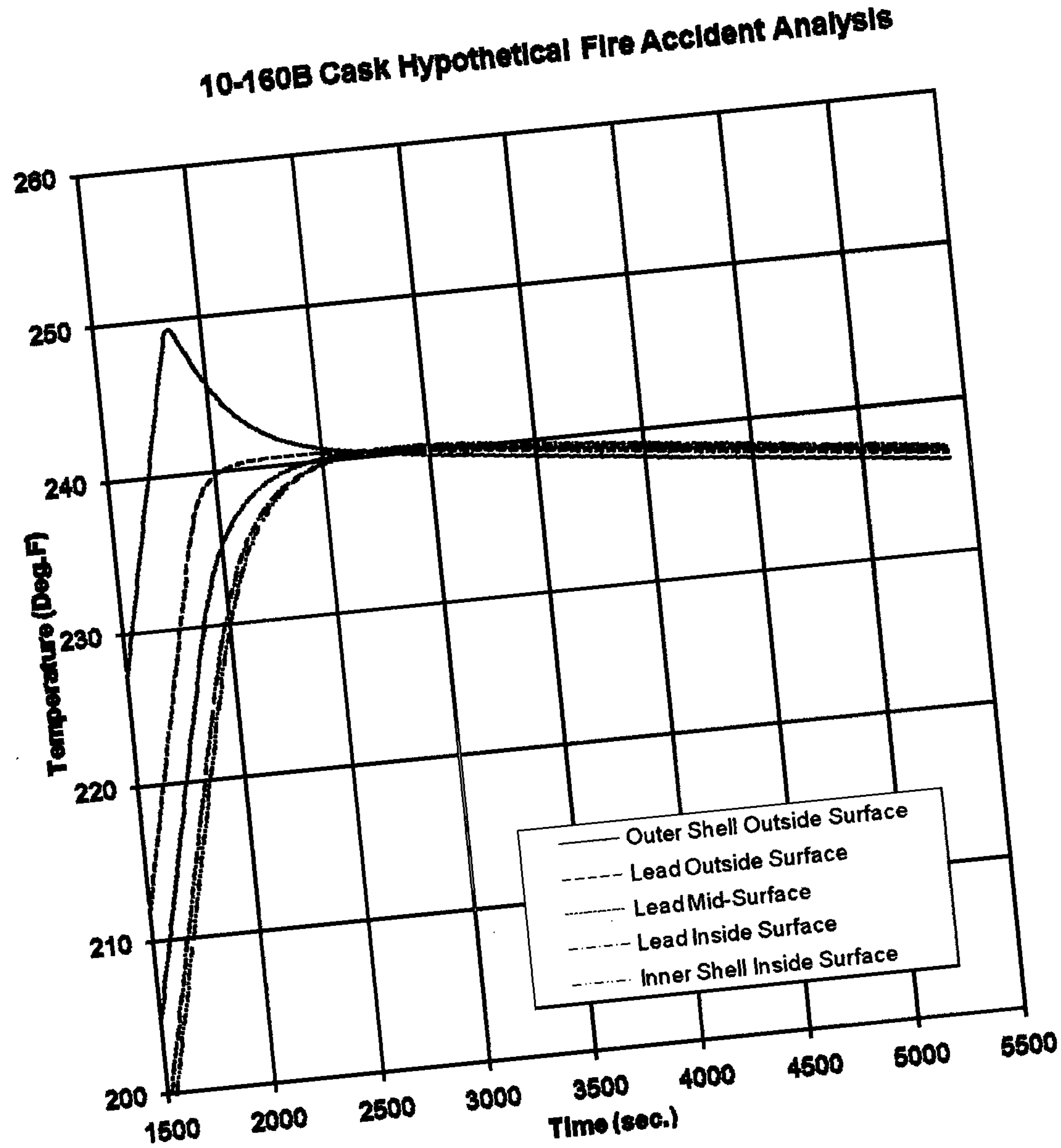


Figure 3.5

Hypothetical Accident - Cooldown:
Temperature Versus Time

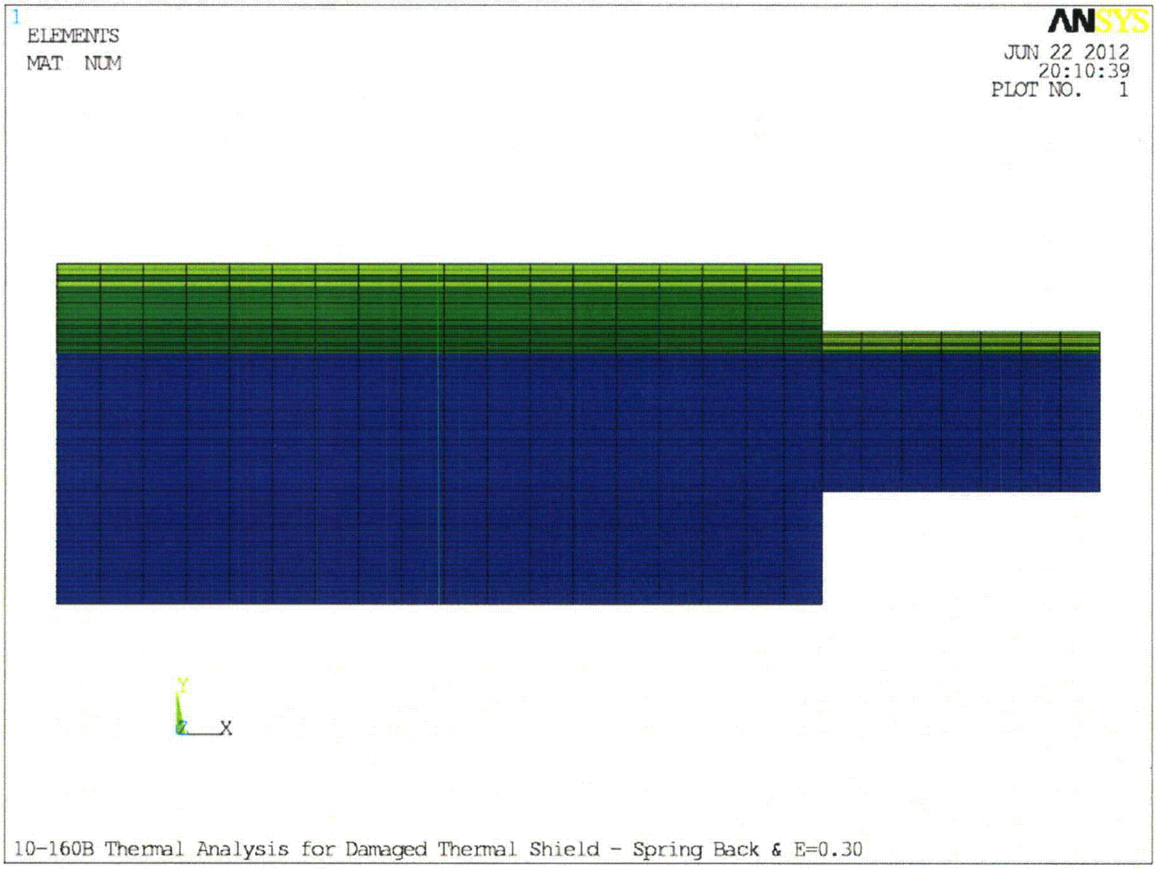


Figure 3.6

Finite Element Model of the Secondary Lid and the Thermal-Shield
(from Reference 12)

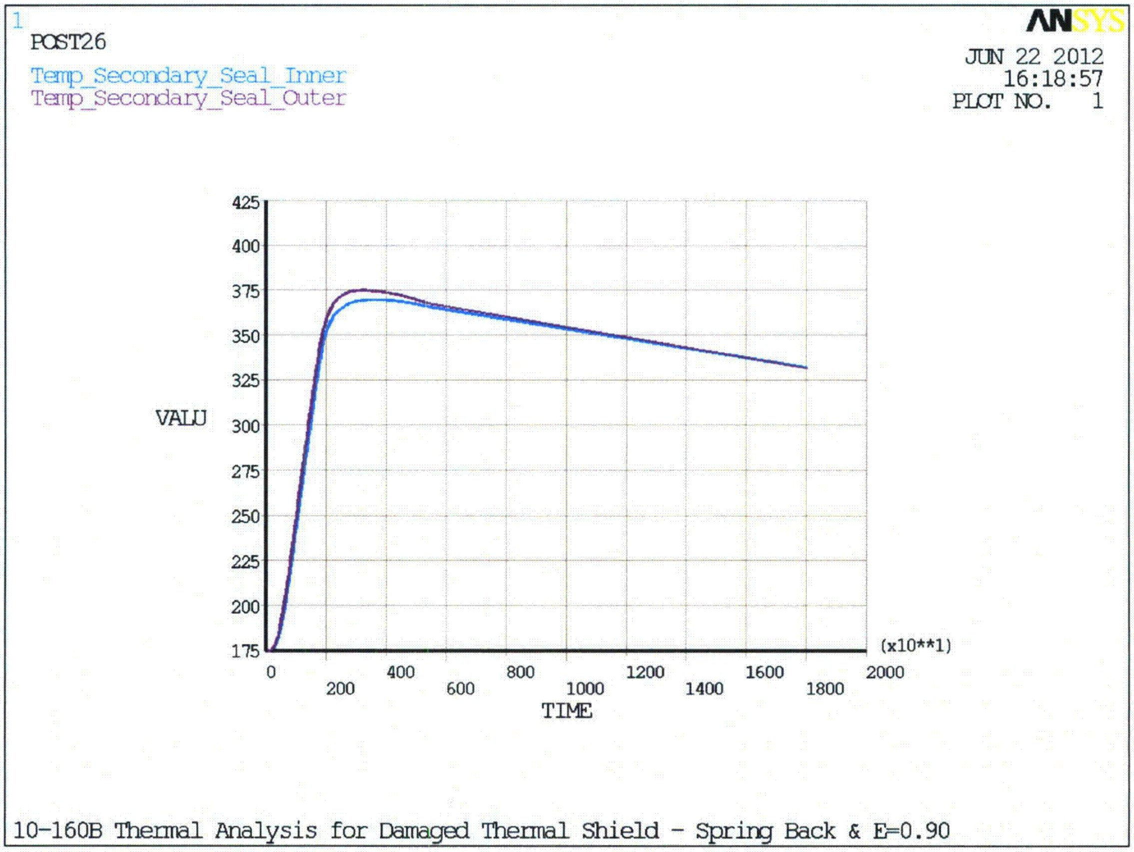


Figure 3.7

Seal Temperature Time-History Plot
(from Reference 12)

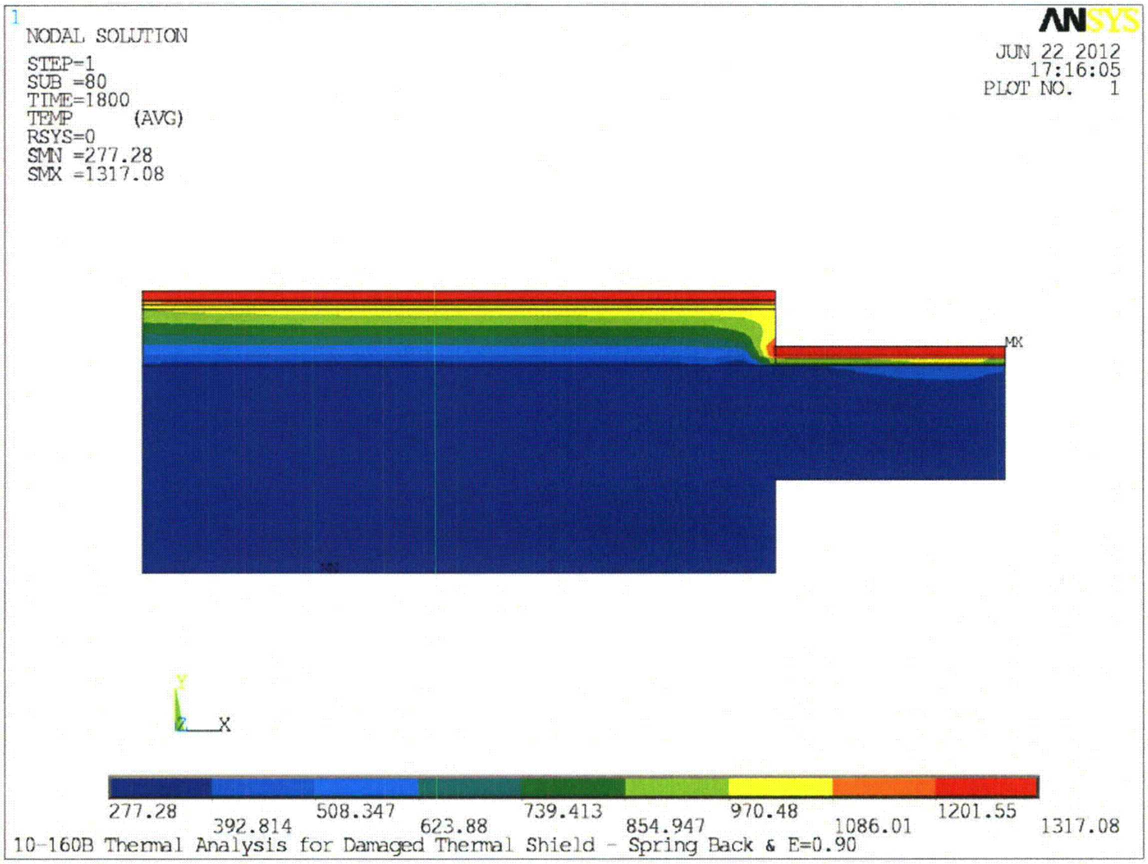


Figure 3.8

<u>Temperature Contour Plot at the end of 30 Minute Fire</u>
(from Reference 12)

3.5.4 Maximum Internal Pressures

The maximum internal pressure of the cask is calculated assuming that the gas within the cask, a mixture of air and water vapor, behaves as an ideal gas. The inside surface of the cask is assumed to be dry.

The temperature of the gas mixture within the cask is determined from the 2-d FEM of Reference 11. The analysis gives the maximum temperature as 281°F but the gas temperature is conservatively set as 290°F. Assuming that atmospheric pressure exists inside the cask at 70°F, the partial pressure of the gas mixture in the cask at 290°F, P_1, may be calculated by the ideal gas relationship given in equation 9.

(Equation 9)

$$P_1 = \frac{T_1}{T_2} * P_2$$

$$P_1 = \frac{(460+290°R)}{(460+70°R)} * 14.70 PSIA$$

$$P_1 = 22.4 PSIA$$

The vapor pressure contributed by water in the cavity at 290°F is 57.6 psia (Reference 10). The maximum gauge pressure in the cask during the hypothetical accident is equal to the pressure within the cask given by Equation 9 plus the water vapor pressure minus the outside ambient pressure. Equation 10 expresses the maximum gauge pressure for this cask during the hypothetical accident.

(Equation 10) 22.4 PSIA + 57.6 PSIA - 14.7 PSIA = 65.2 PSIG

An internal pressure of 94.3 PSIG is conservatively used in calculating the effects of combined thermal and pressure loading as discussed in Attachment 5 to Chapter 2. The allowable pressure due to buildup of gases in the cask (see Appendix 4.10.2) is conservatively set at 31.2 psig.

3.5.5 Maximum Thermal Stresses

The maximum temperature difference between the outside surface of the outer shell and the inside surface of the inner shell during the hypothetical accident is 39.8° F and occurs 30 minutes after the start of the fire. The maximum temperature difference across the outer shell is 20.2°F (occurring 30 minutes after the start of the fire) and the maximum temperature difference across the inner shell is 2.3°F (occurring 30.5 minutes after the start of the fire). The maximum average cask wall temperature (average of the temperatures at the inside surface of the inner shell and the outside surface of the outer shell) is 289°F and occurs at 45 minutes after the start of the fire. Thermal stresses resulting from temperature gradients during the hypothetical accident are discussed in Section 2.7.3.

3.5.6 Evaluation of Package Performance for the Hypothetical Accident Thermal Conditions

All temperatures in the package components due to the hypothetical accident thermal conditions are below their maximum allowable limits. The maximum HAC seal temperature is calculated to be 375°F during the cool-down period of the fire transient (see Reference 11). The seals material is specified to meet the minimum temperature requirement of 375°F. The maximum temperature in the lead shielding is calculated to be 274.4°F, which occurs at 0.73 hours after the start of the fire. This temperature is well below its melting point of 622°F. The steel body is also well below its service limit.

3.6 References

1. ASME Boiler and Pressure Vessel Code an American Standard, Section II, Part B Materials, The American Society of Mechanical Engineers, New York, NY, 1995.

2. Heat Transfer, J.P. Holman, Mc-Graw Hill Book Company, New York, Fifth Edition, 1981.

3. Code of Federal Regulations Title 10 Parts 71, Packaging and Transportation of Radioactive Material, 1998.

4. Cask Designers Guide, L.B. Shappert, et. al, Oak Ridge National Laboratory, February 1970, ORNL-NSIC-68.

5. CRC Handbook of Chemistry and Physics, Robert C. Weast and Melvin J. Astel, eds., CRC Press, Inc., Boca Raton, Florida, 62nd ed., 1981.

6. O-Ring Handbook, Parker Seal Company, Lexington, Kentucky, January 1977.

7. ANSYS Rev. 11 Computer Software, ANSYS Inc., Cannonsburgh, Pennsylvania, 2007.

8. IAEA Safety Series No.6, Regulations for the Safe Transport of Radioactive Material, 1985 Edition (As Amended 1990), International Atomic Energy Agency, Vienna, 1990.

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10. Chemical Engineers' Handbook, Fifth Edition, Robert H. Perry and Cecil H. Chilton, McGraw-Hill Book Company, 1973.

11. Energy*Solutions* Document CSG-01.1000, Rev.4, 10-160B Transportation Cask Thermal Analyses.

12. Energy*Solutions* Document No. TH-0002, Rev.3, Evaluation of Effectiveness of the Secondary Lid Thermal-Shields for the 8-120B and 10-160B Casks.

5. SHIELDING EVALUATION

5.1 Discussion and Results

5.1.1 Operating Design

The Model 10-160B packaging consists of a lead and steel containment vessel which provides the necessary shielding for the various radioactive materials to be shipped within the package. (Refer to Section 1.2.3 for packaging contents.) Tests and analysis performed under chapters 2.0 and 3.0 have demonstrated the ability of the containment vessel to maintain its shielding integrity under normal conditions of transport. Prior to each shipment, radiation readings will be taken based on individual loadings to assure compliance with applicable regulations as determined in 10CFR71.47 (see Section 7.1, step 13c).

The 10-160B will be operated under "exclusive use" such that the contents in the cask will not create a dose rate exceeding 200 mrem/hr on the cask surface, or 10 mrem/hr at two meters from the outer lateral surfaces of the vehicle. The package shielding must be sufficient to satisfy the dose rate limit of 10CFR71.51(a) (2) which states that any shielding loss resulting from the hypothetical accident will not increase the external dose rate to more than 1000 mrem/hr at one meter from the external surface of the cask.

5.1.2 Shielding Design Features

The cask side wall consists of an outer 2-inch thick steel shell surrounding 1 7/8 inches of lead and an inner containment shell wall of 1 1/8-inch thick steel.
The primary cask lid consists of two steel layers with a total thickness of 5½ inches. The lid closure is made in a stepped configuration to eliminate radiation streaming at the lid/cask body interface.
A secondary lid is located at the center of the main lid, covering a 31-inch opening. The secondary lid is constructed of steel plates with a total thickness of 5½ inches with multiple steps machined in its periphery. These steps match those in the primary lid, eliminating radiation streaming pathways. A stainless steel thermal shield covers the secondary lid and is attached to the secondary lid lifting lugs. The thermal shield is conservatively ignored in the shielding evaluation.
The cask bottom has an identical shielding effectiveness to the cask lids. It also consists of two layers of steel with a total thickness of 5 ½ inches.
Foam filled impact limiters cover the top and bottom of the vertically oriented cask. The impact limiters are conservatively ignored for the purpose of the shielding evaluation.

5.1.3 Maximum Dose Rate Calculations

Table 5.1 gives both Normal Conditions of Transport (NCT) and Hypothetical Accident Conditions (HAC) dose rates resulting from the maximum point sources (neutron and gamma) which may be in contact with either the side wall or the top (or bottom) of the cask. Maximum allowable dose rates given in 10CFR71 are shown in Table 5.1 for comparison. The following assumptions were used to develop the values shown in the table.

5.1.3.1 Normal Conditions

° The source is conservatively modeled as a point source centered in the cask cavity.

5.1.3.2 Accident Conditions

- The source is modeled as a point source on the inner liner adjacent to the location of the lead slump and in contact with the lid.

- Lead slump (see Section 2.7.1.1) considers the effect of loss of lead shielding from the slumped region in the side wall.

Table 5.1
Summary of Maximum Dose Rates (mrem/hr)

	Package Surface		1 m from Surface		2m from 8' trailer
Condition	Side	Top/Bottom	Side	Top/Bottom	Side
NCT					
Neutron Source	114	86.3	N.A	N.A.	9.44
Gamma Source	126	179	N.A	N.A.	9.96
Allowable	200	200	N.A.	N.A.	10.0
HAC					
Neutron Source	N.A.	N.A.	82.7	39.5	N.A.
Gamma Source	N.A.	N.A.	144	99.9	N.A
Allowable	N.A.	N.A.	1000.0	1000.0	N.A

5.2 Source Specification

5.2.1 Methodology

A unit point source is placed at the cask center. A neutron source and a gamma source are evaluated independently. The dose rate from the unit source is determined at the cask outer surface and at 2m from the 8' wide trailer. The ratio between the dose limit and the calculated value is determined. An equivalent source is set equal to the activity of the unit source times the smallest ratio of the surface limit to the calculated dose rate from the unit source. This equivalent source, which is the largest activity source that meets the cask NCT dose limits, is then used to evaluate the effects of the hypothetical accident. If the HAC limits are met for the maximum activity source, the cask complies with the requirements of 10 CFR 71. A mixed gamma and neutron source will also comply as the sum of the gamma and neutron dose rates must be less than the NCT dose limit and thus, as shown for the independently evaluated sources, the HAC limits will be met.

5.2.2 Gamma Source

SCALE models of the 10-160B cask are evaluated with a Co-60 source. The resulting equivalent source, approximately 13.4 Ci, gives a gamma dose rate of approximately 9.96 mrem/hr at 2m from the 8' wide trailer.

5.2.3 Neutron Source

SCALE models of the 10-160B cask are evaluated with a Pu-Be neutron source. A ^{239}Pu-Be source produces neutrons at a rate of approximately 1.4E+06 n/sec per Ci (Ref. 5.6.3). A 325 FGE (approximately 20 Ci) ^{239}Pu-Be source will produce approximately 2.8E+07 n/sec. The equivalent neutron source, which produces a dose rate of 9.4 mrem/hr at 2m from the 8' wide trailer, has an emission rate of 1.1 E+08 n/sec. Thus, the equivalent source used for the dose rate calculation is larger than the fissile gram limit imposed by the criticality evaluation of Chapter 6 and gives a conservative dose rate result. The neutron energy spectrum for a Pu-Be source is shown below.

Neutron Energy Spectrum for a Pu-Be Source (Ref. 5.6.3)

Energy Interval, E_i (MeV)	Fraction of neutrons in E_i
0-0.5	0.038
0.5-1	0.049
1-1.5	0.045
1.5-2	0.042
2-2.5	0.046
2.5-3	0.062
3-6.5	0.459
6.5-10.5	0.259
Total	1.000

5.3 Model Specification

5.3.1 Description of Radial and Axial Shielding Configuration

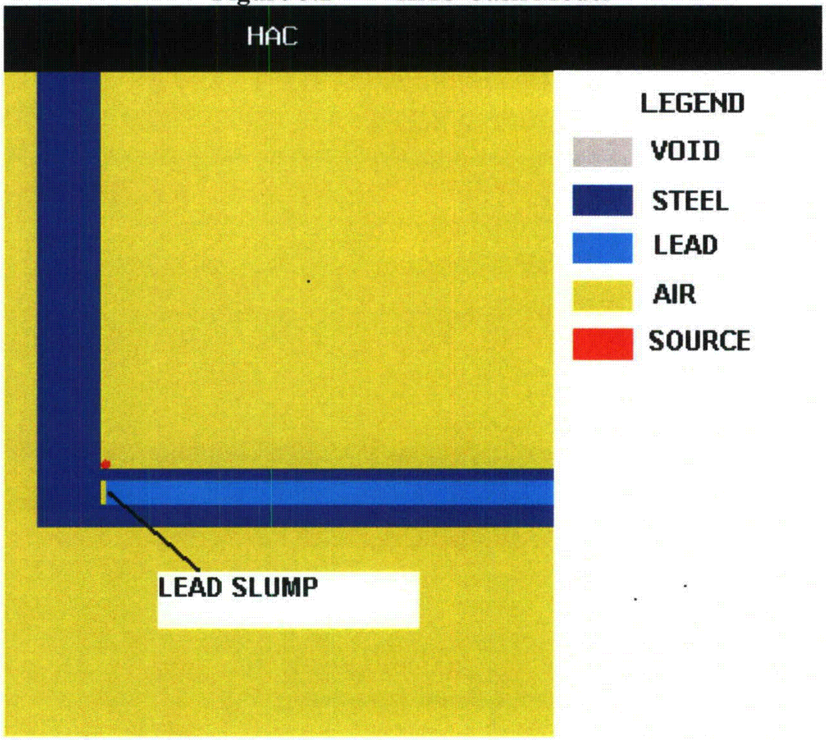
Normal Conditions of Transport (NCT)

The walls of the 10-160B cask, 1.125" inner and 2" outer steel walls with a 1.875" lead layer between, are modeled as cylindrical shells around the cavity cylinder. The base and lid of the cask is a 5.5" steel plate. Impact limiters are conservatively ignored. This geometry is shown in Figure 5.1. In terms of shielding, the cask lid and bottom are the same so only one end is modeled. The cask is transported upright, i.e., with the axis of the cylinder vertical. Doses are evaluated at contact with the cask sidewall, with the cask lid, and at 2m from the 8' wide trailer.

