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Enclosure 3

Safety Analysis Report for Model 10-160B Type B Radwaste Shipping Cask
Consolidated SAR Revision 7, November 2013
Public Version
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SAFETY ANALYSIS REPORT

For

MODEL 10-160B
TYPE B RADWASTE SHIPPING CASK

CONSOLIDATED SAR REVISION 7

NOVEMBER 2013

Submitted by:

ENERGYSOLUTIONS

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1. 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 Appendices 4.11.2 through 4.11.7. 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.

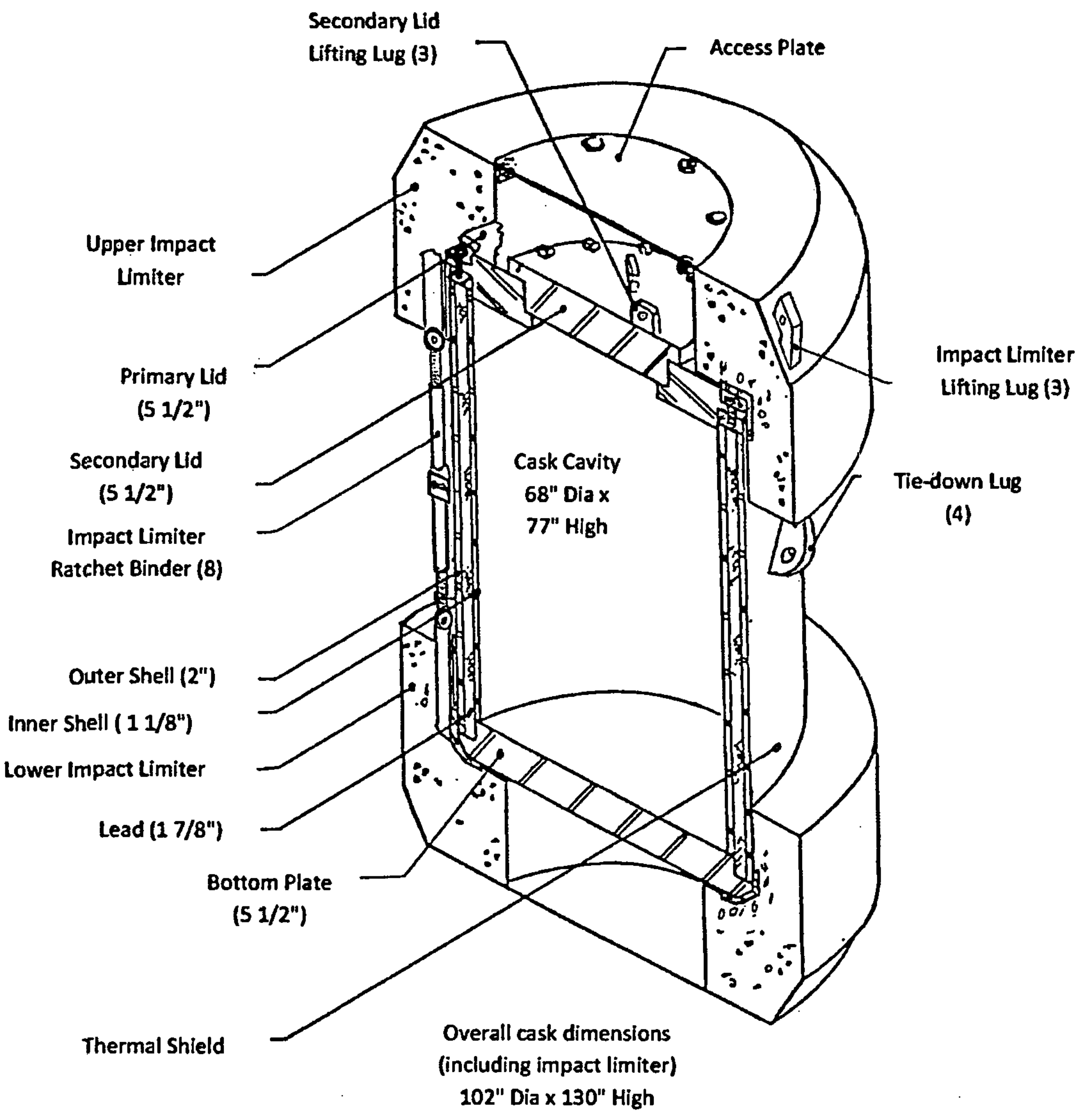


Figure 1-1 10-160B General Arrangement

(Top themal shield not shown)

1.3 APPENDIX - 10-160B SHIPPING CASK DRAWINGS

- Drawing No. C-110-D-29003-010, *"Cask Assembly General Notes/Parts List"*
- Drawing No. DWG-CSK-12CV01-EG-0002, *"10-160B Cask Secondary Lid Thermal-Shield Details"*

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

2. STRUCTURAL EVALUATION

This Chapter identifies and describes the structural design of the 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 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 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.

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.

(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:

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

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 = Ar2 = moment of inertia.

The above equation could be written as follows:

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

$E = 27.8 \times 10^6$ psi

$I = \pi R^3 t$

Where R = cylinder radius

t = cylinder thickness

Inner Shell

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

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

Outer Shell

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

$Pcr_o = 1.51 \times 10^{10}$ 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: $\gamma z > \frac{\pi^2 K_{co}}{2\sqrt{3}}$

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		
ti	=	1 in	to	=	2 in
Ri	=	34.5 in	Ro	=	37.625 in
Li	=	77 in	Lo	=	78 in
ν	=	.3	ν	=	.3 in
zi	=	163.94	zo	=	77.13

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

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

Ri/ti = 34.50 yields γi = .74

Ro/to = 18.81 yields γo = .8

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

Both shells will be treated as moderately long cylinders.

From (ref. 6) Page 229

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

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

σei = 360,906 psi

and

σeo = 715,482 psi

HOOP STRESS LIMIT

(Ref. 6) PAGE 236

$$\sigma h = \sigma cr/\eta \quad = \quad kp\,\pi\,\frac{{}^{2}E}{12\,(1-\nu^{2})}\left(\frac{t}{L}\right)^{2}$$

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)

$\sigma_e = \sigma_{cr}/\eta$ ....(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

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

Where:

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

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

σ_{cr} = critical stress

$\in$ = strain

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

$\sigma = A\,\varepsilon 2 + B\,\varepsilon + C$ (3)

Where,

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

B = 6.0233×10^{7}

C = -1.5517×10^{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:

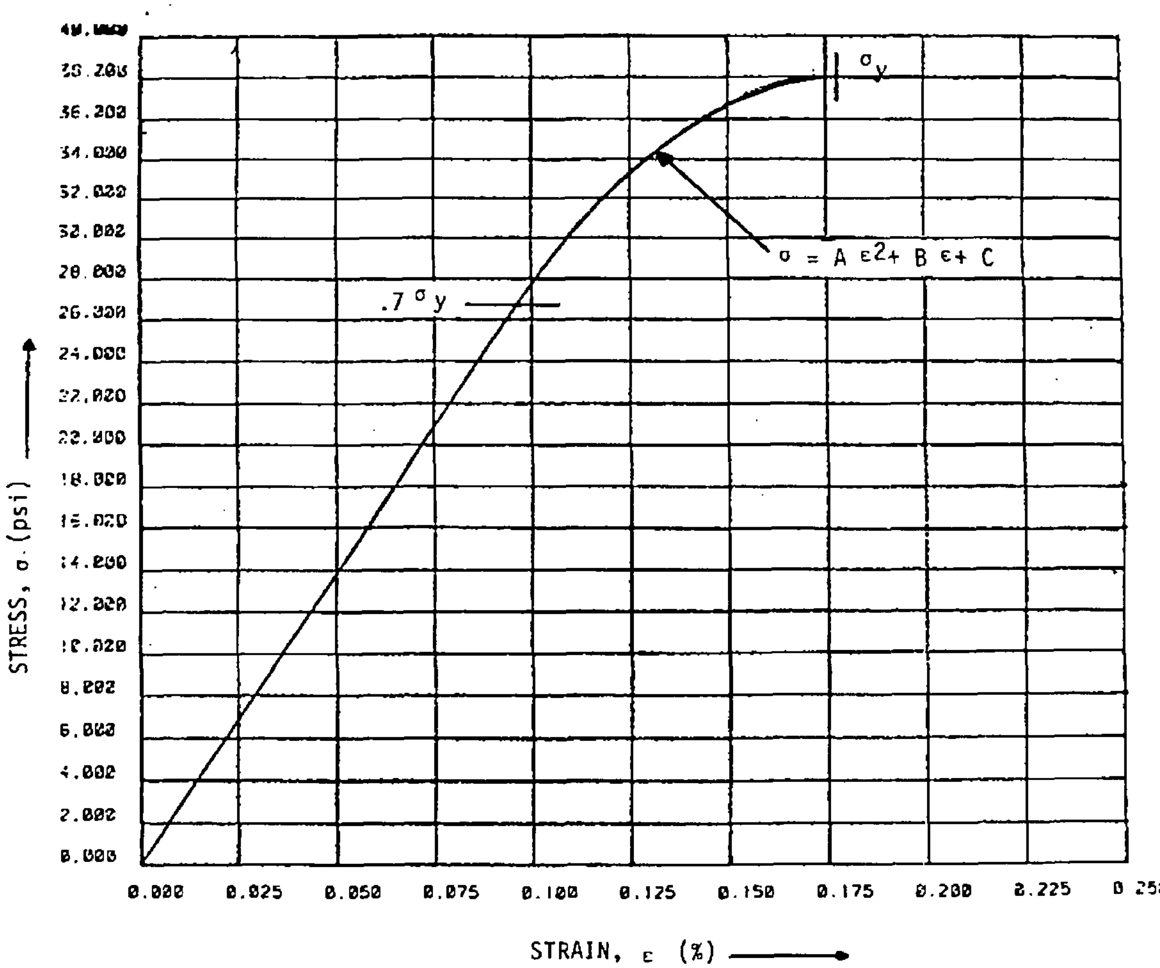


Figure 2.1.1
Constituted Stress-Strain Curve for A516 GR.70

Axial

	Inner	Outer
σe, psi	360,906	715,482
∈cr	1.7653 x 10-3	1.774 x 10-3
η	0.1051	0.0539
σcr, psi	37,921	37,948

Hoop

	Inner	Outer
σh, psi	44,497	132,155
∈cr	1.165 x 10-3	1.6928 x 10-3
η	0.854	0.2875
σcr, 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.

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

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
σe psi	360,906	715,482
σH psi	44,497	132,155
σi psi	340,843	659,413
∈cr	1.7639 x 10-3	1.77347 x 10-3
η	0.1112	0.0576
σcr (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 si (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:

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

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 10-160B 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 (2)	70	70	38,000	70,000	23,300	29.5E6	6.50E-6
		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 (1)	F	70	100,000	115,000	38,300	29.5E5	6.27E-6
		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 (3)	BD	100	130,000	150,000	-------	29.9E6	6.20E-6
LEAD B-29 (6)	Chemical	-40	-	-	-	2.46E6	15.56E-6
		-20	-	-	-	2.43E6	15.65E-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	-	-	-	-

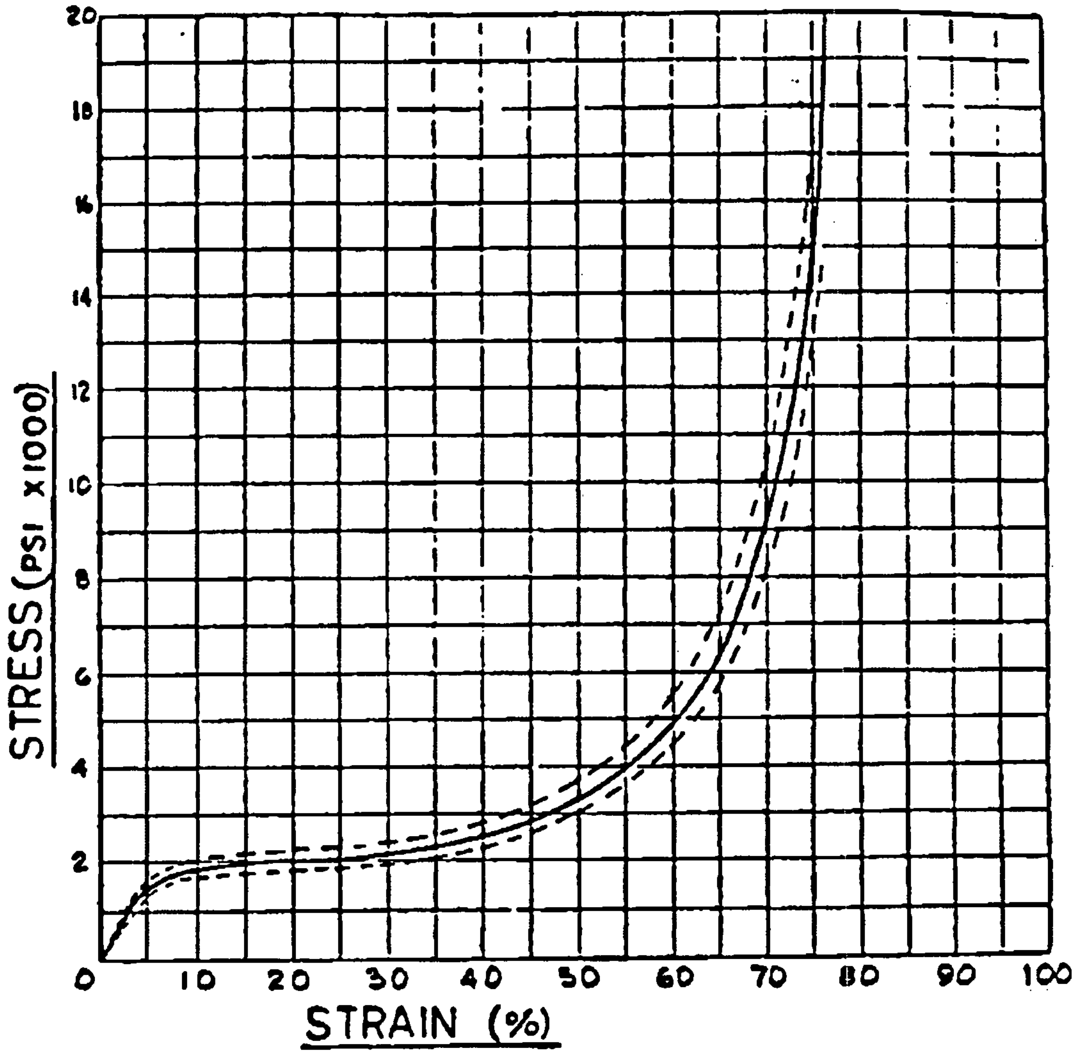


Figure 2-1
Compressive Stress-Strain Curve for Foam

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:

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

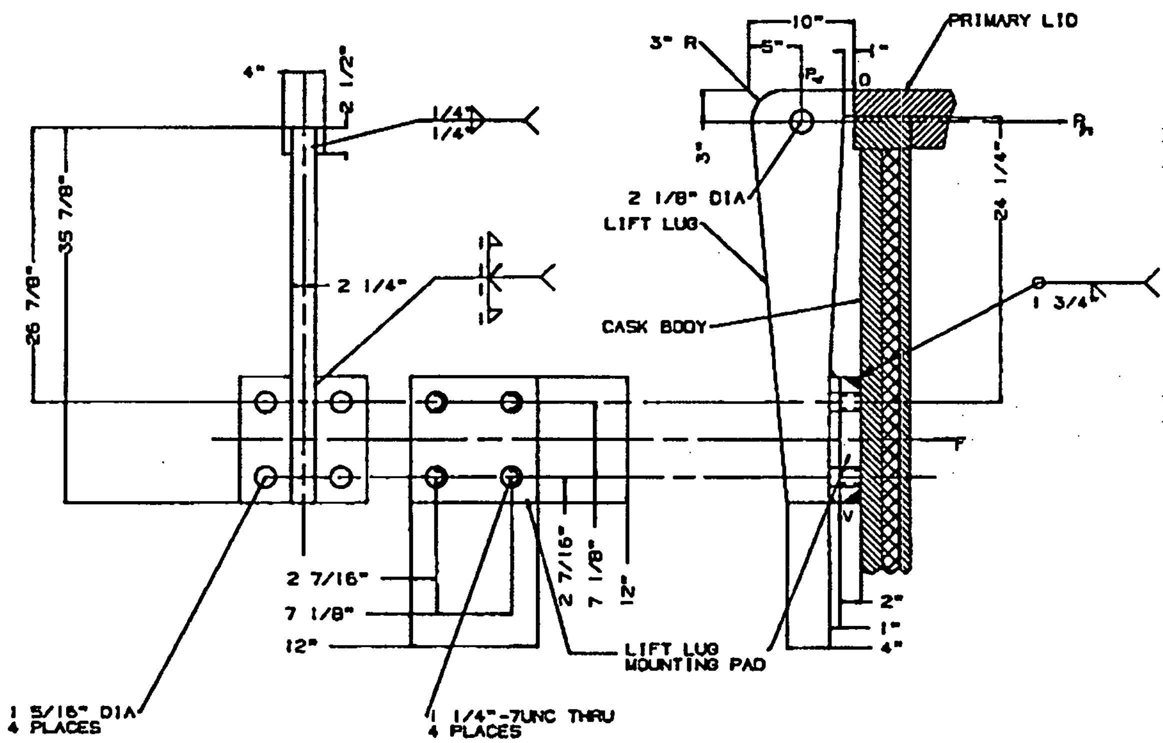


Figure 2-2
Cask Lift Lug

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, $t_w = 1\ ¾ \times .707 = 1.24"$

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

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

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

Allowable stress in pure shear is $1/3 \times .577 \times S_y =$

$1/3 \times .577 \times 38,000 = 7,309$ psi

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

Stress Intensity of Weld

2 x 606 = 1,212 psi

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

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, $A_w = 28 \times .707 = 19.8\ in^2$

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

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

Allowable stress in pure shear is

$1/3 \times .577 \times 38,000 = 7.309$ 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 $\tau_b = \dfrac{4 \times 27864}{3}$

τ_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 $in.^2$

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 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

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

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

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

Shear out of lug

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

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

N = 2

t = 1"

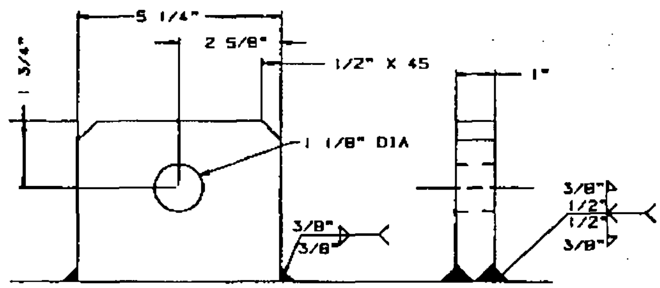
A_s = N.L.t = 2 x 1.1875 x 1 = 2.375 in^2

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

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

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

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



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

Shear in weld

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 Lug	45,252.7	---------	-----------	------------	57,700	1.28
	10,414.6	16,313	8900.31	32,704.24	100,000	3.06
Weld Stress	21,195.1	------------	-----------	-------------	57,700	2.72

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.

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

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

Eq. A into Eq. B yields the following:

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

Where

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

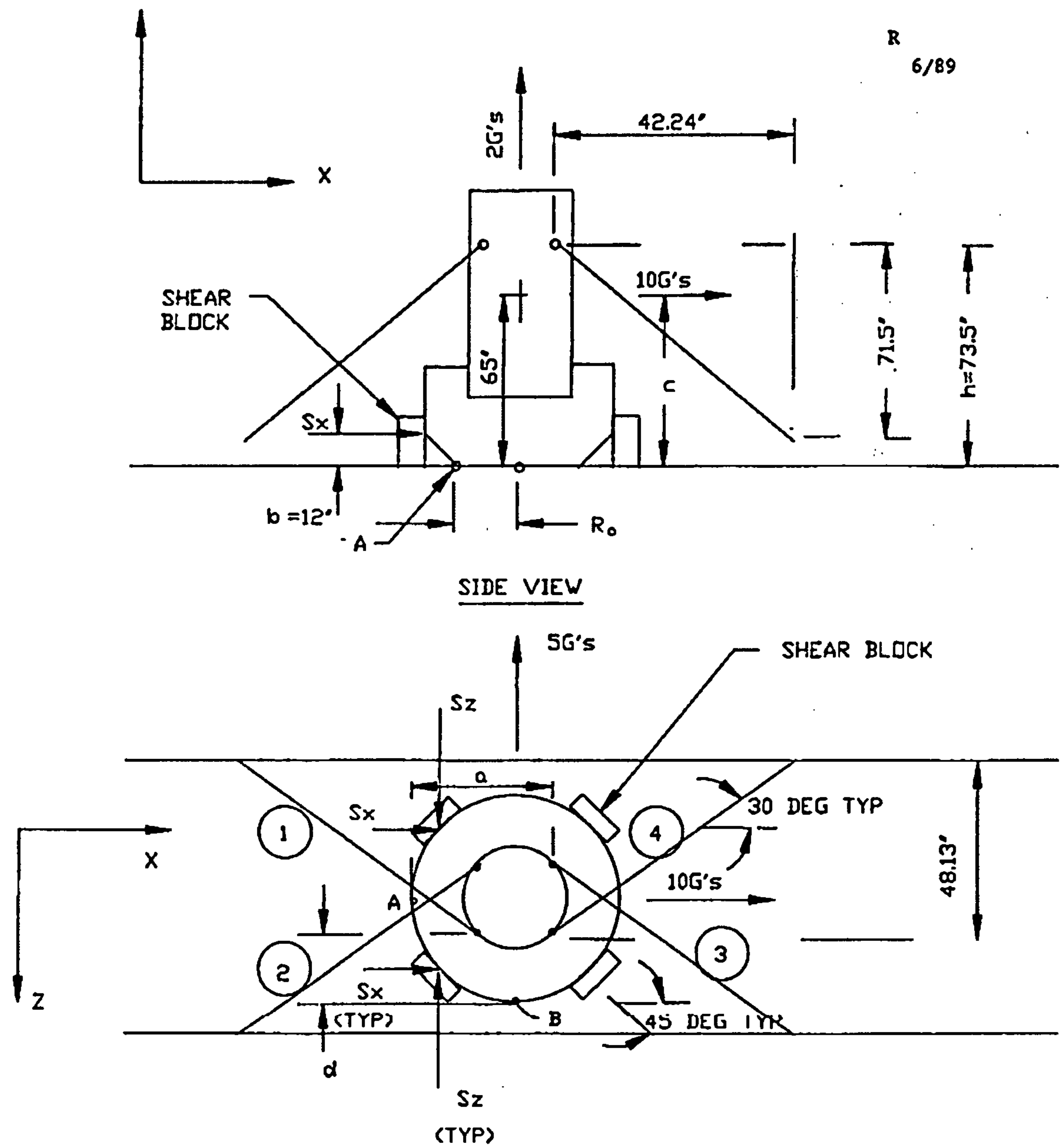
$L_x \quad =$ X-component of cable length

$L_y \quad =$ Y-component of cable length

$L_z \quad =$ Z-component of cable length

$S_x \quad =$ X-component of shear block force

$S_z \quad =$ 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	=	$\dfrac{-10(72{,}000)(65)+72{,}000(45)+10(72{,}000)(12)}{-2(.4401)(73.5)-2(.7449)(81.05)+2(.4401)(12)}$
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:

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

2.4.4.1 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, $\tau = V/A_{ES} = 410{,}125.38/9.063$
$\tau = 45{,}252.71$

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

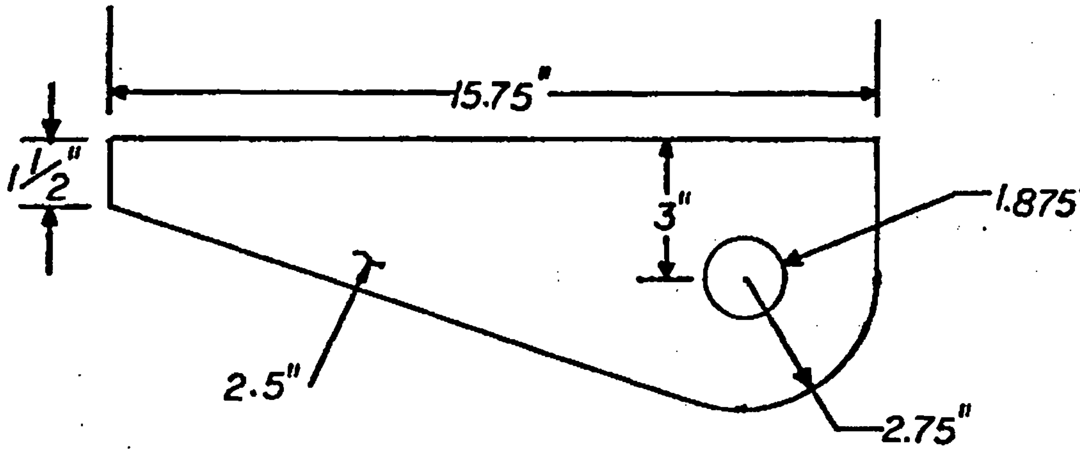


Figure 2-4
Tie-Down Lug Detail

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

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

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

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

Direct stress is $\sigma t + \sigma b = 25{,}213.39$ psi

Shear Stress

Use v = 410,125.38 lbs (conservative)

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

$\tau = V/A_{ES} = 410{,}125.38/39.38 = 10{,}414.56$ 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. = $\dfrac{100{,}000}{25{,}213.39} = 3.06$

2.4.4.2 Stresses in the Welds

Length of weld, $L_W = (15.75 \times 2 + 2.5 \times 2)$

$L_W = 36.5"$

Width of weld, $W_W = .707 \times ¾ = .53"$

Area of weld, $A_W = 36.5 \times .53 = 19.35\ in^2$

Conservatively assume the force acting on weld:

F = 410,125.38 lbs

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

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

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 <u>HEAT</u>

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.

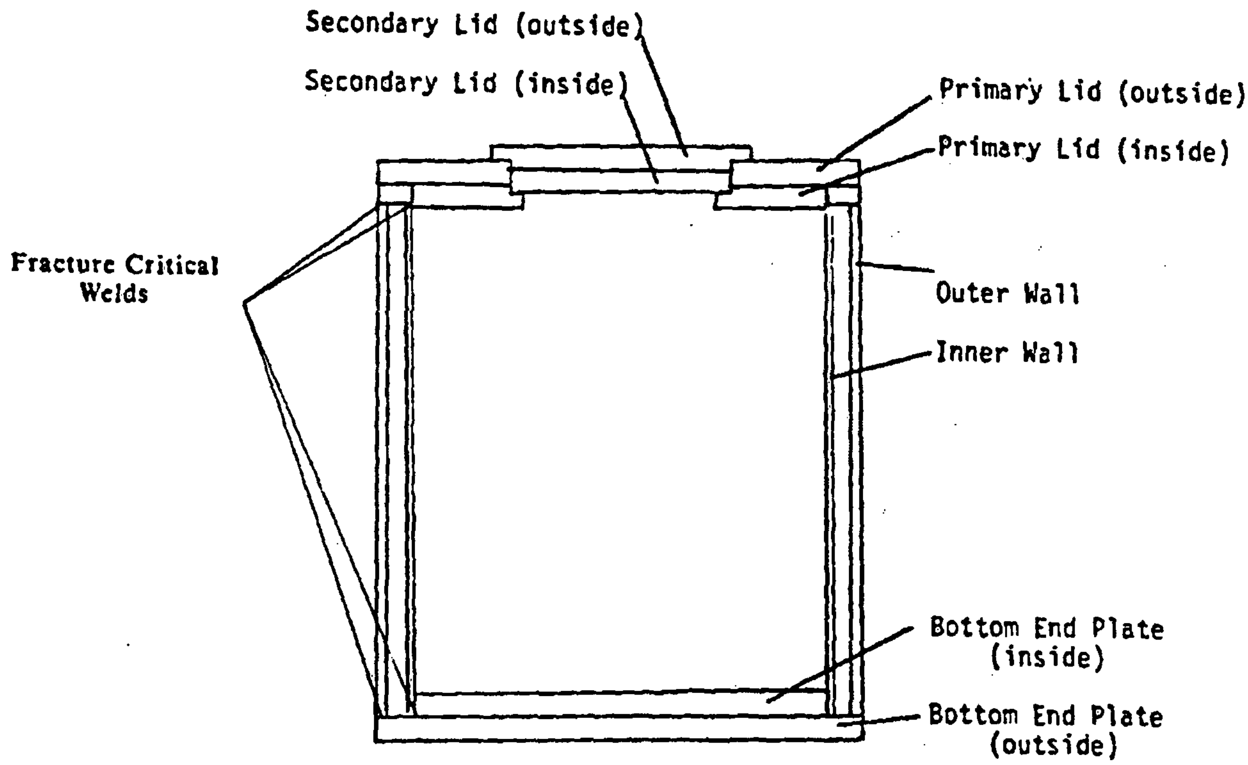


Figure 2-9
Fracture Critical Components

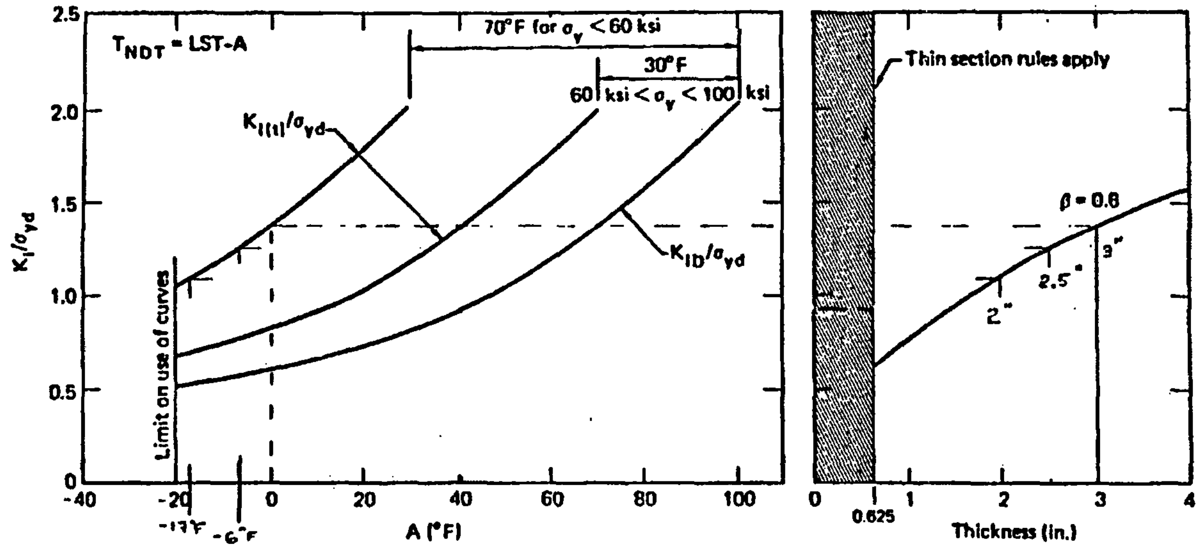


Figure 2-9A
Design Chart for Category 11 Fracture Critical Components

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.

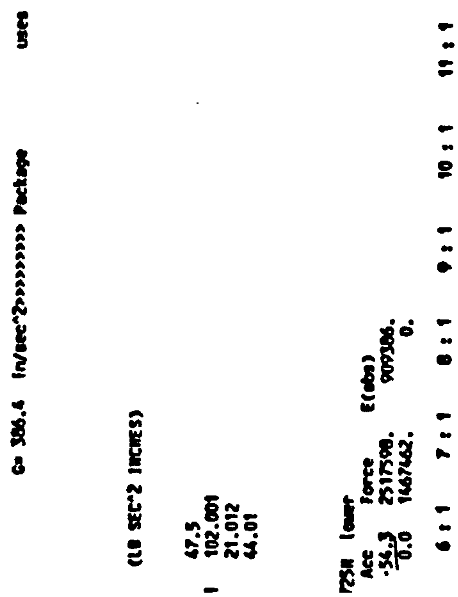


Figure 2-10
1-Foot End Drop CASKDROP

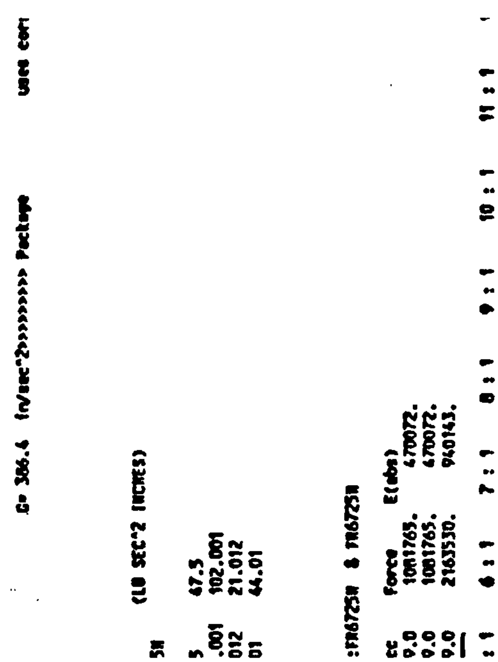


Figure 2-11
1-Foot Side Drop CASKDROP Print-out

```
G= 386.4  in/sec^2>>>>>>>>> Package          uses c(

          (LB SEC^2 INCHES)
fr6725h
)
  47.5        47.5
  102.001     102.001
  21.012      21.012
  44.01       44.01
3:17:45

pack:fr6725h

lection  Acc      Force      E(abs)
 4.7770   -9.6     747115.    1227023.

   5 : 1    6 : 1    7 : 1    8 : 1    9 : 1    10 : 1    11 : 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: 12-20-84   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:50RONT   50r cask over wt                    G= 386.4  in/sec^2)))))))))) Package          uses correction factor tabl
Weight              (lb) W      72000
Outer diameter      (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:50RONT   50r cask over wt    Overpack:fr6725s  lower
  ============Iteration   Time     Deflection  Acc      Force     E(abs)
Projection         20     .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: EWD17B   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 diameter      (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)

Table- 2-11
Maximum Stress Intensities In Cask Components
Hypothetical Accident – 30 Ft End Drop(1)

Cask Component	Stress Classification	S.I.(2) (psi)	Allowable (psi)	Safety Factor
Baseplate	Membrane	651.89	49,000	75.17
	Membrane Plus Bending	14,557.3	70,000	4.81
Outer Shell	Membrane	6,955	49,000	7.05
	Membrane plus Bending	16,971	70,00	4.12
Inner Shell	Membrane	11,196	49,000	4.38
	Membrane plus Bending	17,992	70,000	3.89
Bolting Ring	Membrane	10,288	49,000	4.76
	Membrane plus Bending	11,087	70,000	6.31
Primary Lid	Membrane	5,674.5	49,000	8.64
	Membrane plus Bending	20,309.9	70,000	3.45
Secondary Lid	Membrane	224.76	49,000	218
	Membrane plus Bending	23,845.8	70,000	2.94

NOTE: (1) See Table 2-1 for accident condition load combination.
(2) See Table A2-13 for the load combination per Regulatory Guide 7.8.

Stress intensities throughout the cask are well below allowables, with the maximum stress intensity of 23,846 psi occurring in the secondary lid at the section shown in Figure A2-40. The corresponding minimum factor of safety is:

$$S.F. = \frac{70{,}000}{23{,}846} = 2.94$$

The stress intensity distribution in the solid elements in the critical region is shown in Figure 2-13.

2.7.1.1.1 End Drop Secondary Lid Bolt Forces

The loads required to hold the secondary lid in place for the end drop were calculated using the results of ANSYS stress analysis. The forces on the bolts were computed in the axial (tensile) and radial (shear) direction. Because of the axisymmetry for this load case, no tangential (shear) forces should exist. However, since the grid geometry is not axisymmetric, a slight difference in weight and the element centroid location around the circumference of the cask model exists. This gives rise to a nonaxisymmetric inertia loading on the cask. Therefore, the results tangential (shear) forces on the bolt locations. Also, because of the reasons mentioned, a slight variation in nodal forces at the bolt locations around the circumferential directions is predicted by ANSYS model. Table 2-12(a) lists the load and the intensities in the bolts (1 3/4" – 8UN) are also presented in the table. The highest stress intensity was found to be 57,310 psi, and the corresponding safety factor, is

$$S.F. = \frac{130{,}000}{57{,}310} = 2.27$$

2.7.1.1.2 End Drop Primary Lid Bolt Forces

No forces are developed in the primary lid bolts during this condition.

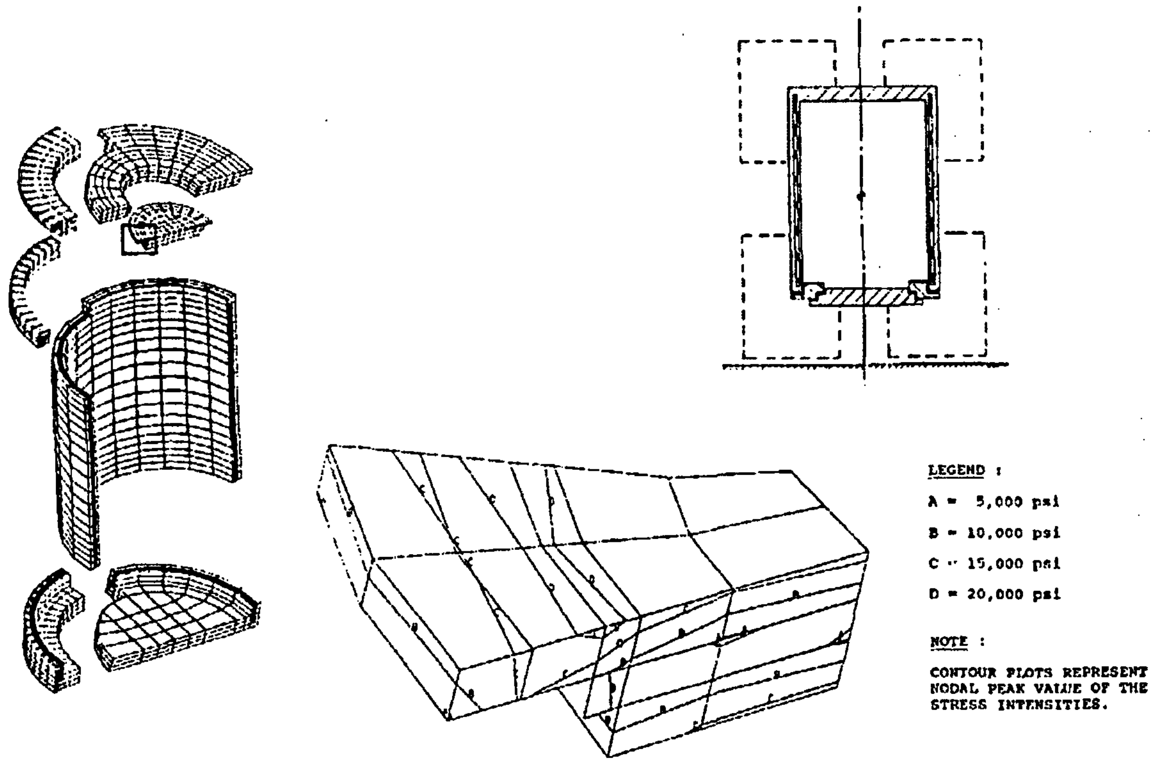


Figure 2-13
End-Drop – Stress Intensity Contour Plot Secondary Lid

Table 2-12
10-160B Cask – End Drop Analysis
Secondary-Lid Bolt Loading

Location (Degrees)	FEMNODE NO.	FX(1) (lbs)	FY(1) (lbs)	FZ(1) (lbs)	Axial Load(lbs)	Shear Load(lbs)	S.I.(3) (psi)
0	114	28,341	-(2)	80,475	80,475	28,341	47,341 (4)
30	116	38,903	7,132	88,003	88,003	39,551	56,910 (4)
60	118	39,580	7,235	87,884	87,884	40,236	57,310 (4)
90	120	32,619	2,639	82,017	82,017	32,726	50,467 (4)
120	122	37,554	1,537	84,975	84,975	37,585	54,565 (4)
150	124	38,604	424	86,208	86,208	38,606	55,661 (4)
180	126	38,477	-(2)	86,496	86,496	38,477	55,682 (4)

Notes:
(1) FX is force on the node in radial, FY in tangential and FZ in axial directions.
(2) Tangential loads at the plane of symmetry do not go through the bolts.
(3) For 1 3/4" – 8UN bolts (stress area 2.0792 in^2).
(4) Because of non-uniform grid size in the model, a small amount of moment, in addition to axial loading, exists giving non-axisymmetric S.I. distribution. The largest value is conservatively assumed to exist uniformly. See section 2.10 for more detail.

2.7.1.2 Lead Slump

Lead slump is derived directly from the finite element model used to compute stresses and deflections in the cask for the end drop analysis. From that analysis, lead slump is predicted to be less than 0.02 inches. This agrees well with test results of other Type B packages using foam impact limiters in which no measurable lead slump was found. No bonding is assumed between the lead and the steel shells in evaluating lead slump. The analysis shown in Section 5.4.3 shows that a localized loss of lead, due to slump, is acceptable.

2.7.1.3 Free Drop Impact – Side Drop

Behavior of the impact limiters during the side drop conditions has been evaluated using the analysis described in Appendix 2.10.1.1. Using the lower bound foam stiffness, a deflection of 7.8 inches was computed. Using the upper bound foam stiffness, a peak acceleration of 120.6 G's was found. The results of the analyses are shown in Tables 2-13 and 2-14.

Detailed cask stress calculations were made using the cask finite element model discussed in Section 2.6.1. The constraints and loads placed on the cask for the side drop analysis are shown in Appendix 2.10.1.3 with the resulting reaction forces to show moment and force equilibrium. The stresses associated with a side impact deceleration of 120.6 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 2-15. While high stresses occur mostly at the plane of the impact, some of the highest stresses are also found at other locations. Figures 2-14 to 2-16 show the contour plots of stress intensities in the critical regions of the cask.

Table 2-13
Caskdrop Program Output for Side Drop (Soft Foam)

```
01-31-1984 17:13:44
C A S K   G E O M E T R Y
  Side Drop Analysis
Cask:SORDWT   SOR OVERWEIGHT                    G= 386.4  in/sec^2)))))))))) Package        uses correction factor tabl
e:standard
Weight              (lb) W     77000
Outer diameter      (in) POD   78
Length              (in) LC    88
Drop height         (ft) H     30
CG (cask btm)       (in) LCG   44
Moment of Inertia        ICG   0               (LB SEC^2 INCHES)
Ovp materials: Top: FR6725S   Bottom: FR6725S
Upper    Lower  (All values in inches)
Inner diameter  (in) DID             47.5      47.5
Outer diameter  (in) ODD             102.001   102.001
Inner thickness (in) LI              21.012    21.012
Outer thickness (in) LO              44.01     44.01
01-31-1984 17:13:44
C A S K   D R O P   R E S U L T S
  Side Drop Analysis
METHOD  I
Cask:SORDWT   SOR OVERWEIGHT  .  Overpacks:FR6725S  & FR6725S

        Iteration    Time    Deflection   Acc      Force      Elabs
 Top         66     0.0227    7.8270    -110.7    4022590.   13245131.
 Bottom  .                    7.8270    -110.7    4022590.   13245131.
 Combined                               -110.7    8045180.   26490262.
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
   14 : 1   15 : 0
```

Table 2-14
Caskdrop Program Output for Side Drop (Hard Foam)

```
02-01-1985 15:23:38
C A S K   G E O M E T R Y
  Side Drop Analysis
Cask:5ORDWT   5OR OVERWEIGHT                          G= 386.4  in/sec^2))))))))) Package         uses correction factor tabl
e:standard
Weight              (lb) W      77000
Outer diameter      (in) POD    78
Length              (in) LC     88
Drop height         (ft) H      30
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
02-01-1985 15:23:39
C A S K   D R O P   R E S U L T S
  Side Drop Analysis
METHOD  2
Cask:5ORDWT   5OR OVERWEIGHT      Overpacks:FR6725H  & FR6725H

       Iteration     Time   Deflection   Acc      Force      E(abs)
 Top        45      0.0166    5.3959   -120.6    4379012.   13154409.
 Bottom                       5.3959   -120.6    4379012.   13154409.
 Combined                              -120.6    8758024.   26308818.
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
```

Table- 2-15
Maximum Stress Intensities in Cask Components
Hypothetical Accident – 30 ft Side Drop[1]

Cask Component	Stress Classification	S.I.[2] (PSI)	Allowable (PSI)	Safety Factor
Baseplate	Membrane	13,918.79	49,000	3.52
	Membrane Plus Bending	32,897.3	70,000	2.13
Outer Shell	Membrane	33,494	49,000	1.46
	Membrane Plus Bending	41,711	70,00	1.68
Inner Shell	Membrane	43,055	49,000	1.14
	Membrane Plus Bending	58,589	70,000	1.19
Bolting Ring	Membrane	47,220	49,000	1.04
	Membrane Plus Bending	51,410	70,000	1.36
Primary Lid	Membrane	13,324.5	49,000	3.68
	Membrane Plus Bending	35,749.9	70,000	1.96
Secondary Lid	Membrane	13,801.46	49,000	3.55
	Membrane Plus Bending	37,395.8	70,000	1.87

NOTE: (1) See Table 2-1 for accident condition load combination.
(2) See Table A2-17 for the load combination per Regulatory Guide 7.8.

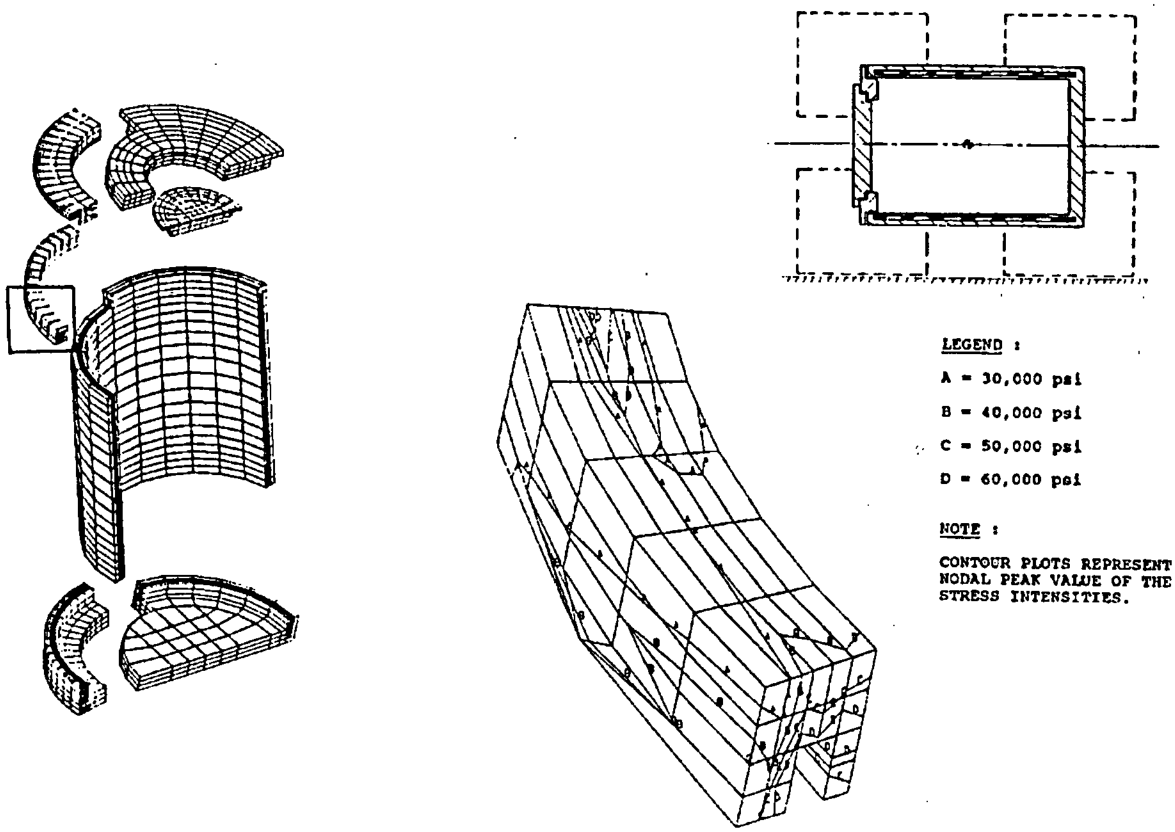


Figure 2 – 14
Side Drop – Stress Intensity Contour Plot Bolt Ring

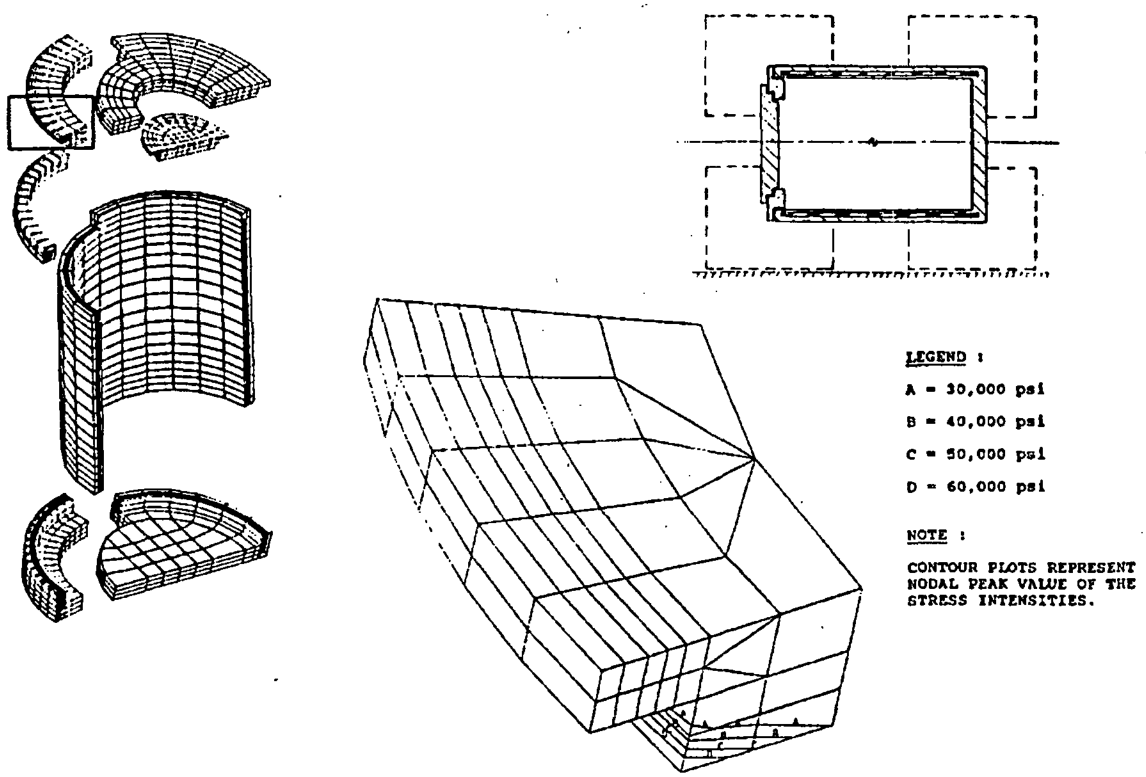


Figure 2 – 15
Side Drop – Stress Intensity Contour Plot Primary Lid

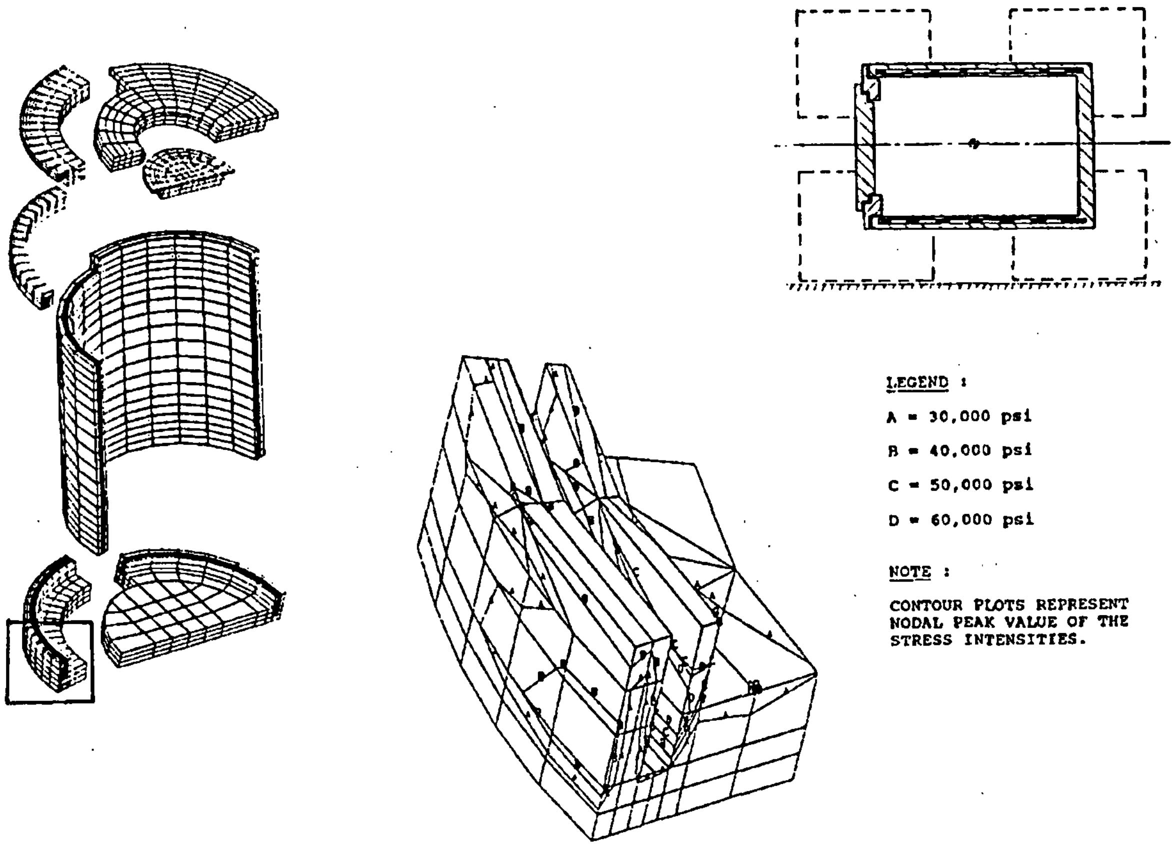


Figure 2-16
Side Drop – Stress Intensity Contour Plot Lower Shell

Stress intensities throughout the cask during the thirty-foot side drop are below allowables with the maximum stress intensity of 47,230 psi occurring in the bolting ring at the section. The corresponding minimum factor of safety is:

$$\text{S.F.} \quad = \quad \frac{49{,}000}{47{,}230} \quad = \quad 1.04$$

Side Drop Secondary Lid Bolt Forces

The loads required to hold the secondary lid in place were computed using the calculated ANSYS loads 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 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 direction, while radial "tensile" forces are those which tend to separate the parts in the radial direction. The resulting stress intensities, (for 1¾" bolts) as a function of angular position of the bolts, are shown in Table 2-16(a) for the secondary 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 120,494 psi, and the corresponding safety factor is:

$$\text{S.F.} \quad = \quad \frac{130{,}000}{120{,}494} \quad = \quad 1.08$$

Side Drop Primary Lid Bolt Forces

The loads required to hold the primary lid in place are obtained using the results of ANSYS model. The resulting stress intensities (for 1¾" 8UN bolts) as a function of angular position of the bolts, are shown in Table 2-16(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 121,796 psi, and corresponding safety is:

$$\text{S.F.} \quad = \quad \frac{130{,}000}{121{,}796} \quad = \quad 1.07$$

Table 2-16(a)
10-160B Cask – Side 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	172,712[2]	-[3]	5,675	-[2]	-[2]	0
30	116	51,792[2]	-121,519	-281	281	121,519	116,889
60	118	-100,457	-74,818	-2,910	2,910	125,257	120,494
90	120	-122,577	1,784	-1,909	1,909	122,590	117,924
120	122	-52,788	66,538	-606	606	84,935	81,700
150	124	28,722[2]	59,002	1,563	-[2]	59,002	56,754
180	126	62,413[2]	-[3]	2,611	-[2]	0	0

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 for more explanation.
(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).
(5) 0° corresponds to the point of impact.

Table 2-16(b)
10-160B Cask – Side 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	-10,813	-(3)	35,499	-[2]	10,813	10,401
30	438	-21,851	-83,065	9,754	-[2]	85,891	82,619
60	443	-118,307	-45,071	-4,193	4,193	126,602	121,796
90	464	-25,966	60,660	1,579	-[2]	65,984	63,470
120	222	29,010	110,172	-9,788	9,788	113,927	109,688
150	224	36,227	59,072	1,343	-[2]	69,296	66,656
180	226	18,860	-[3]	6,495	-[2]	18,860	18,842

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 for more explanation.
(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).
(5) 0° corresponds to the point of impact.

2.7.1.3 Free Drop Impact – Corner Drop

An energy balance analysis, described in Appendix 2.10.1, was used to predict loads on the cask during the corner drop. The angle of the cask with respect to the impact surface was chosen so that the center of pressure at full deformation was directly beneath the cask center of gravity. Because no drop energy is converted to rotational energy of the cask, this is the worst case.

For a thirty-foot corner impact drop, deformation of the impact limiter amounted to 17.0 inches. In order to predict maximum deflection, the curve of stress vs. strain for the lower bound of foam stiffness was used and only the regions of the impact limiter that are backed by the cask are considered effective. Results of the analysis are shown in Table 2.18. A second analysis, using the upper bound of material stiffness and all regions considered effective was used to predict the maximum deceleration experienced by the cask upon impact. This maximum deceleration was found to be 71.13 G's. The results of this analysis are shown in Table 2-19.

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 corner drop analysis are shown in Appendix 2.10.3 with the resulting reaction forces to show moment and force equilibrium. The stresses associated with a corner impact deceleration of 71.13 G's were combined with maximum normal temperature and pressures stresses as outlined in NRC Regulatory Guide 7.8. Maximum stress intensities are summarized in Table 2-20. While high stresses occur mostly at the plane of impact, some of the highest stresses are also found at other locations. Table 2-20 also indicates the location of high stress intensities in the cask components. Figures 2-17 thru 2-18 show contour plots of stress intensities in the critical regions of the cask.

Stress intensities throughout the cask are well below allowables with the maximum stress intensity of 28,029 psi occurring in the inner shell at the section shown in Figure A2-43. The corresponding minimum factor of safety is:

$$S.F. = \frac{49{,}000}{28{,}029} = 1.75$$

```
                    G= 386.6  in/sec^2>>>>>>>>>> Package          uses co


      (LB SEC^2 INCHES)
55

.5      47.5
!.001   102.001
.012    21.012
.01     44.01
:01


:FR67255


ion  Acc      Force      E(abs)
585  -61.1    4471391.   27130076.

 : 0   6 : 1   7 : 0   8 : 0   9 : 1   10 : 1   11 : 0
```

Table 2-18
Caskdrop Program Output for Corner Drop (Soft Foam)

```
                    G= 386.4  in/sec^2>>>>>>>>> Package        uses

            (LB SEC^2 INCHES)
fr6725h
)
  47.5      47.5
  102.001   102.001
  21.012    21.012
  44.01     44.01
7:11:08

pack:fr6725h

lection  Acc     Force     E(abs)
14.8797  -71.2   5197715.  27009068.