Figure 5.1 NCT Cask Model

Hypothetical Accident Conditions (HAC)
As discussed in Section 2, the hypothetical accident conditions do not affect the geometry of the steel shells or the base or lid (see Section 5.3.1, above). The HAC model is shown in Figure 5.3. The lead slump resulting from the 30' drop (< 0.02") discussed in Section 2.7.1.1, is included in the HAC model as a void 0.05 cm high at the top of the lead shell. Doses are determined at 1 m from the sidewall and the lid.

Figure 5.2 HAC Cask Model



5.3.2 Material Properties

The properties of the cask materials are shown in Table 5.2

Table 5.2 Material Properties

Material	Composition	Density (g/cm^3)
Source	beryllium / cobalt	1.85 / 8.9
Cask inner wall	Steel	7.82
Cask outer wall	Steel	7.82
Cask shield layer	Lead	11.34

5.4. Shielding Evaluation

5.4.1. Methods

The gamma and neutron dose rates were calculated using SCALE, Module SAS4 (Ref.3), using the geometry described in Section 5.3. The dose locations are surface or point detectors at the cask surface or at 2m from the trailer for NCT and at 1m from the cask surface for HAC.

5.4.2. Input and Output Data

The SCALE input and output files are provided in 5.8. The input file lists the inputs that define the source dimensions, shield dimensions, materials and density, and source spectrum.

5.4.3. Flux-to-Dose-Rate Conversion

The flux to exposure rate conversion factors are listed in Table 5.3 and Table 5.4 (Ref. 5.6.2). These are the default conversion factors in SCALE.

Table 5.3 Gamma-Ray-Flux-To-Dose-Rate Conversion Factors

Photon Energy-E (MeV)	$DF_g(E)$ Rem/hr)/(photons/cm^2-s)
0.01	3.96-06
0.03	5.82-07
0.05	2.90-07
0.07	2.58-07
0.1	2.83-07
0.15	3.79-07
0.2	5.01-07
0.25	6.31-07
0.3	7.59-07
0.35	8.78-07
0.4	9.85-07
0.45	1.08-06
0.5	1.17-06
0.55	1.27-06
0.6	1.36-06
0.65	1.44-06
0.7	1.52-06
0.8	1.68-06
1.0	1.98-06
1.4	2.51-06
1.8	2.99-06
2.2	3.42-06
2.6	3.82-06
2.8	4.01-06
3.25	4.41-06
3.75	4.83-06
4.25	5.23-06
4.75	5.60-06
5.0	5.80-06
5.25	6.01-06
5.75	6.37-06
6.25	6.74-06
6.75	7.11-06
7.5	7.66-06
9.0	8.77-06
11.0	1.03-05
13.0	1.18-05
15.0	1.33-05

Table 5.4 Neutron Flux-To-Dose-Rate Conversion Factors And Mean Quality Factors ($\overline{QF}$)

Neutron Energy-E (MeV)	$\overline{QF}$*	$DF_n(E)$ (rem/hr) (n/cm^2-s)
2.5-08	2	3.67-06
1.0-07	2	3.67-06
1.0-06	2	4.46-06
10.-05	2	4.54-06
1.0-04	2	4.18-06
1.0-03	2	3.76-06
1.0-02	2.5	3.56-06
1.0-01	7.5	2.17-05
5.0-01	11	9.26-05
1.0	11	1.32-04
2.5	9	1.25-04
5.0	8	1.56-04
7.0	7	1.47-04
10.0	6.5	1.47-04
14.0	75	2.08-04
20.0	8	2.27-04

*Maximum value of QF in a 30-cm phantom.
#Read as 2.5 x 10^{-8}

5.4.4. External Radiation Levels

The SCALE model used to determine external radiation levels uses point or surface detectors to calculate the dose rates at various distances from the cask surface either radially or axially. The point detectors are aligned with the point sources, thus normally giving the maximum dose rates. The highest dose rate from the point or surface detectors is reported. Table 5.5 contains the maximum neutron and gamma dose rates found for each of the four cases, i.e., NCT radial, NCT axial, HAC radial, and HAC axial for each of the sources, neutron and gamma.

Table 5.5 Maximum External Radiation Levels

Normal Conditions of Transport	**Package Surface (mrem/h)**			**2 Meters from Trailer (mrem/h)**
Radiation	Top	Side	Bottom	Side
Neutron Source	86.3	114	86.3	9.44
Gamma Source	179	126	179	9.96
10 CFR 71.47 Limit[1]	200	200	200	10

1. shipped as "exclusive use"

Hypothetical Accident Conditions	**1 Meter from Package Surface mSv/h (mrem/h)**		
Radiation	Top	Side	Bottom

Neutron Source	39.5	82.7	39.5
Gamma Source	99.9	143.6	99.9
10 CFR 71.51(a)(2) Limit	1000	1000	1000

5.5 Gamma Activity Limits

Using the cask model described in 5.3, additional calculations were performed to determine the maximum activity that can be contained in the 10-160B and meet the dose rate limits of 10 CFR 71.47. Since the results in Table 5.5 show that contents meeting NCT limits will meet HAC limits, maximum activity was determined only for NCT.

Two contents configurations were evaluated:

Point source – activity in a right circular cylinder; OD = 1 cm and height = 1 cm, centered in the cask cavity. The required secondary container is ignored for the shielding calculation.

Distributed source – activity homogeneously distributed in a right circular cylinder centered in the cask cavity with H=2r (approximately the geometry of the cask cavity) and Vρ=14,500 lbs (maximum allowed weight of contents); with a maximum r and H of 86cm and 194 cm, respectively (the cask cavity size is r=86.4cm and H=195.6cm). The required secondary container is ignored for the shielding calculation. Density (ρ) ranged from 0.5 to 8 g/cc. The material of the source was selected as Zr (z=40); multiple calculations with various materials showed a material selection of Zr was conservative.

Dose rates were calculated at 2m from the edge of the 8' wide cask trailer with a single energy group for each calculation varying from 0.3 to 4.0 MeV and an activity of 1×10^{12} gammas/sec. A surface detector was placed at 322cm from the centerline (x=322) extending from the midpoint (z=0) to 100 cm, divided into 10 segments. The maximum segment dose rate value was used. The flux to exposure rate conversion factors are the same as used previously and are listed in Table 5.4 (Ref. 5.6.2).

The maximum allowed gamma activity in gammas/sec for each gamma energy was determined by multiplying the modeled source activity (1×10^{12} gammas/sec) by the ratio of the dose rate limit (10 mrem/hr) to the calculated dose rate. The distributed source results are for contents with a density of 1 g/cc (unit density). Results of the maximum activity calculations for the point source are given in Table 5.6

Table 5.6 Point Source Activity Limits

Gamma Energy Group Range (MeV)	Group Mid-Point Energy (MeV)	SAS4 result at 2m (Rem/hr)	Activity equivalent to 10 mrem/hr (γ/s)
0.3-0.4	0.35	3.99E-07	2.51E+16
0.4-0.6	0.5	8.94E-06	1.12E+15
0.6-0.8	0.7	2.52E-04	3.96E+13
0.8-1.0	0.9	1.58E-03	6.31E+12
1.0-1.33	1.17	7.03E-03	1.42E+12
1.33-1.66	1.5	1.88E-02	5.31E+11
1.66-2.0	1.83	3.47E-02	2.88E+11
2.0-2.5	2.25	5.95E-02	1.68E+11
2.5-3.0	2.75	8.50E-02	1.18E+11

3.0-4.0	3.5	1.11E-01	8.98E+10

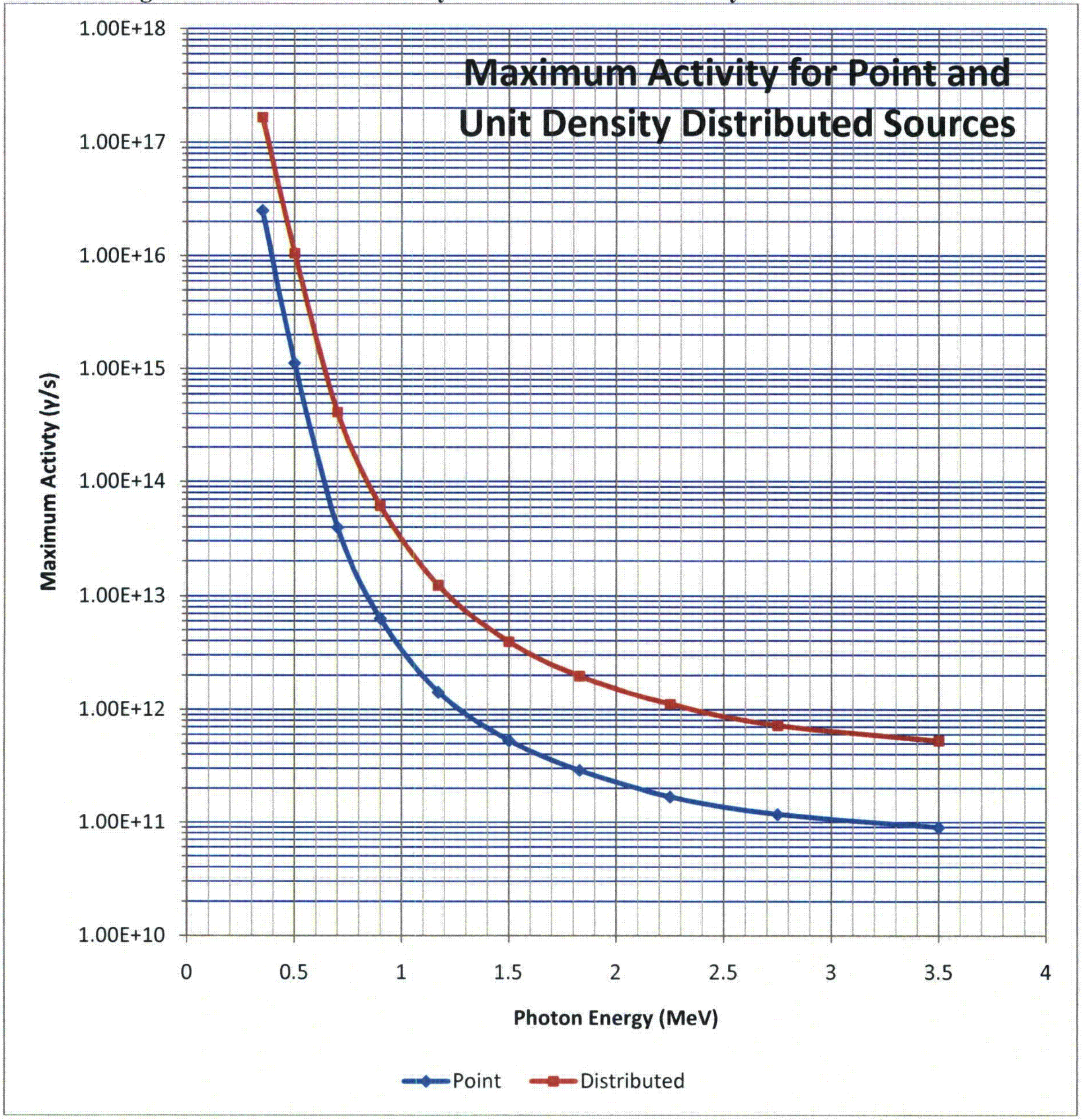
Results of the maximum activity calculations for the distributed unit density source are given in Table 5.7

Table 5.7 Distributed Unit Density Source Activity Limits

Gamma Energy Group Range (MeV)	Group Mid-Point Energy (MeV)	SAS4 result at 2m (Rem/hr)	Activity equivalent to 10 mrem/hr (γ/s)
0.3-0.4	0.35	6.03E-08	1.66E+17
0.4-0.6	0.5	9.50E-07	1.05E+16
0.6-0.8	0.7	2.43E-05	4.12E+14
0.8-1.0	0.9	1.62E-04	6.18E+13
1.0-1.33	1.17	8.10E-04	1.23E+13
1.33-1.66	1.5	2.55E-03	3.93E+12
1.66-2.0	1.83	5.08E-03	1.97E+12
2.0-2.5	2.25	8.93E-03	1.12E+12
2.5-3.0	2.75	1.39E-02	7.22E+11
3.0-4.0	3.5	1.89E-02	5.29E+11

The cask activity limits for a point source and a unit density distributed source are plotted in Figure 5.3. The mid-point group energy values are used for plotting purposes.

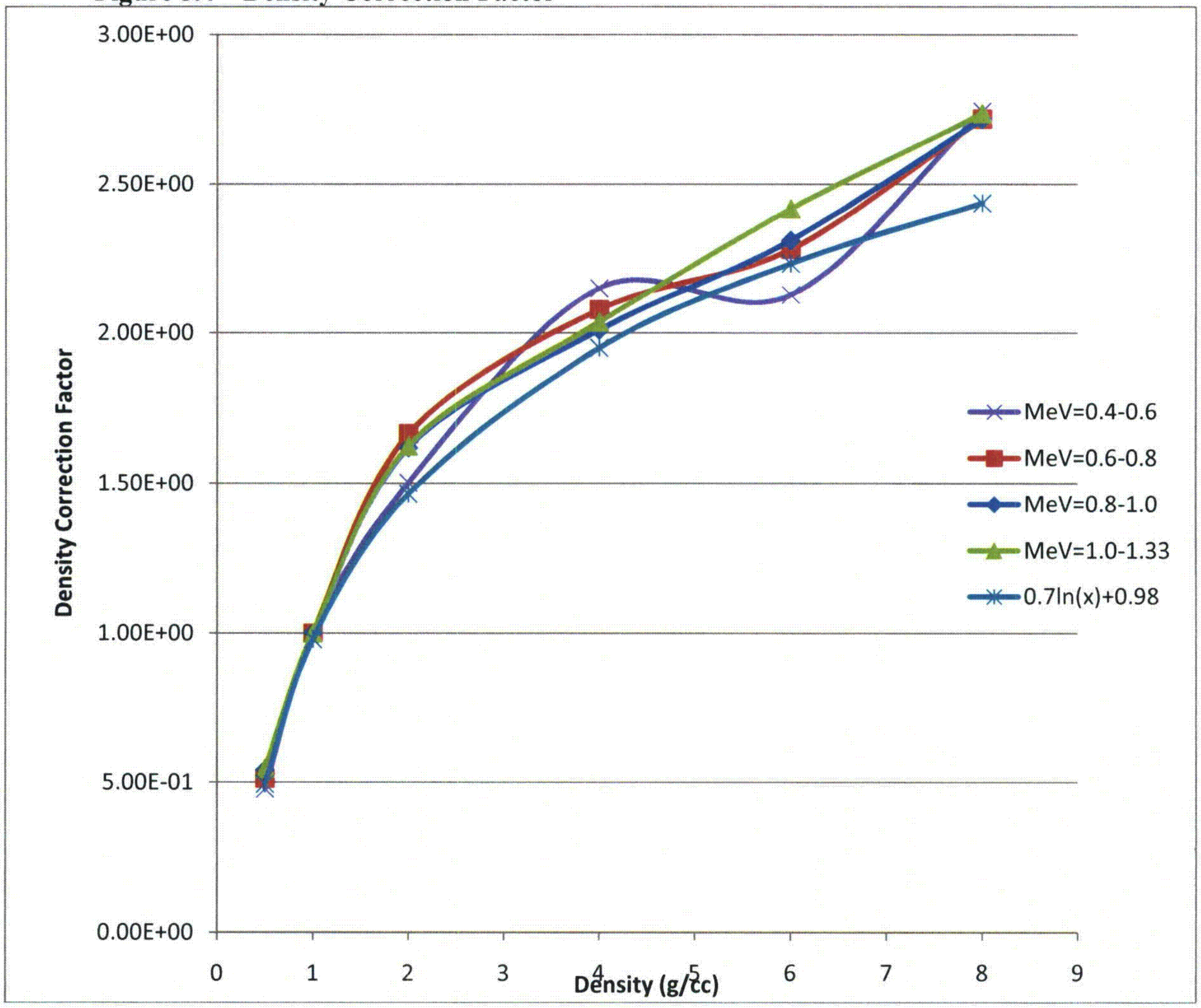
Figure 5.3 Maximum Activity for Point and Unit Density Distributed Sources



Due to self absorption and geometry (radius and height change with density), the dose rates from distributed sources will change with density, decreasing as density increases, resulting in a maximum activity that increases with density. A correction factor for the actual source density is applied to the distributed unit source results to give the source specific gamma activity limit. Maximum activity results for gamma energies from 0.4 to 1.33 MeV with source density varying from 0.5 to 8 g/cc (with a corresponding change in source geometry) were used to determine the density correction factor (DCF). The DCF is the ratio of the maximum activity at a density other than 1 to the maximum activity for the unit activity source. The DCFs for each energy group were plotted versus density and a curve was

conservatively fitted to the results. The equation of the curve is used to determine the DCF for any density of contents. Results of the density correction factor (DCF) calculations are plotted in Figure 5.4.

Figure 5.4 – Density Correction Factor



The equation for the fitted curve is:

$$DCF = 0.7\ln(\rho)+0.98$$

The maximum activity plot and the DCF, if applicable, are used to determine the maximum activity for any contents. A procedure for determining the maximum activity is provided in Chapter 7.

5.6 Conclusion

The cask shielding must be able to limit the dose rate to 1000 mrem/hr at 1 meter from any surface of the cask after the cask goes through the hypothetical accident. This section demonstrates compliance with this requirement. Structural analysis (Section 2.0) demonstrates that the cask wall will not fail during the hypothetical accident. However, lead slump may occur during a drop giving an isolated region in the sidewall without lead. Lead slump cannot occur in the lid or bottom of the cask since lead is not present in these parts of the cask. The dose rate at 1 meter from the cask in the slumped region (assuming a localized lead void) was determined to be

less than the 1000 mrem/hr limit for a source at the NCT dose rate limit. With application of the gamma activity limits from Section 5.5, the contents will meet the dose rate limits.

5.7 References

5.7.1 SCALE: A Modular Code System for Performing Standardized Computer Analyses for Licensing Evaluations, NUREG/CR-0200, Rev.6 (ORNL/NUREG/CSD-2/R6), Vols. I, II, III, May 2000

5.7.2 ANSI/ANS 6.1.1-1977, "Neutron and Gamma-Ray Flux-to-Dose-Rate Factors."

5.7.3 Cember, H, *Introduction to Health Physics,* Pergamon Press, New York, 1987

5.7.4 Guide to Verification andValidation of the SCALE-4Radiation Shielding Software, NUREG/CR-6484, November 1996

5.8 SCALE Input Files for 10-160B Consolidated SAR Rev. 0

5.8.1 10-160b-pt-axial-HAC.inp

```
'Input generated by Espn 89 Compiled on 06-07-2002
=sas4     parm=size=500000
10-160B pt axial
27n-18couple  infhommedium
 carbonsteel 1 1 293 end
 lead 2 1 293 end
 beryllium 3 1 293 end
 arbm-air 0.0002 2 0 0 0 7014 82 8016 18 4 1 293 end
 cobalt 5 1 293 end
end comp
 idr=0 ity=2 izm=5 isn=8 irf=9504 ifs=1 mhw=5 frd=86.36 szf=1  end
 86.36 89.218 93.98 99.06 199.06   end
 4 1 2 1 4   end
xend
 ran=000000091807 tim=120 nst=1000 nmt=4000 nit=1000 nco=4 ist=0 ipr=0
 iso=0 nod=16 sfa=1e+12 igo=4 inb=0 ine=0 mfu=5 isp=0 ipf=0 isd=4
 nda=1000  end
 soe 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
 0 0 22 78 0 0 0 0 0 0 0 0 end
 det 199.06 0 76.79 199.06 0 81.79 199.06 0 86.79 199.06 0 91.79 199.06
 0 96.79 199.06 0 101.79 199.06 0 106.79 199.06 0 111.79 199.06 0
 116.79 199.06 0 121.79 199.06 0 126.79 199.06 0 131.79 199.06 0
 136.79 199.06 0 141.79 199.06 0 146.79 199.06 0 151.79 end
 sdl 99.06 199.06 299.06 399.06 end
 sdr 70 120 70 140 70 90 70 90 end
 sds 10 0 14 36 0 0 0 0 end
 sxy 5 84.36 86.36 -1 1 95.79 97.79 86.36 97.79 99.06 111.76   end
gend
10-160b pt hac
 0 0 0 0
 sph 85.36 0 96.79 1
 rcc 0 0 -97.79 0 0 195.58 86.36
 rcc 0 0 -98.79 0 0 197.58 89.218
 rcc 0 0 -97.79 0 0 195.53 93.98
 rcc 0 0 -111.76 0 0 223.52 99.06
 sph 0 0 0 300
 sph 0 0 0 500
 rcc 0 0 -97.79 0 0 195.58 93.98
 rcc 0 0 -211.76 0 0 423.52 199.06
  end
 src +1
 cav +2 -1
 inn +3 -2
 shd +4 -3
 our +5 -8
 inv +6 -9
 exv +7 -6
 slp +8 -3 -4
 det +9 -5
  end
 1 1 1 1 1 1 1 1 1
 0 0 0 0 0 0 0 0 0
 5 4 1 2 1 1000 0 4 4
 0
```

```
end
```

5.8.2 10-160b-pt-axial-igo0.inp

```
'Input generated by Espn 89 Compiled on 06-07-2002
=sas4     parm=size=500000
10-160B pt
27n-18couple  infhommedium
 carbonsteel 1 1 293 end
 lead 2 1 293 end
 beryllium 3 1 293 end
 arbm-air 0.0002 2 0 0 0 7014 82 8016 18 4 1 293 end
 cobalt 5 1 293 end
end comp
 idr=1 ity=2 izm=3 isn=8 irf=9504 ifs=1 mhw=4 frd=1 szf=1  end
 1 97.79 111.76   end
 5 4 1   end
xend
 ran=000000111507 tim=120 nst=1000 nmt=4000 nit=1500 nco=4 ist=0 ipr=0
 iso=0 nod=0 sfa=1e+12 igo=0 inb=0 ine=0 mfu=5 isp=0 ipf=0 isd=4
 nda=1000  end
 soe 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
 0 0 22 78 0 0 0 0 0 0 0 0 end
 sds 10 0 18 0 10 0 10 0 end
gend
point source
 fue 1 97.78 end
fend
 inn 1 89.218 98.79 end
 rs1 2 93.98 97.79 end
 our 1 99.06 111.76 end
 as1 1 89.218 99.79 end
 hol 1 end
 cav 4 86.36 97.79 end
cend
end
```

5.8.3 10-160b-pt-HAC.inp

```
'Input generated by Espn 89 Compiled on 06-07-2002
=sas4     parm=size=500000
10-160B pt axial
27n-18couple  infhommedium
 carbonsteel 1 1 293 end
 lead 2 1 293 end
 beryllium 3 1 293 end
 arbm-air 0.0002 2 0 0 0 7014 82 8016 18 4 1 293 end
 cobalt 5 1 293 end
end comp
 idr=0 ity=2 izm=5 isn=8 irf=9504 ifs=1 mhw=5 frd=86.36 szf=1  end
 86.36 89.218 93.98 99.06 199.06   end
 4 1 2 1 4   end
xend
 ran=000000091807 tim=120 nst=1000 nmt=4000 nit=1000 nco=4 ist=0 ipr=0
 iso=0 nod=16 sfa=1e+12 igo=4 inb=0 ine=0 mfu=5 isp=0 ipf=0 isd=4
 nda=1000  end
 soe 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
 0 0 22 78 0 0 0 0 0 0 0 0 end
```

```
 det 199.06 0 76.79 199.06 0 81.79 199.06 0 86.79 199.06 0 91.79 199.06
 0 96.79 199.06 0 101.79 199.06 0 106.79 199.06 0 111.79 199.06 0
 116.79 199.06 0 121.79 199.06 0 126.79 199.06 0 131.79 199.06 0
 136.79 199.06 0 141.79 199.06 0 146.79 199.06 0 151.79 end
 sdl 99.06 199.06 299.06 399.06 end
 sdr 70 120 70 140 70 90 70 90 end
 sds 10 0 14 36 0 0 0 0 end
 sxy 5 84.36 86.36 -1 1 95.79 97.79 86.36 97.79 99.06 111.76   end
gend
10-160b pt hac
 0 0 0 0
 sph 85.36 0 96.79 1
 rcc 0 0 -97.79 0 0 195.58 86.36
 rcc 0 0 -98.79 0 0 197.58 89.218
 rcc 0 0 -97.79 0 0 195.53 93.98
 rcc 0 0 -111.76 0 0 223.52 99.06
 sph 0 0 0 300
 sph 0 0 0 500
 rcc 0 0 -97.79 0 0 195.58 93.98
 rcc 0 0 -211.76 0 0 423.52 199.06
  end
 src +1
 cav +2 -1
 inn +3 -2
 shd +4 -3
 our +5 -8
 inv +6 -9
 exv +7 -6
 slp +8 -3 -4
 det +9 -5
  end
 1 1 1 1 1 1 1 1 1
 0 0 0 0 0 0 0 0 0
 5 4 1 2 1 1000 0 4 4
 0

end
```