   5 : 1    6 : 1    7 : 1    8 : 1    9 : 1    10 : 1    11 : 1
```

Table 2-19

Caskdrop Program Output for Corner Drop (Hard Foam)

Table 2-20
Maximum Stress Intensities in Cask Components
Hypothetical Accident – 30-Ft Corner Drop[1]

Cask Component	Stress Classification	S.I. [2] (PSI)	Allowable (PSI)	Safety Factor
Baseplate	Membrane	10,618.79	49,000	4.61
	Membrane Plus Bending	18,927.3	70,000	3.70
Outer Shell	Membrane	12,779	49,000	3.83
	Membrane Plus Bending	17,481	70,000	4.0
Inner Shell	Membrane	28,029	49,000	1.75
	Membrane Plus Bending	30,952	70,000	2.26
Bolting Ring	Membrane	24,100	49,000	2.03
	Membrane Plus Bending	32,628	70,000	2.15
Primary Lid	Membrane	23,504.5	49,000	2.08
	Membrane Plus Bending	33,099.9	70,000	2.11
Secondary Lid	Membrane	11,029.46	49,000	4.44
	Membrane Plus Bending	20,235.8	70,000	3.46

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

[2] See Table A2-21 for the load combination per Regulatory Guide 7.8.

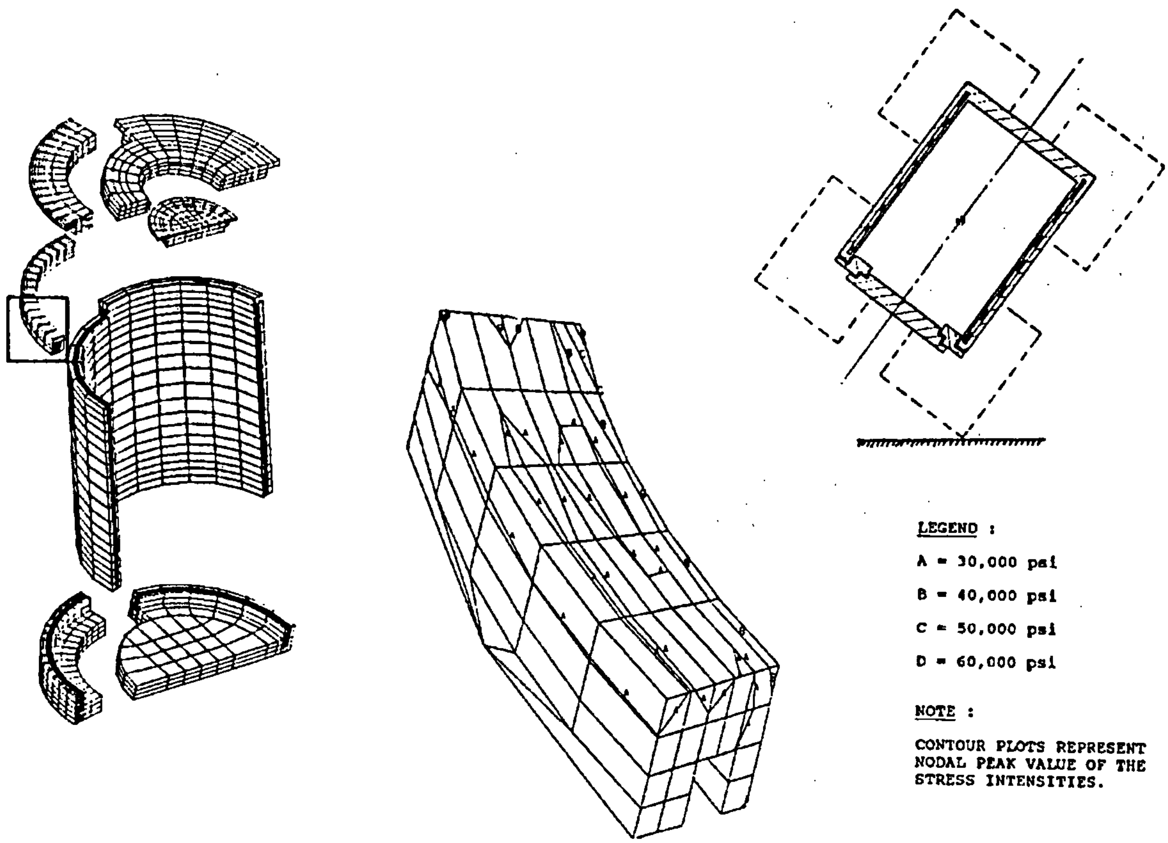


Figure 2-17
Corner Drop – Stress Intensity Contour Plot Bolt Ring

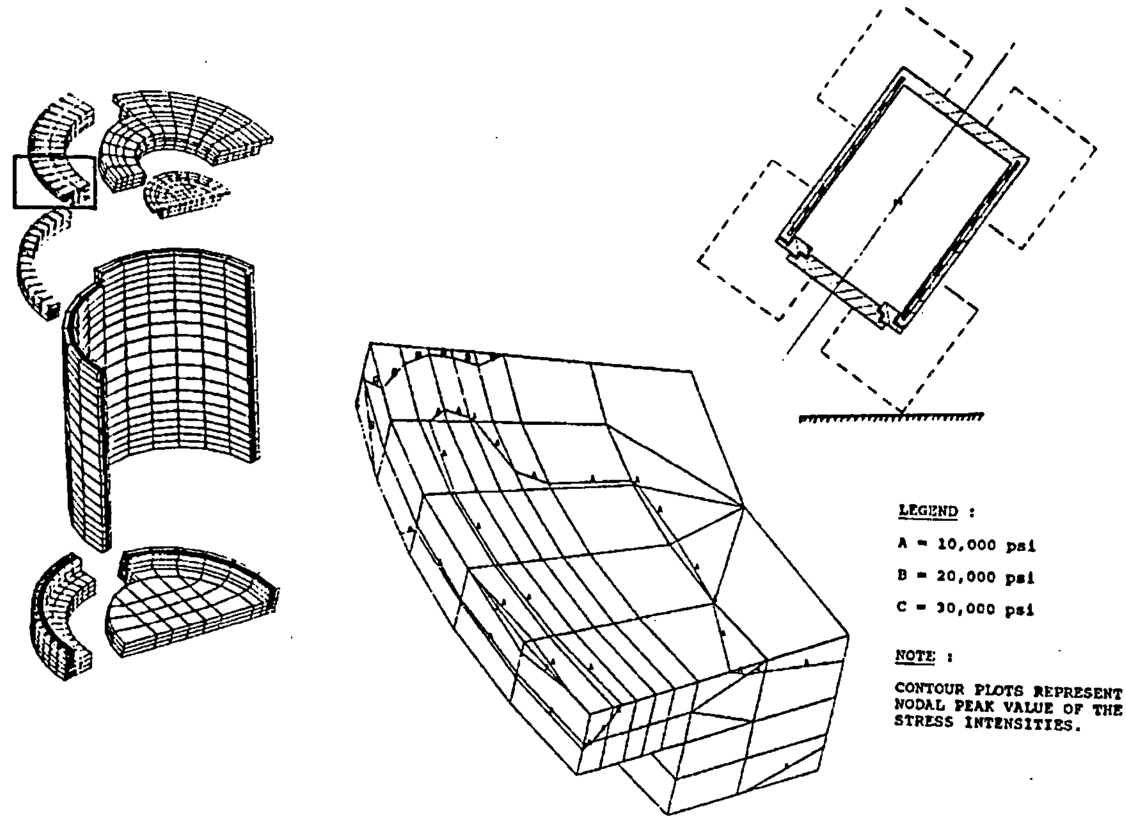


Figure 2-18
Corner Drop – Stress Intensity Contour Plot Primary Lid

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:

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

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:

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

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.
(3) Tangential loads at the plane of symmetry do not go through the bolts.
(4) For 1 ¾" – 8UN bolts (stress area 2.0792 in2).

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 in2).

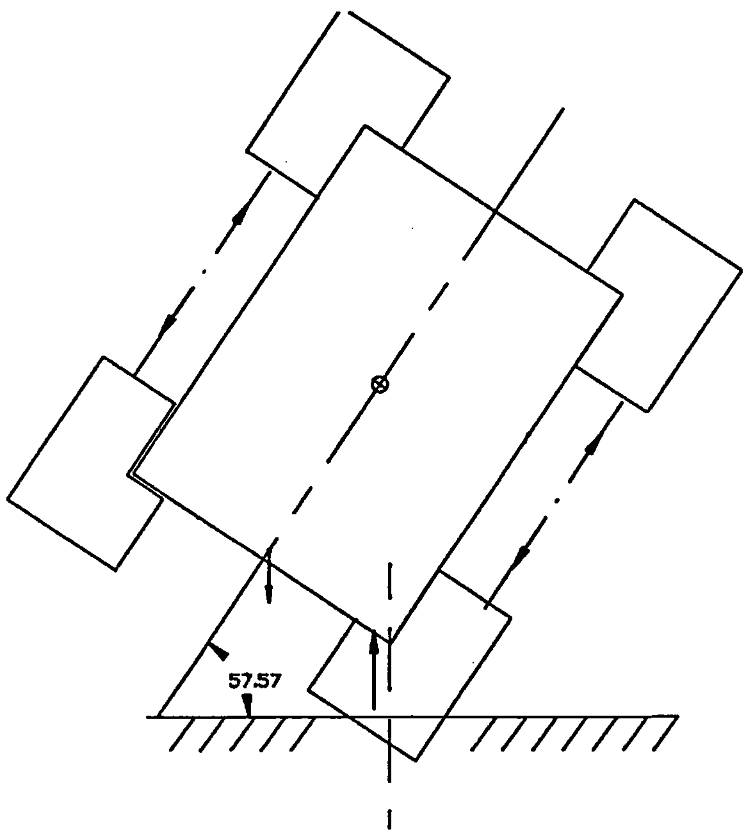
2.7.1.5 Impact Limiter Attachment Forces

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.

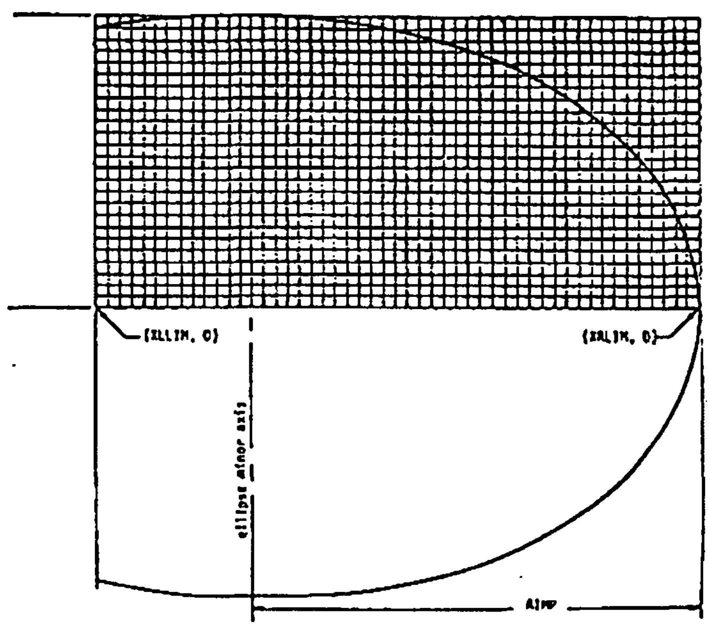
For most oblique angle orientations and crush depths, the impact limiter reaction is transmitted to the cask body in direct compression. Therefore, the forces transmitted to the impact limiter ratchet binders are near zero. This is not true for near vertical (90°) and near horizontal (0°) orientations 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.

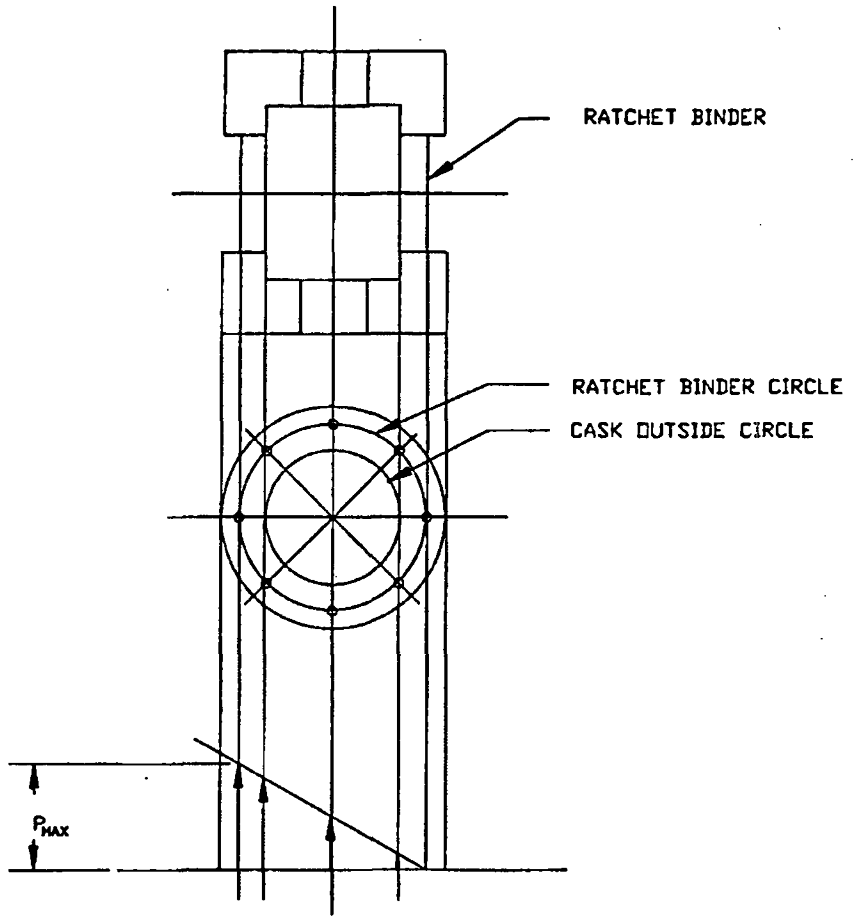
This moment will be resisted by the ratchet binder load and the cask shell-impact limiter interface load. Since the moment arising due to cask shell impact limiter load helps reduce the ratchet binder load, it has been neglected.

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
	=	$P_{max} \times \text{Sin}(\theta_i/2)$
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,

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

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	= $0.28\times\pi/4\times46^2\times0.25$	=	116 lb
Mass of Item #2	= $0.28\times\pi/4\times46^2\times0.12$	=	56 lb
Mass of Item #3	= $7\times0.28\times5.58\times1.75$	=	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:

$$A = 3\times2\times(\pi/4)\times0.875^2 = 3.608 \text{ in}^2$$

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

$V = 3.608 \times 45{,}000 = 162{,}360$ 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
- Su = 70,000 psi

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

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

$$Fmax = Ak_s$$

K_s = plastic flow stress of mild steel (45000 psi assumed)

A = 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 = outer radius (in)

R_I = 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

$$U = \int_o^\delta P \; dy$$

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

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

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,

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,

$P = 1.9292 \times 10^6$ 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

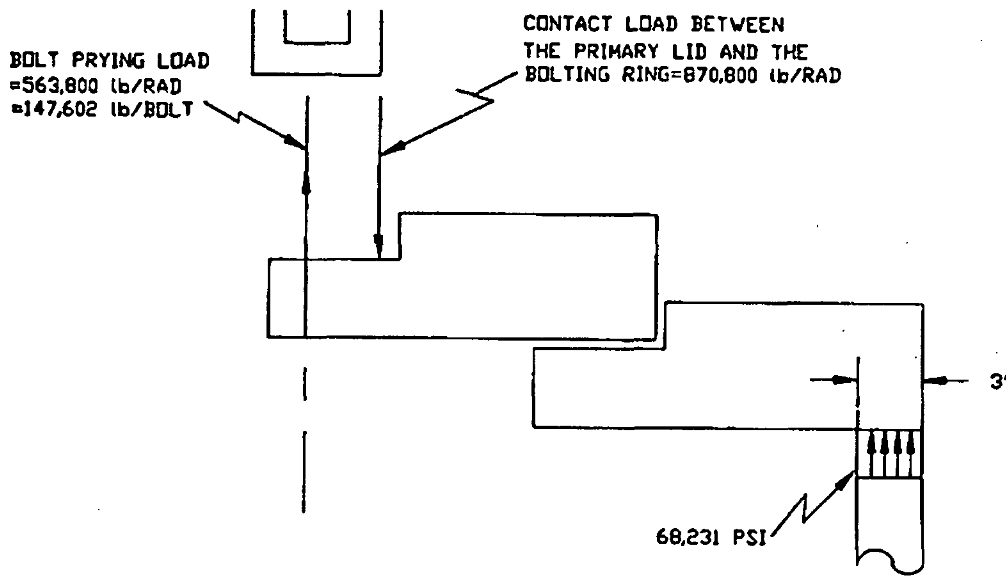


Figure 2-18.1
Load Distribution During the Puncture Accident

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,

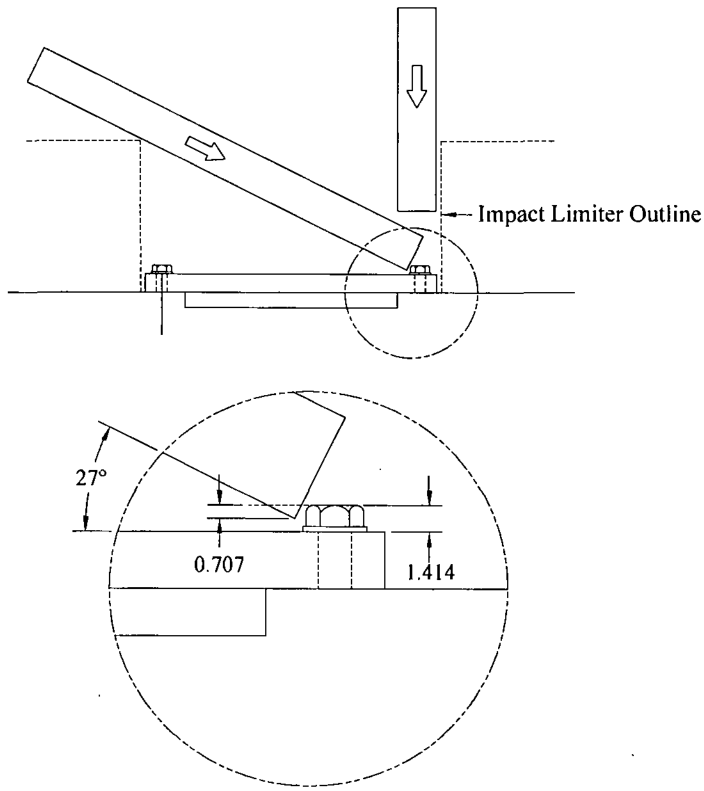
The bolt tensile stress = 147,602 lbs / 2.0792 in^2
= 70,990 psi

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.

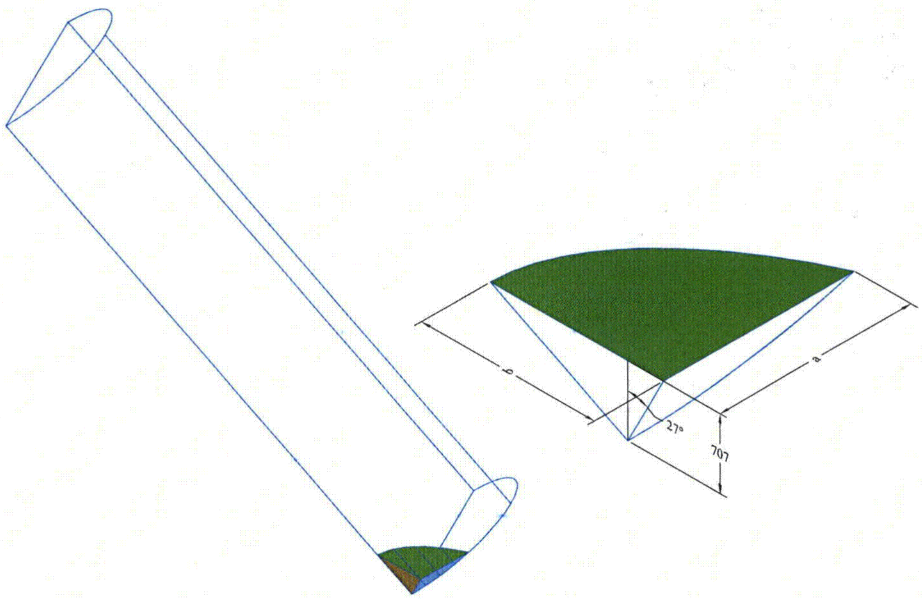
The rod, according to the regulations (Reference 2-1) is specified to be mild steel. Typical value of the ultimate tensile strength of mild steel is 45,000 to 55,000 psi (e.g. A-675 Gr. 45). The bolt has been specified as ASTM-354 Gr. BD for which the ultimate tensile strength is 150,000 psi. Taking 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 = $0.6 \times 55{,}000 = 33{,}000$ psi

Bolt material shear strength = $0.6 \times 150{,}000 = 90{,}000$ psi

The bolt shear area is $(\pi/4) \times 1.75^2 = 2.405$ 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 = $4.74 \times 33{,}000 = 156{,}420$ 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 3Sm 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 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.

2.9 FUEL RODS

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

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

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

2.10 APPENDIX TO SECTION 2.0

2.10.1 Foam Impact Limiter Analytical Methods

2.10.2 ANSYS Finite Element Analysis of Cask Body Structure

2.10.3 Summarized Results of Cask Structural Calculations

2.10.4 References

2.10.1 ANALYTICAL METHODS

2.10.1.1 General Discussion Foam Impact Limiter

A summarized discussion of the analytical methods used to evaluate the cask during the drop conditions are provided in this section. The most significant assumption is the use of a quasi-static model wherein the energy absorbing impact limiter is analyzed separately from the cask. The cask is initially assumed rigid in order to determine the maximum loads imposed on it. These maximum loads are applied statically to the cask to permit evaluation of the stresses in the cask. This uncoupled assumption is a realistic approach since most of the impact energy is absorbed by the impact limiter. The impact limiter's design criteria is specifically selected to justify this uncoupled analysis.

The rigid foam impact limiters are designed to absorb all the energy of the drop. No energy is absorbed by the unyielding surface or by deformation of the cask. The analytical methods used to predict the impact limiter's behavior in the end, side and corner drops are all similar. The determination of the impact limiter's behavior is determined from the following energy equation:

$$E = W(h + \delta) = \int F dx$$

where W = Package Weight
H = drop height
δ = maximum impact limiter's deformation
F = Total force developed by the impact limiter at deformation
dx = incremental displacement of the foam

This equation is solved in all three drop orientations. The only difference among the three orientations is the calculation of the total force for the different crushed foam geometries.

Chem-Nuclear Systems has developed a computer program CASKDROP (References 13, 14 & 15) to solve this equation for all three drop orientations. This program accounts for the non-linear stress-strain relationship of the foam. The actual stress-strain values (see Figure 2.1) for the foam used are input to the program.

2.10.1.2 Cask Drop Computer Model

The following discussion presents the techniques used in the CASKDROP program to evaluate the three drop orientations. The primary variations are (1) the geometrical evaluations used to evaluate the crushed foam portions, and (2) the means of evaluating the crushing effectiveness of the various geometrical regions. The CASKDROP program divides the crushed foam portions into a grade of up to 100 rectanguloid solids and iterates on 2% increments of material strain up to a predetermined limit (70 percent – see Section 2.1.2.1). The effectiveness relates to whether the foam volume is "backed" by the cask body or is unbacked. A constant multiplier is utilized for crushing effectiveness, wherein 1.0 equates to full backing and 0.0 is unbacked. The foam properties (see Figure 2.1) are input into the program at 1% increments of strain.

2.10.1.2.1 End Drop Model

The CASKDROP code calculates the total force, at a given displacement of the impact limiter, with an equation of the following general form:

$$F = K_1A_1\sigma_1 + K_2A_2\sigma_2$$

where, A_1, A_2 = Areas of regions 1 and 2, respectively, (See Fig. A2-1 for region definition.)

σ_1, σ_2 = Stresses in regions 1 and 2, respectively.

K_1, K_2 = Constants for regions 1 and 2, respectively. (1.0 for backed 0.0 for unbacked)

The first term corresponds to the foam that is directly below the cask (backed), and the second term is the foam around the sides of the cask (unbacked), as shown in Figure A2-1.

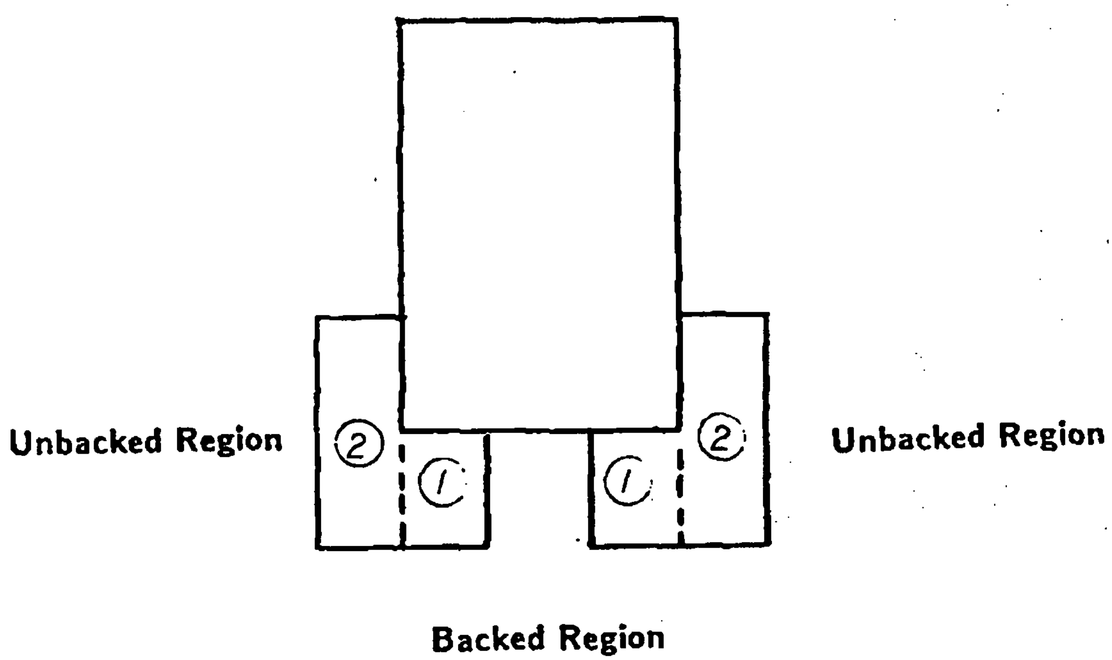


Figure A2-1
End Drop – Region Definition

The program increments the impact limiter deformation until the impact energy is totally absorbed. The maximum force and G load are determined from the impact limiter force at the last displacement increment after all the energy has been absorbed. This load is applied to the cask as an inertia load, as described in Section 2.7.1.1.

2.10.1.2.2 Side Drop Model

The procedure for calculating the force in the side drop is slightly different than the end drop. The strain and stress vary with X as shown in Figure A2-2. The total force is the integration of the stress times the contributing area at a point.

The geometrical parameters are shown in Figure A2-3. In addition, the user can control the effectiveness of the regions shown in Figure A2-4. Control of these regions allows the user to bound the behavior of the impact limiter. Control of the backed and unbacked regions (see Section 2.10.1.2 for a description), variation of foam stiffness properties and other parameters within the CASK DROP code allows the user to conservatively bound the behavior of the impact limiter.

The side drop calculation results in forces, or pressures, on contributing areas as a function of X as shown in Figure A2-3.

Once the maximum load developed by the impact limiter on the cask has been determined, the load is applied statically to the cask, and resisted by the deceleration inertia of the cask and contents. It should be noted that bounding assumptions are used to conservatively bound the uncertainties of the impact limiter's behavior.

2.10.1.2.3 Corner Drop

(a) General

The corner drop method is very similar to the side drop, except the strains, stresses and forces on the cask are calculated on a two dimensional grid shown in Figure A2-5.

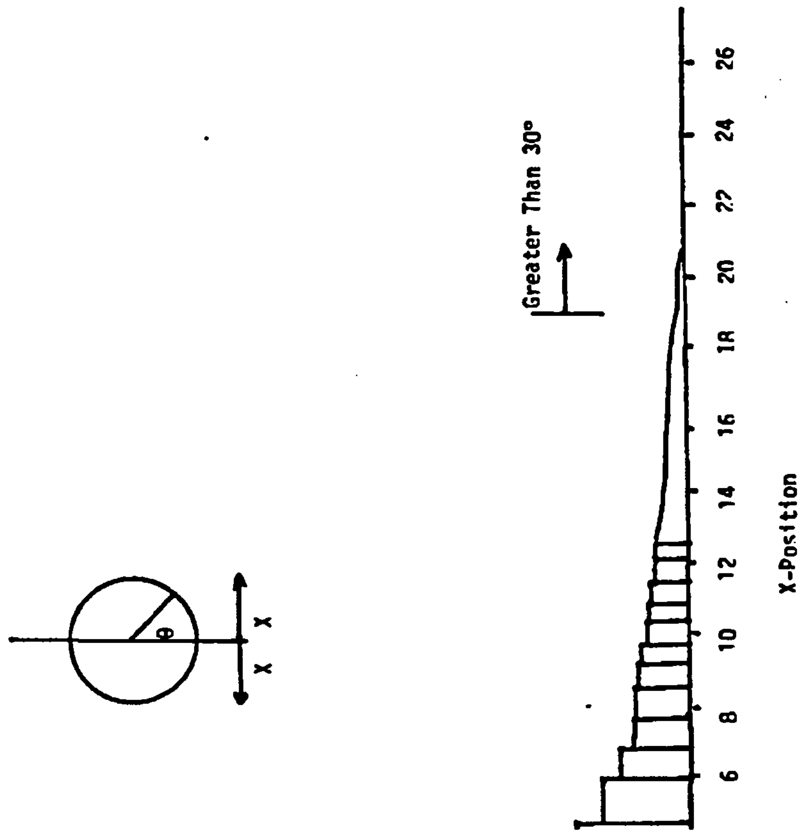


Figure A2-2
Side Drop – Circumferential Load Distribution

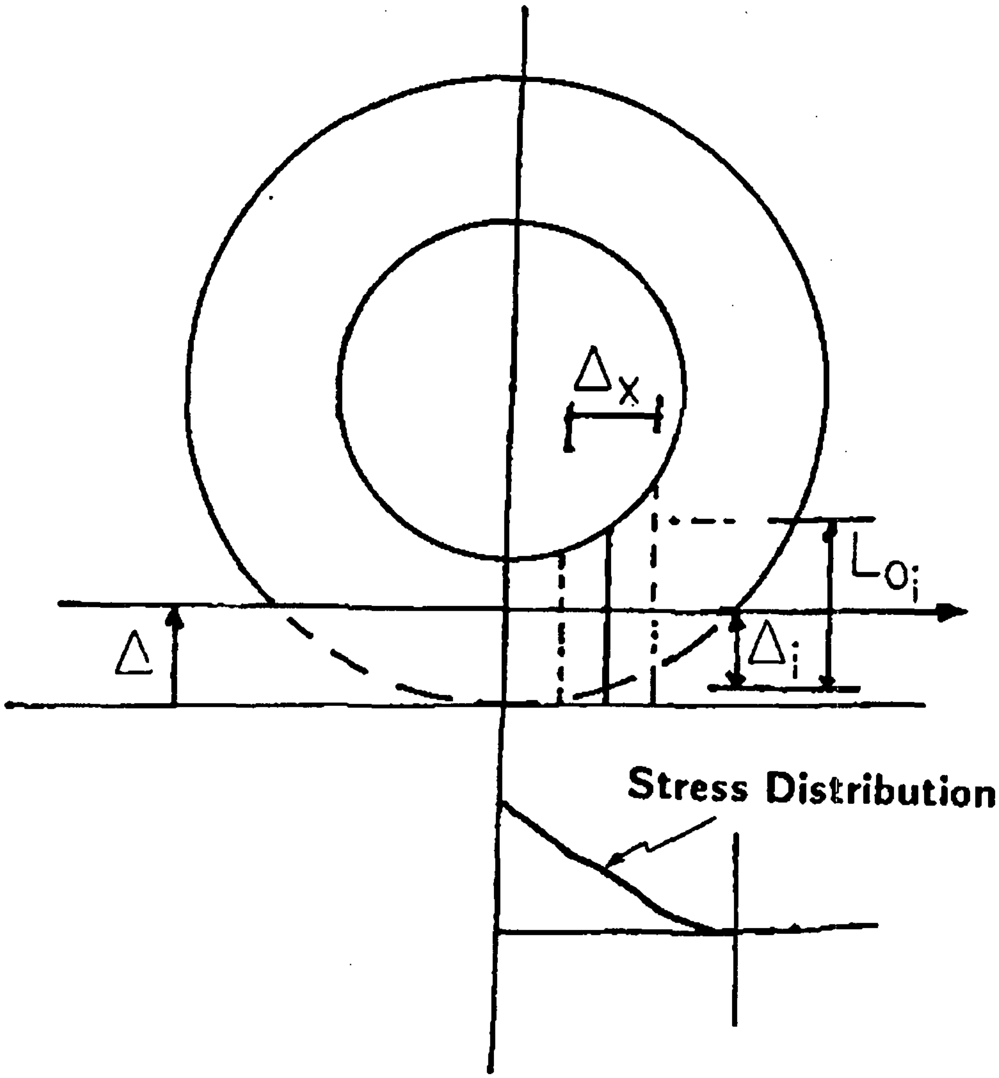


Figure A2-3
Side Drop – Variable Definition

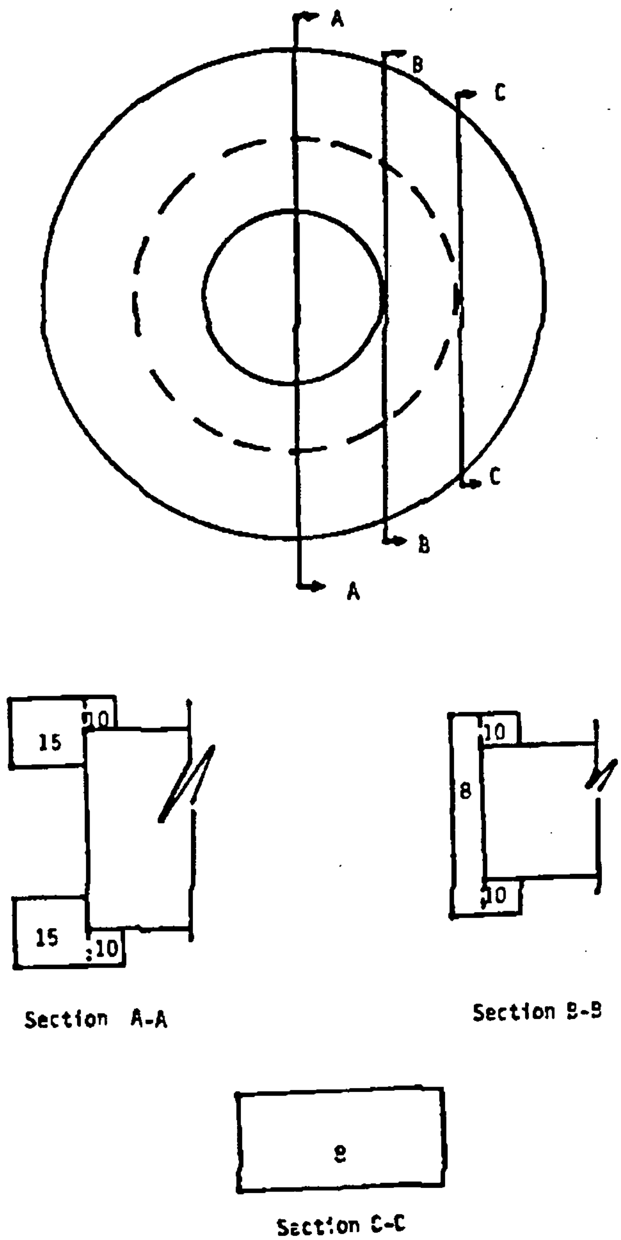


Figure A2-4
Side Drop – Region Definition

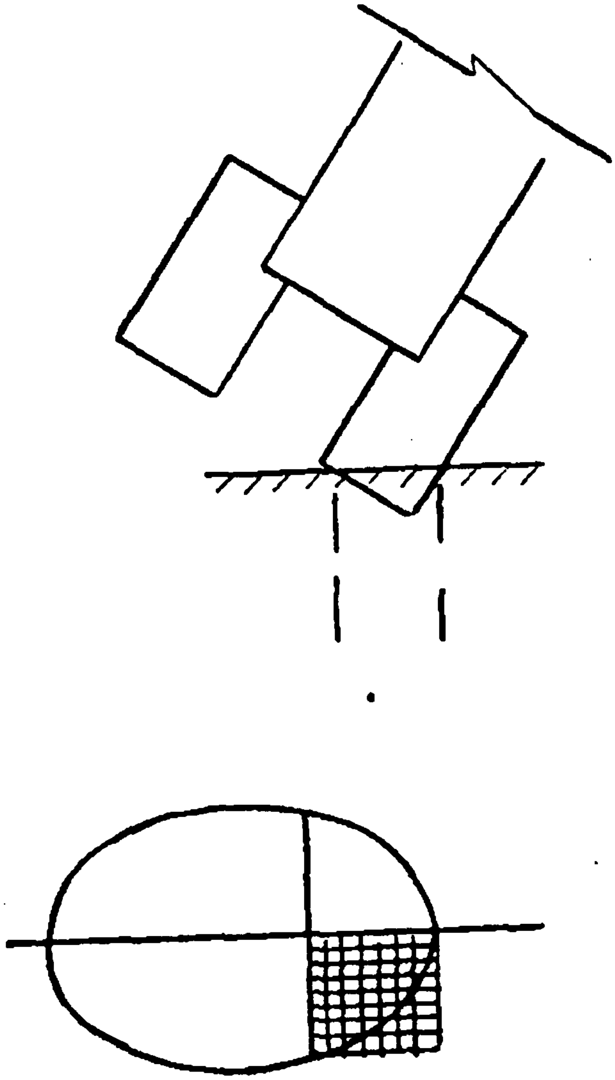


Figure A2-5
Corner Drop – Crush Plane and Grid

At each iteration, or displacement of the impact limiter, the program calculates strain, stress and force at each grid point. The displacement is incremented until all the energy of the drop is absorbed. The forces and pressures on the grid area corresponding to the last iteration are printed by the program.

The corner drop portion of the code also allows the user to selectively control the effectiveness of different regions of the impact limiter. The regions for the 10-160B cask at 33.4° (impact angle where the cask corner is over the center of gravity) are shown in Figure A2-6.

(b) Loading

The vertical loading on the cask is according to the following equation, which assumes the impact limiter and the cask are uncoupled and rigid.

$F_T = M_c\, a_c + M_p\, a_p + M_{UIL}\, a_{UIL}$

F_T = Total lower impact limiter load on the cask (lbs)

M_c = Mass of the cask (lbs)

M_p = Mass of the payload (lbs)

M_{UIL} = Mass of the upper impact limiter

a_c = Acceleration of cask (G's)

a_p = Acceleration of payload (G's)

a_{UIL} = of upper impact limiter (G's)

For a static analysis $a_c = a_p = a_{UIL}$, therefore,

$F_T = (M_c + M_p + M_{UIL})\, A_c$

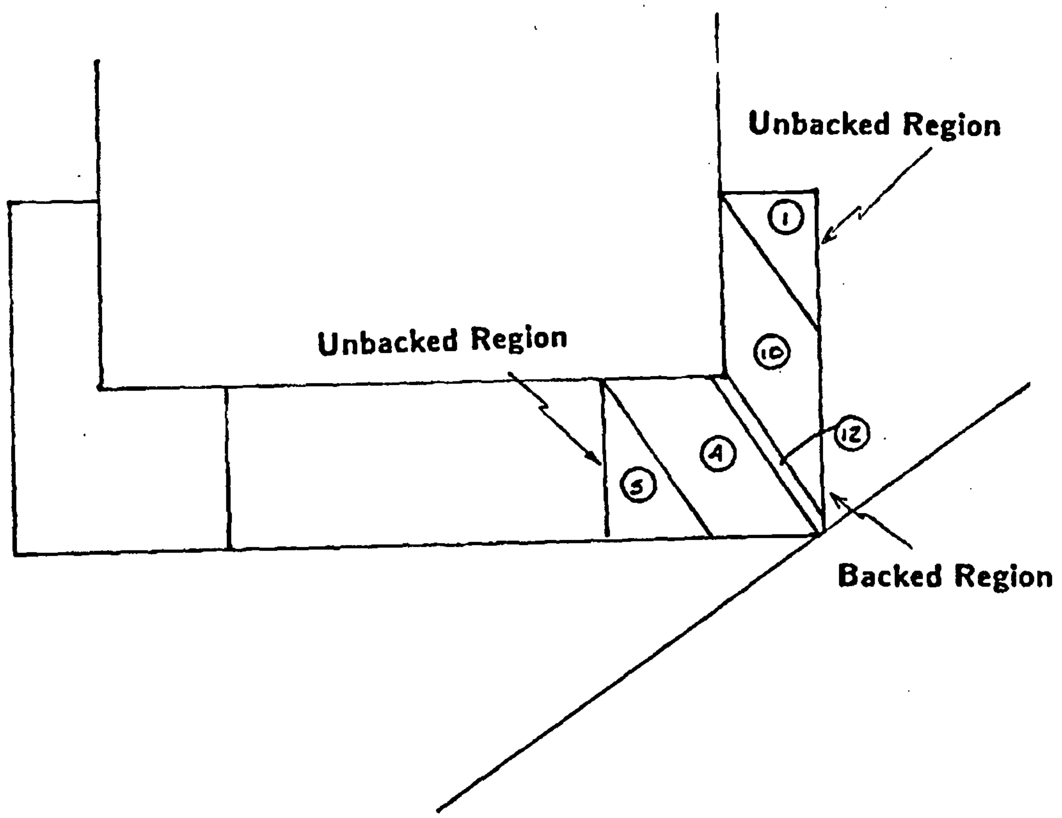


Figure A2-6
Corner Drop – Regions Along Center Line

(c) Load Application

These loads are applied to the finite element model in the following manner:

(1) The F_T component of load is applied as nodal loads on the cask with the CORNVT program (Ref. 16). This program projects the footprint pressure calculated by the CASKDROP code up to the nodal locations on the model. This program requires the nodal point location and corresponding contributing area on the surface of the code to be input.

(2) The inertia load of the cask, $M_c\, a_c$, is applied as an inertia load in the finite element model.

(3) The payload's inertia load, $M_p\, a_p$, is applied as nodal loads to the inside of the cask. The longitudinal component of the payload inertia is uniformly distributed over the inside of the lid. The transverse component of load is distributed along the inside of the cask as a cosine variation of radial pressure. Both these load or pressure distributions are shown in Figure A2-7. The PAYLOAD program (Ref. 17) performs this transformation.

(4) The upper impact limiter's inertia load, M_{UIL}, a_{UIL}, is uniformly distributed around the upper edge of the cask as shown in Figure A2-8.

The acceleration of the cask A_c, is determined with the following equation:

$$a_c = \frac{F_T}{M_c + M_p + M_{UIL}}$$

It should be noted that the mass of the lower impact limiter is conservatively neglected. The F_T value calculated by the CASKDROP code does include the inertia loads of the lower impact

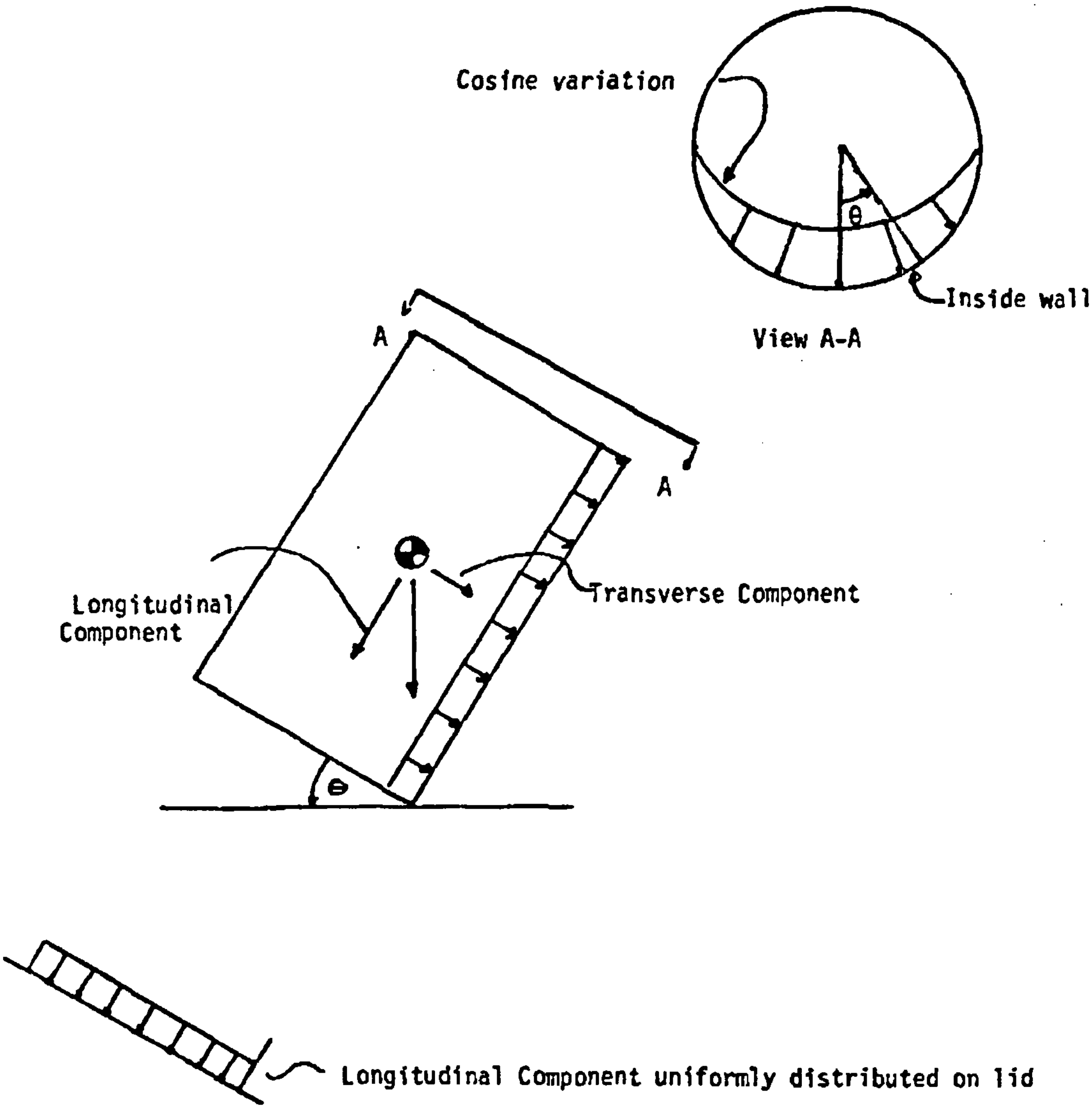


Figure A2-7
Corner Drop – Payload Inertia Distribution

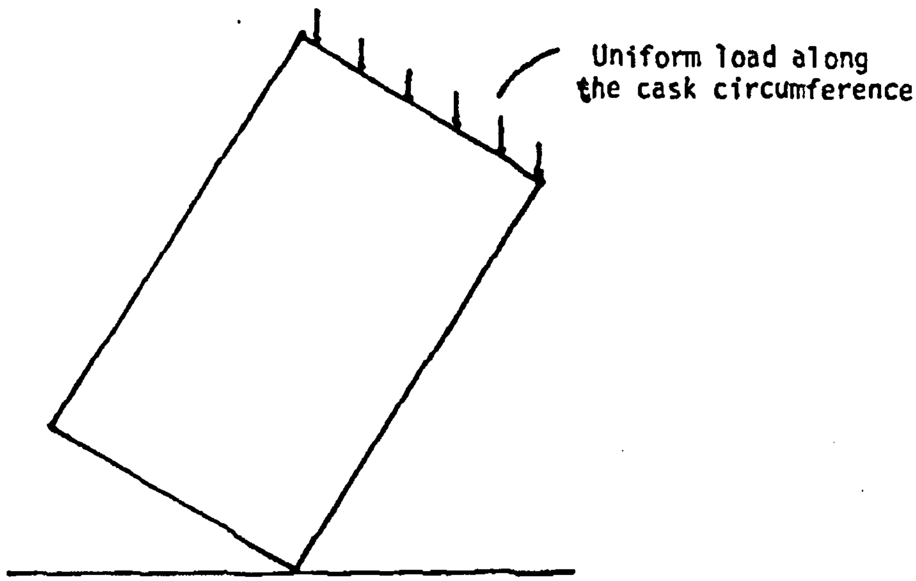


Figure A2-8
Upper Impact Limiter Inertia Distribution

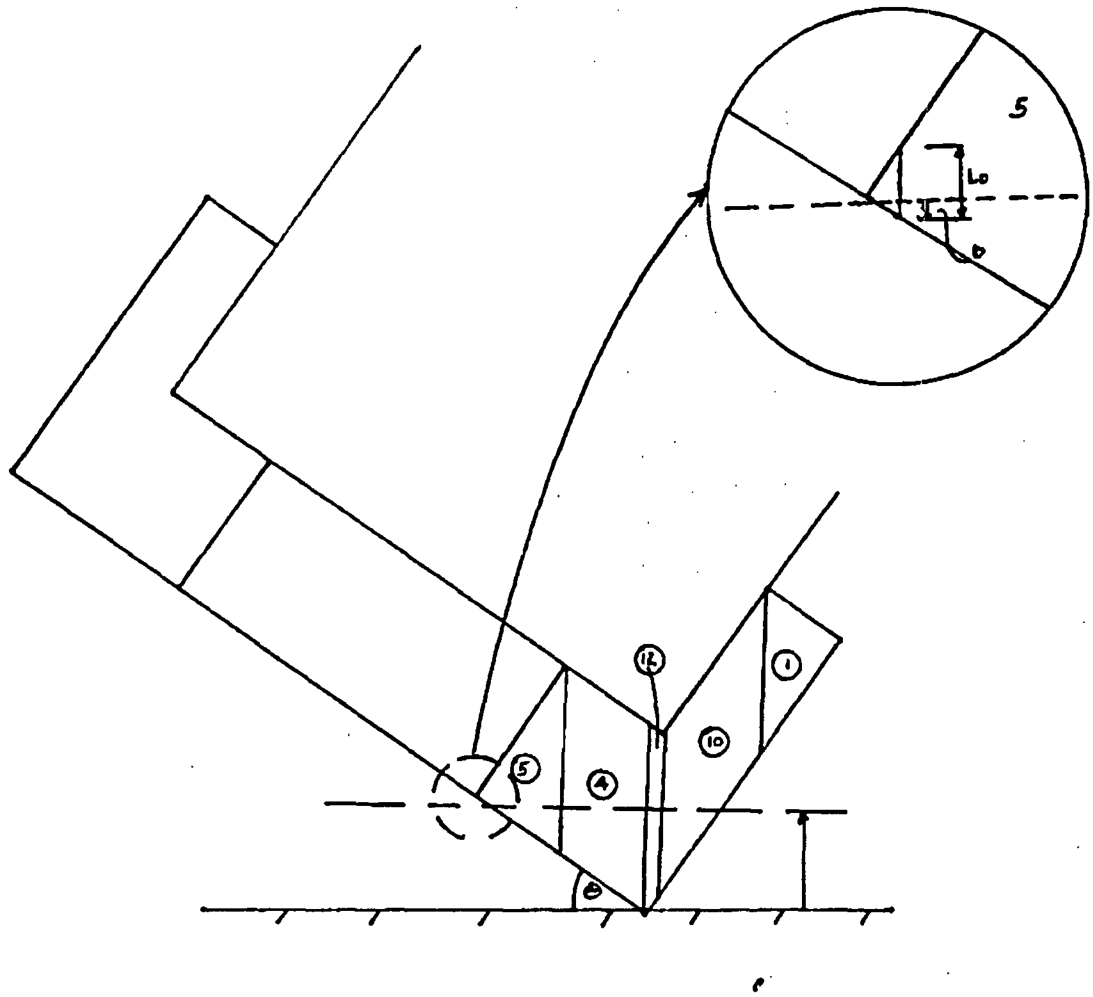


Figure A2-9
Corner Drop – Regions Along Cask Centerline

limiter, therefore, the acceleration in this equation is conservatively calculated.

(d) Angle of Impact

The angle of impact is selected so that effectively the center of pressure of the inertia loads is directly over the center of pressure of the impact limiter loads at the maximum load. This results in no net moment applied to the cask and no energy transformed into rotational energy of the cask. The entire drop energy is absorbed by the lower impact limiter.

(e) Foam Effectiveness

The impact limiter has two classes of regions, backed and unbacked. Backed regions project vertically up to the cask body, and unbacked regions do not project vertically up to the cask body. Figure A2-6 illustrates backed and unbacked regions of the impact limiter.

The maximum load the impact limiter imposes on the cask during a 30 foot drop is determined by considering all regions of the impact limiter effective and using the stiffer stress – strain curve of the foam. The maximum deceleration of the cask corresponding to this fully backed case is 71 G's. This is the acceleration applied to the cask for the structural evaluation of the cask body.

This 71 G's is a conservative calculation of the maximum G load on the cask during the corner drop. The calculational method of the CASKDROP code for strain in region 5, shown in Figure A2-6, results in a very significant contribution from region 5, an unbacked region. The CASKDROP code's definition of strain in region 5 results in very large strains and loads in this region that could not physically develop. The CASKDROP results for the stiff foam, excluding region 5, is only 60 G's on the cask body. Hence, the 71 G applied to the cask is a very conservative upper limit of load on the cask body.

2.10.1.3 Impact Limiter Chamfer

The impact limiters are chamfered around the bottom and top corners, as shown in Figure A2-10. The change in behavior of the impact limiter due to the chamfer is discussed in the following sections:

End Drop

The chamfer is in the unbacked region. Hence, the chamfer will not alter the predicted maximum displacement or maximum G-load obtained by bounding analysis.

Side Drop

The chamfer is in the unbacked region. Hence, the Chamfer will not alter the predicted maximum displacement or maximum G-load obtained by bounding analysis.

Corner Drop

Some of the material removed by the chamfer is in the backed region of the impact limiter during the corner drop, hence, the behavior of the impact limiter will be altered slightly. Removal of the chamfer material results in more uniform strain with the maximum strain lowered. The resultant effect is seen in the following analysis:

Since material is removed, the crush end-point is moved slightly inward (towards the cask body). To determine the crush distance end point, it is assumed that the volume removed by the chamfer results in an increased crushing of the foam corresponding to the volume removed by the chamfer.

From the CASKDROP results (Ref. 18) for a backed corner drop, at 33.4°, the displacement and crush plane area are 15.61 in. and 2224 in.^{2}, respectively.

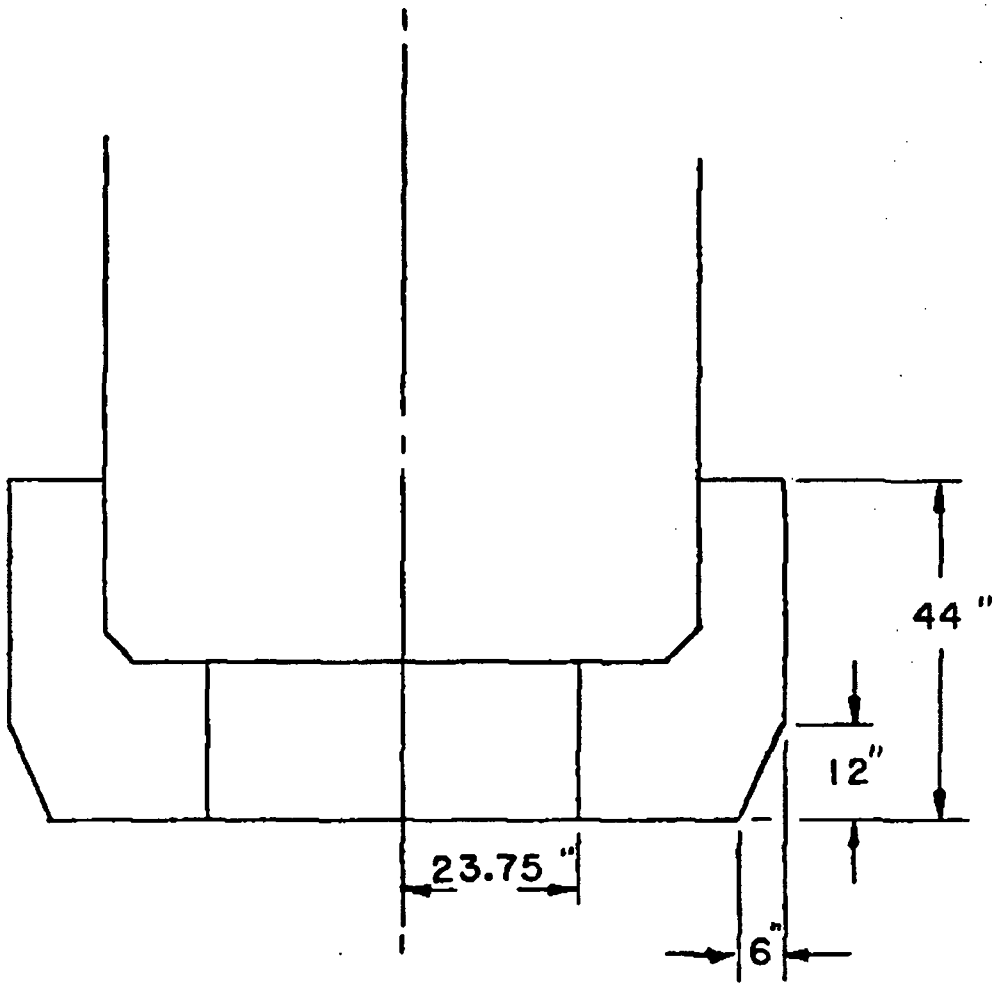
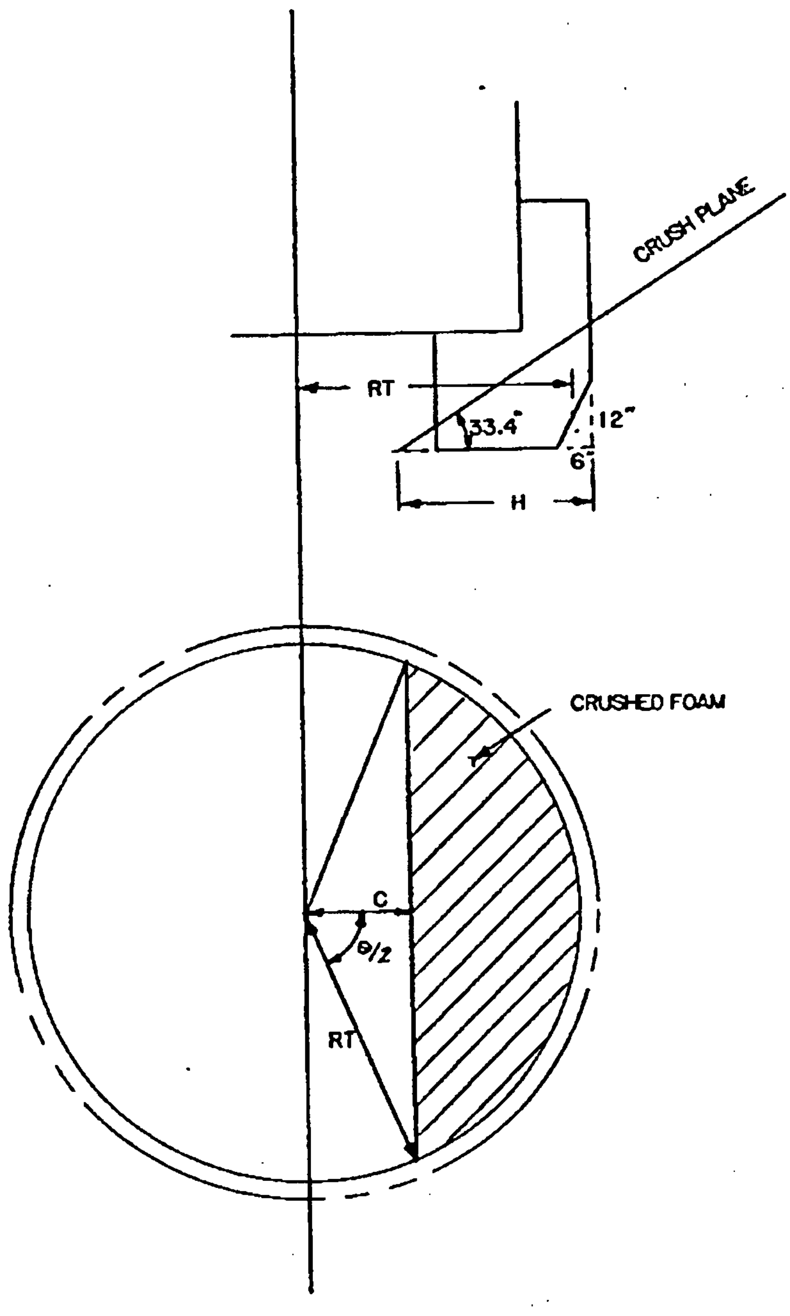


Figure A2-10
Chamfer Geometry

The radius of the centroid of the chamfer triangle is:

$R_T = 51\text{-}2 = 49"$



$$H = \frac{15.61}{\sin 33.4°} = 28.36 \text{ in.}$$

C = 51-28.36= 22.64 in.

$$\frac{\theta}{2} = \cos^{-1}\frac{(22.64)}{49} = 1.09 \text{ rads}$$

θ= 2.180 rads

S = arc length of centroid of chamfer = $R_T\ \theta$

= (2.180) (49) = 107 in

The area of the chamfer is:

1/2 (12) (6) = 36 in^2

Volume of crushed chamfer

A_S = (36) (107) = 3876 in^3

Assuming that energy absorption is proportional to the crushed volume (ie. a rigid-plastic stress-strain curve), the increase in displacement, assuming the crush area is constant, is:

$$\frac{3876}{2224} = 1.7 \text{ in.}$$

The maximum strain in the CASK DROP results at Section A-A in Figure A2-11 is (obtained graphically)

original length = 24.0 in.
crush distance = 14.75 in.

$$\text{strain at A-A} = \frac{14.75}{24} = .615 \text{ or } 61.5\%$$

For the case with the chamfer,

original length at A-A = 18.25 in.
crush distance at A-A = 10.25 in.

$$\text{strain} = \frac{10.25}{18.25} = .56 = 56\%$$