5.8.4 10-160b-pt-igo0.inp

```
'Input generated by Espn 89 Compiled on 06-07-2002
=sas4     parm=size=500000
10-160B pt
27n-18couple  infhommedium
 carbonsteel 1 1 293 end
 lead 2 1 293 end
 beryllium 3 1 293 end
 arbm-air 0.0002 2 0 0 0 7014 82 8016 18 4 1 293 end
 cobalt 5 1 293 end
end comp
 idr=0 ity=2 izm=5 isn=8 irf=9504 ifs=1 mhw=4 frd=1 szf=1  end
 1 86.36 89.218 93.98 99.06   end
 5 4 1 2 1   end
xend
 ran=000000111207 tim=120 nst=1000 nmt=4000 nit=10000 nco=4 ist=0 ipr=0
 iso=0 nod=0 sfa=1e+12 igo=0 inb=0 ine=0 mfu=5 isp=0 ipf=0 isd=4
 nda=1000  end
 soe 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
```

```
 0 0 22 78 0 0 0 0 0 0 0 0 end
 sdl 99.06 199.06 322 344 end
 sdr 0 20 0 100 0 100 0 10 end
 sds 5 1 10 1 10 1 1 1 end
gend
point source
 fue 1 97.78 end
fend
 inn 1 89.218 98.79 end
 rs1 2 93.98 97.79 end
 our 1 99.06 111.76 end
 as1 1 89.218 99.79 end
 hol 1 end
 cav 4 86.36 97.79 end
cend
end
```

5.8.5 10-160b-pt-n-axial-HAC.inp

```
'Input generated by Espn 89 Compiled on 06-07-2002
=sas4     parm=size=500000
10-160B pt neutron
27n-18couple  infhommedium
 carbonsteel 1 1 293 end
 lead 2 1 293 end
 beryllium 3 1 293 end
 arbm-air 0.0002 2 0 0 0 7014 82 8016 18 4 1 293 end
 cobalt 5 1 293 end
end comp
 idr=1 ity=1 izm=4 isn=8 irf=9029 ifs=1 mhw=3 frd=86.36 szf=1  end
 97.79 98.79 111.76 211.76   end
 4 1 1 4   end
xend
 ran=000000111607 tim=120 nst=1000 nmt=4000 nit=500 nco=4 ist=0 ipr=0
 iso=0 nod=9 sfa=1..1e+08 igo=4 inb=0 ine=0 mfu=3 isp=0 ipf=0 isd=4
 nda=1000  end
 soe 0.259 0.459 0.108 0.042 0.045 0.049 0.038 0 0 0 0 0 0 0 0 0 0 0
 0 0 0 0 0 0 0 0 end
 det 45.36 0 211.76 55.36 0 211.76 65.36 0 211.76 75.36 0 211.76 85.36
 0 211.76 95.36 0 211.76 105.36 0 211.76 115.36 0 211.76 125.36 0
 211.76 end
 sdl 111.76 211.76 311.76 411.76 end
 sdr 80 90 0 150 80 90 80 90 end
 sds 0 0 15 36 0 0 0 0 end
 sxy 3 84.36 86.36 -1 1 95.79 97.79 86.36 97.79 99.06 111.76   end
gend
10-160b pt hac
 0 0 0 0
 sph 85.36 0 96.79 1
 rcc 0 0 -97.79 0 0 195.58 86.36
 rcc 0 0 -98.79 0 0 197.58 89.218
 rcc 0 0 -97.79 0 0 195.53 93.98
 rcc 0 0 -111.76 0 0 223.52 99.06
 sph 0 0 0 400
 sph 0 0 0 500
 rcc 0 0 -97.79 0 0 195.58 93.98
 rcc 0 0 -211.76 0 0 423.52 199.06
  end
```

```
 src +1
 cav +2 -1
 inn +3 -2
 shd +4 -3
 our +5 -8
 inv +6 -9
 exv +7 -6
 slp +8 -3 -4
 det +9 -5
  end
 1 1 1 1 1 1 1 1 1
 0 0 0 0 0 0 0 0 0
 3 4 1 2 1 1000 0 4 4
 0
 end
```

5.8.6 10-160b-pt-n-axial-igo0.inp

```
'Input generated by Espn 89 Compiled on 06-07-2002
=sas4     parm=size=500000
10-160B pt
27n-18couple  infhommedium
 carbonsteel 1 1 293 end
 lead 2 1 293 end
 beryllium 3 1 293 end
 arbm-air 0.0002 2 0 0 0 7014 82 8016 18 4 1 293 end
end comp
 idr=1 ity=1 izm=3 isn=8 irf=9029 ifs=1 mhw=4 frd=1 szf=1  end
 1 97.78 111.76   end
 3 4 1   end
xend
 ran=000000091807 tim=120 nst=1000 nmt=4000 nit=500 nco=4 ist=0 ipr=0
 iso=0 nod=0 sfa=1.1e+08 igo=0 inb=0 ine=0 mfu=3 isp=0 ipf=0 isd=4
 nda=1000  end
 soe 26 46 11 4 5 5 4 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 end
 sdr 0 100 0 100 0 10 0 10 end
 sds 10 0 10 0 1 0 1 0 end
gend
point source
 fue 1 97.78 end
fend
 inn 1 89.218 98.79 end
 rsl 2 93.98 97.79 end
 our 1 99.06 111.76 end
 asl 1 89.218 99.79 end
 hol 1 end
 cav 4 86.36 97.79 end
cend
end
```

5.8.7 10-160b-pt-n-HAC.inp

```
'Input generated by Espn 89 Compiled on 06-07-2002
=sas4     parm=size=500000
10-160B pt neutron
27n-18couple  infhommedium
 carbonsteel 1 1 293 end
 lead 2 1 293 end
 beryllium 3 1 293 end
```

```
 arbm-air 0.0002 2 0 0 0 7014 82 8016 18 4 1 293 end
 cobalt 5 1 293 end
end comp
 idr=0 ity=1 izm=5 isn=8 irf=9029 ifs=1 mhw=3 frd=86.36 szf=1  end
 86.36 89.218 93.98 99.06 199.06   end
 4 1 2 1 4   end
xend
 ran=000000091807 tim=120 nst=1000 nmt=4000 nit=1000 nco=4 ist=0 ipr=0
 iso=0 nod=10 sfa=1.1e+08 igo=4 inb=0 ine=0 mfu=3 isp=0 ipf=0 isd=4
 nda=1000  end
 soe 0.259 0.459 0.108 0.042 0.045 0.049 0.038 0 0 0 0 0 0 0 0 0 0 0 0
 0 0 0 0 0 0 0 0 end
 det 199.06 0 57.79 199.06 0 67.79 199.06 0 77.79 199.06 0 87.79 199.06
 0 97.79 199.06 0 107.79 199.06 0 117.79 199.06 0 127.79 199.06 0
 137.79 199.06 0 147.79 end
 sdl 99.06 199.06 322 344 end
 sdr 70 120 0 140 80 100 80 100 end
 sds 10 0 14 36 10 0 10 0 end
 sxy 3 84.36 86.36 -1 1 95.79 97.79 86.36 97.79 99.06 111.76   end
gend
10-160b pt hac
 0 0 0 0
 sph 85.36 0 96.79 1
 rcc 0 0 -97.79 0 0 195.58 86.36
 rcc 0 0 -98.79 0 0 197.58 89.218
 rcc 0 0 -97.79 0 0 195.53 93.98
 rcc 0 0 -111.76 0 0 223.52 99.06
 sph 0 0 0 400
 sph 0 0 0 500
 rcc 0 0 -97.79 0 0 195.58 93.98
 rcc 0 0 -211.76 0 0 423.52 199.06
  end
 src +1
 cav +2 -1
 inn +3 -2
 shd +4 -3
 our +5 -8
 inv +6 -9
 exv +7 -6
 slp +8 -3 -4
 det +9 -5
  end
 1 1 1 1 1 1 1 1 1
 0 0 0 0 0 0 0 0 0
 3 4 1 2 1 1000 0 4 4
 0

end
```

5.8.8 10-160b-pt-n-igo0.inp

```
'Input generated by Espn 89 Compiled on 06-07-2002
=sas4     parm=size=500000
10-160B pt
27n-18couple  infhommedium
 carbonsteel 1 1 293 end
 lead 2 1 293 end
 beryllium 3 1 293 end
```

```
 arbm-air 0.0002 2 0 0 0 7014 82 8016 18 4 1 293 end
 cobalt 5 1 293 end
end comp
 idr=0 ity=1 izm=5 isn=8 irf=9029 ifs=1 mhw=4 frd=1 szf=1  end
 1 86.36 89.218 93.98 99.06   end
 3 4 1 2 1   end
xend
 ran=000000111307 tim=120 nst=1000 nmt=4000 nit=100 nco=4 ist=0 ipr=0
 iso=0 nod=0 sfa=1.1e+08 igo=0 inb=0 ine=0 mfu=3 isp=0 ipf=0 isd=4
 nda=1000  end
 soe 26 46 11 4 5 5 4 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 end
 sdl 99.06 199.06 322 344 end
 sdr 0 20 0 100 0 100 0 10 end
 sds 5 1 10 1 10 1 1 1 end
gend
point source
 fue 1 97.78 end
fend
 inn 1 89.218 98.79 end
 rs1 2 93.98 97.79 end
 our 1 99.06 111.76 end
 as1 1 89.218 99.79 end
 hol 1 end
 cav 4 86.36 97.79 end
cend
end
```

7.0 OPERATING PROCEDURE

This chapter describes the general procedure for loading and unloading of the 10-160B cask.

An optional steel insert may be used to shield the contents of the cask. The appropriate thickness of insert that should be used is determined from calculations and experience with previous, similar shipments. However, the insert must be thick enough so that dose rates on the exterior of the cask do not exceed the limits of 10 CFR 71.47, but must be no thicker than the maximum permissible size described in section 1.0.

The maximum permissible activity, for gamma emitting radionuclides, is the maximum activity in gammas/sec, determined per Attachment 1. For other radionuclide contents, the maximum activity is that which meets the decay heat limit of 200 watts. Radioactive contents are to be transported as exclusive use, per 10 CFR 71.4.

The maximum permissible payload of the cask is 14,500 pounds, including contents, secondary containers, shoring, and optional steel insert (if used).

For contents that could radiolytically generate combustible gases, the criteria of Section 4.8 must be addressed. For DOE TRU waste, compliance with the 5% hydrogen concentration limit shall be demonstrated by the methods discussed in Appendix 4.10.2. For other contents, which exceed the 5% concentration limit, the procedures in Section 7.4 can be used to satisfy the criteria of Section 4.8.

Powdered solids shipments require the cask to be leaktight. The most recent periodic leak test must meet the requirements of Chapter 4, Section 4.9, Periodic Verification Leak Rate Determination for Leaktight Status.

7.1 Procedure for Loading the Package

7.1.1 Initial Preparation

7.1.1.1 Remove Impact limiter and Secondary Lid Thermal Shield

7.1.1.1.1 Loosen and disconnect ratchet binders from upper impact limiter.

7.1.1.1.2 Using suitable lifting equipment, remove upper impact limiter. Care should be taken to prevent damage to impact limiter during handling and storage.

7.1.1.1.3 Remove the three pins from secondary lid lift lugs.

7.1.1.1.4 Using suitable lifting equipment, remove the secondary lid thermal shield. Care should be taken to prevent damage to thermal shield during handling and storage.

7.1.1.2 Determine if cask must be removed from trailer for loading purposes. To remove cask from trailer:

7.1.1.2.1 Disconnect cask to trailer tie-down equipment.

7.1.1.2.2 Attach cask lifting ears and torque bolts to 200 ft-lbs ± 20 ft-lbs lubricated.

7.1.1.2.3 Using suitable lifting equipment, remove cask from trailer and lower impact limiter and place cask in level loading position.

NOTE **THE CABLES USED FOR LIFTING THE CASK MUST HAVE A TRUE ANGLE, WITH RESPECT TO THE HORIZONTAL OF NOT LESS THAN 60°.**

7.1.2 Loosen and remove the twenty-four bolts (24, 1¾" – 8 UN) which secure the primary lid to cask body.

7.1.3 Remove primary lid from cask body using suitable lifting equipment and the three lifting lugs on the secondary lid. Care should be taken during lid handling operations to prevent damage to cask or lid seal surfaces.

NOTE **THE CABLES USED FOR LIFTING THE LID MUST HAVE A TRUE ANGLE, WITH RESPECT TO THE HORIZONTAL OF NOT LESS THAN 45°.**

NOTE **IN CERTAIN CIRCUMSTANCES, LOADING MAY BE ACCOMPLISHED THROUGH THE SECONDARY LID AND THE PRIMARY LID WILL REMAIN ON. IN THIS CASE, THE FOLLOWING ALTERNATE (A) STEPS WILL BE USED:**

7.1.1.A (ALTERNATE) REMOVE THE IMPACT LIMITER CENTER COVER PLATE. THIS WILL PROVIDE ACCESS TO THE SECONDARY LID AND LIFTING LUGS.

7.1.1.1.A (ALTERNATE)REMOVE THE THREE PINS FROM THE SECONDARY LID LIFT LUGS.

7.1.1.2.A (ALTERNATE)USING SUITABLE LIFTING EQUIPMENT, REMOVE THE SECONDARY LID THERMAL SHIELD. CARE SHOULD BE TAKEN TO PREVENT DAMAGE TO THE SHIELD DURING HANDLING AND STORAGE.

7.1.2.A (ALTERNATE) WORKING THROUGH THE CENTER HOLE IN THE UPPER IMPACT LIMITER, LOOSEN AND REMOVE THE 12 1¾" – 8 UN LID BOLTS WHICH SECURE THE SECONDARY LID TO THE PRIMARY LID.

7.1.3.A (ALTERNATE) REMOVE THE SECONDARY LID USING SUITABLE LIFTING EQUIPMENT AND THE THREE LUGS ON THE LID. CARE SHOULD BE TAKEN DURING LID HANDLING OPERATIONS TO PREVENT DAMAGES TO SEAL SURFACES OR THE LID

7.1.4 Visually inspect accessible areas of the cask interior for damage, loose materials, or moisture. Clean and inspect seal surfaces. Replace seals when defects or damage is noted which may preclude proper sealing.

NOTE **RADIOACTIVELY CONTAMINATED LIQUIDS MAY BE PUMPED OUT, REMOVED BY USE OF AN ABSORBENT MATERIAL, OR VIA DRAIN LINE. REMOVAL OF ANY MATERIAL FLOW INSIDE THE CASK SHALL BE PERFORMED UNDER THE SUPERVISION OF QUALIFIED HEALTH PHYSICS (HP) PERSONNEL WITH THE NECESSARY HP MONITORING AND RADIOLOGICAL HEALTH SAFETY PRECAUTIONS AND SAFEGUARDS.**

NOTE **WHEN SEALS ARE REPLACED (INCLUDING SEALS ON THE OPTIONAL VENT AND DRAIN PORTS), LEAK TESTING IS REQUIRED AS SPECIFIED IN SECTION 8.2.2.1.**

7.1.5 Check the torques on the cavity vent and drain line cap screws to determine that the cap screws are properly installed using O-rings. This step is not required if the cask does not have the optional vent and drain lines, or if the tamper seals on the vent or drain lines have not been removed. Torque the cap screws to 20 ± 2 ft-lbs.

7.1.6 Place radwaste material, disposable liners, drums, or other containers into cask and install shoring or bracing, if necessary to restrict movement of contents during transport.

7.1.7 Clean and inspect lid seal surfaces.

7.1.8 Replace the primary lid and secure the lid to the cask body by installing the 24 lid bolts. Ensure that the lid orientation stripe is in alignment with the cask stripe. Torque bolts to 300 ± 30 ft-lbs.

7.1.8.A (Alternate) Replace secondary lid (if removed) and secure to the primary lid with 12 bolts. Ensure that the lid orientation stripe is in alignment with the stripe on the primary lid. Torque the bolts to 300 ± 30 ft-lbs.

<u>NOTE</u> **PERFORM PRESSURE DROP LEAK TEST OF THE CASK PRIMARY LID, SECONDARY LID, VENT LINE, OR DRAIN LINE (AS APPLICABLE) IN ACCORDANCE WITH SECTION 8.2.2.2 PRIOR TO SHIPMENT OF PACKAGE LOADED WITH LARGE QUANTITIES OF LSA MATERIALS OR TYPE B QUANTITIES OF NON-LSA MATERIAL.**

7.1.9 If upper impact limiter was not removed, proceed as follows to install anti-tamper seals and Secondary Lid Thermal Shield

7.1.9.1 Install anti-tamper seals to the designated lid bolts, or to vent and/or drain line plugs (if applicable).

7.1.9.2 Using suitable lifting equipment, lift, inspect for damage and install the secondary lid thermal shield.

7.1.9.3 Install the three secondary lid thermal shield retaining pins into the secondary lid lift lugs.

7.1.10 If cask has been removed from trailer, proceed as follows to return cask to trailer:

7.1.10.1 Using suitable lifting equipment, lift and position cask into lower impact limiter on trailer in the same orientation as removed.

7.1.10.2 Unbolt and remove cask lifting ears.

7.1.10.3 Reconnect cask to trailer using tie-down equipment.

7.1.11 If upper impact limiter was removed, proceed as follows to install anti-tamper seals, secondary lid thermal shield, and upper impact limiter

7.1.11.1 Install anti-tamper seals to the designated lid bolts, or to vent and/or drain line plugs (if applicable).

7.1.11.2 Using suitable lifting equipment, lift, inspect for damage and install the secondary lid thermal shield.

7.1.11.3 Install the three secondary lid thermal shield retaining pins into the secondary lid lift lugs.

7.1.11.4 Using suitable lifting equipment, lift, inspect for damage and install upper impact limiter on cask in the same orientation as removed.

7.1.12 Attach and hand tighten ratchet binders between upper and lower impact limiters.

7.1.13 Cover lift lugs as required.

7.1.14 Install anti-tamper seals to the designated ratchet binder.

7.1.15 Replace center plate on the upper impact limiter (If Removed).

7.1.16 Inspect package for proper placards and labeling.

7.1.17 Complete required shipping documentation.

7.1.18 Prior to shipment of a loaded package the following shall be confirmed:

(a) That the licensee who expects to receive the package containing materials in excess of Type A quantities specified in 10 CFR 20.1906(b) meets and follows the requirements of 10 CFR 20.1906 as applicable.

(b) That trailer placarding and cask labeling meet DOT specifications (49 CRF 172).

(c) That the external radiation dose rates of the 10-160B are less than or equal to 200 millirem per hour (mrem/hr) at the surface and less than or equal to 10 mrem/hr at 2 meters in accordance with 10 CFR 71.47. Perform sufficient surveys to ensure that a non-uniform distribution of radioactivity does not cause the surface or 2m limit to be exceeded.

(d) That all anti-tamper seals are properly installed.

(e) For powdered solids shipments, the most recent periodic leak test demonstrated the cask was leaktight.

7.2 Procedure for Unloading Package

In addition to the following sequence of events for unloading a package, packages containing quantities of radioactive material in excess of Type A quantities specified in 10 CFR 20.1906(b) shall be received, monitored, and handled by the licensee receiving the package in accordance with the requirements of 10 CFR 20.1906 as applicable.

7.2.1 Move the unopened package to an appropriate level unloading area.

7.2.2 Perform an external examination of the unopened package. Record any significant observations.

7.2.3 Remove anti-tamper seals.

7.2.4 Removing Impact limiter and Secondary Lid Thermal Shield

7.2.4.1 Loosen and disconnect ratchet binders from upper impact limiter.

7.2.4.2 Using suitable lifting equipment, remove upper impact limiter. Care should be taken to prevent damage to impact limiter during handling and storage.

7.2.5 Removing Secondary Lid Thermal Shield

7.2.5.1 Remove the three pins from secondary lid lift lugs.

7.2.5.2 Using suitable lifting equipment, remove the secondary lid thermal shield. Care should be taken to prevent damage to thermal shield during handling and storage.

7.2.6 If cask must be removed from trailer, refer to Step 7.1.1.2.

7.2.7 (Optional if vent port installed). Vent cask cavity removing plugs from the vent line.

7.2.8 Loosen and remove the twenty-four (24) 1¾" – 8 UN primary lid bolts.

7.2.9 Using suitable lifting equipment, lift lid from cask using care during handling operations to prevent damage to cask and lid seal surfaces.

NOTE: **THE CABLES USED FOR LIFTING THE LID MUST HAVE A TRUE ANGLE WITH RESPECT TO THE HORIZONTAL OF NOT LESS THAN 45°.**

7.2.10 Remove contents to disposal area.

NOTE: **RADIOACTIVELY CONTAMINATED LIQUIDS MAY BE PUMPED OUT, REMOVED BY USE OF AN ABSORBENT MATERIAL, OR VIA DRAIN LINE. REMOVAL OF ANY MATERIAL FROM INSIDE THE CASK SHALL BE PERFORMED UNDER THE SUPERVISION OF QUALIFIED HEALTH PHYSICS (HP) PERSONNEL WITH THE NECESSARY HP MONITORING AND RADIOLOGICAL HEALTH SAFETY PRECAUTIONS AND SAFEGUARDS.**

7.2.11 Assemble package in accordance with loading procedure (7.1.7 through 7.1.17).

7.3 Preparation of Empty Packages for Transport

The Model 10-160B cask requires no special transport preparation when empty. Loading and unloading procedures outlined in this chapter shall be followed as applicable for empty packages. The requirements of 49 CFR 173.428 shall be complied with.

NOTE: EACH PACKAGE USER WILL BE SUPPLIED WITH A COMPLETE DETAILED OPERATING PROCEDURE FOR USE WITH THE PACKAGE.

7.4 Procedures for Shipment of Packages Which Generate Combustible Gases

Procedures for preparing packages for shipment which radiolytically generate combustible gases are outlined below. These procedures are divided into two categories:

a. Combustible gas control by inerting, and

b. Combustible gas suppression.

7.4.1 Combustible Gas Control by Inerting

7.4.1.1 Dewater the secondary container. The bulk of the free water is removed from the secondary container by displacing the water with nitrogen gas.

7.4.1.2 Inert the secondary container (and, if necessary, the cask). The inerting operation is done at the dewatering station just before the cask is loaded. Inerting is performed if the hydrogen generated will be greater than 5% in any portion of the package for a time period that is twice the expected shipping time. Inerting is intended to limit the oxygen concentration to less than 5% including any oxygen that is radiolytically generated over the same period considered for hydrogen generation. If a leak path can develop between the secondary container and the cask, the cask will also be inerted.

7.4.1.3 Inerting of the secondary container and / or the cask cavity, to achieve an oxygen concentration of less than 5%, can be performed per the following:

- Connect a nitrogen supply.
- Pressurize with nitrogen to 15 ±1 psig. for fifteen minutes.

- Depressurize to ~ 0 psig.
- Repeat this pressurization / depressurization cycle two more times

7.4.2 Combustible Gas Suppression

7.4.2.1 Dewater the secondary container. See paragraph 7.4.1.1.

7.4.2.2 Install the previously qualified* combustible gas suppression system (e.g., a vapor pressure catalytic recombiner).

*Previous qualification means that the catalytic recombiner design to be used has been tested for a period of twice the expected shipping time under conditions expected in transport and has proven satisfactory.

7.4.2.3 Sample the gas in the secondary container and measure static pressure. This will assure that the combustible gas control method is working properly and that the combustible gas criteria specified in Section 4.4 will be met.