As noted above, the chamfer results in lower strains at the point of maximum strain. The strain, and pressures applied to the cask, are distributed more uniformly. Similar results were calculated for the unbacked cases.

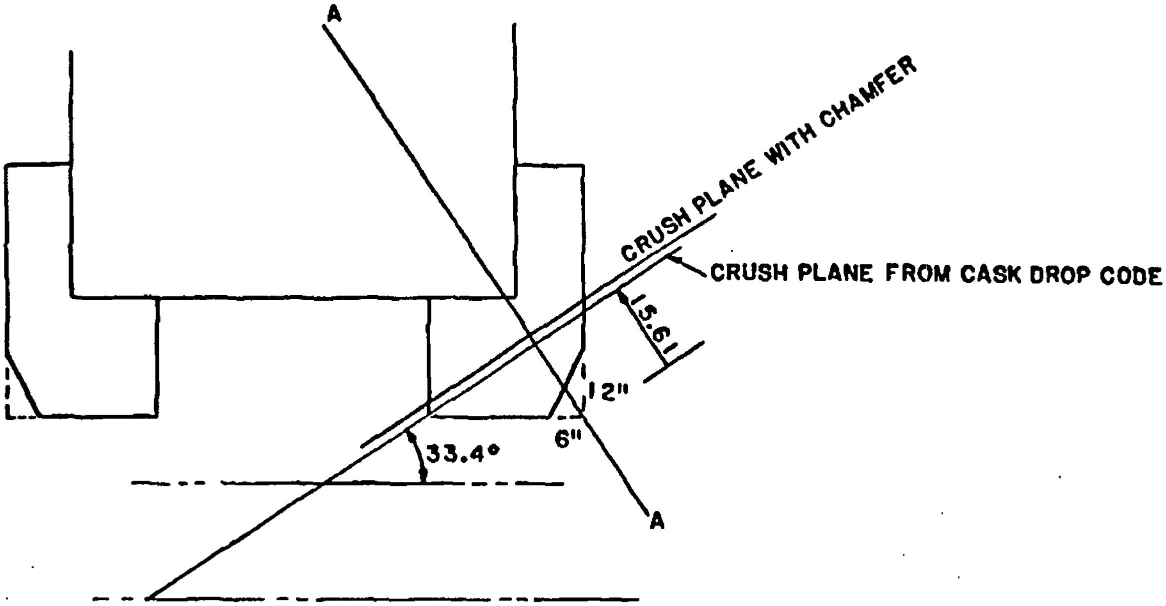


Figure A2-11
Corner Drop – Chamfer Effect

The chamfer will not significantly alter the maximum G load applied to the cask (from the maximum load obtained by ignoring the chamfer). The side drop load on the cask were obtained with the CASKDROP code, which did not include the effect of the chamfer (this is conservative).

2.10.2 ANSYS FINITE ELEMENT ANALYSIS

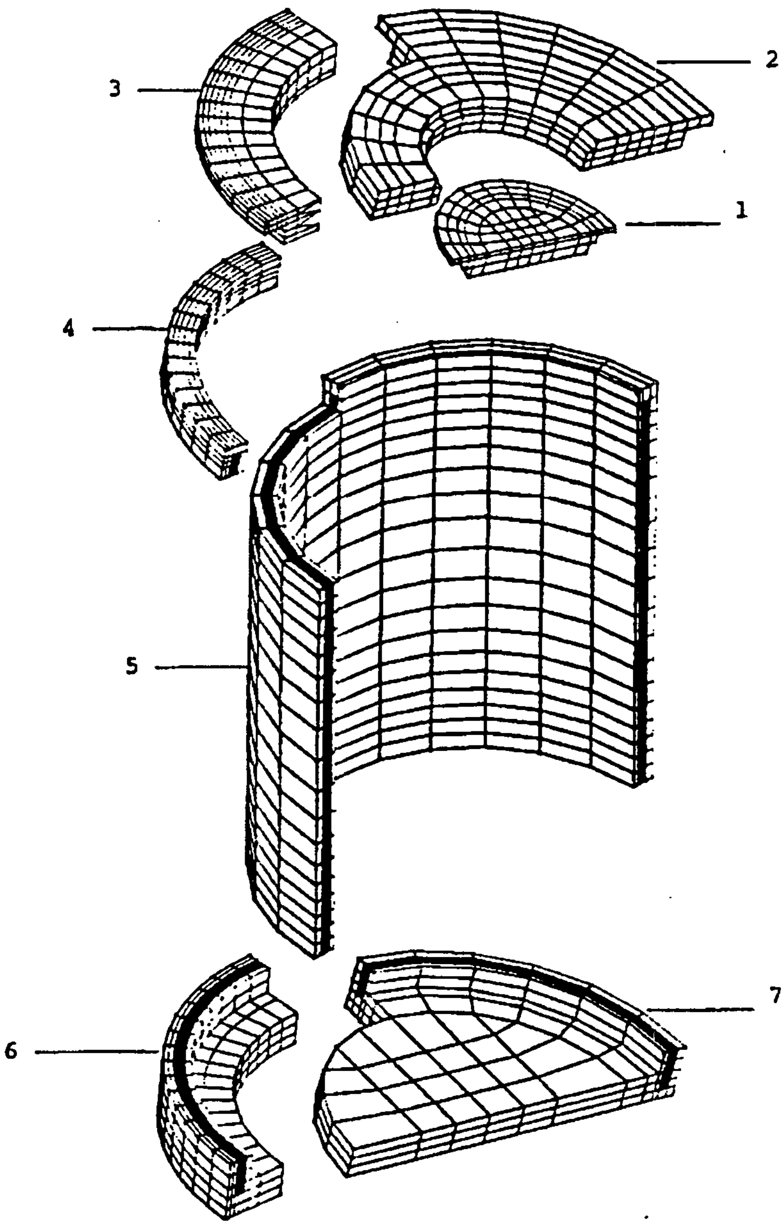
Stress analyses of the cask body for three drop conditions (end, side and corner) were performed using the ANSYS (Ref. 8) finite element program. This section describes the modeling and solution techniques used in the analyses.

2.10.2.1 Finite Element Model Discussion

A three dimensional elastic finite element model of 10-160B cask was constructed using 8-node isoparametric solid elements (ANSYS STIF 45). Since the three drop conditions – side, corner, and end – result in at most one plane of symmetry, only one half of the cask geometry was modeled. The entire cask geometry was divided into seven substructures (see Figure A2-12). Substructuring techniques were employed in the modeling because of the following advantages they offered:

- Independent component modeling.
- Separation of fixed design portion of the cask from portion undergoing design changes.
- Detailed modeling of the portion of the cask where the worst case stress concentration is expected under various loading conditions.

The mesh size in each substructure was determined from two basic considerations, namely, (1) vicinity from the point (or line) of impact and (2) the level of stress anticipated at that location. For instance, the portion of the cask away from the point of impact was modeled by coarser mesh than that near the impact. Also, the portions of the cask near the shell-base plate and shell-upper ring junctures, where higher stresses are expected (due to geometric



X = reference substructure number

Figure A2-12
Finite Element Model – Substructure Overview

discontinuity) were modeled using a finer mesh. The arc angle of the finite element was kept under the ANSYS recommended value of 15 degrees in the coarse mesh and 6 degrees in the fine mesh. The aspect ratio of the elements (i.e. length to width ratio) is always less than eight. Care was taken to ensure that there was a gradual transition between the fine and coarse portions of the model.

Following is a list of the substructures used in the model:

Substructure No. 1 – Secondary Lid (see Figure A2-13)
Substructure No. 2 – Primary Lid away from impact (see Figure A2-14)
Substructure No. 3 – Primary Lid near impact (see Figure A2-15)
Substructure No. 4 – Upper Ring, Shells and Lead near impact (see Figure A2-16)
Substructure No. 5 – Shells, Lead away from impact (see Figure A2-17)
Substructure No. 6 – Shells, Base Plate near impact (see Figure A2-18)
Substructure No. 7 – Shells, Base Plate away from impact (see Figure A2-19)

Figure A2-12 shows these substructures relative to their location in the overall model of 10-160B cask. Figures A2-13 to A2-19 show the enlarged view of each substructure with node numbers and Figures A2-20 to A2-26 show those with the element numbers. Table A2-1 summarizes the size of the substructures used in the analysis. Table A2-2 lists the material properties used in the model.

Table A2-1
10-160B Cask Finite Element Model Substructure Detail

SUBSTRUCTURE NO.	NO. OF NODES	NO. OF ELEMENTS	NO. OF MDOF[(2)]	MASS (lb.)
1	275	156	169	863
2	383	216	385	1,871
3	496	209	266	678
4	576	232	275	437
5	1548	704	450	12,385
6	318	362	298	1,319
7	384	198	274	3,127

Notes:

(1) See Figure A2-12 for substructure geometry plot.

(2) MODF = Master Degrees of Freedom.

Table A2-2
Material Properties Used in the Drop Analysis

Material	Property	ANSYS Symbol	Value	Unit
Steel	Modulus Of Elasticity Coefficient Of Thermal Expansion Poissons's Ratio Weight Density	EX ALPX NUXY DENS	28×10^{6} 8.67×10^{-6} 0.30 0.283	psi in/in-°F - lb/in³
Lead	Modulus Of Elasticity Coefficient Of Thermal Expansion Poissons's Ratio Weight Density	EX ALPX NUXY DENS	2×10^{6} 16.5×10^{-6} 0.40 0.4109	psi in/in-°F - lb/in³

Notes: (1) Material properties are estimated at 150° F.

\

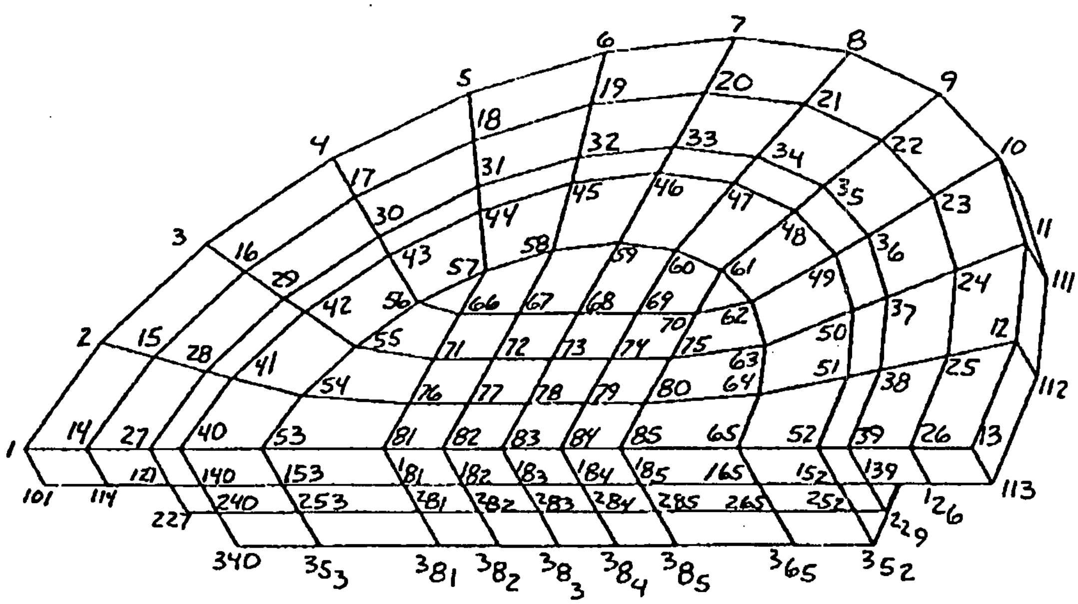


Figure A2-13
Substructure No. 1 – Node Numbers

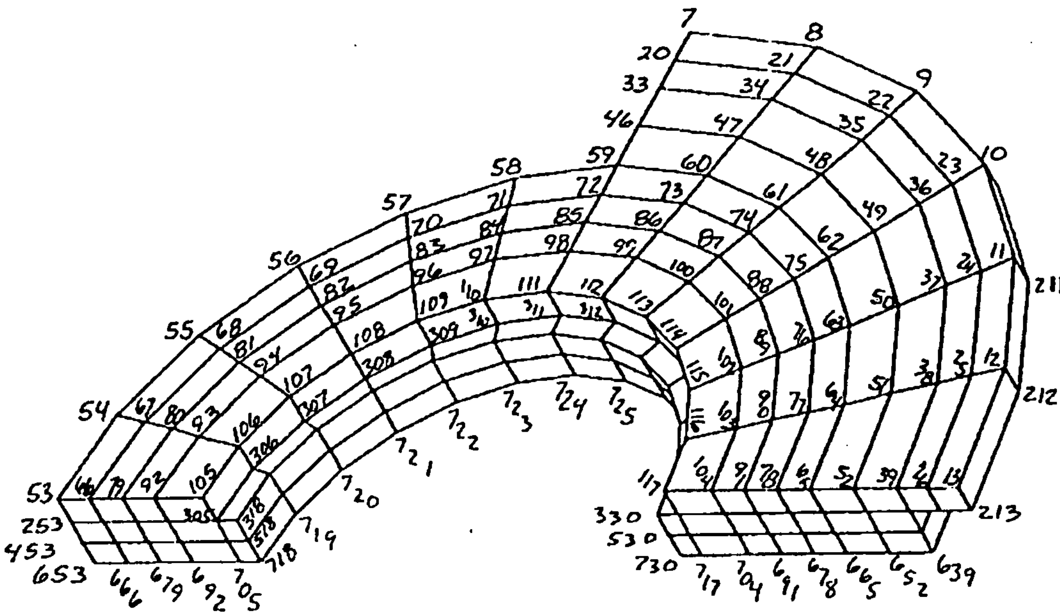


Figure A2-14
Substructure No. 2 – Node Numbers

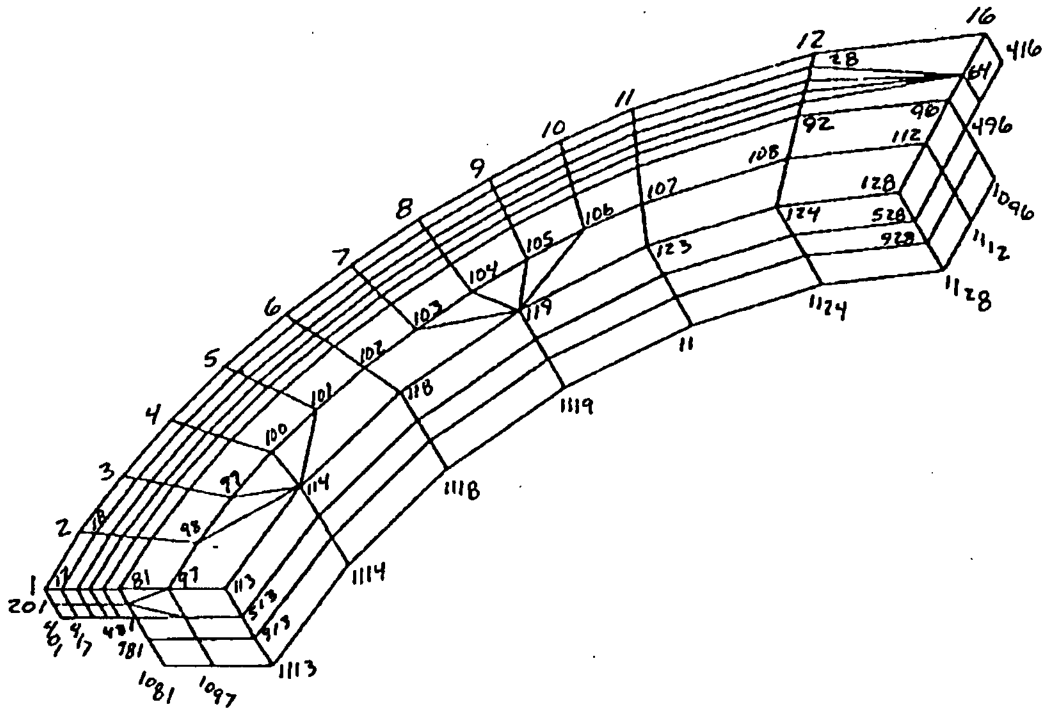


Figure A2-15
Substructure No. 3 – Node Numbers

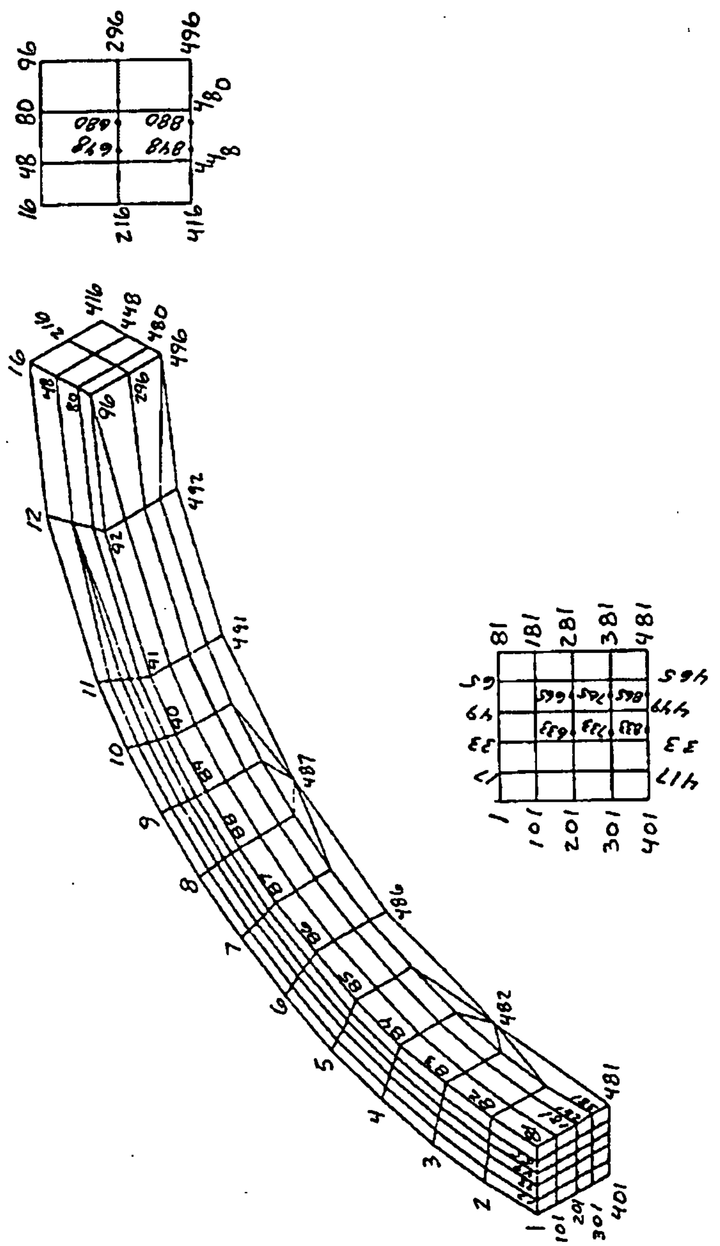


Figure A2-16
Substructure No. 4 – Node Numbers

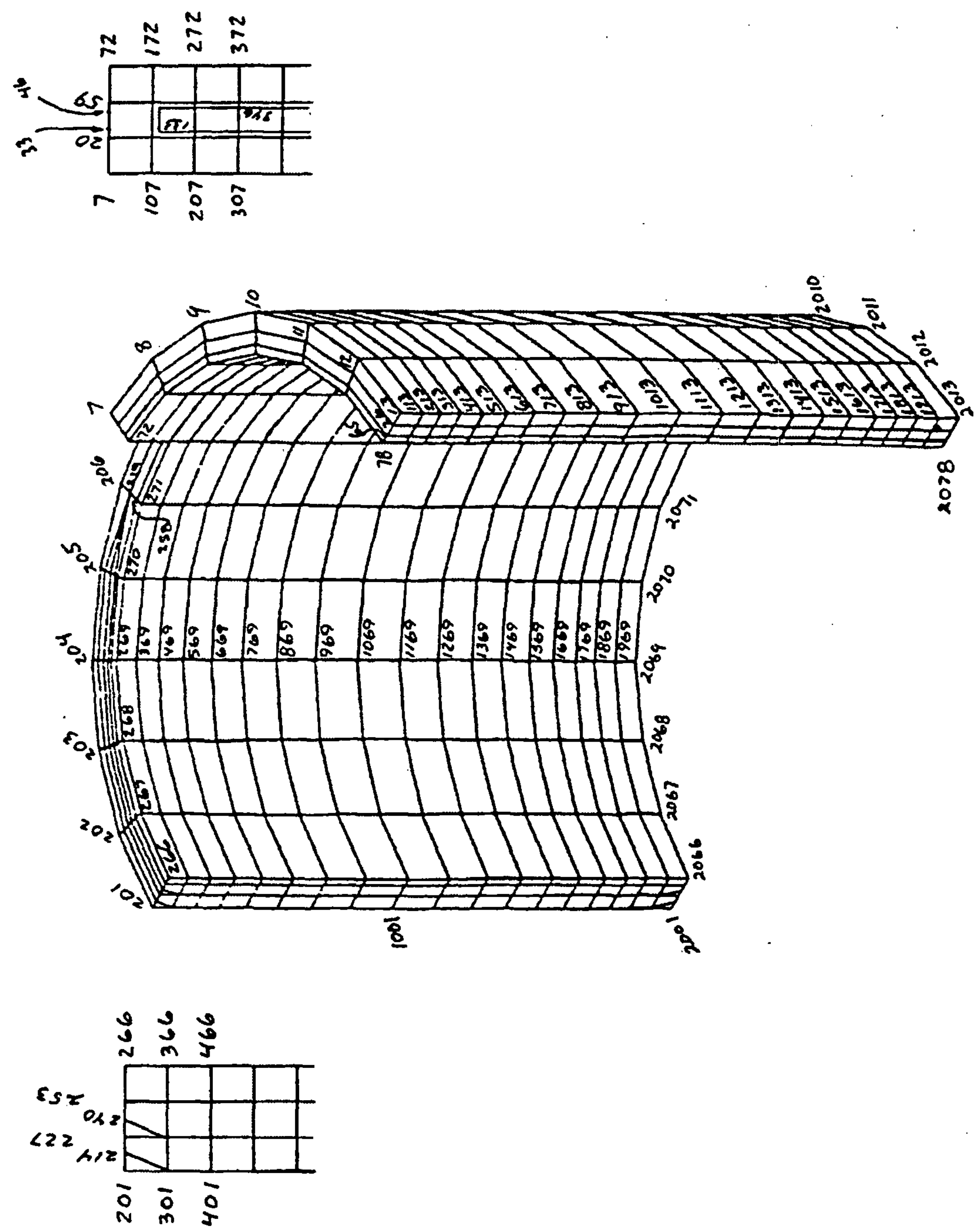


Figure A2-17
Substructure No. 5 – Node Numbers

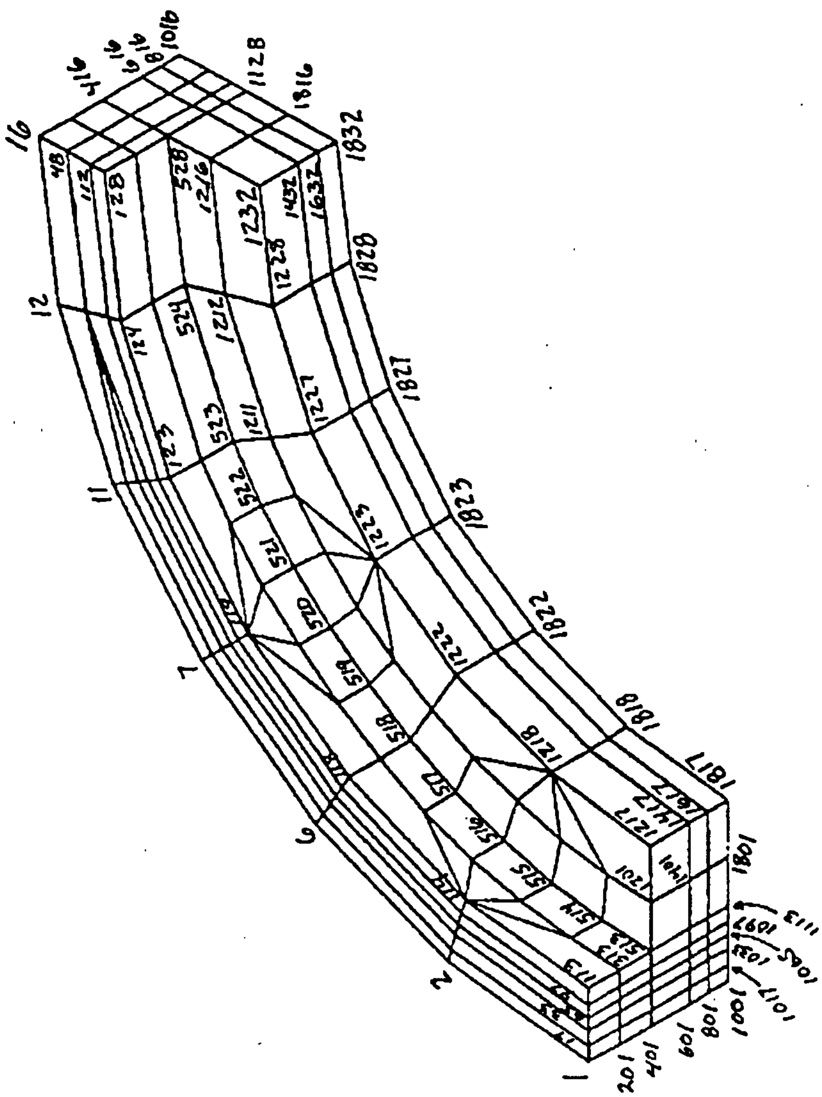


Figure A2-18
Substructure No. 6 – Node Numbers

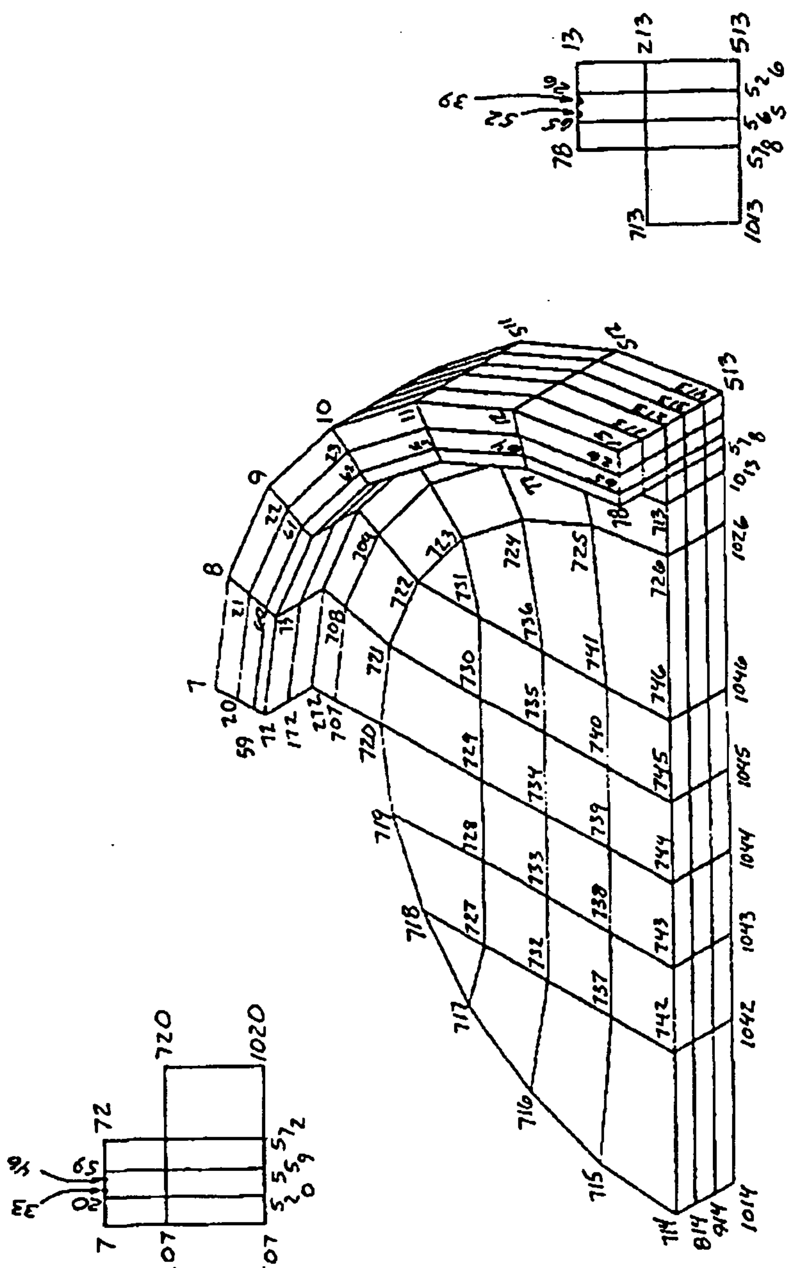


Figure A2-19
Substructure No. 7 – Node Numbers

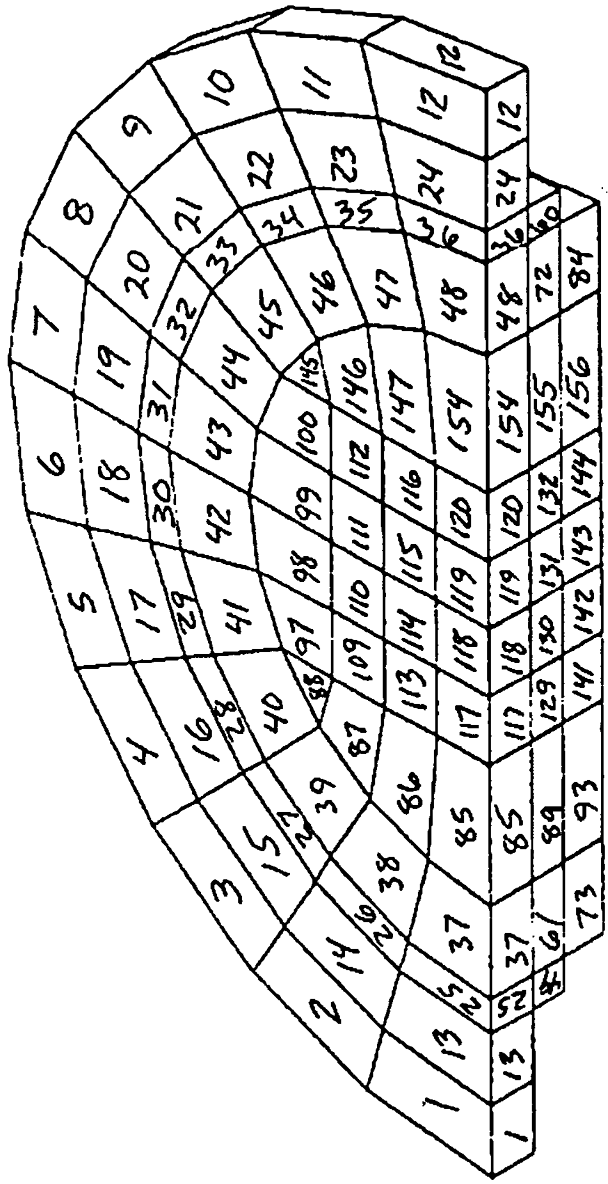


Figure A2-20
Substructure No. 1 – Element Numbers

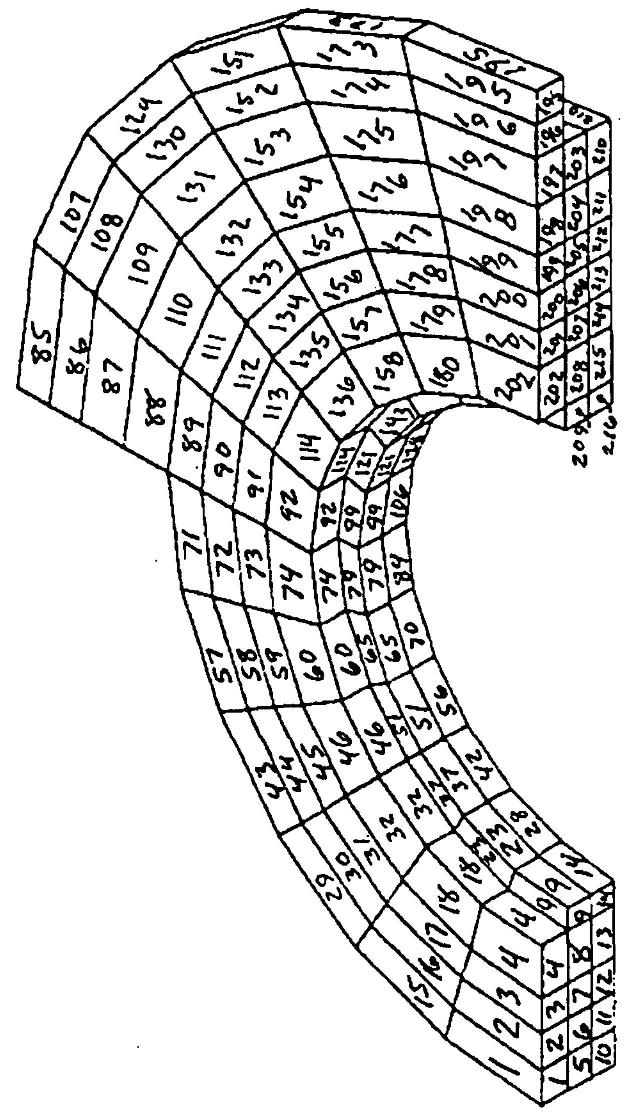


Figure A2-21
Substructure No. 2 – Element Numbers

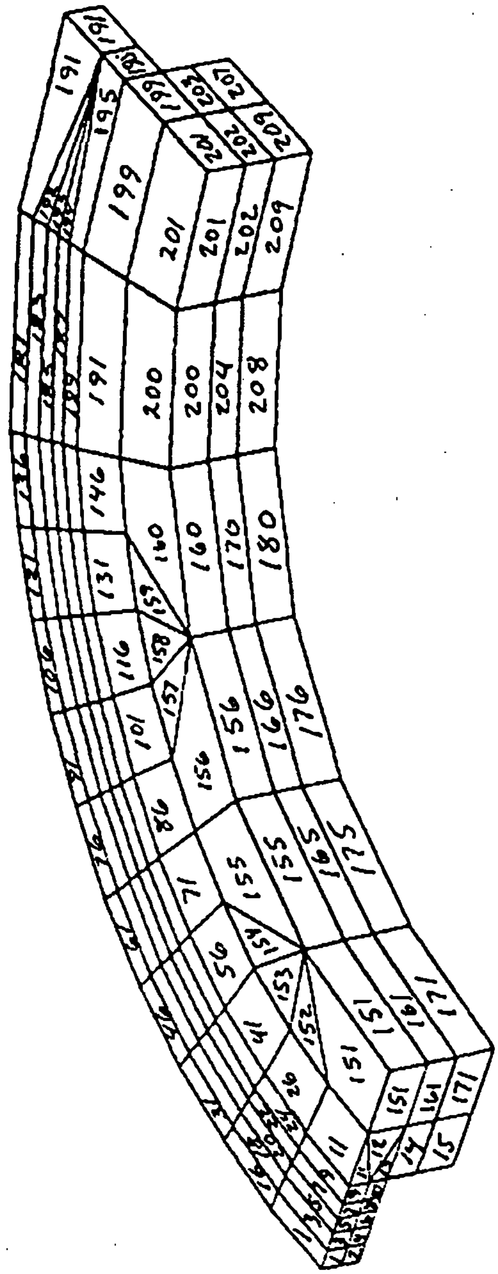


Figure A2-22
Substructure No. 3 – Element Numbers

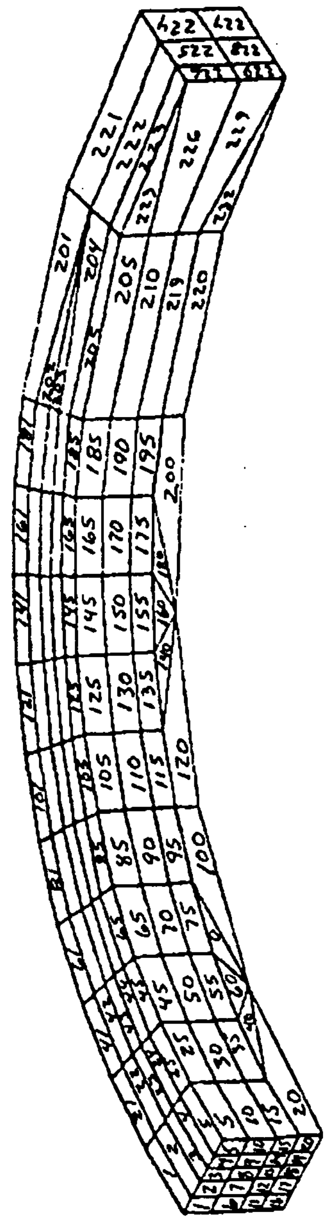


Figure A2-23
Substructure No. 4 – Element Numbers

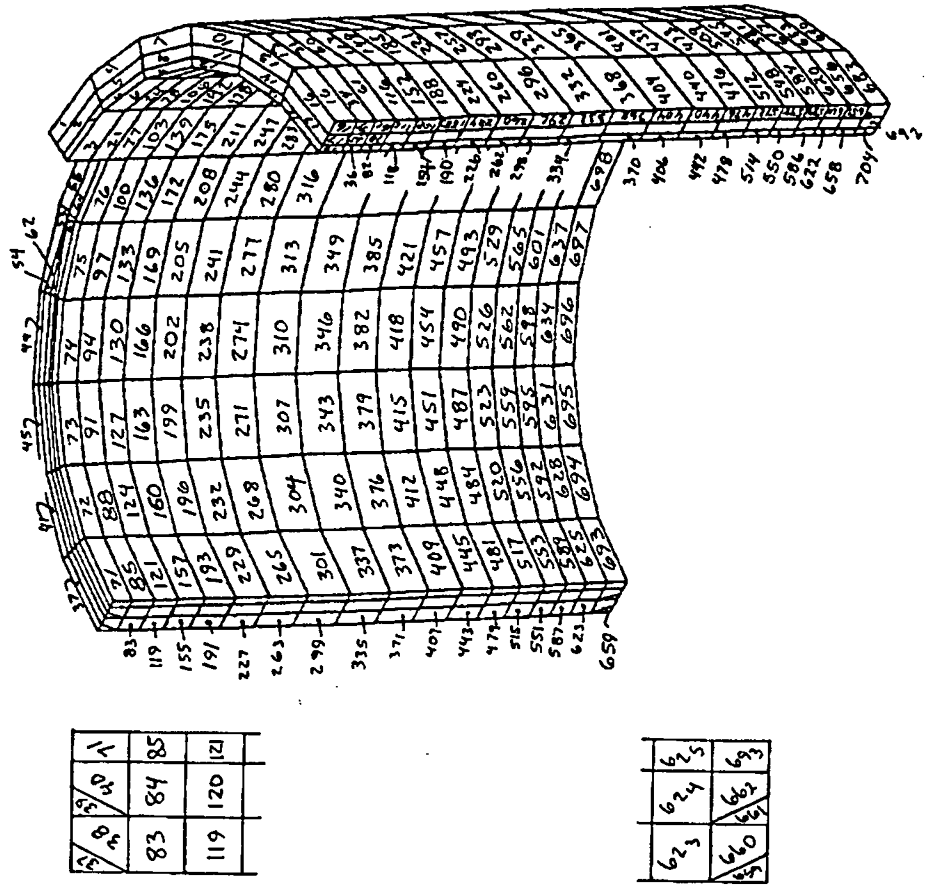


Figure A2-24
Substructure No. 5 – Element Numbers

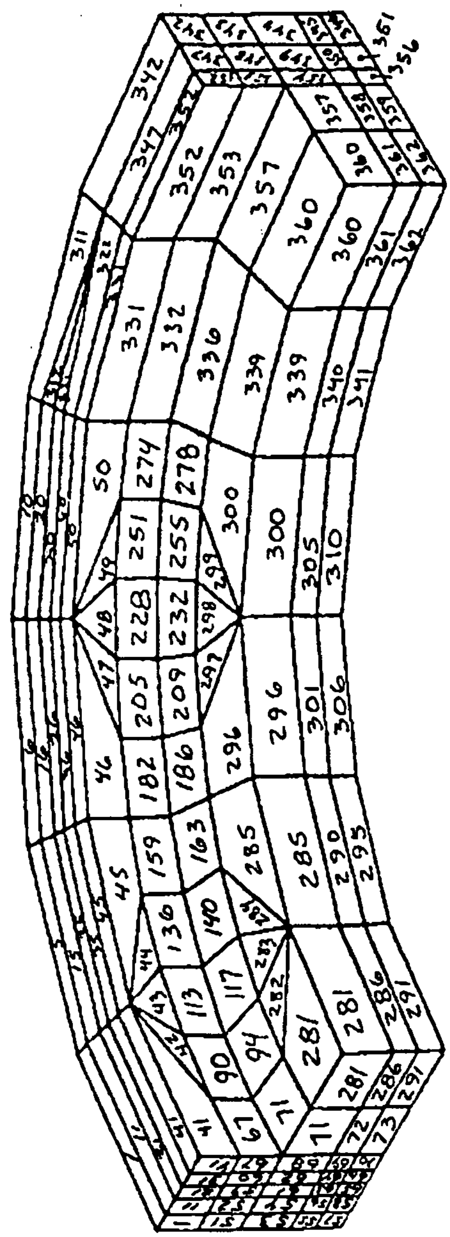


Figure A2-25
Substructure No. 6 – Element Numbers

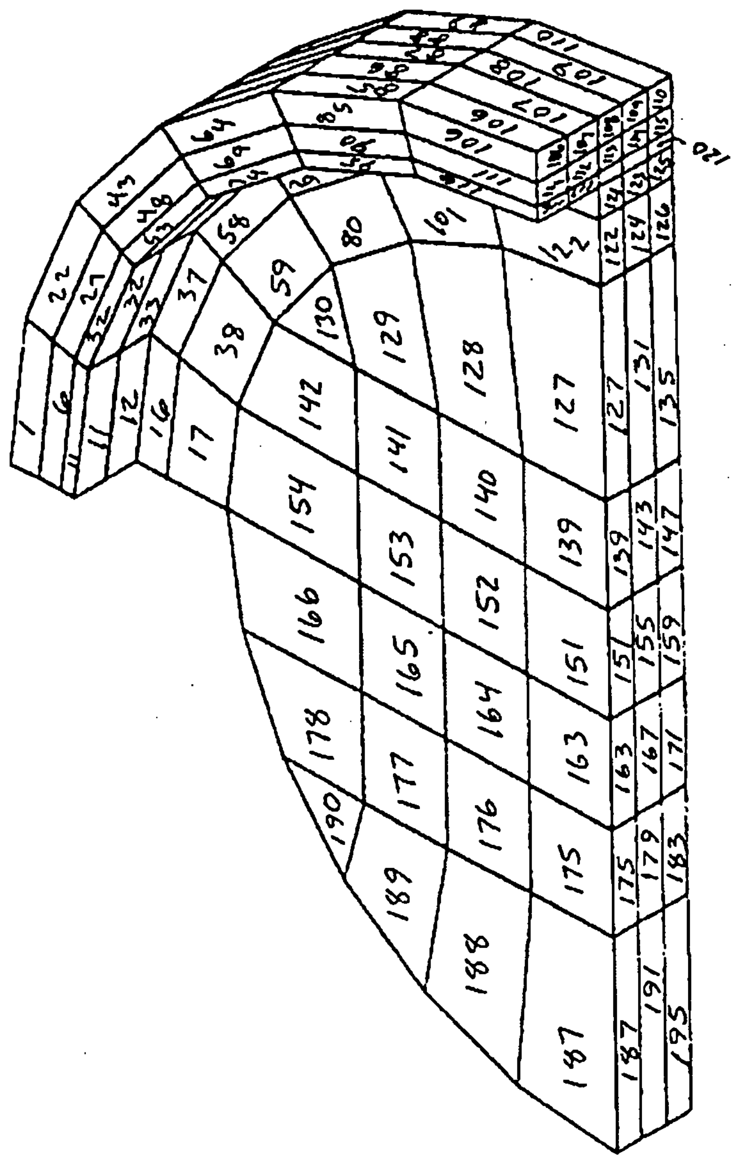


Figure A2-26
Substructure No. 7 – Element Number

2.10.2.2 Finite Element Model Internal Constraints

The connections between various substructures were made by node coupling. Those substructures that consisted of a part of the cask component (Primary Lid, Shells, Base Plate) were connected in all degrees-of-freedom at the interface nodes. The bolted connection between the secondary and primary lid and between the primary lid and the bolting ring were made by coupling the nodes in three translational directions at the location of each bolt.

Since lead bonding between the steel shells is not present, the elements representing the steel shell and lead were allowed to have relative motion with respect to each other along tangential and axial directions. They were coupled in the radial direction. On the two ends, the lead nodes were coupled with the upper ring or base plate in all directions (if the lead had tendency to move towards them), and were kept open (if the lead moved away from them). Figure A2-27 illustrates the internal constraints used to couple the substructures together.

2.10.2.3 Finite Element Model Boundary Conditions

As described earlier, only one-half of the cask geometry was modeled in the finite element model. This required the symmetry boundary conditions be used on the plane that divides the cask into two halves. Also, for a static finite element structural analysis it is required that the structure be restrained in such a way so that there is no rigid body motion of the structure. For the drop analyses the dynamic equilibrium problem is solved using D'Alembert's Principle i.e., the total

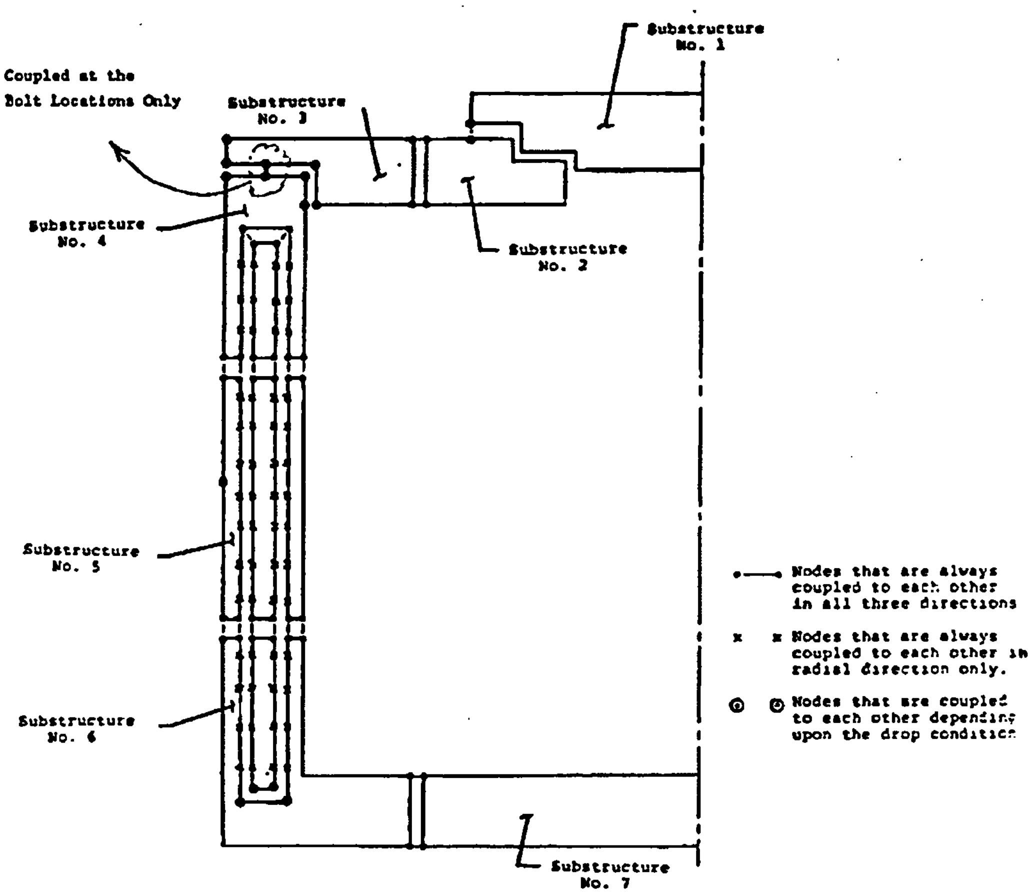


Figure A2-27
Internal Constraints Used in ANSYS Drop Analyses

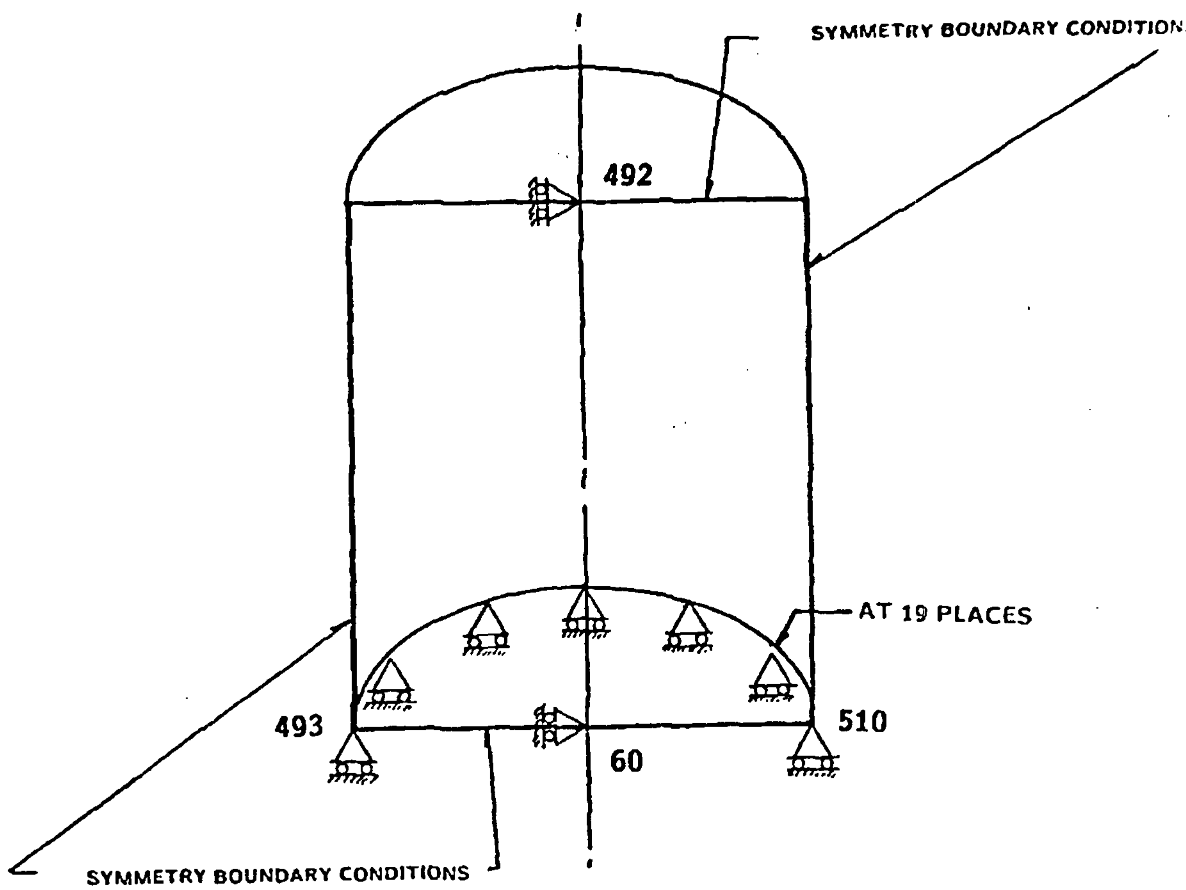


Figure A2-28
Boundary Conditions – End Drop

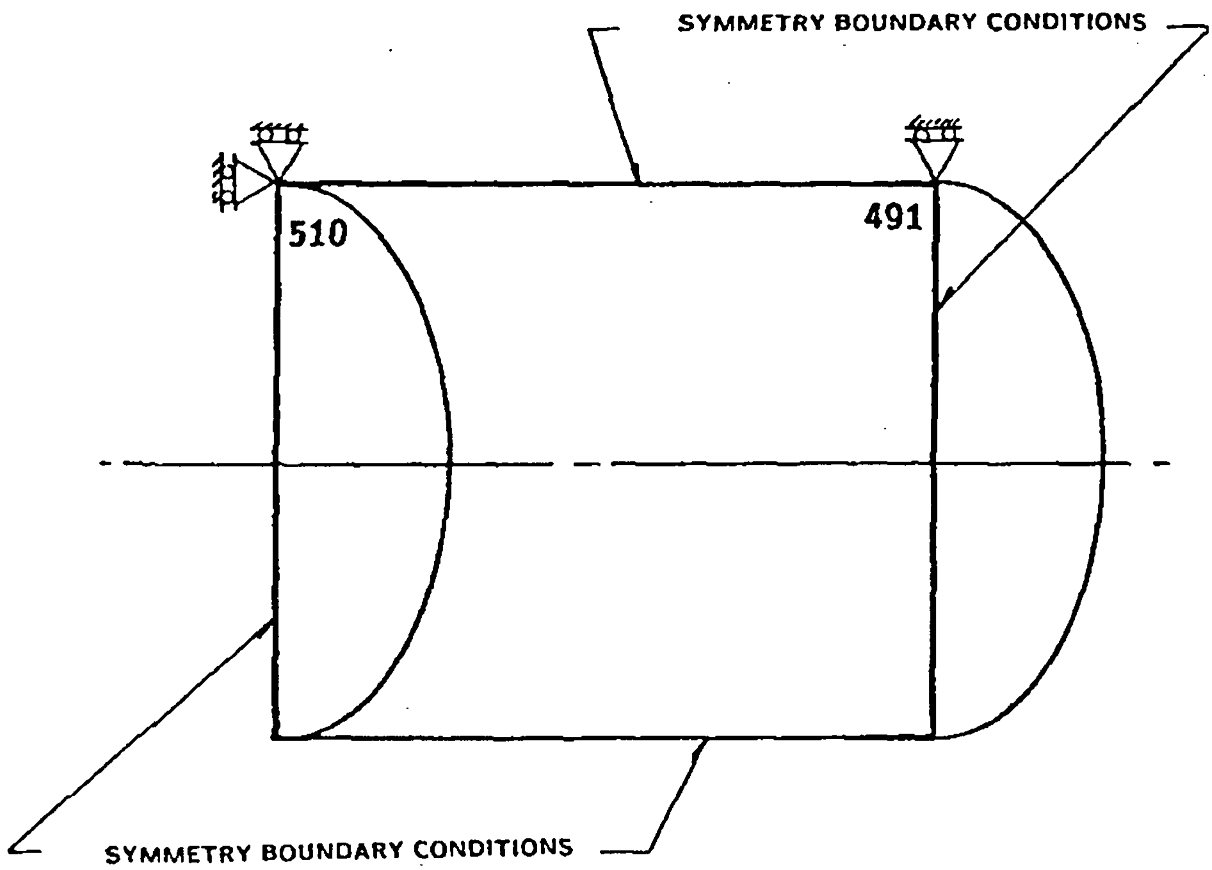


Figure A2-29
Boundary Conditions – Side Drop

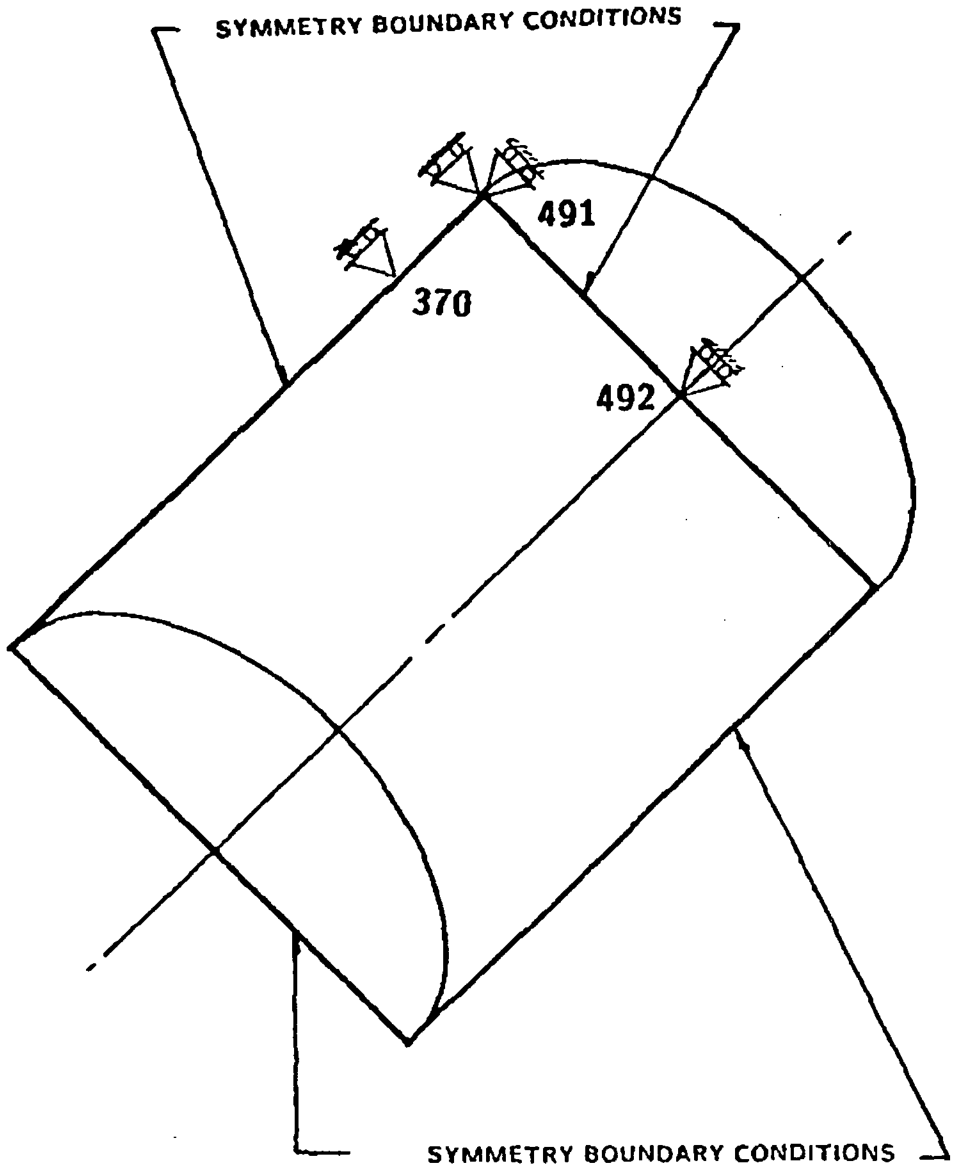


Figure A2-30
Boundary Conditions – Corner Drop

Inertia is balanced with the total reaction forces. In this case there are no physical locations in the structure that are stationary and a rigid body motion may occur. To eliminate this problem, the cask was restrained in such a way that the rigid body motion was removed. The displacement solution was obtained with respect to the restrained nodes. A small reaction at the restrained node assures that the displacement and stress pattern in the cask due to these restraints do not alter the results significantly.

Figures A2-28 to A2-30 show the boundary conditions used for end, side and corner drops, respectively. Tables A2-3 to A2-5 tabulate the constraint reactions at the restrained nodes for the end, side and corn drops respectively.

2.10.2.4 Finite Element Model Solution Techniques

The ANSYS finite element analysis of structural problems using substructures utilizes the technique of matrix condensation. The ANSYS Theoretical Manual (Reference 19) describes this technique in detail. In short, it can be described as follows:

The equilibrium of an eplastic structure in terms of discretized nodal displacement can be written as:

$[K] \langle U \rangle = \langle F \rangle$ eqn. (1)

Where [K] = stiffness matrix

<U> = displacement vector

<F> = load vector

The displacement vector U is separated out into essential and nonessential nodal displacement such that:

$$\langle U \rangle = \begin{Bmatrix} \langle Um \rangle \\ \langle Us \rangle \end{Bmatrix}$$

Table A2-3
Constraint Reactions – 30' End Drop