7.4.2.4 Load the secondary container.

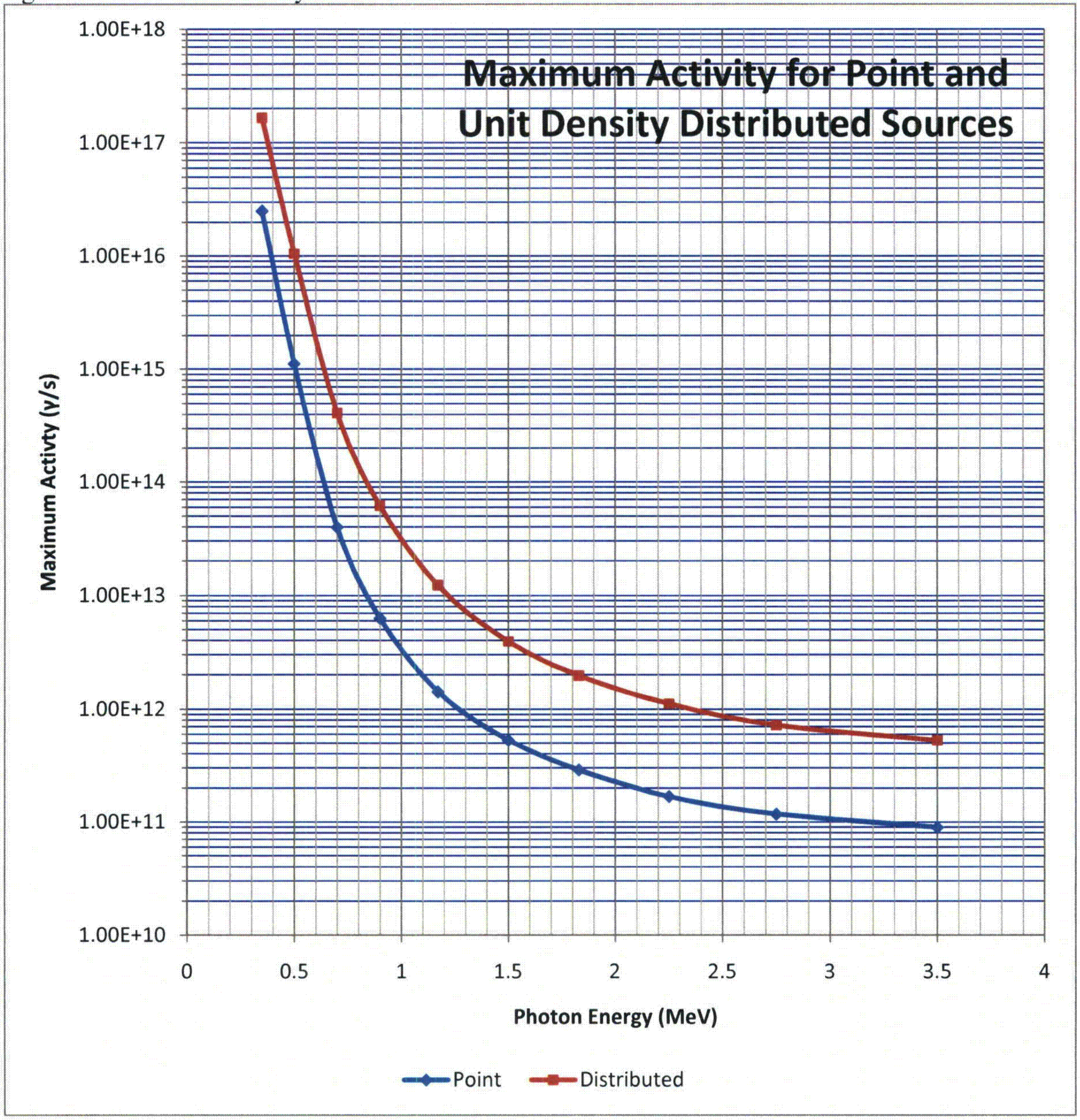
Attachment 1
Determination of Acceptable Activity
(see Chapter 5 for the derivation of the gamma activity limits)

1. Determine the total activity in the contents.
2. Determine if the content should be considered a distributed source. A distributed source is one that meets the definition of "distributed throughout" from NUREG-1608 and has a volume of at least 7.5 ft^3. If the content is a distributed source, determine the density (ρ) of the content, in g/cm^3.
3. Calculate the total gamma/sec for the contents by photon energy. Determine the photons per second for each photon energy, ignoring photon energies below 0.3 MeV. If any photons have energies above 4.0 MeV, the material is unacceptable for transport in the cask. For contents with a large number of gammas, the gammas may be grouped into energy groups and the photons per second determined for the group. Typical energy groupings (in MeV) are: 0.3-0.4, 0.4-0.6, 0.6-0.8, 0.8-1.0, 1.0-1.33, 1.33-1.66, 1.66-2.0, 2.0-2.5, 2.5-3.0, and 3.0-4.0.
4. Determine the unit density gamma activity limit for each photon energy (or for each energy group using the limit at the maximum energy of each photon group) from Step 4 using the plot in Figure A-1. Use the point source or the distributed source limit as appropriate from Step 2.
5. If the content is a distributed source, calculate the Density Correction Factor (DCF) and multiply the unit density gamma limit by the DCF to determine the specific density gamma limit.

$$DCF = 0.7\ln(\rho)+0.98$$

6. Calculate the sum of fractions, i.e., divide the gamma/sec for each photon energy (or for each energy group) by the limit for that energy (or group) and sum the fractions.
7. If the sum is less than 1.0, the contents meet the activity limits of the CoC.
Caution: To ensure compliance, a sum of less than 0.9 is recommended.

Figure A-1 – Gamma Activity Limits



Example 1 - Determine the acceptability of a 50 Ci Cs-137 source. The source is a metal capsule 2 cm in diameter and 10 cm long.

Step 1	The activity is 50 Ci
Step 2	The content is not a distributed source
Step 3	Cs-137 produces 0.85 gammas per decay with an energy of 0.66 MeV. The total gamma/sec is 3.7E+10 d/sec per Ci x 0.85 gamma/d x 50Ci = 1.57E+12 gamma/sec. All the gamma would be in energy group 0.6-0.8MeV.
Step 4	The limit for energy group 0.6-0.8 (mid-point energy = 0.7MeV) for a point source is 3.96+13.
Step 5	NA
Step 6	Sum = 1.57E+12 / 3.96E+13 = 0.04

Step 7 Sum is less than 1. The content meets the activity limits.

Example 2 – Determine the acceptability of a secondary container containing 100 ft^3 of solidified process waste. The activity is homogeneously distributed. The measured weight of the waste is 13,100 lbs. The isotopic activity, determined by analysis of samples of the waste, is: ^{60}Co-5 Ci, ^{137}Cs-10 Ci, ^{55}Fe-50 Ci, ^{54}Mn-4 Ci, ^{90}Sr-8 Ci

Step 1 The activity is 77 Ci
Step 2 The contents are a distributed source. The calculated density is 2.1 g/cm^3.
Step 3 See Table below
Step 4 See Table below
Step 5 DCF = 0.7ln(ρ)+0.98
DCF = 1.50
Step 6

Group No.	Group Mid-Point Energy (MeV)	Activity (photons/sec)	Unit Density Limit (photons/sec)	Specific Density Limit (photons/sec)	F
1	0.35	0.00E+00	1.66E+17	2.49E+17	0.00E+00
2	0.50	0.00E+00	1.05E+16	1.58E+16	0.00E+00
3	0.70	3.15E+11	4.12E+14	6.18E+14	5.10E-04
4	0.90	1.48E+11	6.18E+13	9.28E+13	1.60E-03
5	1.17	1.85E+11	1.23E+13	1.85E+13	9.99E-03
6	1.50	1.85E+11	3.93E+12	5.89E+12	3.14E-02
7	1.83	0.00E+00	1.97E+12	2.95E+12	0.00E+00
8	2.25	0.00E+00	1.12E+12	1.68E+12	0.00E+00
sum					4.35E-02

Step 7 F is less than 1. Thus, the contents meet the activity limits.

SOURCE INSERT ADDENDUM

FOR

MODEL 10-160B

TYPE B RADWASTE SHIPPING CASK

July 2012

Energy*Solutions*
140 STONERIDGE DRIVE
COLUMBIA, SOUTH CAROLINA 29210

1.0 GENERAL INFORMATION

1.1 Introduction

This Addendum demonstrates that the Model 10-160B package, ID number USA/9204/B(U)F-96, can be used as a shipping package to transport a shield insert containing a large quantity of Co-60 in compliance with regulatory requirements under both normal conditions of transport and hypothetical accident conditions as required by 10CFR71.

1.2 Package Description

1.2.1 Packaging

There are no changes to the 10-160B cask described in Chapter 1 of the SAR. A source insert, used to contain the radioactive sources, is added as an additional component of the packaging.

The source insert provides photon (gamma) shielding in the forms of lead and steel for photon shielding. The photon shield has side walls consisting of lead with a total thickness of 6.0 inches, located between an inner 8.0-inch (nominal) SCH 40 steel pipe and an outer 24.0-inch (nominal) SCH 60 steel pipe. The bottom consists of 6.0 inches of lead supported by a 0.75-inch thick steel base plate. The lid includes a steel encased lead plug (nominal lead thickness 8 7/8 inches), steel bolting plate, and flat silicon rubber gasket.

1.2.2 Operational Features

There are no changes to the Operational Features of the Packaging described in Chapter 1 of the SAR. Refer to the General Arrangement Drawing of the package in SAR Chapter 1, Appendix 1.3.

1.2.3 Contents of Packaging

1.2.3.1 Cask Contents

The radioactive material consists of solid items with a maximum of 10,000 Curies (Ci) of Cobalt-60 (Co-60). The radioactive items will be loaded into the shield insert.

For this Addendum,

The type and form of material will include:

1) Byproduct material as normal form solid metal.

Maximum quantity of material per package:

1) 10,000 Ci of Co-60 contained in a shield insert specified in Drawing C-038-145082-004.

2) The maximum decay heat will not exceed 200 watts.

3) The contents of the source insert have a maximum mass of 500 pounds.

4) The total weight of contents, shoring, and source insert shall not exceed 14,500 pounds.

5) The contents of the source insert shall not include water or organic materials, explosives, corrosives, pyrophorics, or compressed gases.

1.3 Appendix - Source Insert Drawing (C-038-145082-004)

2.0 STRUCTURAL EVALUATION

No changes.

2.1 Structural Design

No changes.

2.2 Weights and Center of Gravity

The 10-160B Cask SAR limits the payload to 14,500 lbs. The weight of the Co-60 source insert is itemized as follows:

Source Insert Body	6,500	lb
Source Insert Lid	500	lb
Source Payload	500	lb
Source Insert	7,500	lb
Design Source Insert Weight	8,000	lb

The steel cribbing that will be used to support the insert inside the 10-160B cask will weigh less than 5,000 lbs. Therefore, the combined maximum load inside the 10-160B cask will be 10,500 lbs – much smaller than the licensed weight of 14,250 lbs.

The Source Insert is placed in the 10-160B cask in such a way that its C.G. is located near the C.G. of the 10-160B Cask. Therefore, the combined C.G. of the 10-160B package will remain at the same location as that analyzed in the SAR.

2.3 Mechanical Properties of Materials

The steel (A-516 Gr. 70) and the lead (B-29) material used for the construction of the source insert are the same as those specified in the SAR. The bolts used for the attachment of the lid to the body are specified to be SAE J-429 Gr.5. The mechanical properties of these bolts are as follows.

Yield Stress, S_y = 92,000 psi

Ultímate Stress, S_u = 120,000 psi

Design Stress Intensity, S_m = 23,000 psi

Under NCT loading the allowable stresses are as follows.

Membrane stress = 46,000 psi

Membrane + bending stress = 69,000 psi

Shear stress = 27,600 psi

Under HAC loading the allowable stresses are as follows.

Membrane stress = 105,000 psi

Membrane + bending stress = 150,000 psi

Shear stress = 50,400 psi

2.4 General Standards for All Packages

No changes.

2.4.1 Chemical and Galvanic Reactions

No changes.

2.4.2 Positive Closure

No changes.

2.4.3 Lifting Devices

The lifting arrangement of the 10-160B Cask package remains the same. No changes in the SAR for lifting analyses of the package are made. The handling of the Co-60 source insert is not directly under the jurisdiction of 10 CFR Part 71 as it is performed in the confines of the controlled area of the shipper. Nonetheless, the lifting arrangement of the Co-60 source insert has been evaluated in Reference 26 based on the requirements of 10 CFR Part 71. It has been shown that the lifting attachments meet those requirements.

2.4.4 Tie-Down Devices

No changes. The tie-down devices of the 10-160B Cask remain the same.

2.5 Standards for Type B and Larger Quantity Packaging

Not applicable.

2.6 Normal Condition of Transport

No changes.

2.6.1 Heat

Evaluation of the temperature distribution in the 10-160B Cask with the Co-60 source insert has been performed in Section 3 Addendum. It has been demonstrated that the temperature distribution in the cask results in temperature values and gradients that are within those analyzed in the SAR. Therefore, no changes in the SAR are needed.

The temperature distribution in the Co-60 source insert is fairly uniform with a little or no temperature gradients (see Figure 10 of Reference 12 in Section 3). Therefore, the stresses in the structural components of the Co-60 source insert will be negligible.

2.6.2 Cold

No changes.

2.6.3 Pressure

The cavity temperature of the 10-160B Cask package, with the Co-60 source insert is conservatively estimated to be 231.2°F. The maximum operating pressure calculated based on this temperature is 3.91 psig (see Section 3.4.4), which is smaller than 8.4 psig used in the SAR.

2.6.4 Vibration

No changes.

2.6.5 Water Spray

No changes.

2.6.6 Free Drop

No changes.

2.6.6.1 End Drop

The effect of 1-ft free drop of the cask package in the end drop orientation on the Co-60 source insert has been analyzed in Section 6.3 of Reference 26 and is shown to meet all the applicable stress allowable values listed in the SAR.

2.6.6.2 Side Drop

The effect of 1-ft free drop of the cask package in the side drop orientation on the Co-60 source insert has been analyzed in Section 6.3 of Reference 26 and is shown to meet all the applicable stress allowable values listed in the SAR.

2.6.6.3 Corner Drop

The effect of 1-ft free drop of the cask package in the corner drop orientation on the Co-60 source insert has been analyzed in Section 6.3 of Reference 26 and is shown to meet all the applicable stress allowable values listed in the SAR.

2.6.7 (Successive) Corner Drop

Not applicable.

2.6.8 Penetration

No changes.

2.7 <u>Hypothetical Accident Conditions</u>

No changes.

2.7.1 Free Drop

The SAR has evaluated the 10-160B Cask package for the hypothetical accident drop test conditions with a generic payload. The specific payload comprising of the Co-60 source insert and the cribbing, meets the payload limits of the SAR. Therefore, there is no change in SAR analyses. The evaluation of the Co-60 source insert during these drop tests are addressed in the following sections.

2.7.1.1 Free Drop Impact – End Drop

The effect of 30-ft free drop of the cask package in the end drop orientation on the Co-60 source insert has been analyzed in Section 6.2.1 of Reference 26 for the impact on the bottom end, and Section 6.2.2 of Reference 26 for the top end impact. It is shown that the stresses in every component of the Co-60 source insert meet all the applicable stress allowable values listed in the SAR.

2.7.1.1.1 End Drop Secondary Lid Bolt Forces

No changes.

2.7.1.1.2 End Drop Primary Lid Bolt Forces

No changes.

2.7.1.1.3 Lead Slump

There are no changes in the lead slump evaluation of the 10-160B Cask body presented in the SAR. The effect of lead slump in the Co-60 source insert has been evaluated in Section 6.4.1 of Reference 26. It has been shown that the lead-shielding used in the insert undergoes a maximum deformation of 0.049 in. Since the stresses in the lead column are much smaller than the plastic flow stress, most of this deformation is recovered resulting in very small lead slump, if any.

2.7.1.2 Free Drop Impact-Side Drop

The effect of 30-ft free drop of the cask package in the side drop orientation on the Co-60 source insert has been analyzed in Section 6.2.3 of Reference 26. It is shown that the stresses in every component of the Co-60 source insert meet all the applicable stress allowable values listed in the SAR.

2.7.1.3 Free Drop Impact-Corner Drop

The effect of 30-ft free drop of the cask package in the corner drop orientation on the Co-60 source insert has been addressed in Section 6.2 of Reference 26. It has been shown that the deceleration loading on the Co-60 source insert during this drop is enveloped by the end drop and side deceleration loadings. No separate evaluation of the Co-60 source insert was needed.

2.7.1.4 Oblique Drop

No changes.

2.7.1.5 Impact Limiter Attachment Forces

No changes.

2.7.2 Puncture

No changes.

2.7.3 Thermal

No changes.

2.7.3.1 Summary of Pressures and Temperatures

The temperature distribution in the 10-160B Cask, with the Co-60 source insert is shown in Reference 26 to envelop the values used in the SAR. No changes in this section are needed.

2.7.3.2 Differential Thermal Expansion

No changes.

2.7.3.3 Stress Calculation

The temperature distribution in the 10-160B Cask, with the Co-60 source container is shown in Reference 26 to envelop the values used in the SAR. No changes in this section are needed.

2.7.4 Water Immersion

No changes.

2.7.5 Summary of Damage

No changes.

2.8 Special Form

Not applicable.

2.9 Fuel Rods

Not applicable.

2.10 Appendix to Section 2.0

2.10.1 Foam Impact Limiter Analytical Methods

No changes.

2.10.2 ANSYS Finite Element Analysis of Cask Body Structure

No changes.

2.10.3 Summarized Results of Cask Structural Calculations

No changes.

2.10.4 References

26. Energy*Solutions* Document ST-663, Rev.0, Structural Evaluation of the Co-60 Source Package for the NCT & HAC Tests.

3.0 THERMAL EVALUATION

No changes.

3.1 Discussion

The 10-160B Cask SAR provides the analyses of the cask package with a generic heat load of 200 Watt. The source container used in the 2-d finite element analyses discussed in Section 3.5.1.3 and Reference 11 was an arbitrary small size container. The thermal analyses of the Co-60 source insert for the NCT and HAC fire test has been performed using 2-d axisymmetric models with the appropriate dimensions and geometry.

The heat load of the Co-60 source is 153.9 Watt. Conservatively 200 Watt of internal heat load is used in the thermal analyses reported in this addendum.

The results of the Co-60 source insert for the NCT are summarized in Table 3.1-3 and for HAC in Table 3.1-4. In these tables it is shown that the summary presented in Tables 3.1-1 and 3.1-2 of the SAR envelop the corresponding results obtained for the Co-60 source package.

3.2 Summary of Thermal Properties of Materials

No new thermal properties have been used in the analyses of the Co-60 source package.

3.3 Technical Specifications of Components

The steel and the lead material used for the construction of the Co-60 source insert are the same as those specified in the SAR.

3.4 Thermal Evaluation for Normal Conditions of Transport

No changes.

3.4.1 Thermal Model

The finite element model used for the thermal analysis of the 10-160B Cask with the Co-60 source insert comprises of 2-dimensional axisymmetric solid and contact elements. The details of the finite element model used in the analyses are provided in Reference 12. The Co-60 source insert model uses some conservative simplifications that are documented in Reference 12.

The boundary conditions used in the analysis of the Co-60 source package are the same as those used in the SAR.

3.4.2 Maximum Temperatures

The maximum temperatures in various parts of the Co-60 source package during NCT are reported in Table 3.1-3. These values are compared with those reported in the SAR.

3.4.3 Minimum Temperature

No changes.

3.4.4 Maximum Internal Pressures

The bulk air temperature of 231.2°F reported in Table 3.1-3 is higher than that reported in the SAR. The maximum internal pressure of the cask with the increased temperature of 231.2°F (rounded to 240°F) is presented below.

The maximum internal pressure of the cask is calculated assuming that the gas within the cask behaves as an ideal gas. To determine the maximum internal pressure under normal conditions in the cask (MNOP) the temperature of the gas mixture within the cask was evaluated. The maximum pressure is due to the increased temperature of the gas in the cavity. The insert and cask cavity are dry and there are no materials in the insert that will generate gas by radiolysis.

1. The cask on loading has an internal pressure equal to ambient, assumed to be 14.7 psi at 70°F.
2. The pressure in the cask at 240°F (T_2, the maximum temperature under normal conditions), P_2, may be calculated by the ideal gas relationship:

   $P_2 = \frac{T_2}{T_1} \times P_1$, where T is in degrees absolute

   $P_2 = 18.3$ psi

Therefore, the calculated maximum normal operating pressure (in gage pressure) is,

$$\text{MNOP} = 18.3 - 14.7 = 3.6 \text{ psig}$$

The value used for MNOP is conservatively set at 35.0 psig. Since the MNOP for the Source Insert in the 10-160B is less than the value in the base SAR, no change is required.

3.4.5 Maximum Thermal Stresses

No changes.

3.4.6 Evaluation of Package Performance for Normal Conditions of Transport

No changes.

3.5 Hypothetical Accident Thermal Evaluation

No changes.

3.5.1 Thermal Model

The finite element model used for the thermal analysis of the 10-160B Cask with the Co-60 source insert comprises of 2-dimensional axisymmetric solid and contact elements. The details of the finite element model used in the analyses are provided in Reference 12. The Co-60 source insert model uses some conservative simplifications that are documented in Reference 12.

The boundary conditions used in the analysis of the Co-60 source package are the as those used in the SAR with some conservative modifications that are detailed in Reference 12.

3.5.2 Package Conditions and Environment

No changes.

3.5.3 Package Temperatures

The maximum temperatures in various parts of the Co-60 source package during HAC fire test are reported in Table 3.1-4. These values are compared with those reported in the SAR.

3.5.4 Maximum Internal Pressures

The bulk air temperature of 296°F reported in Table 3.1-4 is higher than that used in the SAR for evaluation of the cask internal pressure (200°F). The maximum internal pressure of the cask with the increased temperature of 296°F (rounded to 300°F) is presented below.

The maximum internal pressure of the cask is calculated assuming that the gas within the cask behaves as an ideal gas.

The temperature of the gas mixture within the cask is evaluated (see Table 3.1-4). The average gas temperature in the cask under HAC is conservatively set at 300°F. Assuming 14.7 psia (see Section 3.3.2) exists inside the cask at 70°F, the pressure in the cask at 300°F, P_2, may be calculated by the ideal gas relationship:

$$P_2 = \frac{T_2}{T_1} \cdot P_1$$, where T is in degrees absolute

$P_2 = 21.8$ psia

Therefore, the maximum pressure during the HAC fire,

$P_{max} = 21.8 - 14.7 = 6.4$ psig

The value used for P_{max} is conservatively set at 100 psig. Since the P_{max} for the Source Insert in the 10-160B is less than the value in the base SAR, no change is required.

3.5.5 Maximum Thermal Stresses

No changes.

3.5.6 Evaluation of Package Performance for the Hypothetical Accident Thermal Conditions

No changes.

3.6 References

12. Energy*Solutions* Document TH-031, Rev.0, Thermal Analyses of the Co-60 Source Package for NCT & HAC Fire Test.

Table 3.1-3

Summary of NCT Hot Environment Analysis Results

Component	Maximum Temperature °F	
	Calculated Co-60 Source Package Value	SAR Value
Difference across the cask body[1]	0.11	0.2
Difference across the outer shell[2]	0.04	0.0
Difference across the inner shell[3]	0.01	0.0
Average Wall[4]	166.1	173
Lead[5]	166.2	173
Body[6]	168.4	175
Seal[7]	168.1	174
Bulk Air[8]	231.2	188
Payload (Source) [9]	233.1	-

NOTES:

(1) Difference of Node 377 and Node 314 Temperature. See Figure 7 of Reference 12.
(2) Difference of Node 377 and Node 409 Temperature. See Figure 7 of Reference 12.
(3) Difference of Node 283 and Node 314 Temperature. See Figure 7 of Reference 12.
(4) Average of Node 377 and Node 314 Temperature. See Figure 7 of Reference 12.
(5) Average of Node 409 and Node 283 Temperature. See Figure 7 of Reference 12.
(6) Maximum temperature from Figure 8 of Reference 12.
(7) Maximum of Node 153 and Node 80 temperatures. See Figure 7 of Reference 12.
(8) Maximum temperature from Figure 9 of Reference 12.
(9) Maximum temperature from Figure 10 of Reference 12.

Table 3.1-4

Summary of HAC Fire Test Analysis Results

Component	Maximum Temperature °F		
	Calculated Co-60 Source Package Value	Value Calculated in the SAR	Value Used in the Analyses in the SAR
Difference across the cask body(1)	31.7	39.8	45
Difference across the outer shell(2)	15.2	20.2	24
Difference across the inner shell(3)	1.65	2.3	2
Average Wall(4)	294	279	334
Lead(5)	294	274	335
Body(6)	302	289	352
Seal(7)	206	164	352
Bulk Air(8)	296	188	200
Payload (Source) (9)	253	-	-

NOTES:

(1) Difference of Node 377 and Node 314 Temperature. See Appendix 3 of Reference 12.
(2) Difference of Node 377 and Node 409 Temperature. See Appendix 3 of Reference 12.
(3) Difference of Node 283 and Node 314 Temperature. See Appendix 3 of Reference 12.
(4) Average of Node 377 and Node 314 Temperature. See Appendix 3 of Reference 12.
(5) Average of Node 409 and Node 283 Temperature. See Appendix 3 of Reference 12.
(6) Maximum temperature at Node 377. See Figure 7 and Appendix 3 of Reference 12.
(7) Maximum of Node 153 and Node 80 temperatures. See Appendix 3 of Reference 12.
(8) Maximum temperature from Figure 13. See also Appendix 3 of Reference 12.
(9) Maximum temperature from Figure 19. See also Appendix 3 of Reference 12.

4.0 CONTAINMENT

There are no changes to the containment evaluation found in Chapter 4 of the base SAR. The A_2 value of the new content is 909, which is less than the A_2 value used in the containment evaluation, i.e., 3000.

5. SHIELDING EVALUATION

This shielding evaluation supports exclusive use shipment of a shielded source Insert (hereafter referred to as the Insert) containing a maximum 10,000 Curies of Co-60 in the Model 10-160B Transport Cask (hereafter referred to as the Cask). The evaluation results documented in this chapter show that the combined shielding of the Insert and the Cask are adequate to meet the radiological requirements of 10 CFR 71 for exclusive use shipments.

5.1 Description of Shielding Design

5.1.1 Design Features

5.1.1.1 Operating Design

The Cask is designed, constructed, and prepared in accordance with 10 CFR 71.71 so that the maximum external dose rates do not exceed the criteria for NCT. The Cask is authorized by the U.S. Nuclear Regulatory Commission (NRC) to carry a payload of 14,500 pounds (6,577 kilograms) of Type B quantity radioactive byproduct, source, or special nuclear material. Furthermore, since it is a Type B package, it is designed so that the maximum external radiation dose rate will not exceed 1 rem/hr (1000 mrem/hr) at 1 meter from the external surface of the package under HAC. Both normal and accident condition dose rates described below are based on computer models that reflect the post-test package conditions.

The Insert is designed, constructed, and prepared for a one-time shipment as a shielded insert to the Cask. The Insert is comprised of gamma (i.e. photon) shielding that is to be supported and centered in the Cask cavity by steel shoring. The Insert is loaded into the Cask, which is then transported on an 8-foot wide drop-deck trailer.

Tests and analyses have demonstrated the ability of the packaging to maintain its shielding integrity during NCT. However, under HAC, neither the steel shoring nor the Co-60 source are expected to maintain structural integrity. Note that the steel shoring has not been modeled for either configuration. Multiple configurations and positions of the Cask and Insert for HAC are postulated and evaluated.

5.1.1.2. Shielding Design

Representative views of the Cask, Insert, and the Co-60 source are presented in Figures 5-1 through 5-4. A representative view of the shielding model of the Cask and Insert is presented in Figure 5-4 with a corresponding component and material specification summary presented in Table 5-1. Key dimensions are summarized in Table 5-2. The thermal shield, attached to the secondary lid, has been conservatively neglected in this evaluation.