```
***** REACTION FORCES *****   TIME =  0.00000      LOAD STEP=   1  ITERATION=  1  CUM. ITER.=    1

NOTE - REACTION FORCES ARE IN THE NODAL COORDINATE SYSTEM

  NODE      FX              FY              FZ

   60   -0.204149
  151                                    18215.2
  492    0.603040E-01
  493                                    6715.17
  494                                    13709.9
  495                                    15883.3
  496                                    21808.0
  497                                    32769.6
  498                                    21961.0
  499                                   -38198.6
  500                                   -67255.8
  501                                   -66216.1
  502                                   -35642.8
  503                                    39711.8
  504                                    43595.0
  505                                    7133.42
  506                                    503.538
  507                                   -2727.94
  508                                   -5128.98
  509                                   -6502.55
  510                                   -3532.80

 TOTAL  -0.143845       0.000000        -3199.53
```

NOTE: THE NODE NUMBERS LISTED ABOVE ARE NODE NUMBERS FOR REDUCED MODEL. THE FOLLOWING TABLE GIVES THE CORRESPONDING SUBSTRUCTURE NODE NUMBERS.

TRANSFORMED NODE NO.	SUBSTR. NODE NO.	SUBSTR. NO.	TRANSFORMED NODE NO.	SUBSTR. NODE NO.	SUBSTR. NO.
60	105	1	500	8	3
151	7	2	501	9	3
151	16	3	502	10	3
492	1044	7	503	11	3
493	1	3	504	12	3
494	2	3	505	8	2
495	3	3	506	9	2
496	4	3	507	10	2
497	5	3	508	11	2
498	6	3	509	12	2
499	7	3	510	13	2

Table A2-4
Constraint Reactions – 30' Side Drop

```
***** REACTION FORCES *****   TIME =  0.00000      LOAD STEP=   1  ITERATION=  1  CUM. ITER.=    1
NOTE - REACTION FORCES ARE IN THE NODAL COORDINATE SYSTEM

 NODE      FX             FY             FZ

 491     6400.94
 510    -7406.35                        -273.015

TOTAL   -1005.41       0.000000         -273.015
```

NOTE: THE NODE NUMBERS LISTED ABOVE ARE NODE NUMBERS FOR REDUCED MODEL. THE FOLLOWING TABLE GIVES THE CORRESPONDING SUBSTRUCTURE NODE NUMBERS.

TRANSFORMED NODE NO.	SUBSTR. NODE NO.	SUBSTR. NO.	TRANSFORMED NODE NO.	SUBSTR. NODE NO.	SUBSTR. NO.
491	513	7	510	13	2

Table A2-5
Constraint Reactions – 30' Corner Drop

```
***** REACTION FORCES *****   TIME =  0.00000      LOAD STEP=   1  ITERATION=  1  CUM. ITER.=    1

NOTE - REACTION FORCES ARE IN THE NODAL COORDINATE SYSTEM

  NODE      FX            FY             FZ

  370   -4697.81
  491    7439.21                      54577.6
  492                                -62047.8