Figure 5-1. 10-160B Cask General Arrangement

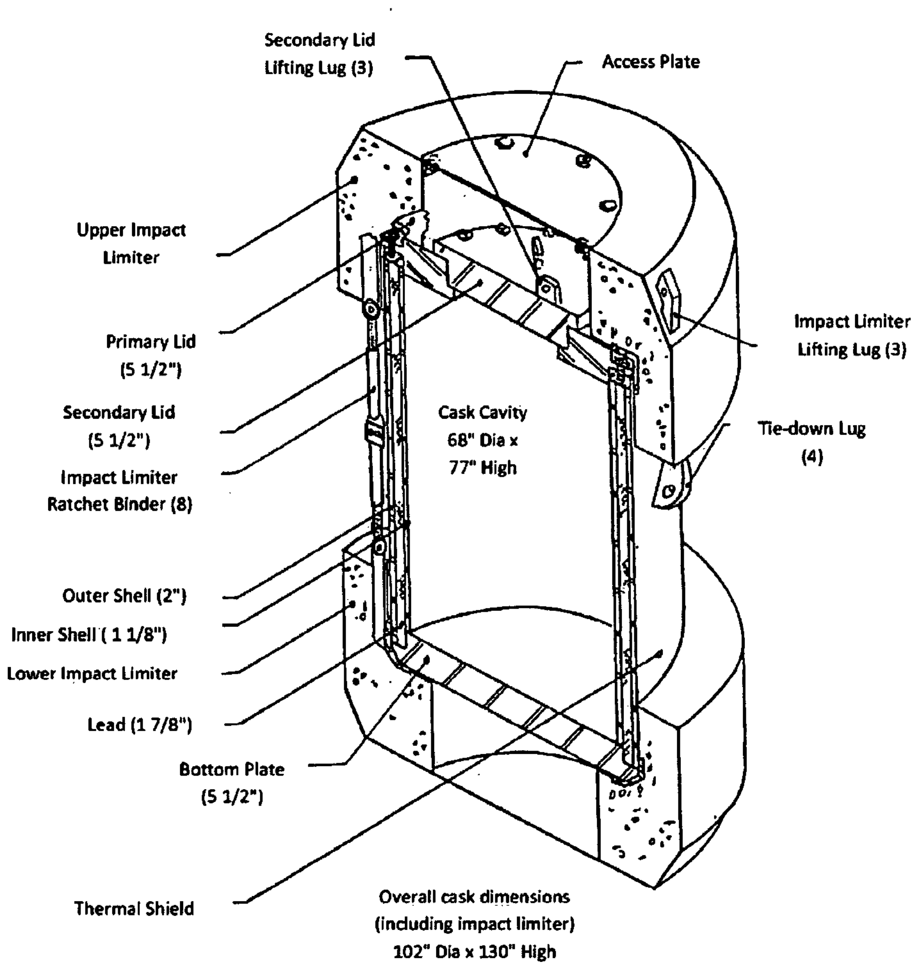


Figure 5-2. Cutaway View of Source Insert

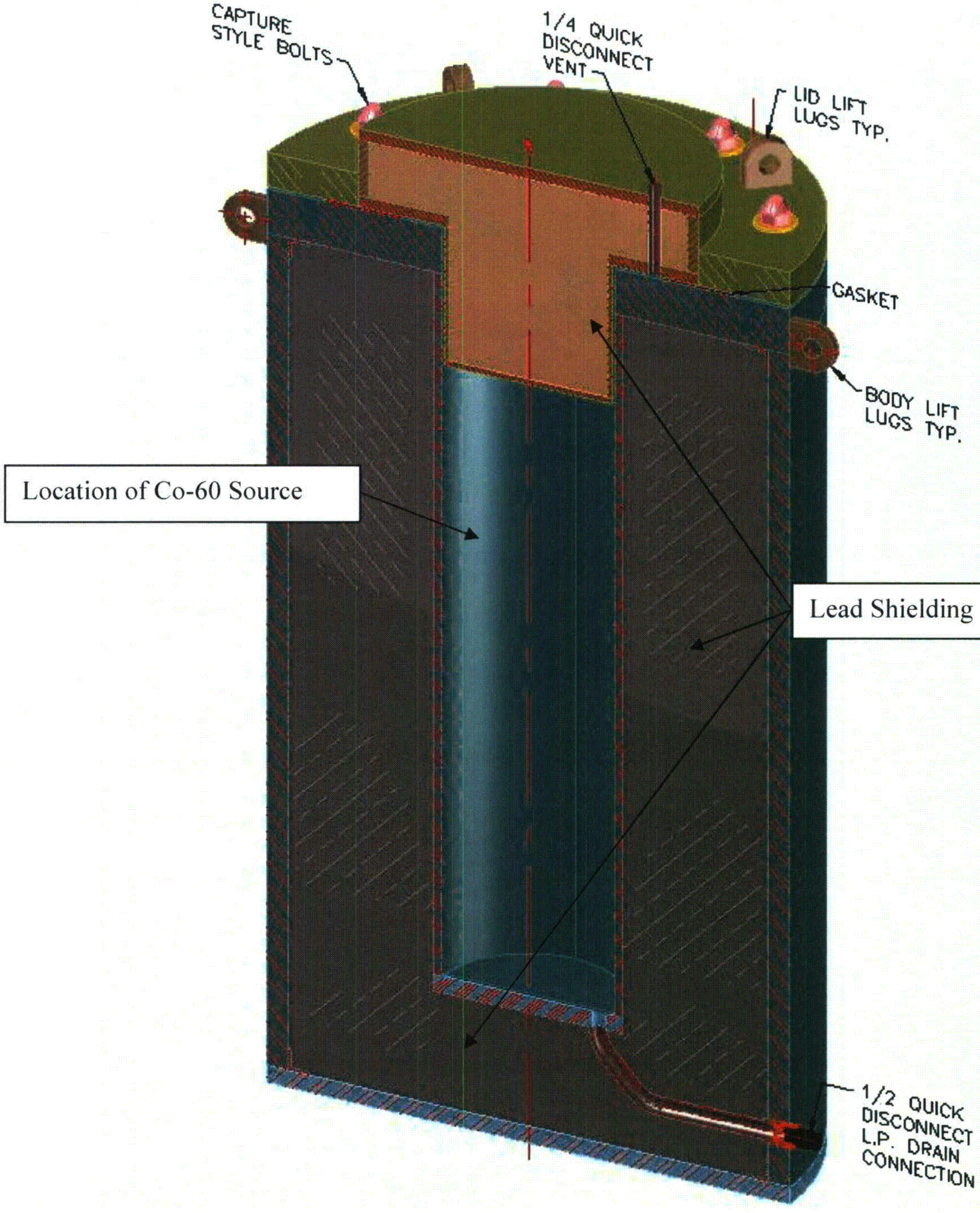


Figure 5-3. Elevation Plan View of Source Insert

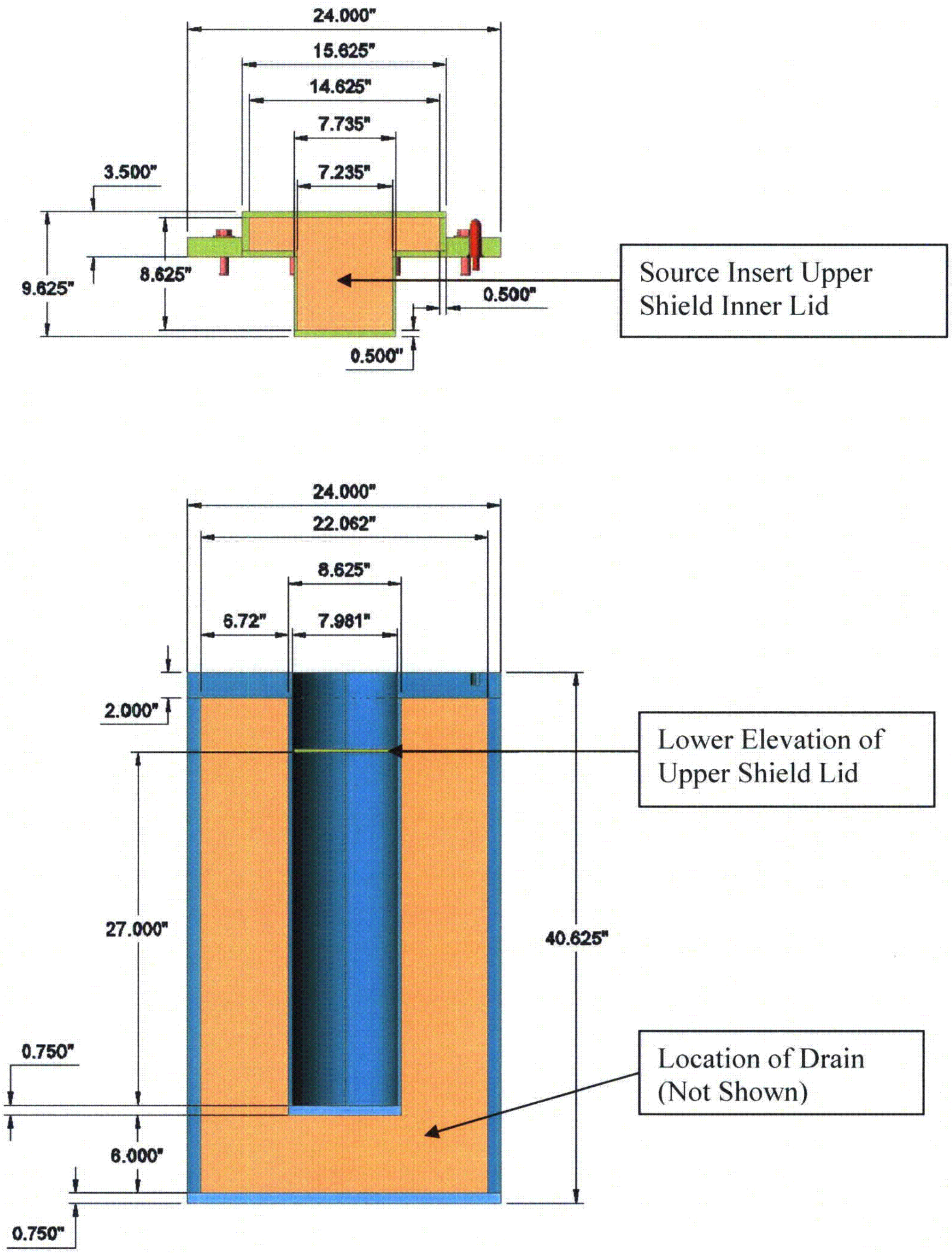


Figure 5-4. Elevation View of Shielding Model for 10-160B Cask with Source Insert Centered for NCT with Some Component Descriptions

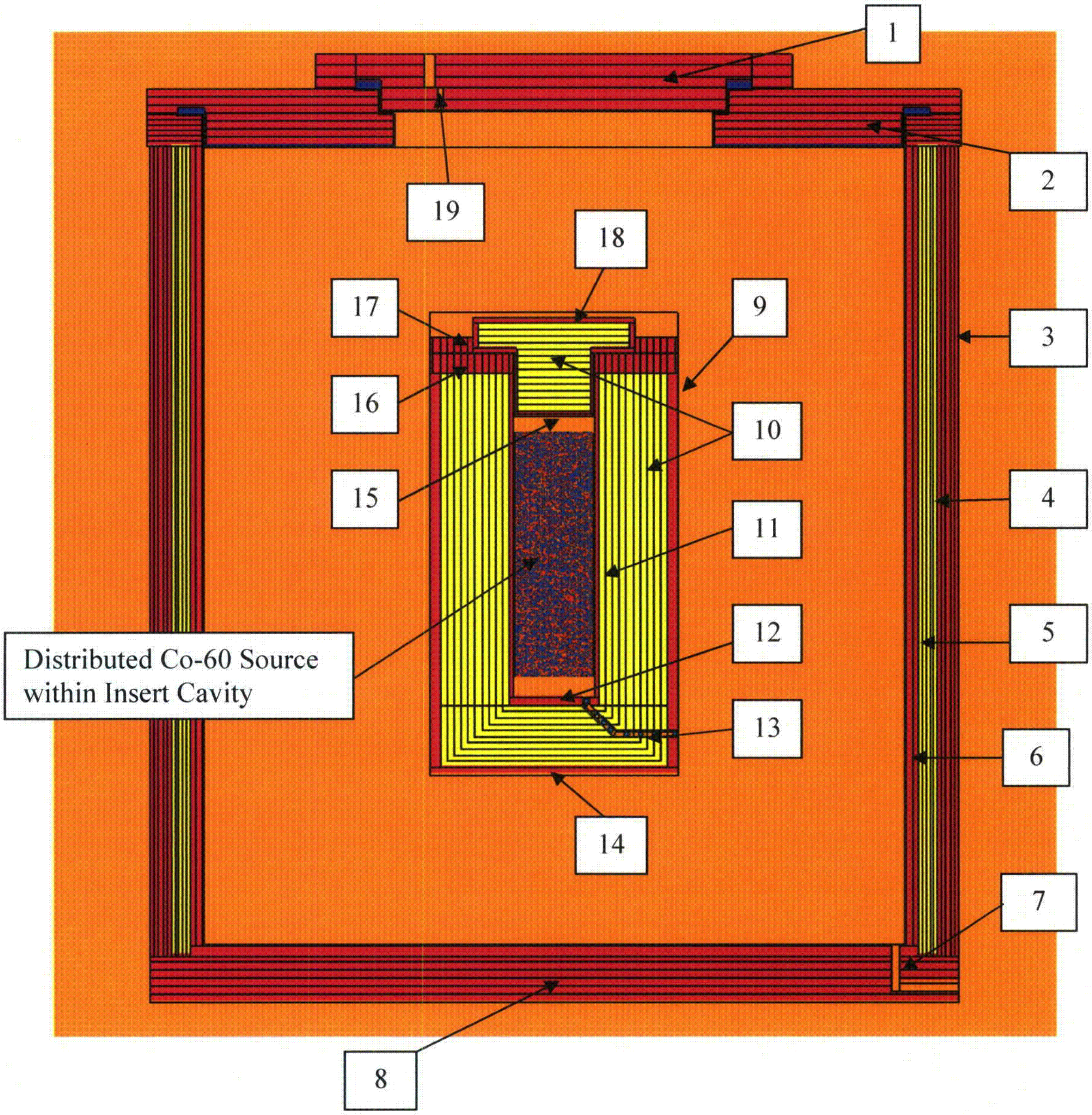


Table 5-1. Component Description and Material Specifications

Item Number (Figure 5-4)	Component Description and Material Specification
1	10-160B Secondary Lid: 5.5-inches thick, ASTM A516 Gr.70
2	10-160B Primary Lid: 5.5-inches thick, ASTM A516 Gr.70
3	10-160B Outer Shell: 2.0-inches thick, ASTM A516 Gr.70
4	Lead Shield: 1.875-inches thick ASTM B29 - Chemical Grade Lead
5	10-160B Inner Shell: 1.125-inches thick, ASTM A516 Gr.70
6	Inner Lining: 11 GA. ASTM 240, Type 304
7	Cask Drain
8	10-160B Base: 5.5-inches thick, ASTM A516 Gr.70
9	Seamless Pipe, 24-in OD, SCH. 60, ASTM A516 Grade B
10	Cast Lead Shield: 6.72-inches thick, ASTM B29 Chemical Grade Lead
11	Seamless Pipe, 8.0-in OD, SCH. 40, ASTM A516 Gr.70
12	Plate: 0.75-inches thick, ASTM A516 Gr.70
13	Insert Drain
14	Plate: 0.75-inches thick, ASTM A516 Gr.70
15	Plate: 0.50-inches thick, ASTM A516 Gr.70
16	Plate: 2.0-inches thick, ASTM A516 Gr.70
17	Plate: 1.5-inches thick, ASTM A516 Gr.70
18	Plate: 05-inches thick, ASTM A516 Gr.70
19	Cask Vents

Table 5-2. 10-160B Cask Dimensions

Component	Diameter (in)	Height (in)	Thickness (in)
Cavity	68	77	-
Liner	67.75 (ID)	76.75	0.125
Inner Shell	68 (ID)	77	1.125
Lead Layer	70.25 (ID)	77	1.875
Outer Shell	74 ID)	77	2
Lid	78 (OD)	-	5.5
Base	78 (OD)	-	5.5

As presented in Table 5-1 (extracted from Reference 10), the Cask side wall consists of an outer 2-inch thick steel shell surrounding 1-$^7/_8$ inches of lead and an inner containment shell wall of 1 1/8-inch thick steel. The cavity height is 76.75 inches. The Cask bottom, outer and inner lids are all comprised of two layers of steel with a total thickness of 5-½ inches. The Cask is modeled as right circular cylinders to define its geometry of lead and steel walls and lids.

The lid closure is made in an overlapping, stepped configuration to eliminate radiation streaming at the lid/Cask body interface such that either one or both lids can be removed for required access. The outer (primary) lid is removed for any object larger than 31 inches in diameter. The inner (secondary) lid is located at the center of the main lid, covering a 31-inch opening. The

secondary lid is constructed with multiple steps machined in its periphery, matching those in the primary lid, eliminating radiation streaming pathways.

Foam filled impact limiters cover the top and bottom of the vertically oriented Cask as located on the trailer. Although the Cask is modeled at 40-inches above the ground, the impact limiters are conservatively ignored for the purpose of the shielding evaluation. The ground is modeled as soil (see Table 5-6) to allow for photon interaction (reflection).

The Co-60 source is loaded into the Insert cavity, as shown in Figure 5-4. (Insert dimensions and materials are given in Reference 11.) The Insert is then centered inside the Cask both radially and axially for NCT. As presented in Figure 5-2, the Insert inner shell side walls are comprised of cast lead (density of 11.3 g/cm3 and a total thickness of 6.72 inches) located between an inner 8.0-inch (nominal) SCH 40 steel pipe and an outer 24.0-inch (nominal) SCH 60 steel pipe. The base consists of 6.0 inches of lead supported by a 0.75-inch thick steel base plate. The upper shield lid consists of 8.625-inches thick lead encased with steel.

All steel is modeled as ASTM A516 Grade 70 carbon steel, except for the 11 gauge Cask liner, which is modeled as ASTM 240, Type 304 stainless steel.

In addition, the Insert drain line was modeled as a series of vertical, 45-degree, and horizontal cylindrical segments (5/8-inch OD x 0.065-inch wall thickness) positioned near the bottom of the source region and penetrating the lead and steel gamma shielding. (See Figures 5-2 and 5-4). Since the Co-60 source may be stored underwater, the drain line allows water to drain from the Insert before loading into the Cask.

5.1.2 Summary of Maximum Dose Rates

Table 5-3 summarizes the dose rates for Normal Conditions of Transport (NCT) given the Cask loaded with the Insert. The maximum allowable NCT dose rates for exclusive use shipments given in 10 CFR 71.47(b) are also shown in Table 5-3 for comparison.

Table 5-3. Peak NCT Dose Rates for 10-160B Cask with Centered Source Insert

Normal Conditions of Transport	Package Surface mSv/h (mrem/h)			2 Meters from Package Surface mSv/h (mrem/h)		
Radiation	Top	Side	Bottom	Top	Side	Bottom
Gamma	0.029 (2.9)	0.008 (0.8)	0.065 (6.5)	0.002 (0.2)	0.001 (0.1)	NA[1]
Neutron	NA[2]	NA[2]	NA[2]	NA[2]	NA[2]	NA[2]
Total	0.029 (2.9)	0.008 (0.8)	0.065 (6.5)	0.002 (0.2)	0.001 (0.1)	NA[1]
10 CFR 71.47(b) Limit	2 (200)	2 (200)	2 (200)	0.1 (10)	0.1 (10)	0.1 (10)

[1]The Cask is assumed centered on a 8-foot wide conveyance with the outer surface of the Cask approximately 40-inches (101.6 cm) above ground level. A dose rate +2m from the base is not available.
[2]The source consists solely of Co-60 and contains no neutron-emitting radioisotopes.

Table 5-4 summarizes the dose rates for Hypothetical Accident Conditions (HAC) given the Insert and Co-60 source positioned in the worst-case geometric configuration following an accident. The maximum allowable HAC dose rates for Type B packages given in 10 CFR 71.53 are also shown in Table 5-4 for comparison.

Table 5-4. Peak HAC Dose Rates for 10-160B Cask with Centered Source Insert

Hypothetical Accident Conditions	1 Meter from Package Surface mSv/h (mrem/h)		
Radiation	Top[1]	Side[2]	Bottom[2]
Gamma	0.445 (44.5)	0.278 (27.8)	0.275 (27.5)
Neutron	NA[3]	NA[3]	NA[3]
Total	0.445 (44.5)	0.278 (27.8)	0.275 (27.5)
10 CFR 71.51(a)(2) Limit	10 (1000)	10 (1000)	10 (1000)

[1]The bounding top HAC dose rate occurs with the Insert inverted and positioned against the Cask inner top surface.
[2]The bounding side and bottom HAC dose rates occur with the Insert lying sideways on the Cask inner bottom surface.
[3]The source consists solely of Co-60 and contains no neutron-emitting radioisotopes.

5.2 Source Specification

5.2.1 Gamma Source

The decay of Co-60 emits photons (gammas) at specific energies, as summarized in Table 5-5. The photon source activity of 10,000 Curies of Co-60 is determined as follows:

$$\text{Co-60 Activity} = (10{,}000\ \text{Ci}) \times (3.7\text{E+10 disintegration/s/Ci}) \times (2\ \gamma/\text{disintegration}) = 7.4\text{E+14}\ \gamma/\text{s}$$

Photon emission probability versus energy for the decay of Co-60 was obtained from www.nndc.bnl.gov/nudata2/dec_search.jsp. The total activity was conservatively derived assuming two photons per decay.

Table 5-5. Co-60 Decay Photons vs. Energy

Energy (MeV)	Photon Emission Probability
0.347147	7.5E-05
0.826103	7.6E-05
1.1732283	0.9985
1.3324924	0.999826
2.158573	1.2E-05
2.5056925	2.0E-06
Total Photons per Decay	1.998485

5.2.2 Neutron Source

The Co-60 source term contains no neutron emitting radioisotopes.

5.3 Shielding Model

5.3.1 Configuration of Source and Shielding

5.3.1.1 Standalone Insert

Figure 5-5 shows the model of the standalone Insert. Figure 5-6 shows the Insert drain line region in greater detail, including the tally spheres used to conduct the streaming analysis of the drain line.

The Insert consists of a gamma shield surrounding a source cavity, and is designed to house a 10,000 curie gamma source. The Co-60 gamma source is modeled as being distributed over the cavity volume, with a nominal void volume above and below the source to allow for dunnage and/or incomplete filling of the cavity. If no dunnage is used, then the model is conservative because it slightly concentrates the maximum source term.

The composition of the source is conservatively modeled as air. This conservatively eliminates any self-shielding due to the source material.

Figure 5-5. Elevation View of Standalone Shielding Model for the Source Insert

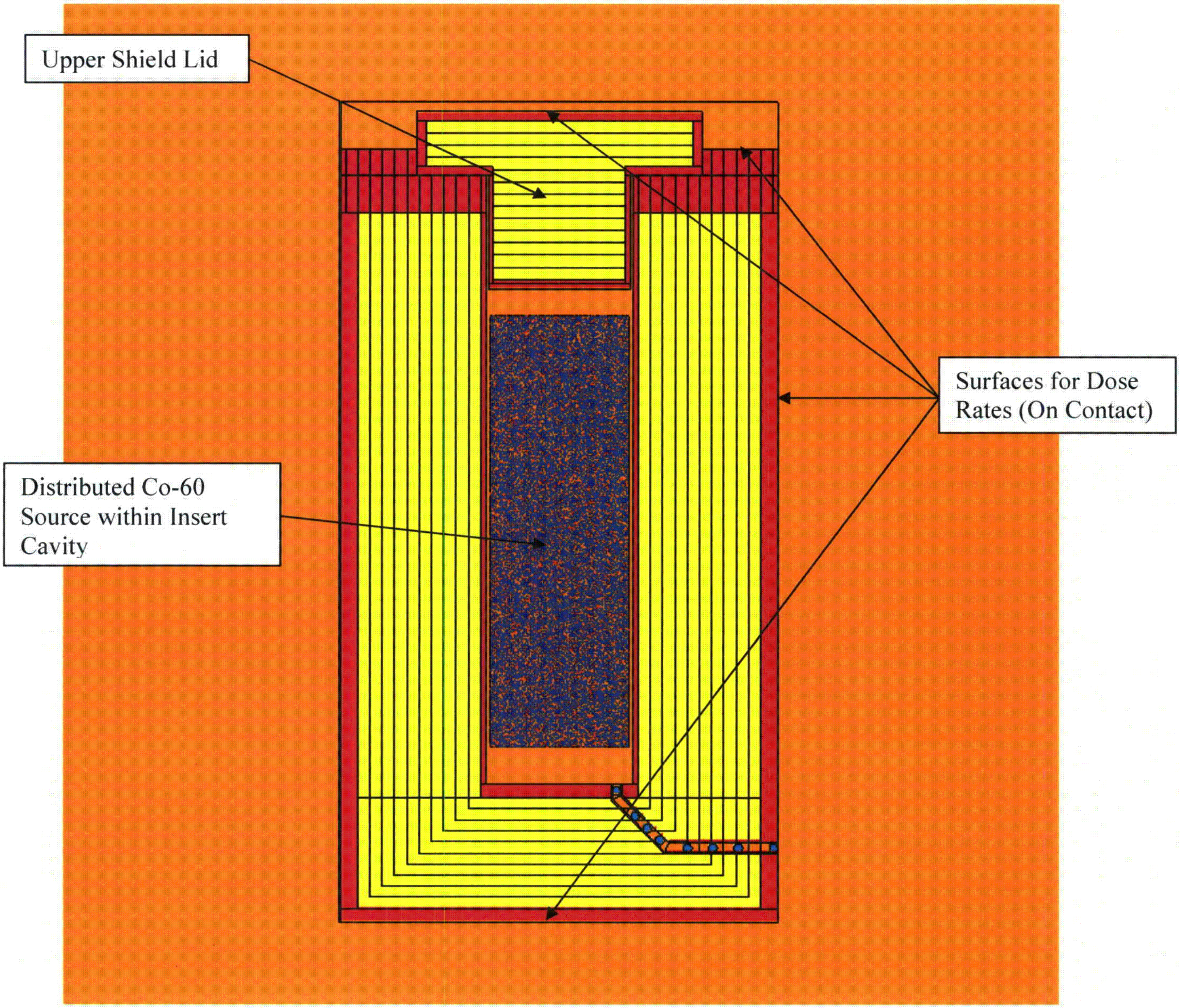
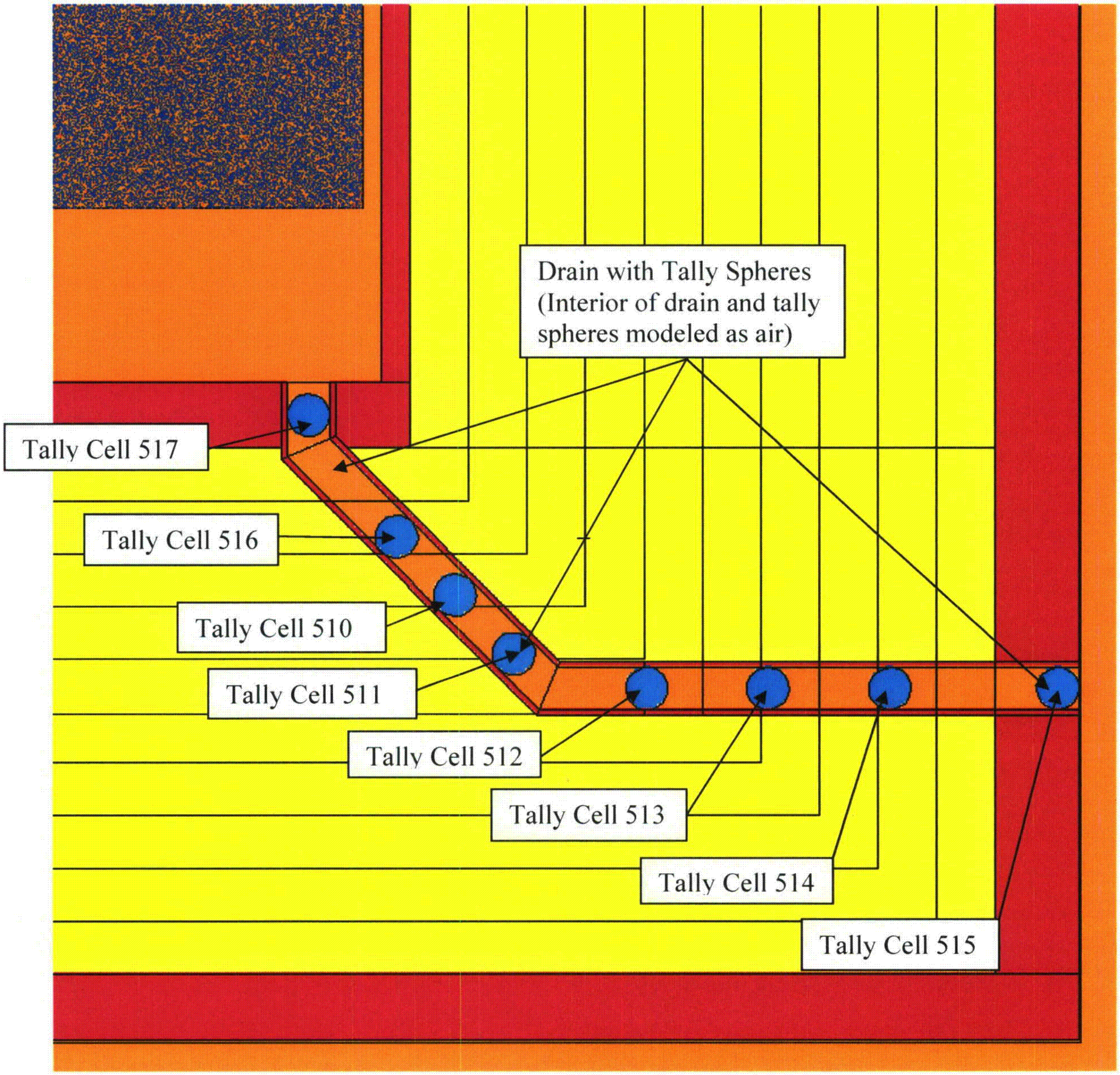


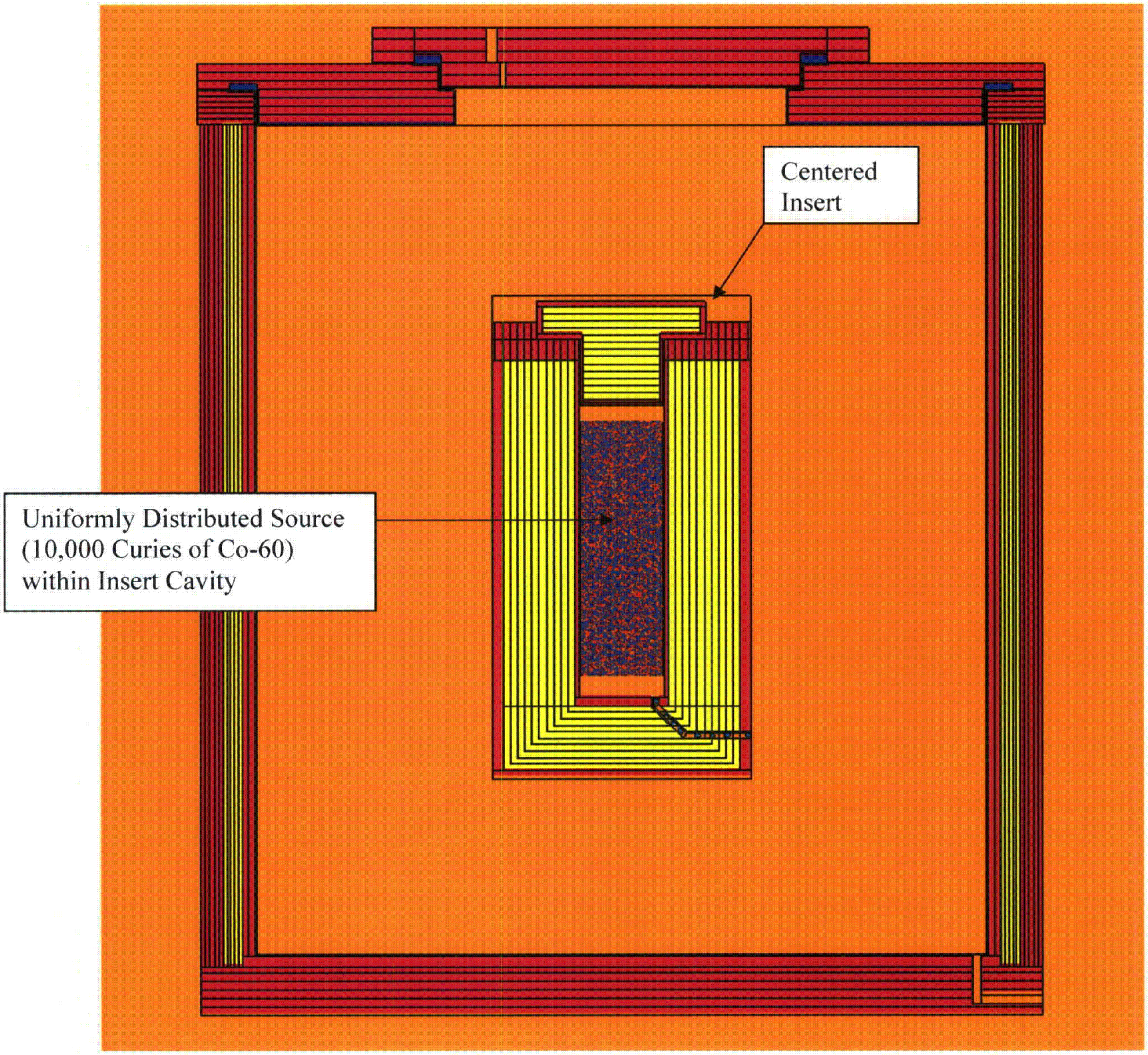
Figure 5-6. Expanded Elevation View of Insert Drain Line Region



5.3.1.2 NCT Model of Cask and Insert

Figure 5-7 shows the NCT model of the Cask containing the Insert and the associated Co-60 source. The Insert portion of the model is identical to Figure 5-5 above, and is centered in the Cask volume where it will be retained by the steel shoring. The steel shoring is not included in the model to conservatively eliminate the small amount of added internal shielding that the shoring would provide.

Figure 5-7. Elevation View of NCT Model for 10-160B Cask and Centered Source Insert



5.3.1.3 HAC Model of Cask and Insert

Figures 5-8 through 5-11 show the four HAC models, labeled as HAC Cases #1 through #4. These four HAC configurations were selected for evaluation as the bounding geometries for maximum HAC dose rates at +1 m from the Cask sidewall, top, and bottom.

Note that for all HAC cases, the Co-60 source term is modeled as a 1-cm sphere positioned against the interior side of the Insert closest to the associated Cask exterior surface. The 1-cm sphere is essentially a point source, which models an extreme collapse of the Co-60 pins and conservatively maximizes the resulting HAC dose rates. As noted in Section 2.7.1.1.3, there is little if any lead slump in the insert, so no lead slump is modeled.

Figure 5-8. Elevation View of 10-160B Cask with Source Insert Vertical Against Cask Interior Sidewall (HAC Case #1)

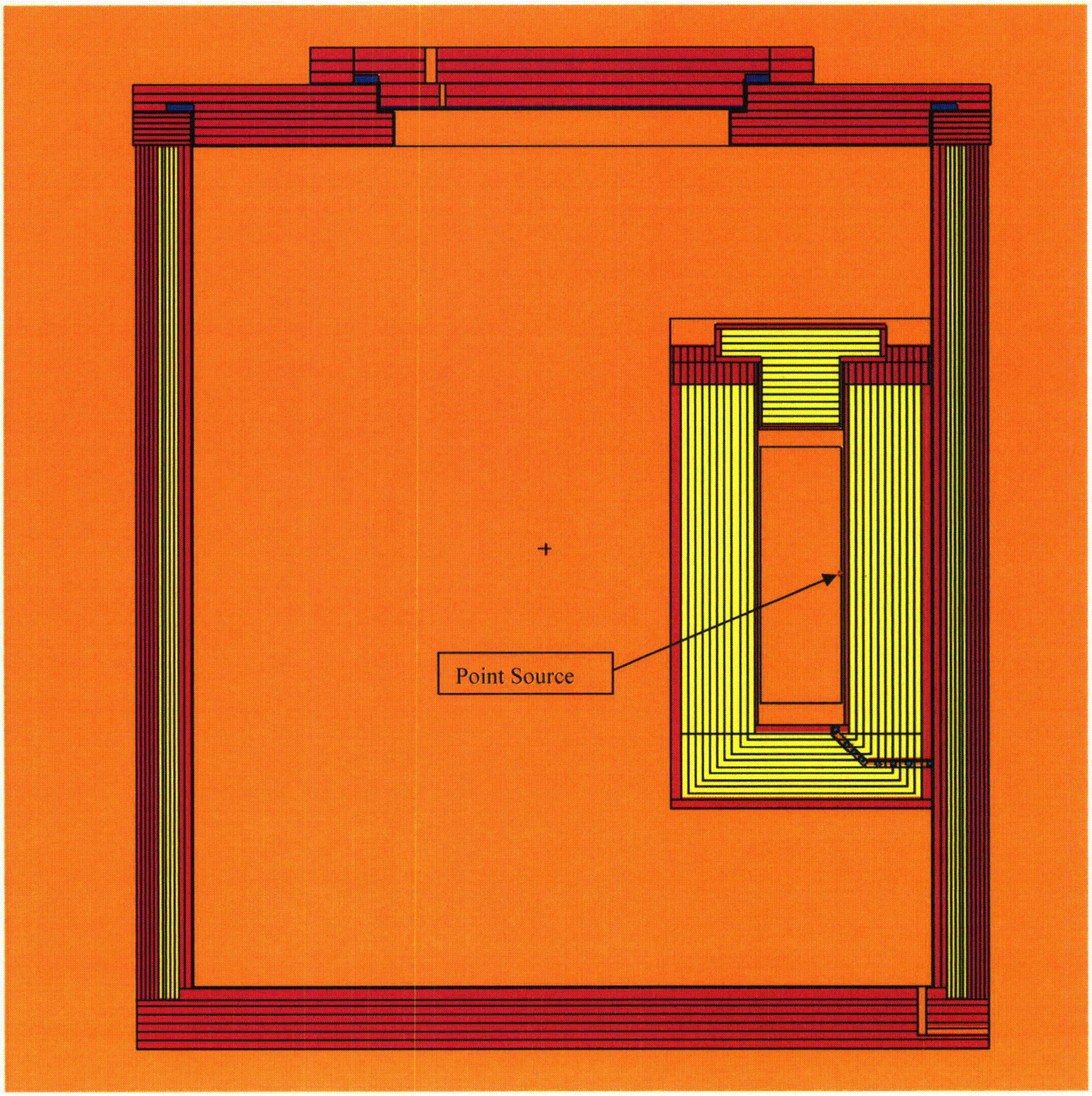


Figure 5-9. Elevation View of 10-160B Cask with Source Insert Rotated 90 Degrees Against Base of Cask Interior (HAC Case #2)

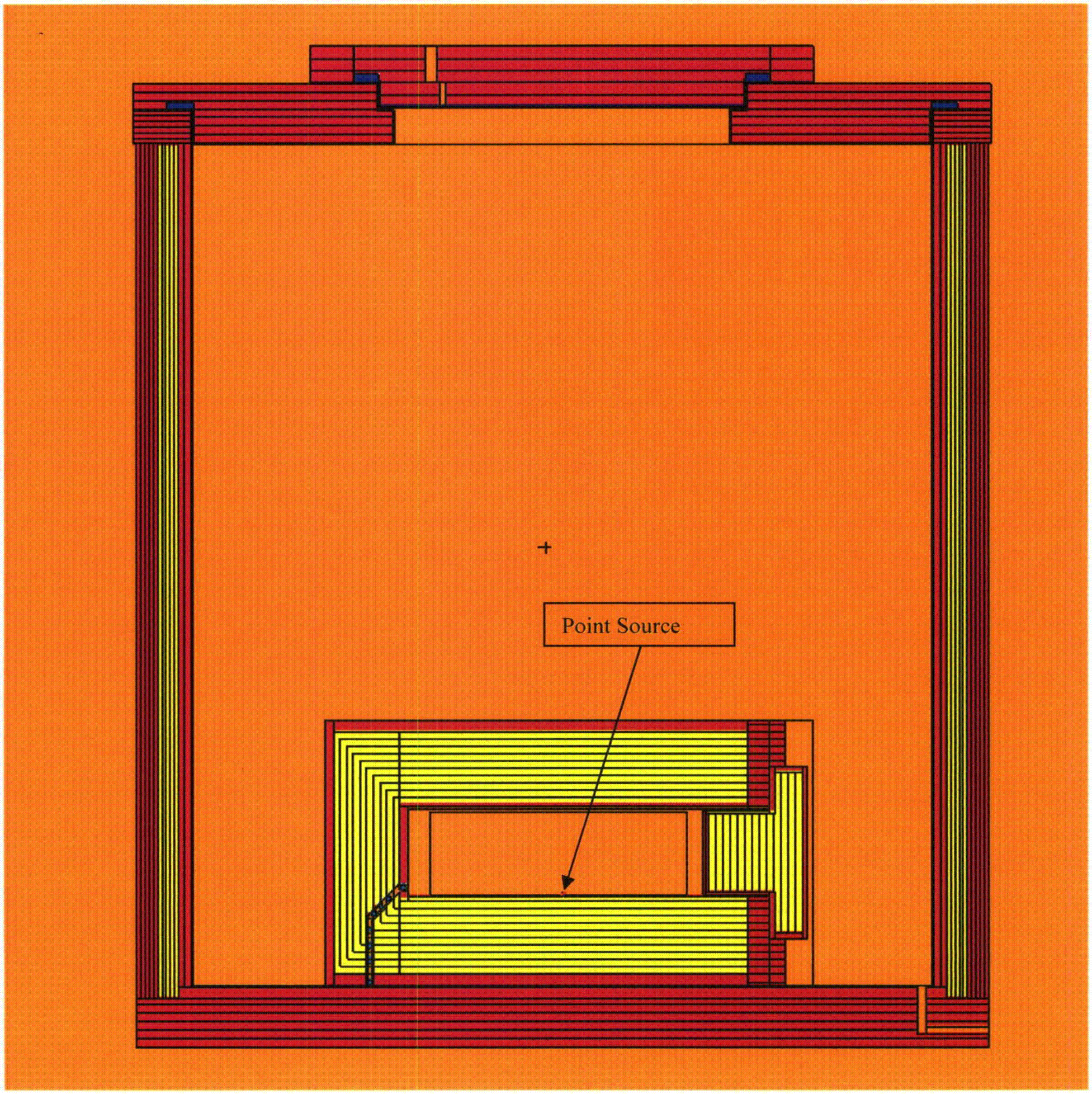


Figure 5-10. Elevation View of 10-160B Cask with Source Insert Rotated 90 Degrees Against Top of Cask Interior (HAC Case #3)

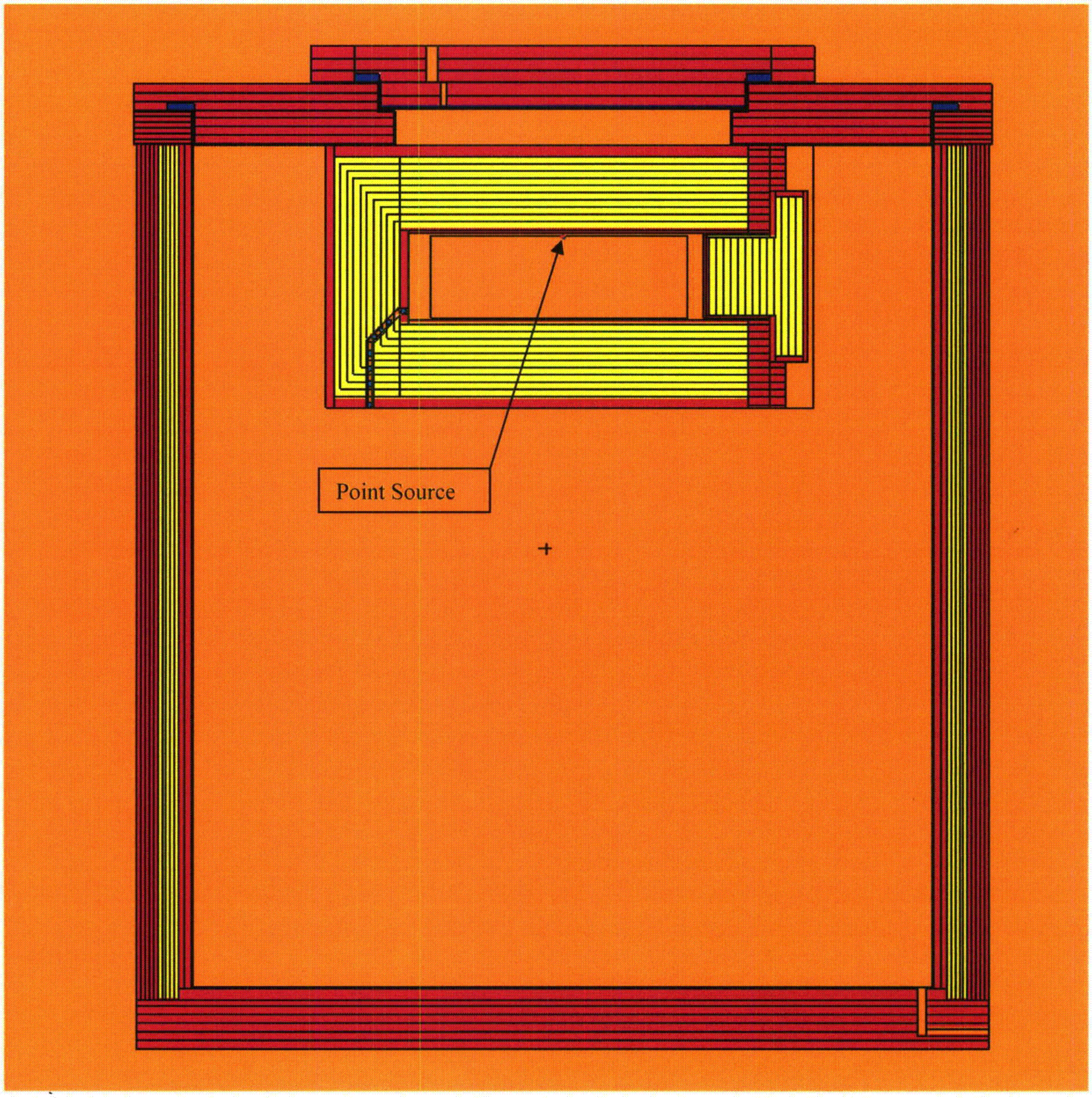
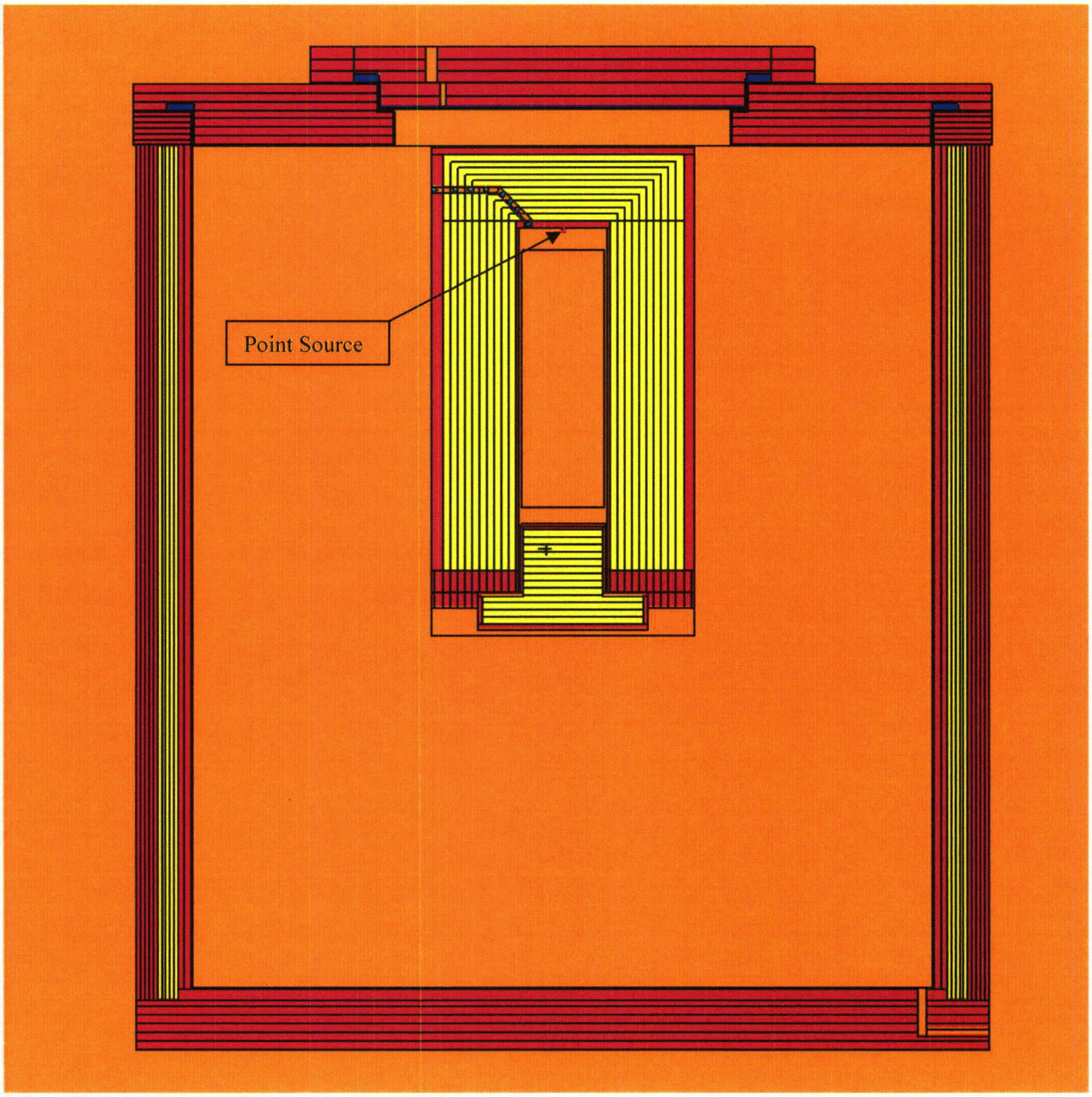


Figure 5-11. Elevation View of 10-160B Cask with Source Insert Rotated 180 Degrees (Inverted) Against Top of Cask Interior (HAC Case #4)



5.3.2 Material Properties

The material descriptions, density elemental compositions, nuclide identification number or ZAID, and mass fractions and used for the shielding were obtained from References 1 through 5, as noted in Table 5-6. Note that the specified lead alloy composition (L51121, commercial grade

lead) was derived from Reference 4 assuming all impurities at maximum values and minimum lead content.