TOTAL    2741.40      0.000000        -7470.23
```

NOTE: THE NODE NUMBERS LISTED ABOVE ARE NODE NUMBERS FOR REDUCED MODEL. THE FOLLOWING TABLE GIVES THE CORRESPONDING SUBSTRUCTURE NODE NUMBERS.

TRANSFORMED NODE NO.	SUBSTR. NODE NO.	SUBSTR. NO.	TRANSFORMED NODE NO.	SUBSTR. NODE NO.	SUBSTR. NO.
370	2013	5	491	513	7
370	13	7	492	1044	7

Where

<Um> = displacement vector with essential or mast degrees-of-freedom.
<Us> = displacement vector with nonessential or slave degrees-of-freedom

then, eqn. (1) can then be reduced to

[K] <Um> = <F> eqn (2)

where

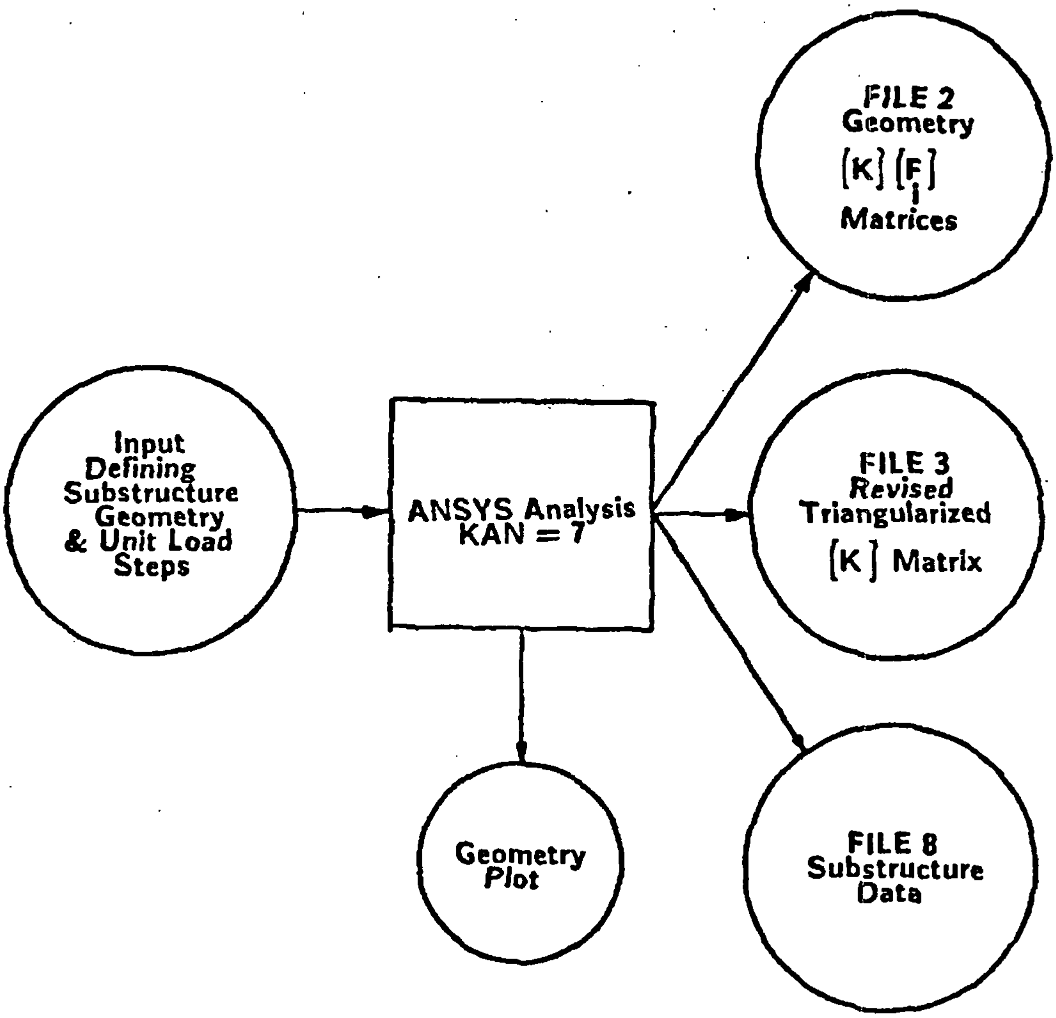
[K] = reduced stiffness matrix
<F> = reduced load vector

Solution of this set of simultaneous equations represented by eqn. (2) gives the displacement at the essential nodes. A back substitution scheme provides the total solution of the set of simultaneous equations represented by eqn. (1). The nodal forces and element stresses are obtained using these displacements.

The total solution of a particular drop analysis requires performing the following steps:

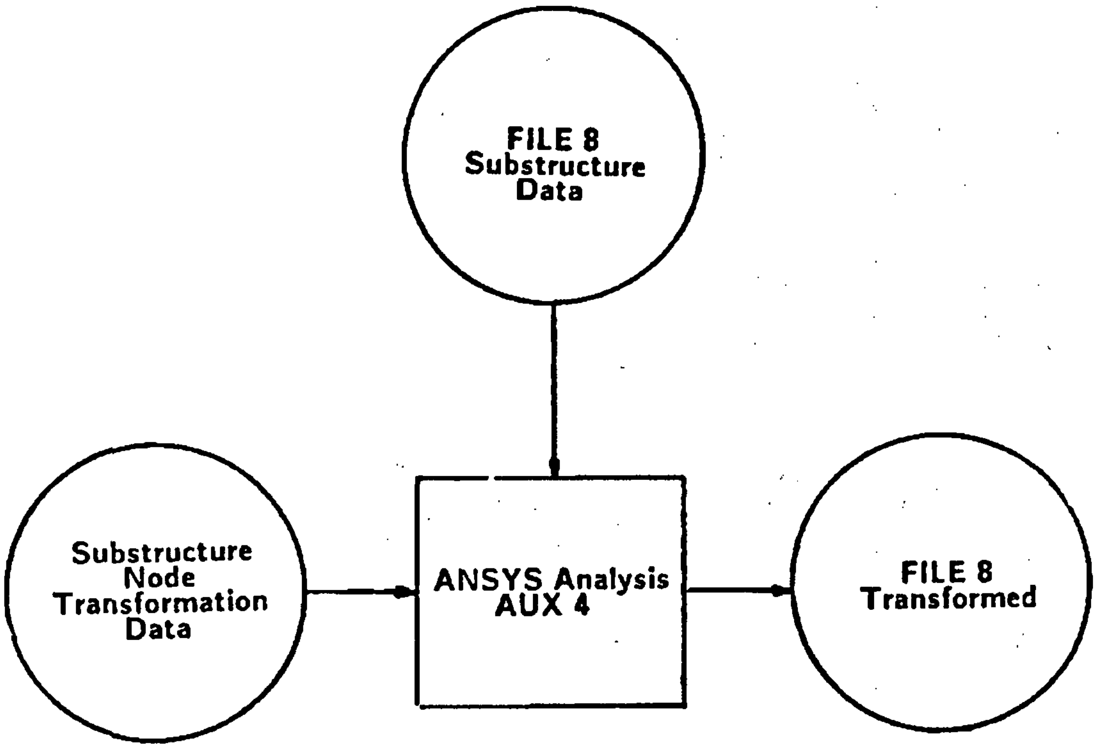
- Stiffness matrix and load vector formulation of each substructure
- Solution of reduced equilibrium equations.
- Load and stress solution for each substructure.

In using ANSYS, some restrictions and limitations have to be considered in performing the above tasks. The flow diagrams shown in Figure A2-31 to A2-35 illustrate the sequence of computation and data saving scheme that was used in performing the drop analysis of the 10-160B cask.



Note: This step is repeated for each substructure.

Figure A2-31
Flow Diagram – Substructure Generation Analysis



Note: This step is repeated for each substructure.

Figure A2-32
Flow Diagram – Substructure Node No. Transformation

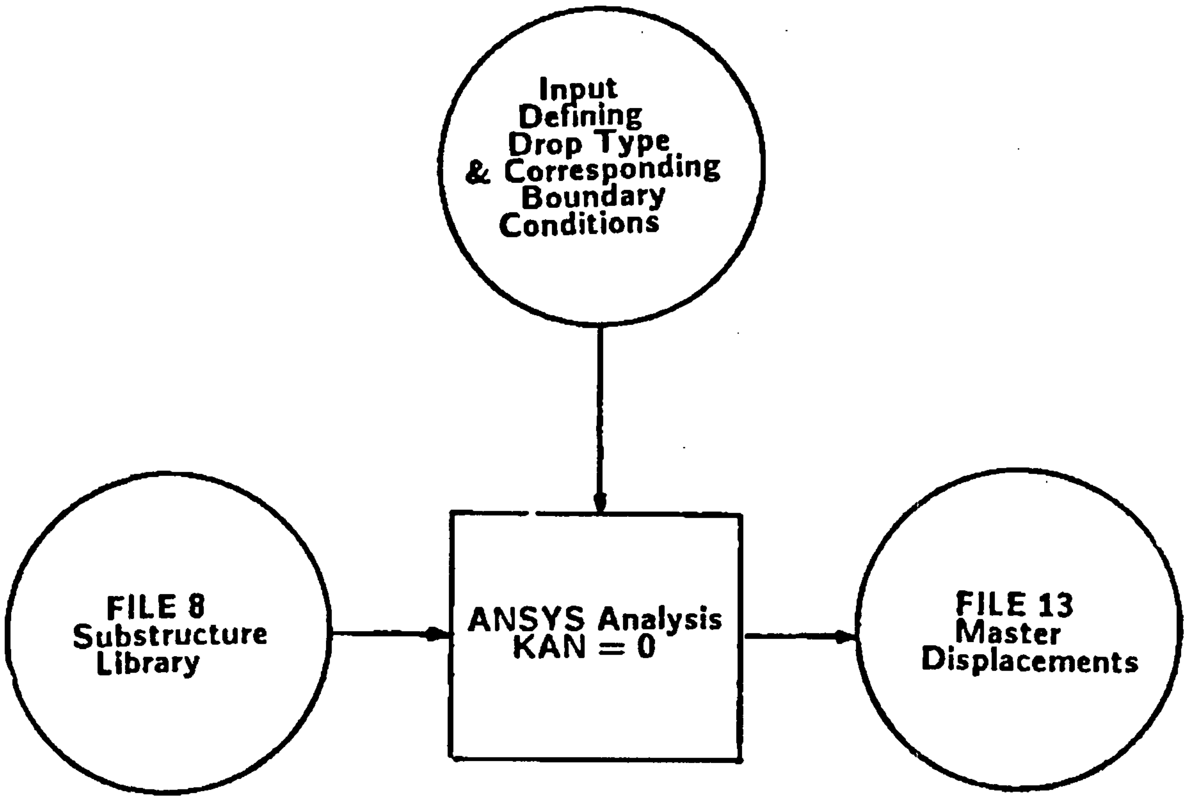
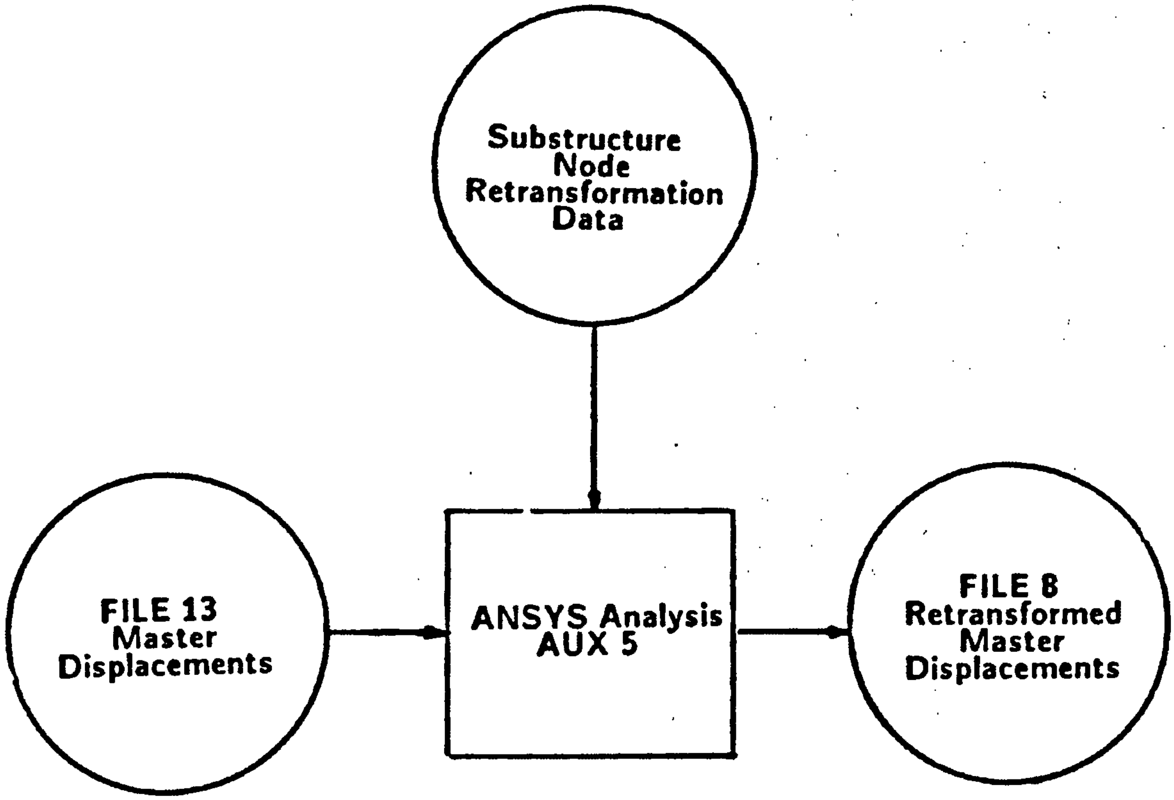
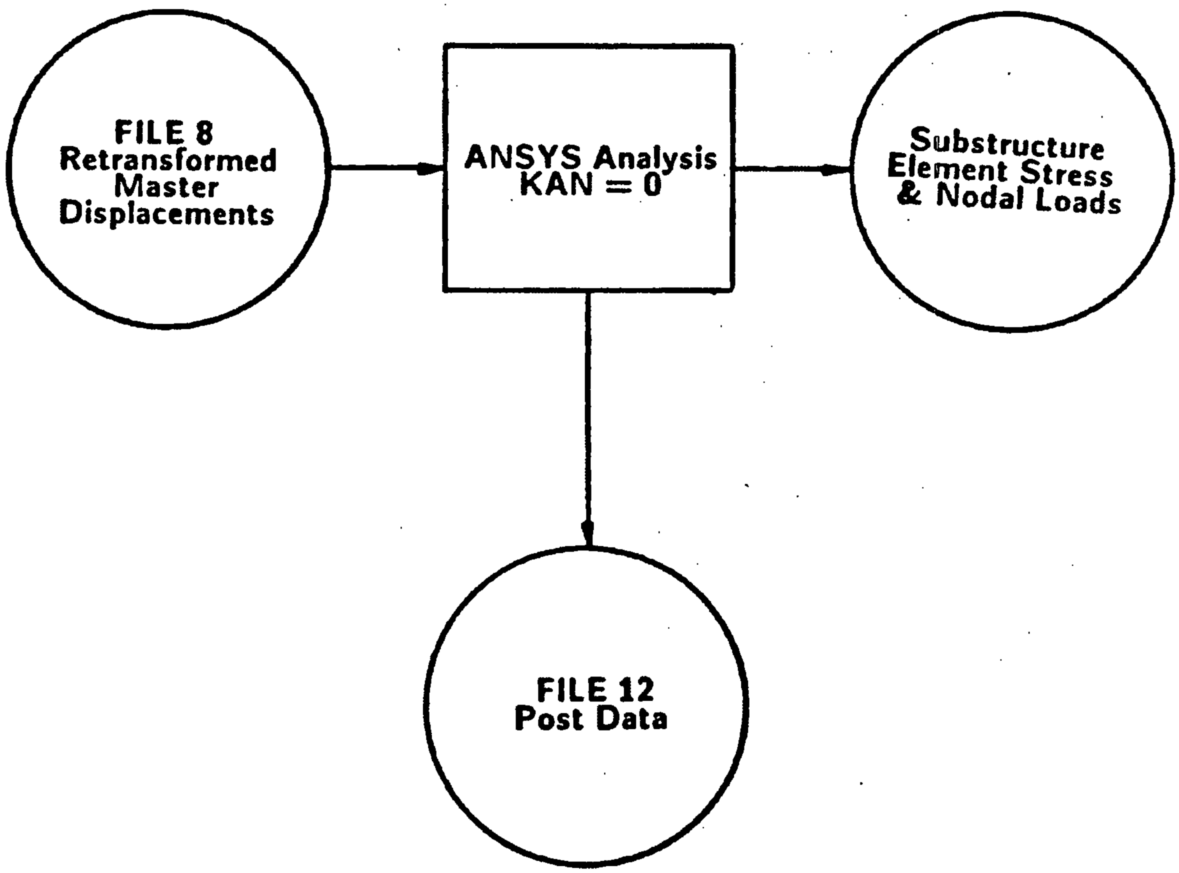


Figure A2-33
Flow Diagram – Cask Drop Analysis



Note: This step is repeated for each substructure.

Figure A2-34
Flow Diagram – Substructure Node No. Retransformation



Note: This step is repeated for each substructure.

Figure A2-35
Flow Diagram – Substructure Stress Pass

2.10.2.5 Loading

For a particular drop condition, the cask is in equilibrium under the influence of the reaction of the impact limiter crush plane load, described in Section 2.10.1.1. and the inertia load of the cask body mass, payload mass and the nonstriking impact limiter mass.

The applied load in each case (end, side and corner) are different. Figures A2-36 to A2-38 show these loads graphically and Table A2-6 summarizes them for a quick reference. A detailed description of the applied loading is given in the following paragraphs.

(a) End Drop

The end drop crush plane forces were applied as a uniform element surface pressure over the end of the cask in bearing contact with the impact limiter (as depicted in Figure A2-36). The cask body inertia was applied as the body force. The payload inertia was applied as a uniform element surface pressure over the entire inner surface of the two lids (primary and secondary). The non-striking impact limiter inertia was applied as a uniform pressure over the annulus formed by the impact limiter on the base plate. The magnitudes of these loadings were obtained from Reference 20.

(b) Side Drop

The side drop crush plane load intensity (as listed in Table A2-7) varies in circumferential direction in such a way that its maximum value occurs along a vertical plane normal to the impact plane, decreases along the circumference and diminishes at an angle of 33 degrees. This load intensity was converted to forces on cask nodes that lie on the crush plane. A uniform distribution along the axial direction was assumed. This is conservative because in actuality, due to larger stiffness of the ends, a proportionately large load will follow the path through the ends, This results in a

Table A2-6
Summary of Distribution of Various Loading Over the Cask Components
Under Different Drop Conditions

Drop Condition	Loading Component	Distribution
30' End Drop (Upper End Down) Ref. A2-36	Cask Inertia	Over entire cask mass
	Non-striking Impact Limiter Inertia	Uniformly on the base plate over the area under the non-striking impact limiter.
	Payload Inertia	On the primary and secondary lids, uniformly over the entire inner surface
	Striking Impact Limiter Reaction	On the primary lid, uniformly over the area under the striking impact limiter
30' Side Drop Ref. Figure A2-37	Cask Inertia	Over entire cask mass.
	Payload Inertia	On the lower half of the cask body, varying sinusoidally along the circumference, uniform along the length of the cask.
	Impact Limiter	On the base plate, primary lid and portion Reaction of cask body under impact limiters, varying along the circumference according to the nature obtained from the cask drop program, uniform along the length of the cask.
30' Corner Drop (Upper End Drop) Ref. Fig. A2-38	Cask Inertia	Over entire cask mass
	Payload Inertia	On the primary and Secondary lids, uniformly over the entire surface and on the lower half of the cask body, varying sinusoidally along, the circumference, uniform along length of the cask.
	Non-Striking Impact Limiter Inertia	On the base plate outside corner, uniformly along the circumference.
	Striking Impact Limiter Reaction	On the primary lid and portion of cask body Under the impact limiter, according to the variation along circumferencial and longitudinal directions as obtained from the cask drop program.

Table A2-7
Side Drops Crush Planes Forces

02-01-1985 15:23:46
FORCE DISTRIBUTION: SIDE DROP, BOTTOM
CASK SORONT
FORCE
STRESS

J	X(J)	FI(J)	FIH(J)	SIG(J)	SIG.H(J)
2	1.748	244493.	159749.	3040.	2174.
3	4.219	98436.	65815.	2961.	2167.
4	5.496	73549.	50206.	2889.	2158.
5	6.515	60338.	42106.	2816.	2151.
6	7.391	51758.	36904.	2747.	2144.
7	8.170	46092.	33190.	2710.	2136.
8	8.879	41743.	30341.	2674.	2127.
9	9.534	38257.	28093.	2638.	2120.
10	10.145	35373.	26247.	2601.	2113.
11	10.719	32930.	24694.	2565.	2105.
12	11.263	30822.	23363.	2529.	2098.
13	11.781	29013.	22204.	2496.	2091.
14	12.276	27372.	21184.	2460.	2083.
15	12.750	25902.	20274.	2423.	2076.
16	13.206	24607.	19457.	2390.	2069.
17	13.646	23395.	18731.	2354.	2063.
18	14.071	22315.	18056.	2321.	2056.
19	14.483	21321.	17438.	2288.	2048.
20	14.882	20386.	16880.	2254.	2042.
21	15.270	19690.	16352.	2239.	2035.
22	15.647	19042.	15811.	2224.	2021.
23	16.015	18437.	15326.	2210.	2010.
24	16.373	17869.	14851.	2195.	1996.
25	16.723	17335.	14424.	2180.	1985.
26	17.065	16832.	13944.	2166.	1963.
27	17.399	16356.	13489.	2151.	1941.
28	17.727	15904.	12982.	2136.	1908.
29	18.047	15476.	12280.	2122.	1842.
30	18.361	15078.	11500.	2108.	1760.
31	18.669	14689.	11000.	2094.	1716.
32	18.971	14328.	10520.	2080.	1672.
33	19.268	13972.	9924.	2066.	1606.
34	19.560	13641.	9217.	2053.	1518.
35	19.846	13314.	8536.	2038.	1430.
36	20.128	12952.	7749.	2016.	1320.
37	20.405	12587.	6989.	1991.	1210.
38	20.678	12149.	6360.	1952.	1119.
39	20.946	11390.	5449.	1859.	.973.
40	21.211	10422.	4567.	1727.	828.
41	21.471	9550.	3908.	1606.	719.
42	21.728	8220.	3075.	1402.	574.
43	21.961	6674.	2456.	1155.	465.
44	22.231	4720.	1787.	828.	343.
45	22.477	2820.	881.	502.	172.

Note (1) See Attachment 1 for the detail output of caskdrop.

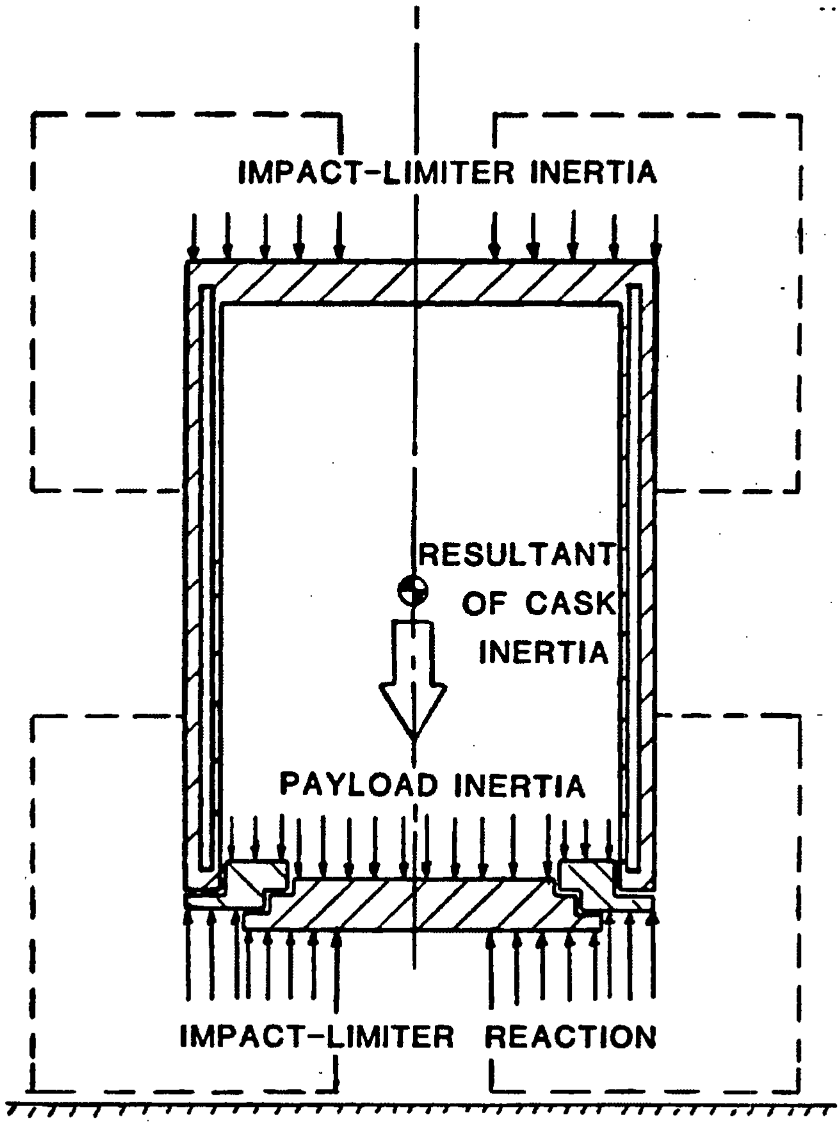


Figure A2-36
Load Distribution – End Drop

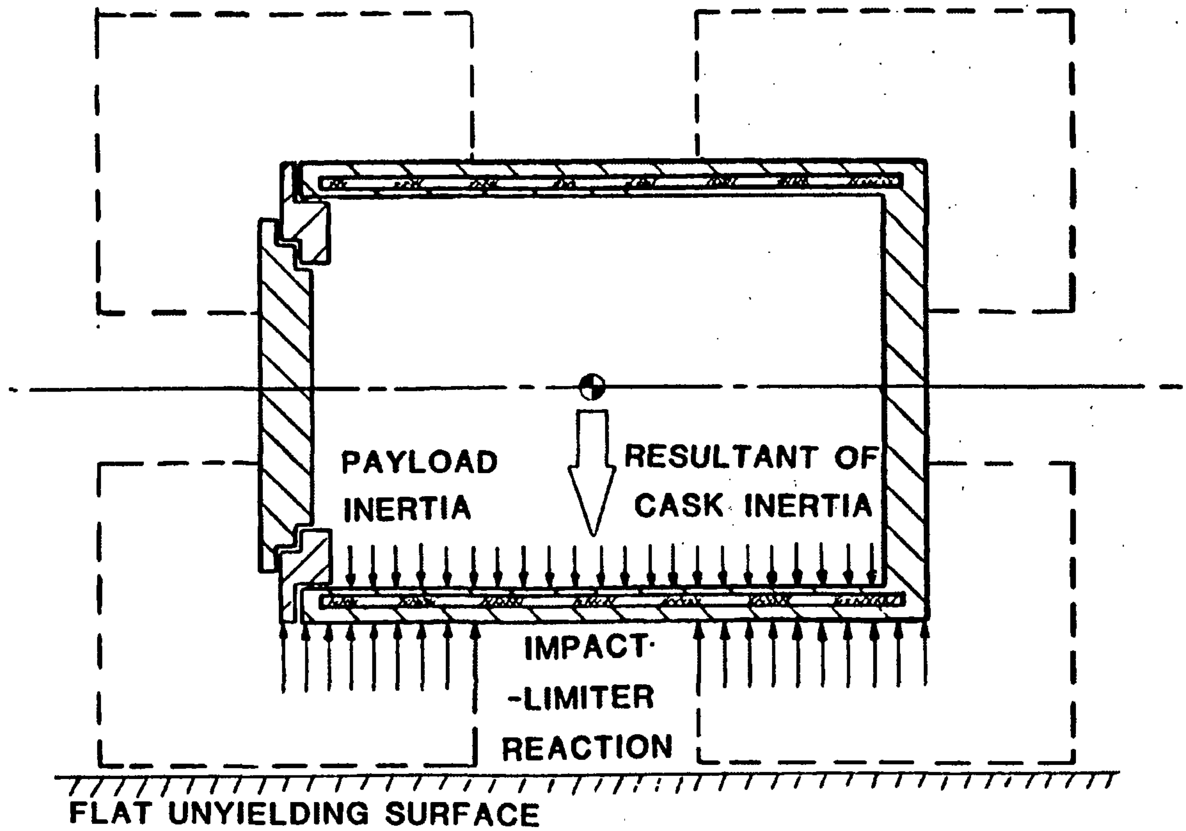


Figure A2-37
Load Distribution – Side Drop

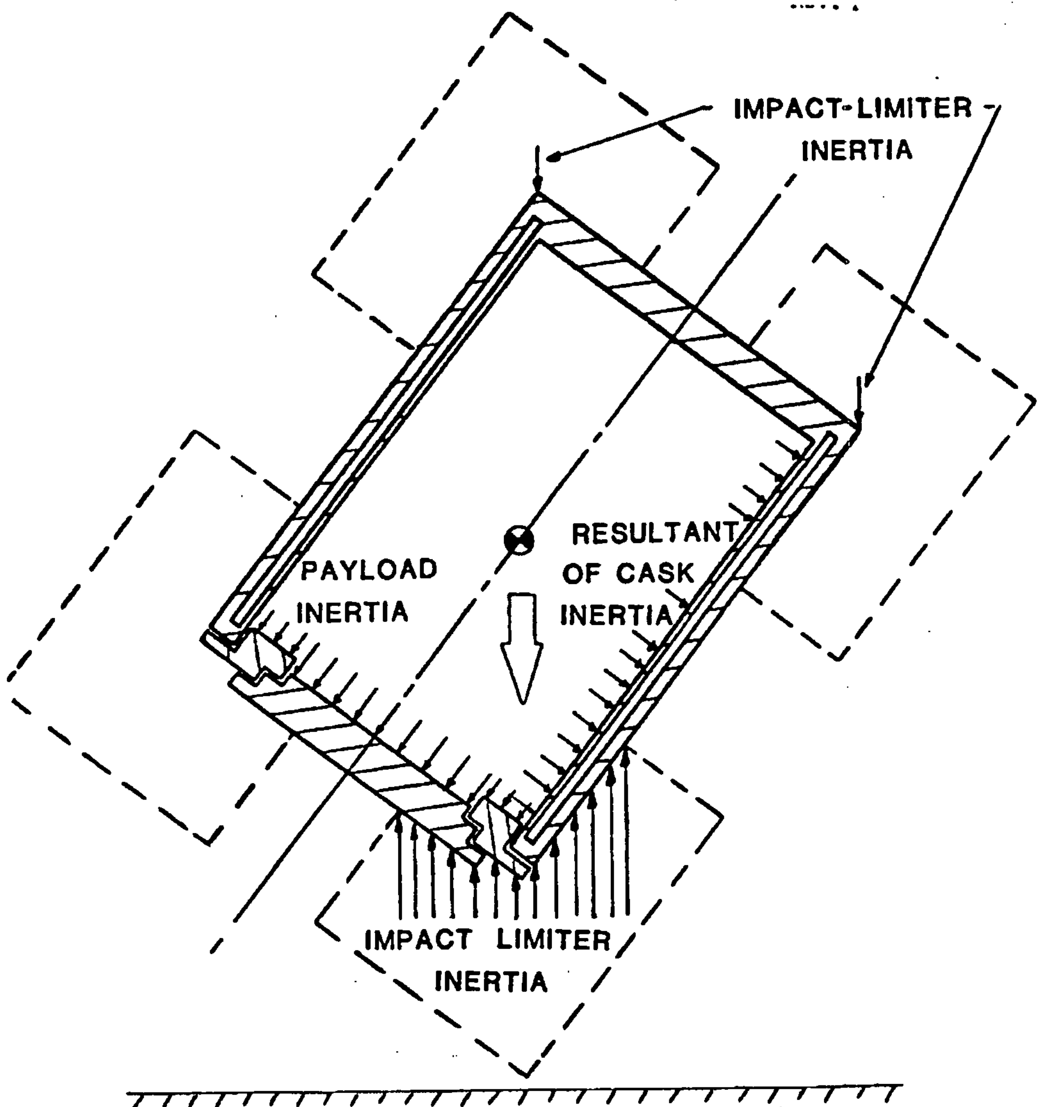


Figure A2-38
Load Distribution – Corner Drop

smaller bending moment at the ends than those obtained from the assumption of uniform distribution along the axial direction. The payload inertia was applied as nodal forces from a load intensity distribution. They were applied sinusoidally along the circumference and uniformly along the axial direction. They were applied at nodes on the lower half of the inside surface of the inner shell. The cask inertia was applied as the body force. The magnitudes of these loading were obtained from Reference 21. Figure A2-37 graphically depicts these loadings.

(c) Corner Drop

The corner drop crush plane load, as listed in Table A2-8, vary along both circumferential and axial directions. These loads were used to obtain the corresponding values at the cask model crush plane nodes. They were applied as the nodal loads in the analysis. The cask inertia was applied as a body force. The payload inertia was resolved into two mutually perpendicular directions (one along the axis of the cask and the other perpendicular to it). The component along the axial direction was distributed uniformly over the inside surface of the primary and secondary lids. The other component was distributed over the lower half of the inside surface of the inner shell. The inertia of the nonstriking impact limiter was distributed as a line load over the outer edge of the base plate. The magnitude of these loadings were obtained from Reference 22. Figure A2-38 graphically depicts these loading.

There are certain requirements for an ANSYS model using ANSYS structure analysis using substructures. The loadings were applied as a linear combination of load vectors corresponding to each substructure. Various unit load vectors were generated for each substructure. The three drop analyses were performed using a combination of these load vectors which are listed in Table A2-9.

Table A2-8
Corner Drops Crush Planes Forces[1]

63	-6.672	-2.900	.872	4.663	8.415	12.186
	36629.	51758.	71350.	33206.	25064.	0.
	36629.	51758.	70189.	32758.	24909.	0.
	36629.	51758.	66580.	31634.	24428.	0.
	36629.	51758.	60577.	29782.	20584.	0.
	36629.	51758.	45456.	27231.	0.	0.
	36629.	51758.	34854.	25761.	0.	0.
	36629.	50227.	29847.	23599.	0.	0.
	36629.	35690.	26249.	0.	0.	0.
	36629.	28777.	23298.	0.	0.	0.
	30946.	25206.	0.	0.	0.	0.
	25806.	0.	0.	0.	0.	0.
	5302.	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.

(1) These results, generated by CNSI CASKDROP Program, illustrate the loading profile on the cask body. See attachment 1 for the detail output of caskdrop.

Table A2-9
Unit Load Vectors Used for Various Substructures

Substructure No.	Load Vector No.								
	1	2	3	4	5	6	7	8	9
1	a	b	c	f	j				
2	a	b	c	f	-	g	i	j	
3	a	b	c	d	f	-	g	i	j
4	a	b	c	d	e	i	j		
5	a	b	c	d	e	i	j		
6	a	b	c	d	e	h	j	k	
7	a	b	c	h	k				

Symbols Used:

a – 100 g acceleration loading in global x-direction
b – 100 g acceleration loading in global y-direction
c – 100 g acceleration loading in global z-direction
d – Side drop impact limiter reaction
e – Side drop payload inertia
f – End drop payload inertia
g – End drop impact limiter reaction
h – End drop impact limiter inertia
i – Corner drop impact limiter reaction
j – Corner drop payload inertia
k – Corner drop impact limiter inertia

2.10.2.6 Stress Linearization

The stresses obtained from the analyses of each drop case is comprised of stress components (normal and shear) along three global directions at the element centroid. Principal stresses and stress intensity are also available at the centroid of each element. A special ANSYS option permits printout of stress quantities at selected faces of an element. These print-outs were utilized in tabulation of stress intensities where a single element through the thickness of a component was used in the modeling. When more than one element was used, stress linearization was performed using the techniques of the ASME Boiler & Pressure Vessel Code Section III (Reference 23).

These are summarized as follows:

Mean and mane-plus-bending values of the stress components along meridianal, normal and hoop directions were obtained using the following scheme.

$$\sigma_m = \frac{1}{d} \sum_{i=1}^{N} \delta_i \sigma_i$$

$$\sigma_{m+b} = \sigma_m + \frac{6}{d^2} \left(\sum_{i=1}^{N} \delta_i \sigma_i X_i - \sigma_m \times d^2 / 2. \right)$$

where

σ_m = Mean value of the stress component
σ_{m+b} = Mean-plus-bending value of the stress component
σ_i = Stress component at the centroid of i-th element
δ_i = Thickness of the i-th element
X_i = Distance of the centroid of the i-th element from the inside face
d = Total thickness of the section
N = No. of elements across the thickness

The linearized mean, P_L, and linearized mean plus bending, $P_L + P_b$, values of the stress intensities were calculated using the values of stress components obtained as described above.

Figure A2-39 shows graphically the concept of stress linearization.

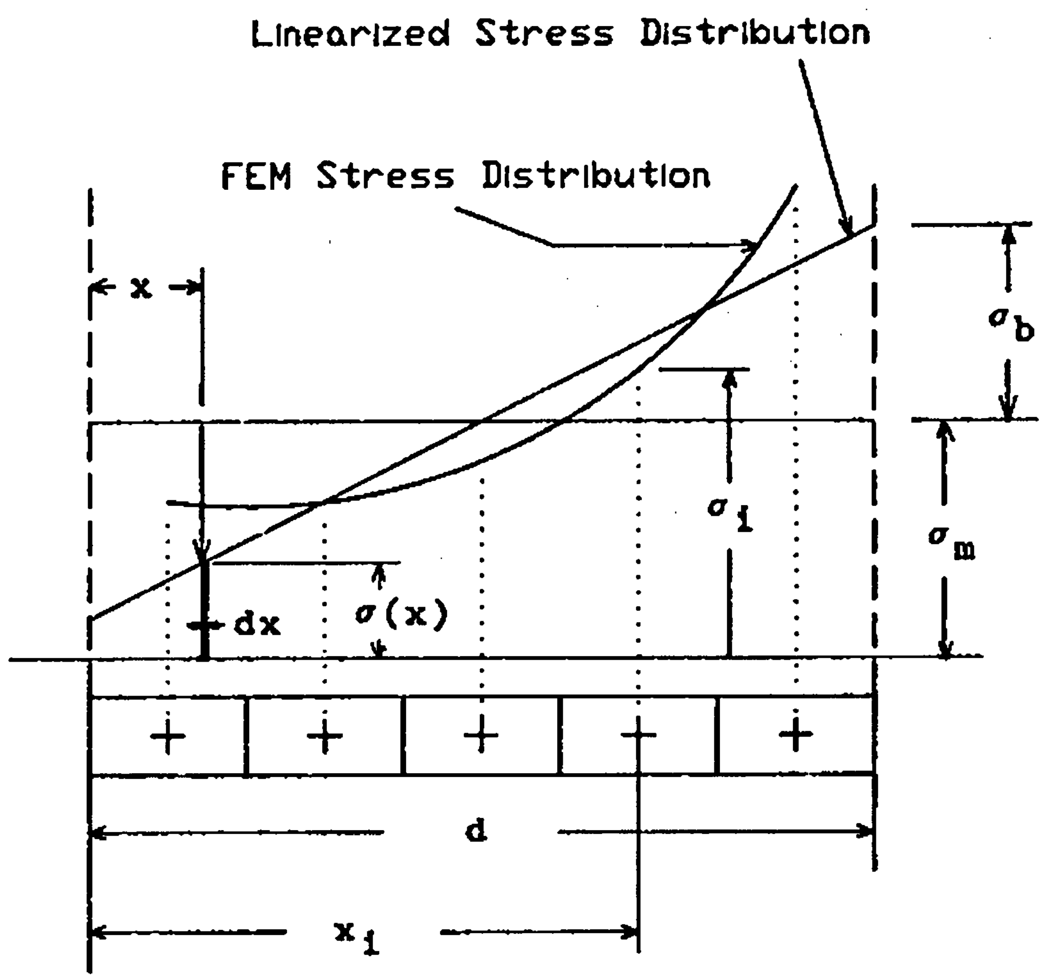


Figure A2-39
Linearization of Finite Element Stress Results

2.10.3 DATA REDUCTION OF CASK STRUCTURAL COMPUTATION RESULTS

2.10.3.1 Results of 3-Dimensional Linear Model

As described under solution techniques, (2.10.2.4) reduced linear static analyses of each drop condition allows stress analysis of each substructure. The stress analysis pint-out consists of an enormous amount of data. To facilitate interpretation of this data, contour plots of stress intensities were obtained for each substructure and every drop orientation case. These plots are congested for a three-dimensional model. Therefore, magnified plots of stress contours in the high stress regions in isometric views were obtained and are shown in Figures 2-13 to 2-18. The largest linearized mean and mean plus bending stress intensities in every component were obtained using the methods described under stress linearization for each drop case. The component stresses, principal stresses and the stress intensities at the critical cross sections are presented in Tables A2-10, 11, 14, 15, 18 and 19 for various drop orientations. The combinations of the other load conditions with the drop condition loading per Regulatory Guide 7.8 is performed on the stress intensity basis and is presented in Tables A2-13, 17, 21, 23, 25 and 27.

2.10.3.2 Results of 2-Dimensional Nonlinear Model

For the analysis of load cases where the applied loading is axisymmetric (e.g. pressure loading, thermal loading and the fire accident loading), a 2-dimensional finite-element model of the cask (Figure A2-44.1) was constructed using axisymmetric isoparametric elements to represent the cask and the lead, 2-dimensional beam elements to represent the bolted connections, and 2-dimensional nonlinear interface elements to represent the lead-steel interfaces and the lid-body interfaces.

Table A2-10
Membrane Stresses in Various Components of the Cask
End Drop (30-Foot)[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	-511.9	41.27	-511.9	0	41.27	-511.9	-511.9	553.1
Outer Shell	B	-2234	-51.72	1834	88.62	1834	-48.13	-2237	4071
Inner Shell	C	-2993	-222	3758	-651	3758	-76.72	-3139	6897
Bolting Ring	D	-756.9	-5802	3219	-197.1	3219	-749.2	-5810	9028
Primary Lid	E	-241.1	-137.9	77.67	-2654	2456	77.67	-2845	5310
Secondary Lid	F	-654.7	-447.4	-654.7	0	-447.4	-654.7	-654.7	207.3

Notes: (1) See Table 2-1 for load information.
(2) See Figure A2-40 for locations indicated in this table.

Table A2-11
Membrane Plus Bending Stresses in Various Components of the Cask
End Drop (30-Foot)(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	12280	-241.3	12280	0	12280	12280	-241.3	12520
	B	-13300	323.9	-13300	0	323.9	-13300	-13300	13630
Outer Shell	C	-353.4	-9029	-843.9	88.62	-352.5	-843.9	-9030	8677
	D	-2148	8769	4512	88.62	88.7	4512	-2149	10920
Inner Shell	E	-3535	-10430	646.2	-651	646.2	-3474	-10490	11130
	F	-2452	9871	6870	-651	9906	6870	-2486	12390
Bolting Ring	G	627.5	-3739	4497	-197.1	4497	636.4	-3748	8245
	H	-1846	-7772	1940	-197.1	1940	-1840	-7779	9709
Primary Lid	I	-691.7	-679.5	-17290	-2896	2210	-3581	-17290	19510
	J	209.5	403.7	17450	-2413	17450	2722	-2109	19560
Secondary Lid	K	-23400	-116.5	-23400	0	-116.5	-23400	-23400	23280
	L	22090	-778.3	22090	0	22090	22090	-778.3	22870