The form of the ZAID is ZZZAAA.nnX where ZZZ is the atomic number of the element or nuclide, AAA is always 000 for photo-atomic data, nn is the unique cross-section table identification number, and X is set to p for continuous-energy. For the subject calculations, the ".04p" data sets were used.

Table 5-6. Material Compositions and Densities

Material	Density (g/cm^3)	Isotope	ZAID	Mass Fraction
Carbon Steel (ASTM A516 Gr. 70) (Ref.1)	7.82	C	6000	0.002800
		Si	14000	0.002900
		P	15000	0.000350
		S	16000	0.000400
		Mn	25000	0.010450
		Fe	26000	0.983100
		Total		1.000000
Air (Ref. 2)	0.001205	C	6000	0.000124
		N	7000	0.755268
		O	8000	0.231781
		Ar	18000	0.012827
		Total		1.000000
Stainless Steel (ASTM-A240 Type 304) (Ref. 3)	7.92	C	6000	0.000300
		N	7000	0.001000
		Si	14000	0.007500
		P	15000	0.000500
		S	16000	0.000300
		Cr	24000	0.190000
		Mn	25000	0.020000
		Fe	26000	0.680400
		Ni	28000	0.100000
		Total		1.000000
Lead (Commercial Grade per ASTM B29-03, UNS # L51121, with impurities at maximum values, and minimum lead content) (Ref. 4)	11.30	Fe	26000	0.000020
		Ni	28000	0.000020
		Cu	29000	0.000800
		Zn	30000	0.000010
		As	33000	0.000010
		Ag	47000	0.000200
		Sn	50000	0.000010
		Sb	51000	0.000010
		Pb	82000	0.998670
		Bi	83000	0.000250
		Total		1.000000

Material	Density (g/cm^3)	Isotope	ZAID	Mass Fraction
Soil (Ref. 5)	1.67	H	1000	0.001220
		O	8000	0.454275
		Na	11000	0.017582
		Mg	12000	0.027318
		Al	13000	0.072401
		Si	14000	0.241898
		P	15000	0.002095
		K	19000	0.010045
		Ca	20000	0.062321
		Ti	22000	0.014384
		Mn	25000	0.001549
		Fe	26000	0.094912
		Total		1.000000

5.4 Shielding Evaluation

5.4.1 Methods

The calculation methodology consists of the following steps:

1) Determine the source activity for 10,000 Curies of Co-60.

2) Determine geometric configuration conditions for both NCT and HAC.

3) Model the NCT and HAC configurations using component and assembly dimensions using the input data given above. Model sufficient component details and photon tally (dose rate) locations to determine the maximum dose rates on the package surfaces and at distances of 1 m (for HAC) and 2 m (for NCT exclusive use) from the package surfaces.

4) Model the drain line and cell tallies in a stand-alone Insert to determine the impact the line will have on reduced shielding (streaming analysis).

5.4.2 Software and Computer Quality Assurance

The Monte-Carlo N-Particle Version 5 (MCNP5) Release 1.51 (Reference 6) computer program were used to perform the analyses documented in this report. The electronic input files associated with the MCNP5 analyses are summarized in Appendix Section 5.5.2.

MCNP5 is a general-purpose, continuous energy, generalized-geometry, time-dependent, coupled neutron/photon/electron Monte Carlo transport code. MCNP5 has been validated and verified for correct installation and functionality in accordance with Reference 8, and approved for use with quality affecting analyses in accordance with Reference 9. The MCNP5 analyses documented in this report were performed on EnergySolutions Engineering and Technology (E&T) Compute Cluster consisting of four Dell Precision T5400 computers. Each computer is

identical with dual quad-core Xenon 2.67 GHz processors, 4 GB of RAM, and Microsoft® Windows® XP Professional x64 Edition.

5.4.3 Input and Output Data

The MCNP input and output files are provided separately from this evaluation on a CD-ROM to avoid a lengthy appendix and to prevent unauthorized access to potentially sensitive computer software. Appendix Section 5.5.2 lists the MCNP input files and the models with which they are associated.

5.4.4 Flux-to-Dose Rate Conversion

User input response functions are required by MCNP to convert photon flux to dose rates. Photon flux-to-dose rate conversion coefficients derived from ANSI/ANS-6.1.1-1977 (Reference 7) were used for this analysis. Table 5-7 summarizes the photon flux-to-dose rate conversion coefficients versus energy.

Table 5-7. Photon Dose Rate Response Functions from ANSI/ANS-6.1.1-1977

Energy [MeV]	Response [mrem/h]/[γ/cm^2-sec]	Energy [MeV]	Response [mrem/h]/[γ/cm^2-sec]
1.00E-02	3.96E-03	1.40E+00	2.51E-03
3.00E-02	5.82E-04	1.80E+00	2.99E-03
5.00E-02	2.90E-04	2.20E+00	3.42E-03
7.00E-02	2.58E-04	2.60E+00	3.82E-03
1.00E-01	2.83E-04	2.80E+00	4.01E-03
1.50E-01	3.79E-04	3.25E+00	4.41E-03
2.00E-01	5.01E-04	3.75E+00	4.83E-03
2.50E-01	6.31E-04	4.25E+00	5.23E-03
3.00E-01	7.59E-04	4.75E+00	5.60E-03
3.50E-01	8.78E-04	5.00E+00	5.80E-03
4.00E-01	9.85E-04	5.25E+00	6.01E-03
4.50E-01	1.08E-03	5.75E+00	6.37E-03
5.00E-01	1.17E-03	6.25E+00	6.74E-03
5.50E-01	1.27E-03	6.75E+00	7.11E-03
6.00E-01	1.36E-03	7.50E+00	7.66E-03
6.50E-01	1.44E-03	9.00E+00	8.77E-03
7.00E-01	1.52E-03	1.10E+01	1.03E-02
8.00E-01	1.68E-03	1.30E+01	1.18E-02
1.00E+00	1.98E-03	1.50E+01	1.33E-02

5.4.5 External Radiation Levels

5.4.5.1 Standalone Insert Shielding Results

Table 5-8 presents the peak dose rates and their locations for the standalone Insert. All dose rates are less than the maximum contractual value of 5 rem/hr (5,000 mrem/hr).

Table 5-8. Peak Dose Rates for Standalone Source Insert

Location of Dose Point	On Contact Peak Dose Rate, mrem/hr (%Relative Error)
Sidewall (Outer Radius)	1,250 (0.7)
Top (Upper Surface of Secondary Lid)	2,540 (2.5)
Top (Upper Surface of Primary Lid)	2,716 (6.3)
Bottom (Lower Outside Surface of Base)	4,260 (1.5)

5.4.5.2 NCT Results

Table 5-9 presents the peak dose rates for NCT, given a Cask with a centered Insert. Note that the maximum dose rate at 2 m from the Cask is less than 2 mrem/hr. Therefore, under normal conditions, the dose rate in any normally occupied space (i.e. driver location) is less than the allowable limit of 2.0 mrem/hr. This demonstrates compliance with 10 CFR 71.47, part (b).

Table 5-9. Peak NCT Dose Rates for 10-160B Cask with Centered Source Insert

Location of Dose Points	Dose Contributor	Peak Dose Rate[4] mrem/hr (%Relative Error)	
		On Contact	+2m
Sidewall (Outer Radius)	Gamma from the Decay of Co-60	0.8 (0.7)	0.1 (2.9)
	LIMIT	200	10
Top (Upper Surface of Secondary Lid)	Gamma from the Decay of Co-60	2.9 (1.3)	0.2 (2.2)
	LIMIT	200	10
Bottom (Lower Outside Surface of Base)	Gamma from the Decay of Co-60	6.5 (0.4)	NA[1]
	LIMIT	200	10

[1]The Cask is assumed centered on a 8-foot wide conveyance with the outer surface of the Cask approximately 40-inches (101.6 cm) above ground level. A dose rate +2m from the base is not available.

5.4.5.3 HAC Results

From Table 5-10, the peak dose rates for HAC given a Cask with a Insert at various locations are 27.8 mrem/hr on contact with the sidewall (outer radius), 44.5 mrem/hr on contact with the upper shield, and 27.5 mrem/hr on contact with the base. The peak dose rate at +1 m from any surface is 3.1 mrem/hr, which is considerably less than the allowable HAC limit of 1000 mrem/hr given in 10 CFR 71.51.

Table 5-10. Peak HAC Dose Rates for 10-160B Cask with Source Insert at Various Locations

Case Description	Location of Dose Point	Peak Dose Rate, mrem/hr (% Relative Error)	
		On Contact	+1m
HAC Case #1 - Source Insert at Sidewall	Outer Radius of Sidewall	10.2 (0.2)	0.5 (0.5)
	Upper Surface of Lid	10.9 (0.6)	1.3 (1.3)
	Lower Surface of Base	6.0 (0.4)	0.8 (0.5)
	LIMIT		1000
HAC Case #2 - Source Insert at Bottom	Outer Radius of Sidewall	27.8 (0.4)	3.1 (0.6)
	Upper Surface of Lid	1.1(1.3)	0.3 (2.6)
	Lower Surface of Base	27.5 (0.1)	1.2 (0.3)
	LIMIT		1000
HAC Case #3 - Source Insert at Top	Outer Radius of Sidewall	16.2 (0.5)	2.2 (0.7)
	Upper Surface of Lid	18.3 (0.2)	1.0 (0.3)
	Lower Surface of Base	0.9 (0.7)	0.3 (0.5)
	LIMIT		1000
HAC Case #4 Source Insert at Top (Inverted)	Outer Radius of Sidewall	1.3 (0.6)	0.2 (1.0)
	Upper Surface of Lid	44.5 (0.1)	2.0 (0.2)
	Lower Surface of Base	0.8 (2.3)	0.2 (2.2)
	LIMIT		1000

5.4.5.4 Insert Drain Line Streaming Analysis

Additional efforts were made to ensure the Insert drain line was adequately designed and would not adversely impact external radiation levels. As shown in Figures 5-5 and 5-6, the drain line was explicitly modeled as a series of vertical, 45-degree, and horizontal cylindrical segments that penetrate the gamma shield and encasing steel. The results presented in Tables 5-8 through 5-10 above include the effect of the drain line.

As shown in Figure 5-6, additional Type 4 cell tallies were modeled as spheres inside and along the drain line to determine the dose rate caused by the penetration through the shielding.

The dose rates presented in Table 5-11 show the dose rates along the drain line as it penetrates the Insert's lead shielding given an uniformly distributed source (NCT Case #1). Tally cells 517, 516, 510 and 511 are located within the 45-dgree segment, with tally cell 517 at the inlet to the drain line. Tally cells 512, 513, 514, and 515 are located within the straight segment, with

tally cell 515 at the discharge of the drain line. See Figure 5-6 for an expanded view of the tally cell locations.

The peak dose rate decreases significantly at the discharge. At the Insert's outside surface, the peak dose rate is approximately 1,058 mrem/hr. This value is less than the peak dose rate of 1,250 mrem/hr (see Table 5-8) on contact with the outer radius at a higher elevation on the side of the Insert. Based on this comparison, the drain line was adequately designed and does not adversely impact external radiation levels.

Table 5-11. Drain Line Dose Rates for Standalone Source Insert with Uniformly Distributed Source

Cell Tally #	Dose Rate, mrem/h (% Relative Error)
517	2.557E+08 (0.2)
516	4.898E+07 (0.4)
510	1.491E+07 (0.5)
511	5.184E+06 (0.9)
512	1.440E+05 (1.3)
513	1.943E+04 (2.4)
514	4.218E+03 (4.5)
515	1.058E+03 (10.4)

5.5 Appendix

5.5.1 References

1. ASTM A516, 2010, "Standard Specification for Pressure Vessel Plates, Carbon Steel, for Moderate and Lower Temperature Service," American Society for Testing and Materials.

2. PNNL-15870, April 2006, "Compendium of Material Composition Data for Radiation Transport Modeling," R. G. Williams, C. J. Gesh and R. T. Pagh, Pacific Northwest National Laboratory, Richland, Washington.

3. ASTM A240, 2011, Rev A, "Standard Specification for Chromium and Chromium Nickel Stainless Steel Plate, Sheet, and Strip for Pressure Vessels and for General Applications," American Society for Testing and Materials.

4. ASTM B29, 2003, "Refined Specification for Lead," American Society for Testing and Materials.

5. *Soil Density and Mass Attenuation Coefficients for Use in Shielding Calculations at the Hanford Waste Vitrification Plant, American Nuclear Society Transactions*, "Topical Meeting on New Horizons in Radiation Protection and Shielding," Pasco, Washington, April 26 - May 1, 1992, pages 144-148, published by American Nuclear Society, La Grange Park, Illinois.

6. MCNP5 – A General Monte Carlo N-Particle Transport Code, Version 5, LA-UR-03-1987, Los Alamos National Laboratory, April 2003.

7. ANSI/ANS-6.1.1-1977, American Nuclear Society, 1977, "Neutron and Gamma-Ray Flux-to-Dose-Rate Factors."

8. ENG-03.30, Rev. 2, "Installation, and Testing of Acquired Software," EnergySolutions, Engineering and Technology, Richland, WA.

9. CSU-ET-NS-0001, MCNP5 Computer Software Installation and In-Use Test Log, Energy*Solutions.*

10. C-110-D-29003-010, Rev. 14, Cask Assembly General Notes/Parts List for 10-160B, Energy*Solutions*.

11. C-038-145083-001, Rev. 0, Gamma Shield Insert, Energy*Solutions*.

5.5.2 Electronic Files

Software	Input File Name	File Description	File Date
MCNP5	Insert1b3.1	Standalone Source Insert (Includes Insert drain line streaming tallies)	08/17/2011
MCNP5	NCT1b3.i	10-160B Cask with Source Insert centered in Cask interior volume	08/19/2011
MCNP5	HAC1b3.i	10-160B Cask with Source Insert vertical against Cask interior sidewall (HAC Case #1)	08/19/2011
MCNP5	HAC2b3.i	10-160B Cask with Source Insert rotated 90 degrees against base of Cask interior (HAC Case #2)	08/20/2011
MCNP5	HAC3b3.i	10-160B Cask with Source Insert rotated 90 degrees against top of Cask interior (HAC Case #3)	08/21/2011
MCNP5	HAC4b3.i	10-160B Cask with Source Insert rotated 180 degrees (inverted) against top of Cask interior (HAC Case #4)	08/22/2011

6.0 CRITICALITY

There is no fissile material in the contents addressed by this addendum. Thus, a criticality evaluation is not applicable.

7.0 OPERATING PROCEDURE

Chapter 7 of the SAR describes the general procedure for loading and unloading of the 10-160B cask. The procedure listed below is for loading the Insert and loading the Insert into the cask with the specified cribbing. The loaded Insert will be unloaded from the cask per Chapter 7 of the base SAR. The Source Insert will not be unloaded.

7.1 Procedure for Loading the Source Insert

NOTE CONFIRM THE SOURCES TO BE LOADED MEET THE LIMITATIONS SPECIFIED IN THE COC.

7.1.1 Loosen and remove the eight (8) ¾-inch bolts which secure the Source Insert lid to the insert body.

7.1.2 Remove the Source Insert lid using the four lifting lugs on the lid. Inspect the gasket for damage and confirm gasket position is in accordance with Drawing C-038-145082-004. Care should be taken during lid handling operations to prevent damage.

7.1.3 Visually inspect accessible areas of the shield cavity for damage, loose materials, or moisture and repair/remove as necessary.

7.1.4 Place sources into cavity.

7.1.5 Replace the Source Insert lid.

7.1.6 Assure bolt threads are adequately lubricated and secure the Source Insert lid by installing the eight (8) ¾-inch lid bolts. Torque the bolts to 75 ± 10 ft-lbs using a star pattern.

7.1.7 If the insert is loaded underwater:
- 7.1.7.1 drain water from the insert cavity
- 7.1.7.2 vacuum dry the cavity (hold cavity pressure at or below 10 torr (0.2 psia) for 10 minutes following pressure stabilization)
- 7.1.7.3 close the vent and drain ports

7.2 Procedure for Loading the Insert into the 10-160B

7.2.1 Determine if cask must be removed from trailer for loading purposes. To remove cask from trailer:

7.2.1.1 Loosen and disconnect ratchet binders from upper impact limiter.

7.2.1.2 Using suitable lifting equipment, remove upper impact limiter. Care should be taken to prevent damage to impact limiter during handling and storage.

7.2.1.3 Disconnect cask to trailer tie-down equipment.

7.2.1.4 Attach cask lifting ears and torque bolts to 200 ft-lbs $\pm$ 20 ft-lbs lubricated.

7.2.1.5 Using suitable lifting equipment, remove cask from trailer and lower impact limiter and place cask in level loading position.

NOTE **THE CABLES USED FOR LIFTING THE CASK MUST HAVE A TRUE ANGLE, WITH RESPECT TO THE HORIZONTAL OF NOT LESS THAN 60°.**

7.2.2 Loosen and remove the twenty-four bolts (24, 1¾" – 8 UN) which secure the primary lid to cask body.

7.2.3 Remove primary lid from cask body using suitable lifting equipment and the three lifting lugs on the secondary lid. Care should be taken during lid handling operations to prevent damage to cask or lid seal surfaces.

NOTE **THE CABLES USED FOR LIFTING THE LID MUST HAVE A TRUE ANGLE, WITH RESPECT TO THE HORIZONTAL OF NOT LESS THAN 45°.**

7.2.4 Visually inspect accessible areas of the cask interior for damage, loose materials, or moisture. Confirm the cribbing per drawing C-038-145083-005 has been installed. Clean and inspect seal surfaces. Replace seals when defects or damage is noted which may preclude proper sealing.

NOTE **RADIOACTIVELY CONTAMINATED LIQUIDS MAY BE PUMPED OUT, REMOVED BY USE OF AN ABSORBENT MATERIAL, OR VIA DRAIN LINE. REMOVAL OF ANY MATERIAL FROM INSIDE THE CASK SHALL BE PERFORMED UNDER THE SUPERVISION OF QUALIFIED HEALTH PHYSICS (HP) PERSONNEL WITH THE**

NECESSARY HP MONITORING AND RADIOLOGICAL HEALTH SAFETY PRECAUTIONS AND SAFEGUARDS.

NOTE **WHEN SEALS ARE REPLACED (INCLUDING SEALS ON THE OPTIONAL VENT AND DRAIN PORTS), LEAK TESTING IS REQUIRED AS SPECIFIED IN SAR SECTION 8.2.2.1.**

7.2.5 Check the torques on the cavity vent and drain line cap screws to determine that the cap screws are properly installed using O-rings. This step is not required if the cask does not have the optional vent and drain lines, or if the tamper seals on the vent or drain lines have not been removed. Torque the cap screws to 20 ± 2 ft-lbs.

7.2.6 Remove the top section of the cribbing.

7.2.7 Place the insert in the cribbing cavity. Replace the top section of the cribbing.

7.2.8 Replace the primary lid and secure the lid to the cask body by installing the 24 lid bolts. Ensure that the lid orientation stripe is in alignment with the cask stripe. Torque bolts to 300 ± 30 ft-lbs.

NOTE **PERFORM PRESSURE DROP LEAK TEST OF THE CASK PRIMARY LID, SECONDARY LID, VENT LINE, OR DRAIN LINE (AS APPLICABLE) IN ACCORDANCE WITH SECTION 8.2.2.2 OF THE SAR.**

7.2.9 Install anti-tamper seals to the designated lid bolts, or to vent and/or drain line plugs (if applicable).

7.2.10 If cask has been removed from trailer, proceed as follows to return cask to trailer:

7.2.10.1 Using suitable lifting equipment, lift and position cask into lower impact limiter on trailer in the same orientation as removed.

7.2.10.2 Unbolt and remove cask lifting ears.

7.2.10.3 Reconnect cask to trailer using tie-down equipment.

7.2.11 Using suitable lifting equipment, lift, inspect for damage and install upper impact limiter on cask in the same orientation as removed.

7.2.12 Attach and hand tighten ratchet binders between upper and lower impact limiters.

7.2.13 Cover lift lugs as required.

7.2.14 Install anti-tamper seals to the designated ratchet binder.

7.2.15 Replace center plate on the upper impact limiter.

7.2.16 Inspect package for proper placards and labeling.

7.2.17 Complete required shipping documentation.

7.2.18 Prior to shipment of a loaded package the following shall be confirmed:

(a) That the licensee who expects to receive the package containing materials in excess of Type A quantities specified in 10 CFR 20.1906(b) meets and follows the requirements of 10 CFR 20.1906 as applicable.

(b) That trailer placarding and cask labeling meet DOT specifications (49 CRF 172).

(c) That the external radiation dose rates of the 10-160B are less than or equal to 200 millirem per hour (mrem/hr) at the surface and less than or equal to 10 mrem/hr at 2 meters in accordance with 10 CFR 71.47.
Perform sufficient surveys to ensure that a non-uniform distribution of radioactivity does not cause the surface or 2m limit to be exceeded.

(d) That all anti-tamper seals are properly installed.

8.0 ACCEPTANCE TESTS AND MAINTENANCE

There are no changes to the acceptance test or maintenance instruction found in Chapter 8 of the SAR for the 10-160B cask. The acceptance tests and maintenance for the Source Insert are given below.

8.1 Acceptance Test

Prior to the first use of the Source Insert, the following tests and evaluations will be performed:

8.1.1 Visual Examination

The container will be examined visually for any adverse conditions in materials or fabrication.

All ferromagnetic material welds are inspected per ASME Code, Section III, Div. I, Subsection NF, NF-5230 for Class 3 support attachments, and Section V Article 7 for magnetic particle (MT) examinations, and Section V Article 6 for liquid penetrant (PT) examinations. Acceptance standards are per ASME Section III, Div. I, Subsection NF, NF-5340 and NF-5350, as appropriate.

Welds on lifting lugs are inspected before and after 150% load test in accordance with the ASME Code requirements for MT examination as specified above.

8.1.2 Structural Tests

Lifting attachments (Lift Lugs) and load carrying components (Lid Fasteners) will be tested equal to 150% of maximum service load.

8.1.3 Leak Tests

No leak tests will be performed on the Source Insert.

8.1.4 Component Tests

The Source Insert will be subjected to Load Testing and Shielding Integrity Testing.

8.1.5 Test for Shielding Integrity

Shielding integrity of the Source Insert will be verified by gamma scan to assure package is free of stream paths in the shield. All gamma scanning will be performed on a 4-inch square or less grid system. The acceptance criteria will be that voids resulting in shield loss in excess of 10% of the normal lead thickness in the direction measured shall not be acceptable.

8.1.6 Thermal Acceptance Tests

No thermal acceptance testing will be performed on the Source Insert.

8.1.7 Impact Limiter Foam

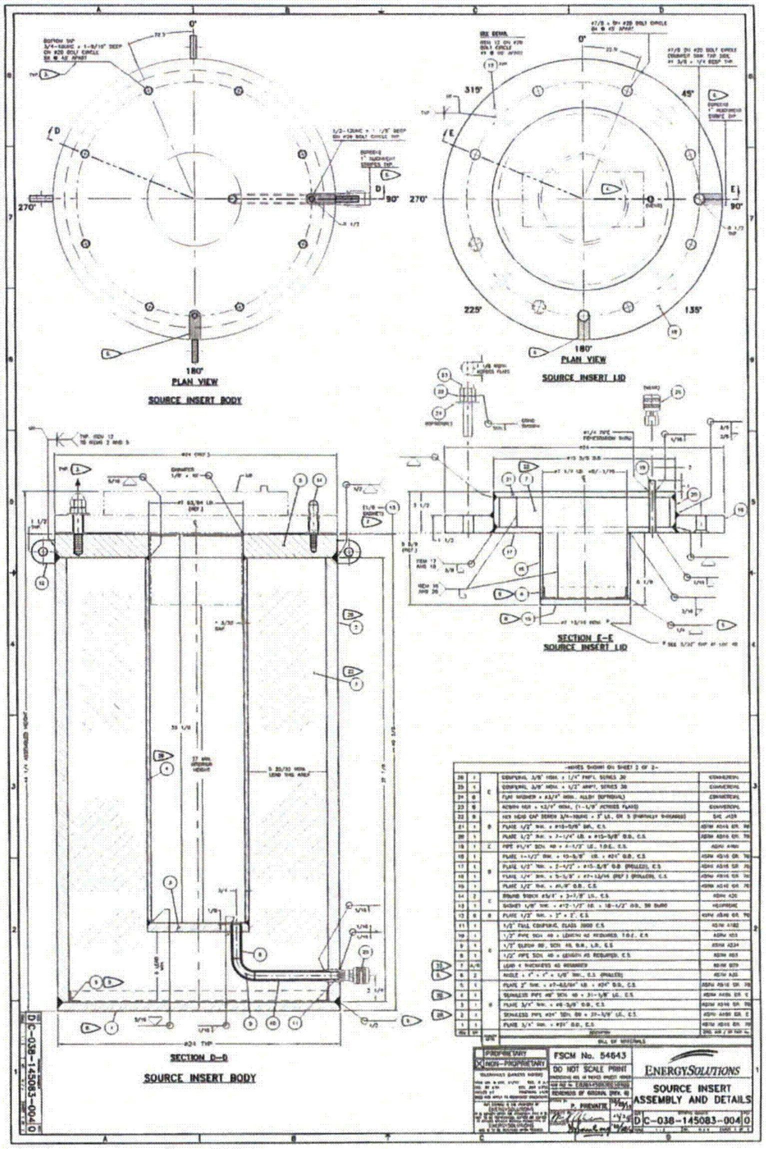
There is no foam in the Source Insert.

8.1.8 Pressure Test

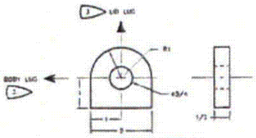
No pressure testing will be performed on the Source Insert.

8.2 Maintenance Program

The Source Insert is a single use container. There are no routine or periodic maintenance activities.

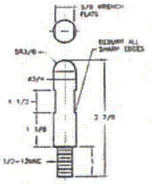


0°
90°
180°
270°
PLAN VIEW
SOURCE INSERT BODY
0°
45°
90°
135°
180°
225°
270°
315°
PLAN VIEW
SOURCE INSERT LID
SECTION E-E
SOURCE INSERT LID
SECTION D-D
SOURCE INSERT BODY
BILL OF MATERIALS
PROPRIETARY
NON-PROPRIETARY
FSCM No. 54643
DO NOT SCALE PRINT
P. PREVATTE
ENERGYSOLUTIONS
SOURCE INSERT
ASSEMBLY AND DETAILS
D C-038-145083-004 0
DC-038-145083-004 0



ITEM 12 DETAIL

SCALE: N.T.S.
4 REQUIRED CONTAINER LID
4 REQUIRED ON BODY



ITEM 14 DETAIL

SCALE: N.T.S.
2 REQUIRED
PAINT (BLACK)

NOTES:

1. NON-DESTRUCTIVE EXAMINATION OF WELDS SHALL MEET THE REQUIREMENTS AND ACCEPTANCE CRITERIA OF ASME CODE SECTION III, DIV. 1 SUBSECTION NF-5000.
2. WELDS ON LIFTING LUGS SHALL BE MT INSPECTED BEFORE AND AFTER 150% LOAD TEST IN ACCORDANCE WITH THE REQUIREMENTS AND ACCEPTANCE CRITERIA OF ASME CODE SECTION III, DIV. 1, SUBSECTION NF-5000.
3. → LOAD TEST DIRECTIONS
4. STAMP OR STENCIL THE FOLLOWING INFORMATION AS SHOWN:

PLACE ON OUTER BODY SHELL APPROX. TYP. 2 PLACES 180° APART AND ON TOP LID AS SHOWN

ENERGYSOLUTIONS
DATE OF MANUFACTURE XX-YY

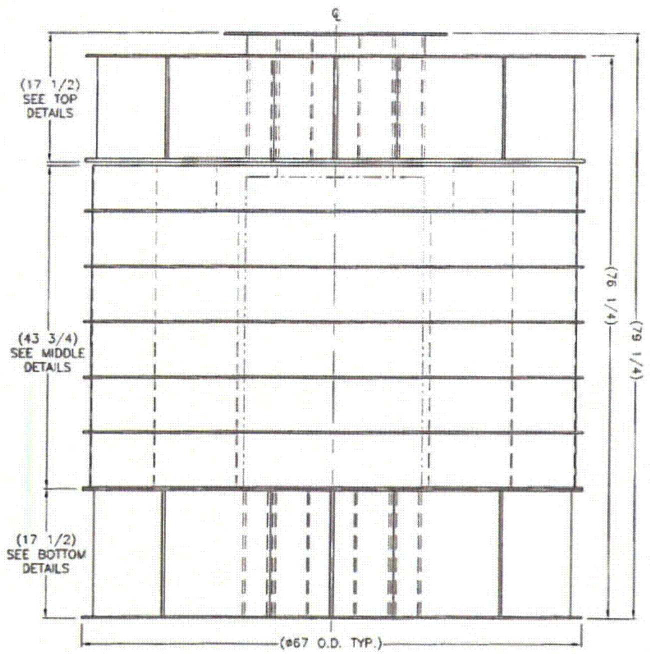
SERIAL No. ______-00?
PACKAGE GROSS WEIGHT: 8,000 lbs.
OUTER LID WEIGHT: ____
INNER LID WEIGHT: ____

5. STENCIL AS SHOWN → LID LIFT ONLY! BLACK, MIN. 1/4" HEIGHT.
6. APPLY ALIGNMENT STRIPE IN-LINE WITH ALIGNMENT PIN AND ADJACENT HOLES TYP.
7. APPLY RTV TYPE ADHESIVE TO SECURE GASKET ITEM 13 TO ITEM 5.
8. THIS PLATE NOT TO BE WELDED UNTIL ITEM 7 HAS BEEN INSTALLED.
9. WELDS SHALL USE A BACKING RING WITH CONFIGURATION APPROVED BY ENERGYSOLUTIONS.
10. ALL WELDS SHALL BE FULL-PENETRATION UNLESS OTHERWISE SPECIFIED. WELD PREPARATION PER FABRICATOR'S CHOICE WITH ENERGYSOLUTIONS APPROVAL.
11. GAMMA SHIELDING INTEGRITY EFFECTIVENESS: ALL SHIELDING SHALL BE APPLIED CONTINUOUSLY TO AVOID GAPS OR RADIATION STREAMING PATHS. GAMMA SCAN OR GAMMA PROBE IS REQUIRED TO ENSURE GAMMA SHIELDING INTEGRITY. LOSS OF SHIELDING AT ANY POINT IN EXCESS OF 10% WILL REQUIRE REMEDY. THE PROCEDURES AND EQUIPMENT TO BE USED FOR THE GAMMA SCAN SHALL BE APPROVED BY ENERGYSOLUTIONS PRIOR TO PERFORMANCE OF THE TEST.
12. TORQUE LID BOLTS TO 75 +10/-0 ft-lbs (LUBRICATED).
13. MAX PAYLOAD WEIGHT: 500 lbs. / MAXIMUM PACKAGE WEIGHT: 8,000 lbs.
14. UNLESS OTHERWISE NOTED ALL DIMENSIONS ARE NOMINAL WITH MAXIMUM TOLERANCES OF ± 1/4". ANGLES ARE ±5°.
15. ALL LISTED MATERIAL AS SHOWN OR AN ENERGYSOLUTIONS APPROVED EQUAL.
16. PAINT SHALL BE IN ACCORDANCE WITH ENERGYSOLUTIONS APPROVED PROCEDURES.
17. ALIGNMENT INDICATORS ARE PROVIDED ON LID, BODY FOR PROPER COMPONENTS ORIENTATION AT ASSEMBLY.
18. ALL FASTENERS SHALL BE MANUFACTURED IN U.S.A. HEAD MARKINGS SHALL BE VERIFIED AGAINST LATEST D.O.E. COUNTERFEIT CHART. ENERGYSOLUTIONS SUPPLIED.
19. VENDOR TO WEIGH COMPONENTS AND STENCIL WEIGHTS.
20. OPTION: THESE COMPONENTS MAY BE FABRICATED FROM A-515 GR. 70 MATERIAL. WHEN USING THIS MATERIAL OPTION - VENDOR SHALL FABRICATE TO DUPLICATE PIPE SIZES AND PROVIDE A FULL PENETRATION SEAM WELD, GRIND SMOOTH ON I.D.
21. WELDING PROCEDURE AND QUALIFICATION OF WELDERS SHALL BE ESTABLISHED IN ACCORDANCE WITH ASME CODE SECTION IX. THE REFERENCE SECTION FOR ALL WELDS SHALL BE ASME CODE SECTION VIII - DIVISION 1 OR SECTION III - SUBSECTION NF.
22. THE LEAD WILL BE PROCURED AS A COMMERCIAL ITEM. A SUCCESSFUL GAMMA - SCAN USING A QUALITY LEVEL B VENDOR WILL BE USED AS PART OF A COMMERCIAL ITEM UPGRADE TO QUALIFY THE SHIELDING AS QUALITY LEVEL B.

☐ PROPRIETARY ☒ NON-PROPRIETARY	FSCM No. 54643	ENERGYSOLUTIONS
	DO NOT SCALE PRINT	SOURCE INSERT ASSEMBLY AND DETAILS
	DRAWN BY: P. PREVATTE	DC-038-145083-004 REV. 0

NOTES

1. FABRICATION, INSPECTION, TESTING, AND ACCEPTANCE SHALL COMPLY WITH ENERGYSOLUTIONS SPECIFICATIONS ES-E-001 AND ITS RELATED DATA SHEET. SEE P.O. FOR DATA SHEET CALLOUTS.
2. NOTCHES MAY BE PROVIDED TO ACCOMMODATE THE INSERT INSIDE THE CRIBBING.
3. LIFTING ATTACHMENTS MAY BE ADDED FOR HANDLING THE INDIVIDUAL CRIBBING SEGMENTS.
4. ALL THE COMPONENTS ON THIS DRAWING ARE CONSIDERED SAFETY CLASS C.
5. ESTIMATED WEIGHT - TOP SEGMENT = 1,400 LBS., MIDDLE SEGMENT = 2,200 LBS., BOTTOM SEGMENT = 1,200 LBS.



ELEVATION VIEW
ASSEMBLY

ITEM	QTY	DESCRIPTION	SPEC. AND / OR PART No.
19	8	PLATE 1/2" THK. x 13-3/4" x 20" LG.	ASTM A36 OR EQ.
18	1	24" PIPE SCH. 20 x 16-3/4" LG.	
17	1	16" PIPE SCH. 30 x 16-3/4" LG.	ASTM A-501 OR EQ.
16	1	6" PIPE SCH. 40 x 16-3/4" LG.	
15	1	PLATE 1/4" THK. x ø30" O.D.	
14	1	PLATE 1/4" THK. x 32" I.D. x ø67" O.D.	
13	1	PLATE 1/2" THK. x ø67" O.D.	
12	1	PLATE 1/8" THK. x 6" x ø65" O.D. (ROLLED)	
11	5	PLATE 1/8" THK. x 7-1/4" x ø65" O.D. (ROLLED)	
10	1	PLATE 1/8" THK. x 6" x ø48" O.D. (ROLLED)	ASTM A36 OR EQ.
9	5	PLATE 1/8" THK. x 7-1/4" x ø48" O.D. (ROLLED)	
8	1	PLATE 1/8" THK. x 6" x ø32" O.D. (ROLLED)	
7	5	PLATE 1/8" THK. x 7-1/4" x ø26" O.D. (ROLLED)	
6	6	PLATE 1/4" THK. x ø24-1/2" I.D. x ø67" O.D.	
5	8	PLATE 1/2" THK. x 17" x 20" LG.	
4	1	24" PIPE SCH. 20 x 17" LG.	
3	1	16" PIPE SCH. 30 x 17" LG.	ASTM A-501 OR EQ.
2	1	6" PIPE SCH. 40 x 17" LG.	
1	2	PLATE 1/4" THK. x ø67" O.D.	ASTM A36 OR EQ.

BILL OF MATERIALS

☐ PROPRIETARY
☒ NON-PROPRIETARY

TOLERANCES (UNLESS NOTED)
HOLE DIA. & LOC. ±1/32 DEC. .X ±.1
DEC. .XX ±.01 DEC. .XXX ±.005
ANGLES ±1° FRACTIONS ±1/8
DOES NOT APPLY TO REFERENCE DIMENSIONS

FSCM No. 54643

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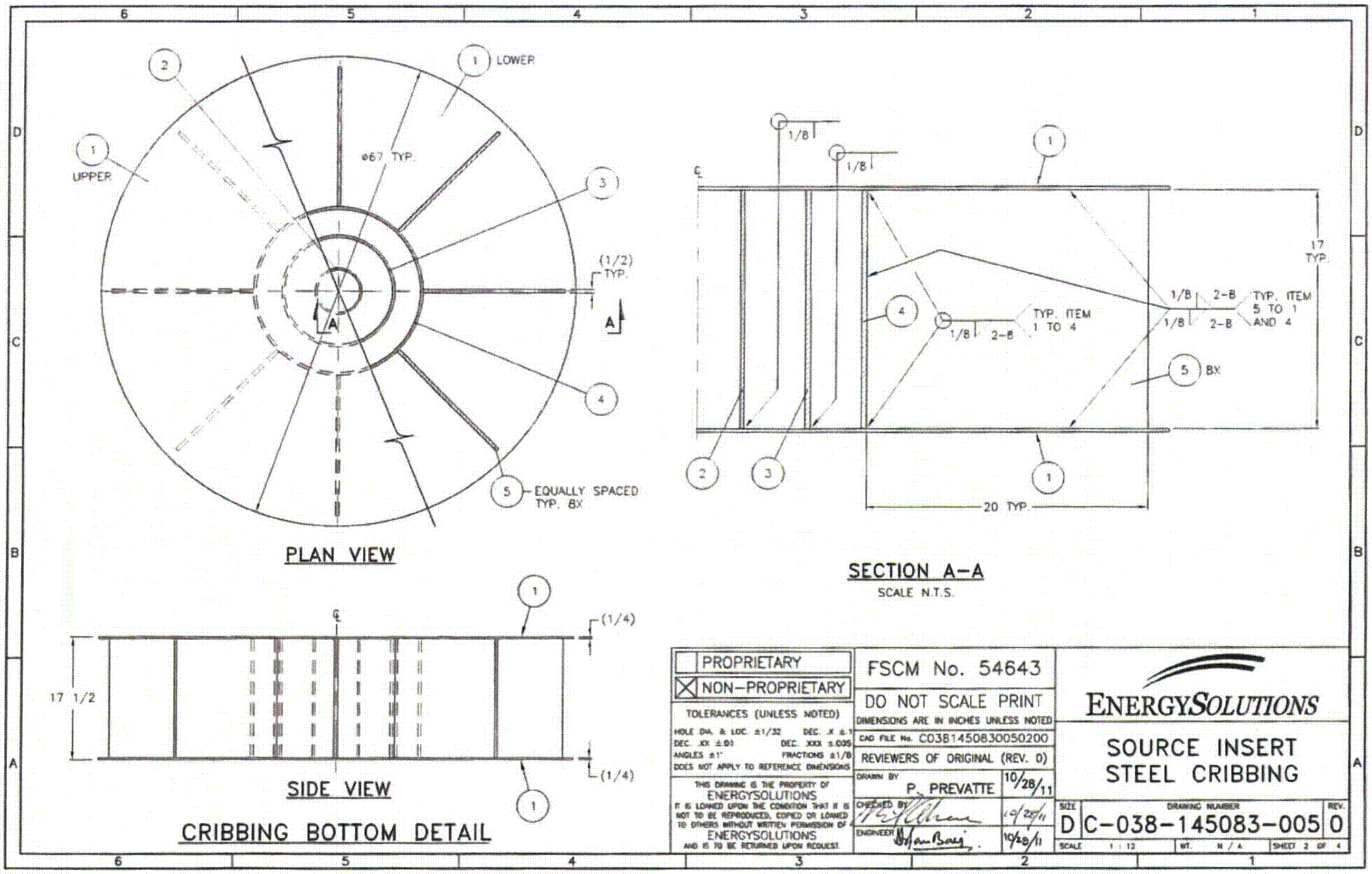
ENGINEER [signature] 10/28/11

ENERGYSOLUTIONS

SOURCE INSERT
STEEL CRIBBING

SIZE B | DRAWING NUMBER C-038-145083-005 | REV 0
SCALE 1 : 12 | WT. N / A | SHEET 1 OF 4



PLAN VIEW
UPPER
LOWER
⌀67 TYP.
(1/2) TYP.
EQUALLY SPACED TYP. 8X
A
SECTION A-A
SCALE N.T.S.
1/8
TYP. ITEM 1 TO 4
2-8
TYP. ITEM 5 TO 1 AND 4
17 TYP.
20 TYP.
8X
SIDE VIEW
17 1/2
(1/4)
CRIBBING BOTTOM DETAIL
PROPRIETARY
NON-PROPRIETARY
TOLERANCES (UNLESS NOTED)
HOLE DIA. & LOC. ±1/32 DEC. .X ±.1
DEC. .XX ±.01 DEC. .XXX ±.005
ANGLES ±1° FRACTIONS ±1/8
DOES NOT APPLY TO REFERENCE DIMENSIONS
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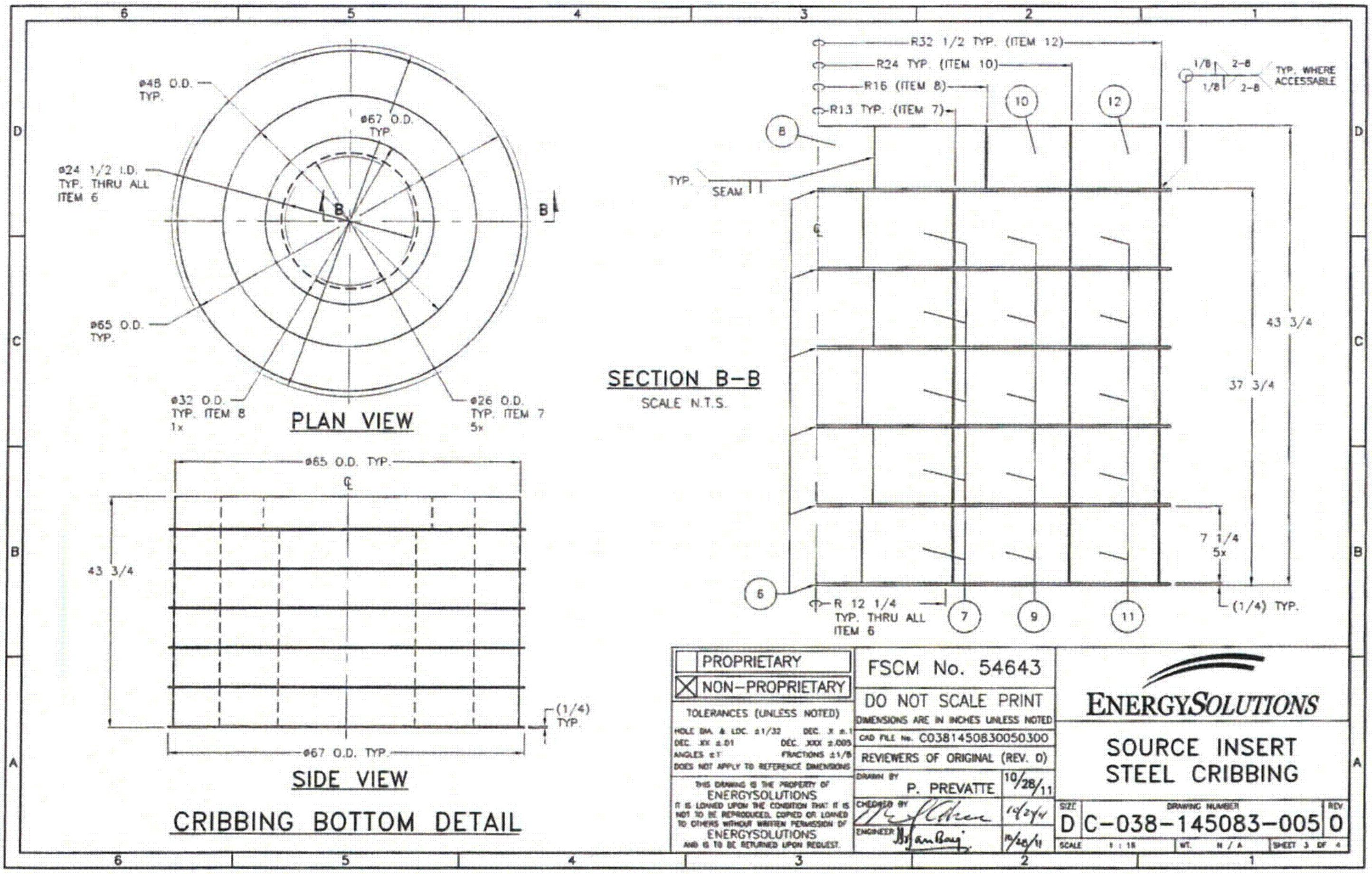
CHECKED BY 10/28/11
ENGINEER 10/28/11
ENERGYSOLUTIONS
SOURCE INSERT STEEL CRIBBING
SIZE D
DRAWING NUMBER C-038-145083-005
REV. 0
SCALE 1 : 12
WT. N / A
SHEET 2 OF 4



PLAN VIEW
ø48 O.D. TYP.
ø67 O.D. TYP.
ø24 1/2 I.D. TYP. THRU ALL ITEM 6
ø65 O.D. TYP.
ø32 O.D. TYP. ITEM 8 1x
ø26 O.D. TYP. ITEM 7 5x
SECTION B-B
SCALE N.T.S.
R32 1/2 TYP. (ITEM 12)
R24 TYP. (ITEM 10)
R16 (ITEM 8)
R13 TYP. (ITEM 7)
TYP. SEAM
43 3/4
37 3/4
7 1/4 5x
(1/4) TYP.
R 12 1/4 TYP. THRU ALL ITEM 6
TYP. WHERE ACCESSABLE
SIDE VIEW
ø65 O.D. TYP.
ø67 O.D. TYP.
CRIBBING BOTTOM DETAIL
PROPRIETARY
NON-PROPRIETARY
TOLERANCES (UNLESS NOTED)
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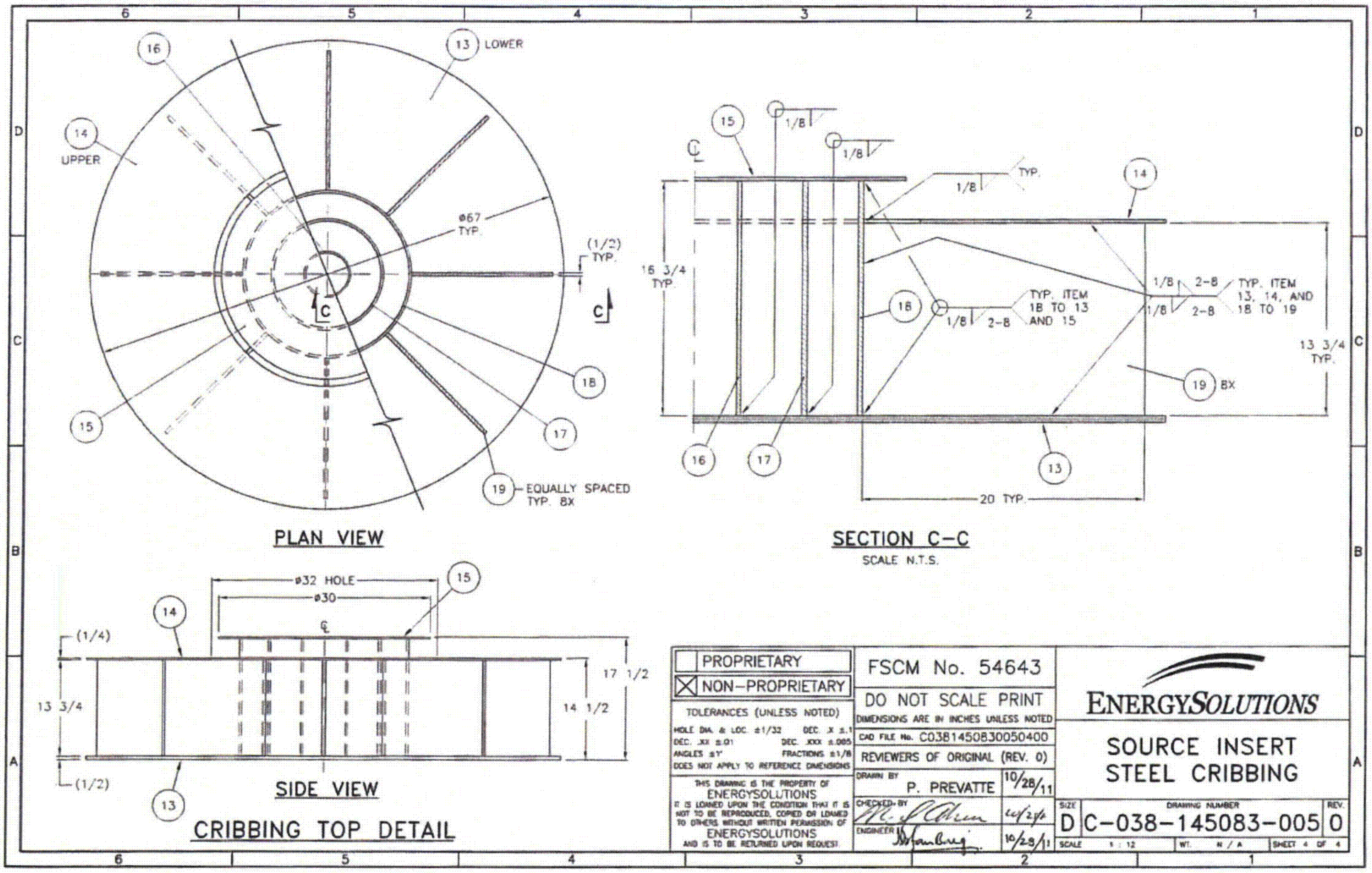
ENERGYSOLUTIONS
SOURCE INSERT STEEL CRIBBING
SIZE D
DRAWING NUMBER C-038-145083-005
REV 0
SCALE 1:16
SHEET 3 OF 4



PROPRIETARY
☒ NON–PROPRIETARY

TOLERANCES (UNLESS NOTED)
HOLE DIA. & LOC. ±1/32 DEC. .X ±.1
DEC. .XX ±.01 DEC. .XXX ±.005
ANGLES ±1° FRACTIONS ±1/8
DOES NOT APPLY TO REFERENCE DIMENSIONS

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CHECKED BY 11/2/11

ENGINEER 10/28/11

ENERGYSOLUTIONS

SOURCE INSERT
STEEL CRIBBING

SIZE D DRAWING NUMBER C–038–145083–005 REV. 0

SCALE 1 : 12 WT. N / A SHEET 4 OF 4