Notes:
(1) See Table 2-1 for load information.
(2) See Figure A2-40 for locations indicated in this table.

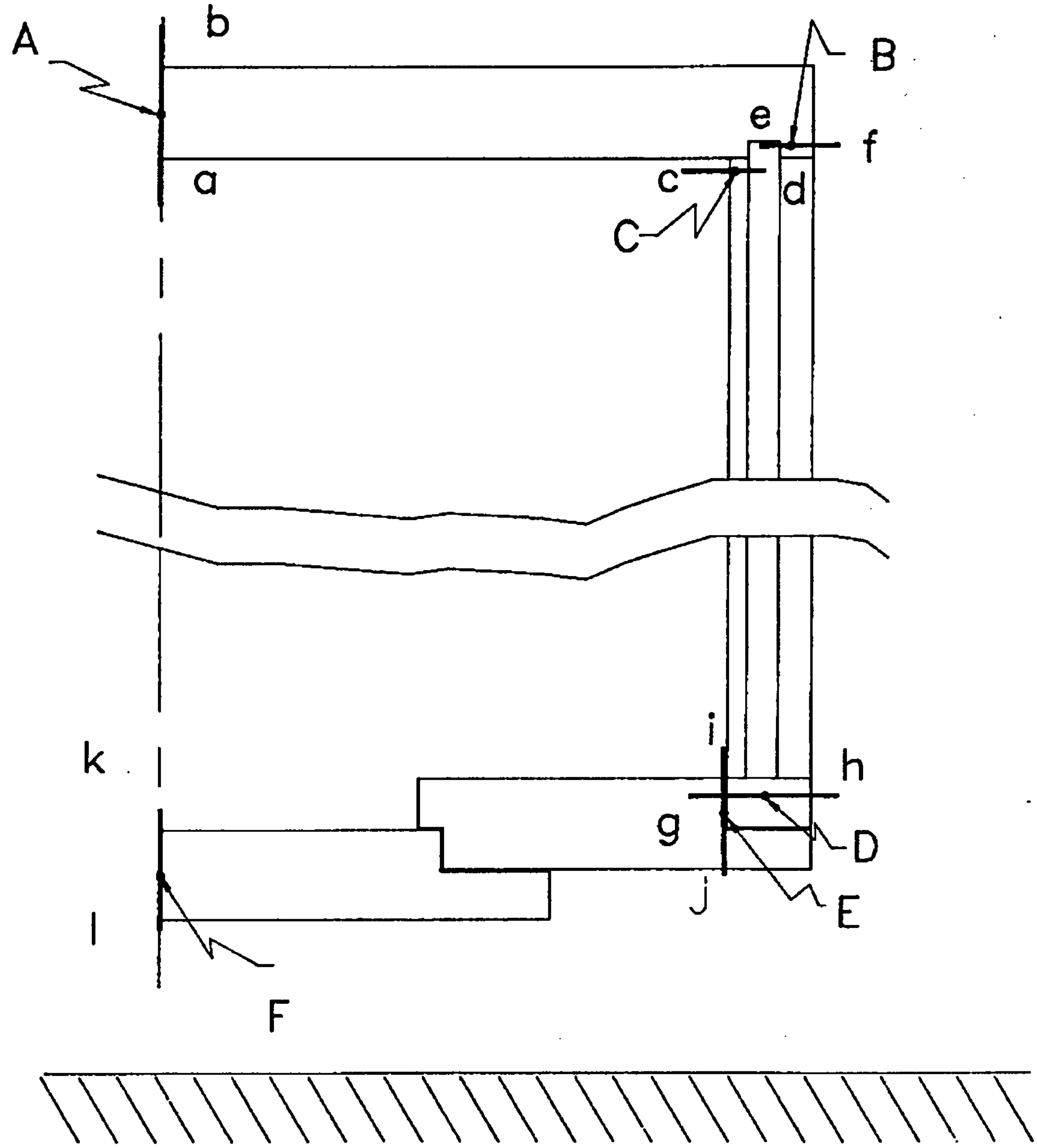


Figure A2-40
Location of Stresses Indicated
in Tables A2-10 and A2-11

Table A2-12
Maximum Stress Intensities in the Cask
Due to 30-Ft End Drop

Cask Component	Stress Category	S.I. Value (psi)	Element No.	Substr. No.
Base Plate	PL	553	151-155-159	7
	PL+PB	13,630	151-155-159	7
Outer Shell	PL	4,071	96-97	4
	PL+PB	10,920	96-97	4
Inner Shell	PL	6,897	95	4
	PL+PB	12,390	95	4
Bolting Ring	PL	9,028	81-85	4
	PL+PB	9,709	81-85	4
Primary Lid	PL	5,310	106-107	3
	PL+PB	19,560	106-107	3
Secondary Lid	PL	207	14	1
	PL+PB	23,280	14	1

Table A2-13
Stress Intensity Combinations
Due to 30-Ft End Drop

Cask Component	Stress Category	S.I. Value Due to					
		①	②	③	④	⑤	⑥
Basic Plate	PL	553.1	90.06	98.79	643.16	651.89	651.89
	PL+PB	13,630	570.5	927.3	14,200.5	14,557.3	14,557.3
Outer Shell	PL	4,071	261.6	2,884	4,332.6	6,955	6,955
	PL+PB	10,920	585.2	6,051	11,505.2	16,971	16,971
Inner Shell	PL	6,897	368	4,299	7,265	11,196	11,196
	PL+PB	12,390	705.2	5,602	13,095.2	17,992	17,992
Bolting Ring	PL	9,028	560.4	1,260	9,588.4	10,288	10,288
	PL+PB	9,709	805.9	1,378	10,514.9	11,087	11,087
Primary Lid	PL	5,310	288.3	364.5	5,598.3	5,674.5	5,674.5
	PL+PB	19,560	749.9	658.3	20,309.9	20,218.3	20,309.9
Secondary Lid	PL	207.3	17.46	7.131	224.76	214.43	224.76
	PL+PB	23,280	565.8	485.8	23,845.8	23,765.8	23,845.8

① 30' end drop loading
② increased external pressure loading
③ minimum external pressure loading
④ loading ① + loading ②
⑤ loading ① + loading ③
⑥ larger of loading ④ and ⑤

Table A2-14
Membrane Stresses in Various Components of the Cask
30-Ft Side Drop[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	-12690	-1795	988	1194	994	-1666	-12830	13820
Outer Shell	B	5945	5448	13230	12870	22960	9313	-7648	30610
Inner Shell	C	6957	29813	22258	12871	37724	22338	1036	38756
Bolting Ring	D	-35510	-9152	9440	-1414	9653	-8567	-36310	45960
Primary Lid	E	-14650	-2223	-9630	-1685	-1997	-8987	-14960	12960
Secondary Lid	F	-10249	-2008	2308	1207	2308	-2008	-10249	13784

Notes:
(1) See Table 2-1 for load combinations.
(2) See Figure A2-41 for locations indicated in this table.

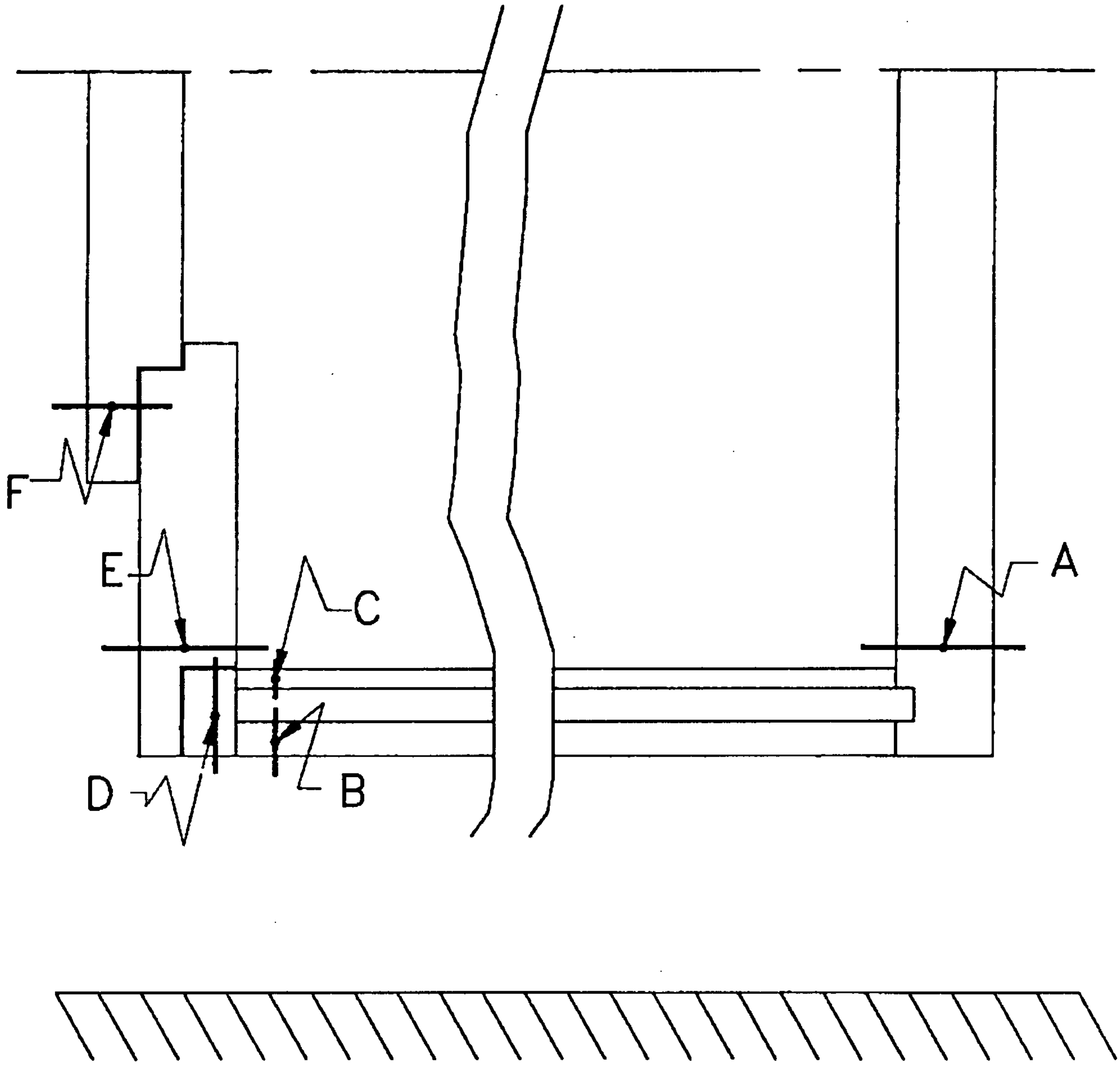


Figure A2-41
Locations of Stresses Indicated in Table A2-14

Table A2-15
Membrane Plus Bending Stresses in Various Components of the Cask
30-Ft Side Drop(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	S4 psi
Base Plate	a	-31120	140	-3428	3352	495	-3425	-31480	31970
	b	5735	-3730	5403	-964	5988	5249	-3825	9816
Outer Shell	c	-5140	-11810	12840	5444	14360	-893	-17570	31930
	d	-8418	22230	13430	5444	24100	14710	-11560	35660
Inner Shell	e	4905	-12427	21476	3466	22649	7332	-16071	38720
	f	-4301	44756	29324	3466	47147	28471	-5838	52987
Bolting Ring	g	-36120	-8845	13250	-1414	13430	-8254	-36890	50032
	h	-14150	-9458	5786	-1414	6141	-7015	-16950	23090
Primary Lid	i	-37820	-4849	-20150	-5871	-3833	-20150	-38830	35000
	j	8510	404	2022	2501	9381	1882	-328	9710

Notes:
(1) See Table 2-1 for load combinations.
(2) See Figure A2-42 for locations indicated in this table.

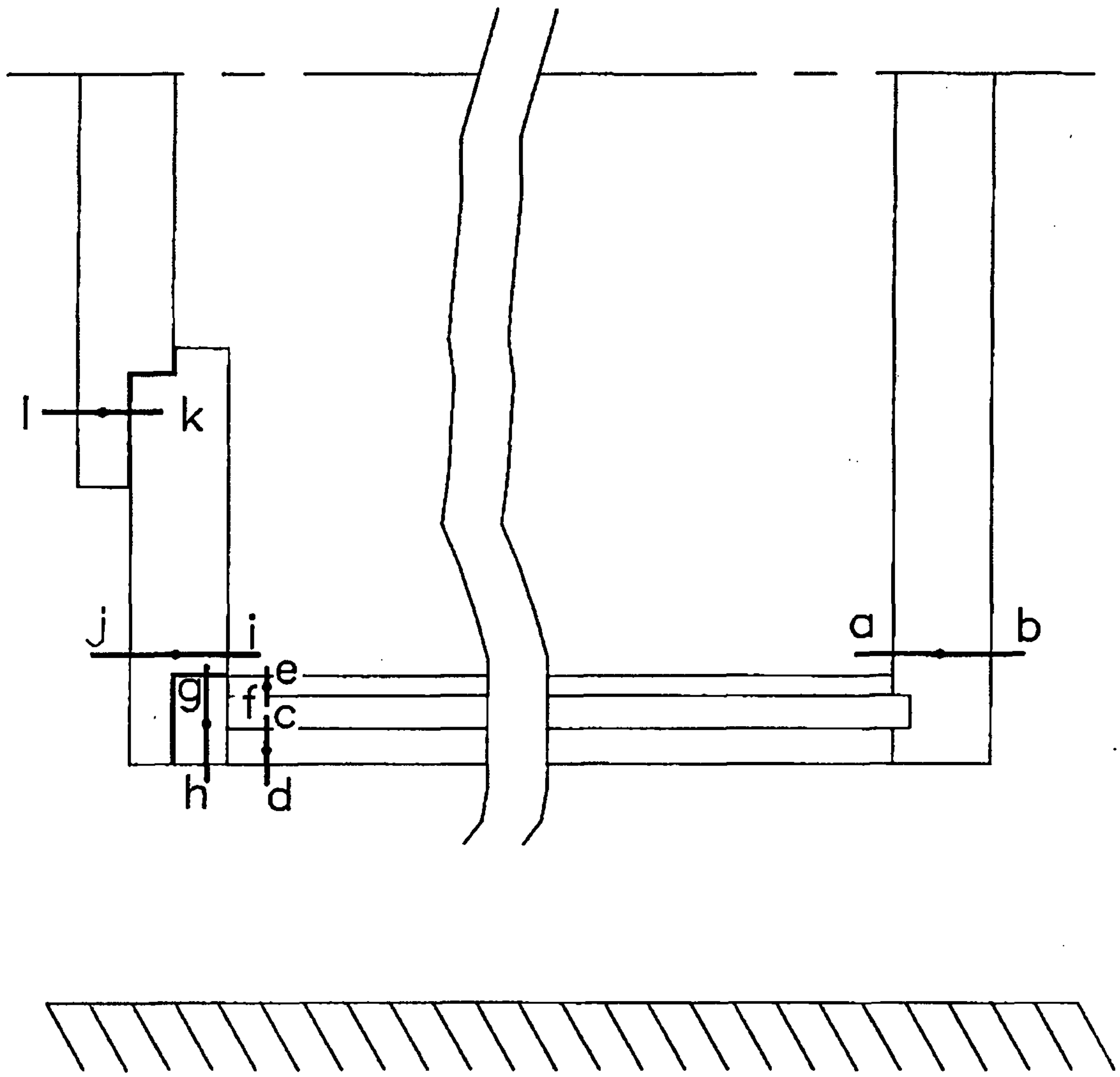


Figure A2-42
30-ft Side Drop
Locations of Stresses Indicated in Table A2-15

Table A2-16
Maximum Stress Intensities in the Cask
Due To 30-ft Side Drop

Cask Component	Stress Category	S.I. value (psi)	Element No.	Substr. No.
Base Plate	PL	13,820	71-73	6
	PL+PB	31,970	71-73	6
Outer Shell	PL	30,610	11-12	4
	PL+PB	35,660	11-12	4
Inner Shell	PL	38,756	15	4
	PL+PB	52,987	15	4
Bolting Ring	PL	45,960	6-10	4
	PL+PB	50,032	6-10	4
Primary Lid	PL	12,960	11-15	3
	PL+PB	35,000	11-15	3
Secondary Lid	PL	13,784	13	1
	PL+PB	36,830	13	1

Table A2-17
Stress Intensity Combinations
Due to 30-ft Side Drop

Cask Component	Stress Category	S.I. Value Due to					
		①	②	③	④	⑤	⑥
Basic Plate	PL	13,820	90.06	98.79	13,910.06	13,918.79	13,918.79
	PL+PB	31,970	570.5	927.3	32,540.5	32,897.3	32,897.3
Outer Shell	PL	30,610	261.6	2,884	30,871.6	33,494	33,494
	PL+PB	35,660	585.2	6,051	36,245.2	41,711	41,711
Inner Shell	PL	38,756	368	4,299	39,124	43,055	43,055
	PL+PB	52,987	705.2	5,602	53,692.2	58,589	58,589
Bolting Ring	PL	45,960	560.4	1,260	46,520.4	47,220	47,220
	PL+PB	50,032	805.9	1,378	50,837.9	51,410	51,410
Primary Lid	PL	12,960	288.3	364.5	13,248.3	13,324.5	13,324.5
	PL+PB	35,000	749.9	658.3	35,749.9	35,658.3	35,749.9
Secondary Lid	PL	13,784	17.46	7.131	13,801.46	13,791.13	13,801.46
	PL+PB	36,830	565.8	485.8	37,395.80	37,315.80	37,395.80

① 30' side drop loading
② increased external pressure loading
③ minimum external pressure loading
④ loading ① + loading ②
⑤ loading ① + loading ③
⑥ larger of loading ④ and ⑤

Table A2-18
Membrane Stresses in Various Components of the Cask
30-Ft Corner Drop[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	-11180	-6152	-2912	-2002	-2286	-5146	-12810	10520
Outer Shell	B	-1849	-116501	-8301	583	-1777	-8352	-11670	9895
Inner Shell	C	-1239	-22600	-7652	149	-1206	-5346	-24940	23730
Bolting Ring	D	3075	-18130	-14200	1460	3641	-13700	-19200	22840
Primary Lid	E	-8698	-1832	-1894	10310	6187	-1662	-16950	23140
Secondary Lid	F	1713	945	10178	2000	11957	1713	945	11012

Notes: (1) See Table 2-1 for load combinations.
(2) See Figure A2-43 for locations indicated in this table.

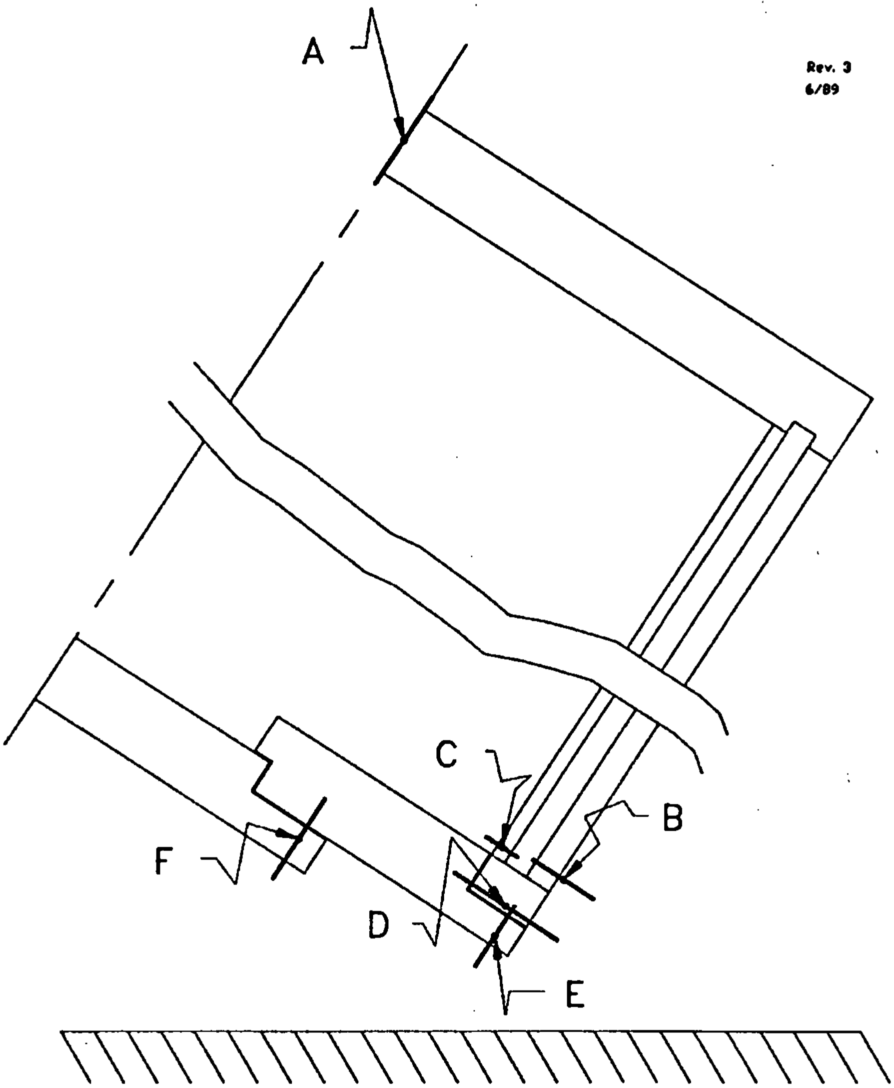


Figure A2-43
30-Ft Corner Drop
Locations of Stresses Indicated in Table A2-18

Table A2-19
Membrane Plus Bending Stresses in Various Components of the Cask
30-ft Corner Drop[1]

Component	Location[2]	Stress Components				Principal Stresses			
		Norm Radial psi	Norm Axial psi	Norm Hoop psi	In-Plane psi	S1 psi	S2 psi	S3 psi	S.I. psi
Base Plate	a	3363	-2658	7850	-849	8030	4308	-3783	11810
	b	-25720	-9647	-13670	-3156	-8940	-13150	-26940	18000
Outer Shell	c	-2254	-13600	-8206	583	-2184	-8261	-13610	11430
	d	-1461	-9711	-8394	583	-1363	-8439	-9735	8372
Inner Shell	e	-1137	-20930	-7044	149	-1101	-4609	-23400	2230
	f	-1164	-24270	-8255	149	-1134	-6068	-26490	25350
Bolting Ring	g	5703	-24600	-13930	1460	6197	-13970	-25060	31250
	h	3201	-11660	-14460	1460	3781	-10690	-16010	19790
Primary Lid	i	-21070	3027	2926	8095	7889	1456	-24460	32350
	j	7979	-1148	-6227	3492	9297	-1067	-7625	16920

Notes:
(1) See Table 2-1 for load combinations.
(2) See Figure A2-44 for locations indicated in this table.

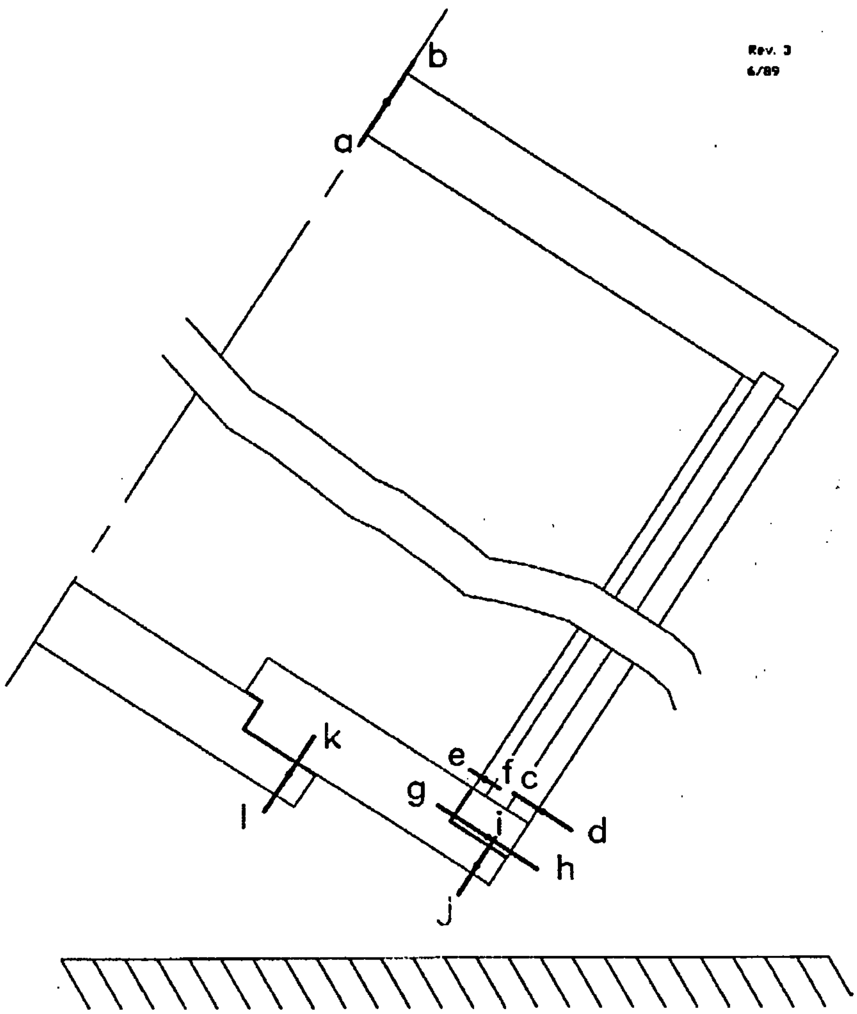


Figure A2-44
30-Ft Corner Drop
Locations of Stresses Indicated in Table A2-19

Table A2-20
Maximum Stress Intensities in the Cask
Due to 30-ft Corner Drop

Cask Component	Stress Category	S.I. Value (psi)	Element No.	Substr. No.
Base Plate	PL	10,520	151-155-159	7
	PL+PB	18,000	151-155-159	7
Outer Shell	PL	9,895	11-12	4
	PL+PB	11,430	11-12	4
Inner Shell	PL	23,730	95	4
	PL+PB	23,350	95	4
Bolting Ring	PL	22,840	81-85	4
	PL+PB	31,250	81-85	4
Primary Lid	PL	23,140	138-139	3
	PL+PB	32,350	138-139	3
Secondary Lid	PL	11,012	21	1
	PL+PB	19,670	21	1

Table A2-21
Stress Intensity Combinations
Due to 30-ft Corner Drop

Cask Component	Stress Category	S.I. Value Due to					
		①	②	③	④	⑤	⑥
Basic Plate	PL	10,520	90.06	98.79	10,610.06	10,618.79	10,618.79
	PL+PB	18,000	570.5	927.3	18,570.5	18,927.3	18,927.3
Outer Shell	PL	9,895	261.6	2,884	10,156.6	12,779	12,779
	PL+PB	11,430	585.2	6,051	12,015.2	17,481	17,481
Inner Shell	PL	23,730	368	4,299	24,098	28,029	28,029
	PL+PB	25,350	705.2	5,602	26,055.2	30,952	30,952
Bolting Ring	PL	22,840	560.4	1,260	23,400.4	24,100	24,100
	PL+PB	31,250	805.9	1,378	32,055.9	32,628	32,628
Primary Lid	PL	23,140	288.3	364.5	23,428.3	23,504.5	23,504.5
	PL+PB	32,350	749.9	658.3	33,099.9	33,008.3	33,099.9
Secondary Lid	PL	11,012	17.46	7.131	11,029.46	11,019.13	11,029.46
	PL+PB	19,670	565.8	485.8	20,235.8	20,155.8	20,235.8

① 30' corner drop loading
② increased external pressure loading
③ minimum external pressure loading
④ loading ① + loading ②
⑤ loading ① + loading ③
⑥ larger of loading ④ and ⑤

Table A2-22
Maximum Stress Intensities in the Cask
Due To 1-ft End Drop[1]

Cask Component	Stress Category	S.I. Value (psi)	Element No.	Substr. No.
Base Plate	PL	171.03	151-155-159	7
	PL+PB	4,214.74	151-155-159	7
Outer Shell	PL	1,258.86	96-97	4
	PL+PB	3,376.74	96-97	4
Inner Shell	PL	2,132.72	95	4
	PL+PB	3,831.30	95	4
Bolting Ring	PL	2,791.69	81-85	4
	PL+PB	3,002.27	81-85	4
Primary Lid	PL	1,641.99	106-107	3
	PL+PB	6,048.45	106-107	3
Secondary Lid	PL	64.102	14	1
	PL+PB	7,198.77	14	1

Note(s) (1) S.I. values for the 1-FT drop conditions have been calculated by ratioing the corresponding 30-FT drop S.I. values by acceleration ratio.

Table A2-23
Stresses Intensity Combinations
Due to 1-ft End Drop

Cask Component	Stress Category	S.I. Value Due to					
		①	②	③	④	⑤	⑥
Basic Plate	PL	171.03	90.06	98.79	261.09	269.82	269.82
	PL+PB	4,214.74	570.5	927.3	4,785.24	5,142.04	5,142.04
Outer Shell	PL	1,258.86	261.6	2,884	1,520.46	4,142.86	4,142.86
	PL+PB	3,376.74	585.2	6,051	3,961.94	9,427.74	9,427.74
Inner Shell	PL	2,132.72	368	4,299	2,500.72	6,431.72	6,431.72
	PL+PB	3,831.30	705.2	5,602	4,536.5	9,433.3	9,433.3
Bolting Ring	PL	2,791.69	560.4	1,260	3,352.09	4,051.69	4,051.69
	PL+PB	3,002.27	805.9	1,378	3,808.17	4,380.27	4,380.27
Primary Lid	PL	1,641.99	288.3	364.5	1,930.29	2,006.49	2,006.49
	PL+PB	6,048.45	749.9	658.3	6,798.35	6,706.75	6,798.35
Secondary Lid	PL	64.102	17.46	7.131	81.56	71.233	81.56
	PL+PB	7,198.77	565.8	485.8	7,764.57	7,684.57	7,764.57

① 1' end drop loading
② increased external pressure loading
③ minimum external pressure loading
④ loading ① + loading ②
⑤ loading ① + loading ③
⑥ larger of loading ④ and ⑤

Table A2-24
Maximum Stress Intensities in the Cask
Due to 1-ft Side Drop[1]

Cask Component	Stress Category	S.I. Value (psi)	Element No.	Substr. No.
Base Plate	PL	3,323.21	71-73	6
	PL+PB	7,687.64	71-73	6
Outer Shell	PL	7,360.61	11-12	4
	PL+PB	8,574.95	11-12	4
Inner Shell	PL	9,319.43	15	4
	PL+PB	12,741.48	15	4
Bolting Ring	PL	11,051.74	6-10	4
	PL+PB	12,030.91	6-10	4
Primary Lid	PL	3,116.42	11-15	3
	PL+PB	8,416.25	11-15	3
Secondary Lid	PL	3,314.56	13	1
	PL+PB	8,856.3	13	1

Note(s) (1) S.I. values for the 1-FT drop conditions have been calculated by ratioing the corresponding 30-FT drop S.I. values by acceleration ratio.

Table A2-25
Stress Intensity Combinations
Due to 1-ft Side Drop

Cask Component	Stress Category	S.I. Value Due to					
		①	②	③	④	⑤	⑥
Basic Plate	PL	3,323.21	90.06	98.79	3,413.27	3,422	3,422
	PL+PB	7,687.64	570.5	927.3	8,258.14	8,614.94	8,614.94
Outer Shell	PL	7,360.61	261.6	2,884	7,622.21	10,244.61	10,244.61
	PL+PB	8,574.95	585.2	6,051	9,160.15	14,625.95	14,625.95
Inner Shell	PL	9,319.43	368	4,299	9,687.43	13,618.43	13,618.43
	PL+PB	12,741.48	705.2	5,602	13,446.68	18,343.48	18,343.48
Bolting Ring	PL	11,051.74	560.4	1,260	11,612.14	12,311.74	12,311.74
	PL+PB	12,030.91	805.9	1,378	12,836.81	13,408.91	13,408.91
Primary Lid	PL	3,116.42	288.3	364.5	3,404.72	3,480.92	3,480.92
	PL+PB	8,416.25	749.9	658.3	9,166.15	9,074.55	9,166.15
Secondary Lid	PL	3,314.56	17.46	7.131	3,332.02	3,321.69	3,332.02
	PL+PB	8,856.3	565.8	485.8	9,422.1	9,342.1	9,422.1

① 1' side drop loading
② increased external pressure loading
③ minimum external pressure loading
④ loading ① + loading ②
⑤ loading ① + loading ③
⑥ larger of loading ④ and ⑤

Table A2-26
Maximum Stress Intensities in the Cask
Due to 1-ft Corner Drop[1]

Cask Component	Stress Category	S.I. Value (psi)	Element No.	Substr. No.
Base Plate	PL	1,390.24	151-155-159	7
	PL+PB	2,378.74	151-155-159	7
Outer Shell	PL	1,307.65	11-12	4
	PL+PB	1,510.5	11-12	4
Inner Shell	PL	3,135.98	95	4
	PL+PB	3,350.06	95	4
Bolting Ring	PL	3,018.36	81-85	4
	PL+PB	4,129.76	81-85	4
Primary Lid	PL	3,058	138-139	3
	PL+PB	4,275.13	138-139	3
Secondary Lid	PL	1,455.26	21	1
	PL+PB	2,599.4	21	1

Note(s) (1) S.I. values for the 1-FT drop conditions have been calculated by ratioing the corresponding 30-FT drop S.I. values by acceleration ratio.

Table A2-27
Stress Intensity Combinations
Due to 1-ft Corner Drop

Cask Component	Stress Category	S.I. Value Due to					
		①	②	③	④	⑤	⑥
Basic Plate	PL	1,390.24	90.06	98.79	1,480.3	1,489.03	1,489.03
	PL+PB	2,378.74	570.5	927.3	2,949.24	3,306.04	3,306.04
Outer Shell	PL	1,307.65	261.6	2,884	1,569.25	4,191.65	4,191.65
	PL+PB	1,510.5	585.2	6,051	2,095.7	7,561.5	7,561.5
Inner Shell	PL	3,135.98	368	4,299	3,503.98	7,434.98	7,434.98
	PL+PB	3,350.06	705.2	5,602	4,055.26	8,952.06	8,952.06
Bolting Ring	PL	3,018.36	560.4	1,260	3,578.76	4,278.36	4,278.36
	PL+PB	4,129.76	805.9	1,378	4,935.66	5,507.76	5,507.76
Primary Lid	PL	3,058	288.3	364.5	3,346.3	3,422.5	3,422.5
	PL+PB	4,275.13	749.9	658.3	5,025.03	4,933.43	5,025.03
Secondary Lid	PL	1,455.26	17.46	7.131	1,472.72	1,462.39	1,472.72
	PL+PB	2,599.40	565.8	485.8	3,165.20	3,085.20	3,165.20

① 1' corner drop loading
② increased external pressure loading
③ minimum external pressure loading
④ loading ① + loading ②
⑤ loading ① + loading ③
⑥ larger of loading ④ and ⑤

Figure A2-28
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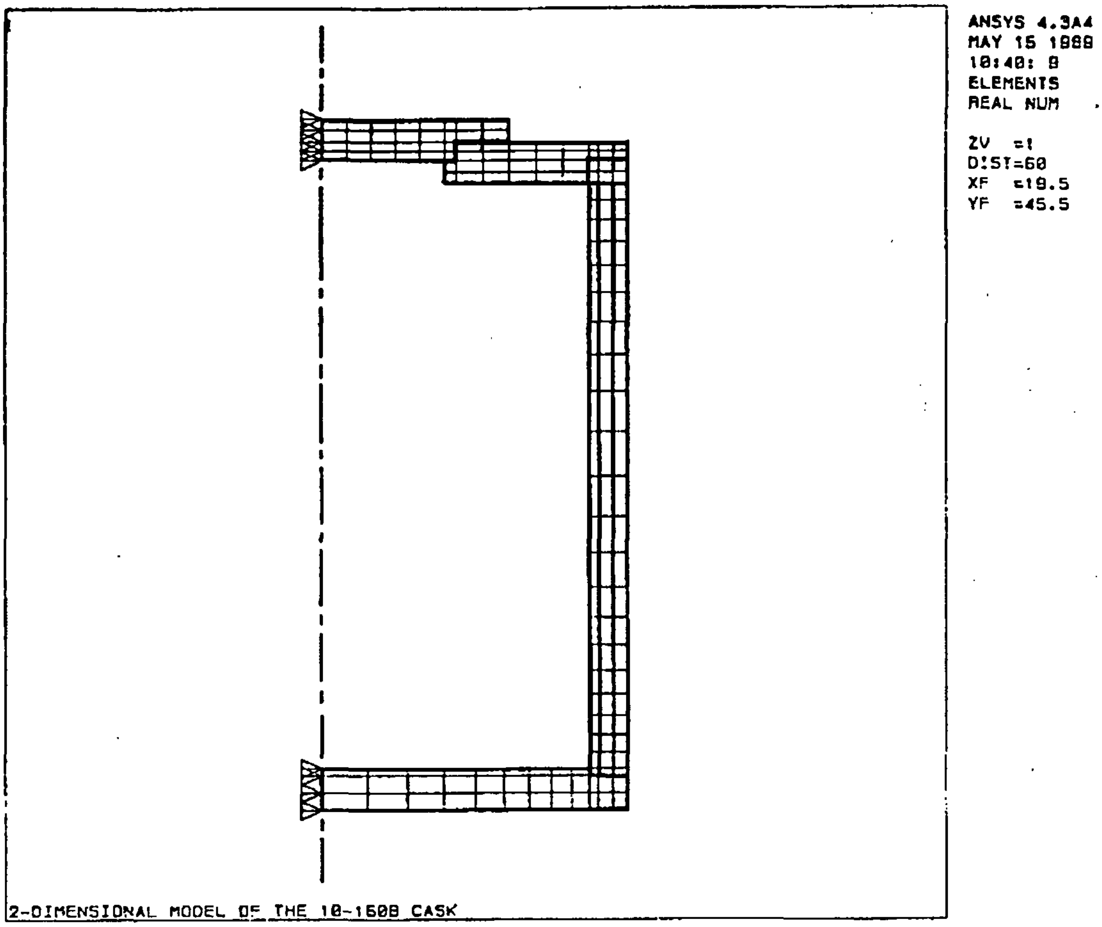

Figure A2-44.1
Two-Dimensional Finite Element Model Used in the Analysis of 10-160B Cask Under Axisymmetric Loading

Temperature dependent material properties of the steel and the lead, as listed in Table 2-3, were used in the model. The loading to the model was applied as the element pressures and element temperatures corresponding to each loading case. The results of the analyses are presented in tabular form and the locations of the maximum mean and mean-plus-bending stress intensities are identified in Figures. The load cases analyzed using this model with the corresponding loading and the result tables and figures are listed in the following paragraphs:

(1) Hot Environment:

Ambient Temperature	=	100°F
Internal Pressure	=	8.4 psi
External Pressure	=	0 psi
Result Table	=	A2-31 and A2-32
Corresponding Figure	=	A2-45

(2) Cold Environment

Ambient Temperature	=	-40°F
Internal Pressure	=	11.2 psi
External Pressure	=	0 psi
Result Table	=	A2-29 and A2-30
Corresponding Figure	=	A2-45

(3) Increased External Pressure

Ambient Temperature	=	-20°F
Internal Pressure	=	0 psi
External Pressure	=	20 psi
Result Table	=	A2-33 and A2-34
Corresponding Figure	=	A2-45

(4) Minimum External Pressure

Ambient Temperature	=	100°F
Internal Pressure	=	23.1 psi
External Pressure	=	3.5 psi
Result Table	=	A2-35 and A2-36
Corresponding Figure	=	A2-45

(5) Fire Accident

Ambient Temperature	=	1475°F
Internal Pressure	=	31.2 psi
External Pressure	=	0 psi

Temperature in various components of the cask per Table 3.1 and shown in

Figure A2-47

Result Table	=	A2-41 and A2-42
Corresponding Figure	=	A2-48

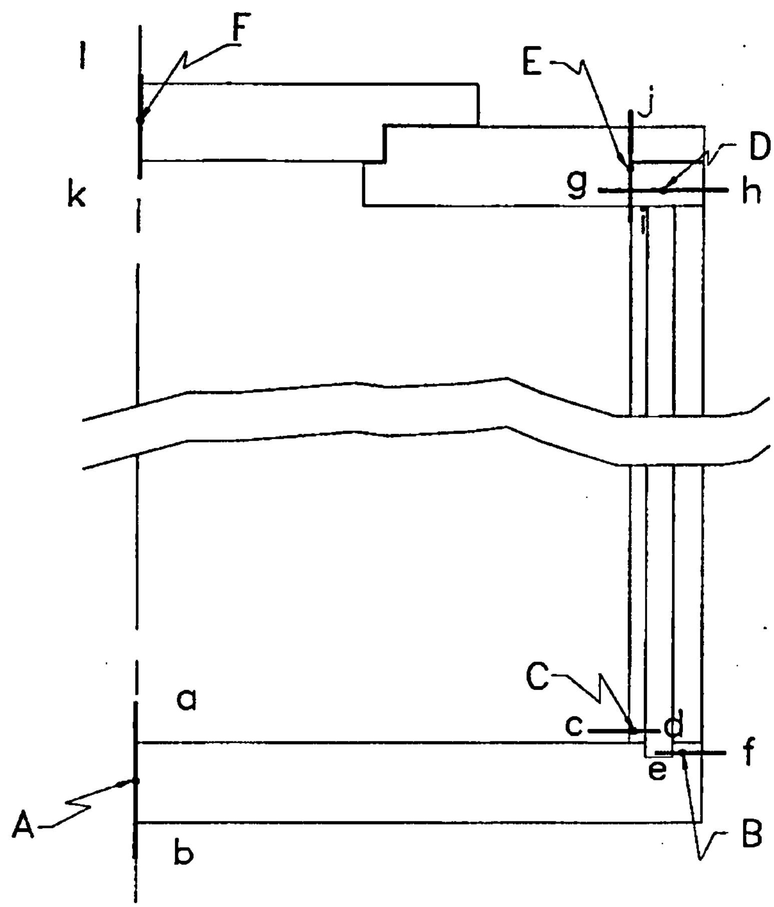

Figure A2-45
Locations of Stresses Indicated
in Tables A2-29 Through A2-36

Table A2-29
Membrane Stresses in Various Components of the Cask
Cold Environment [1]

Component	Location[2]	Stress Components (psi)				Principal Stresses (psi)			
		Normal Radial	Normal Axial	Normal Hoop	In-Plane	S_1	S_2	S_3	S_4
Base Plate	A	-26.86	-7.162	-26.86	0	-7.162	-26.86	-26.86	19.7
Outer Shell	B	211.8	-43.17	-109.7	7.674	212	-43.41	-109.7	321.7
Inner Shell	C	-264.1	99.56	-394	-59.35	109	-273.5	-394	503
Bolting Ring	D	-49.28	17.93	-131.3	0.187	17.93	-49.28	-131.3	149.2
Primary Lid	E	33.43	-77.01	180.7	-39.19	180.7	45.93	-89.5	270.2

Notes: (1) See Table 2-1 for load combinations.
(2) See Figure A2-45 for locations indicated in this table.

Table A2-30
Membrane Plus Bending Stresses in Various Components of the Cask
Cold Environment(1)

Component	Location(2)	Stress Components (psi)				Principal Stresses (psi)			
		Normal Radial	Normal Axial	Norml Hoop	In-Plane	S_1	S_2	S_3	S_4
Base Plate	a	-706.2	-1.773	-706.2	0	1.773	-706.2	-706.2	708
	b	-652.5	-16.1	652.5	0	652.5	652.5	-16.1	668.6
Outer Shell	c	50.9	590.8	127.3	7.674	590.9	127.3	50.79	540.1
	d	184.2	-666.1	-346.7	7.674	184.3	-346.7	-666.2	850.5
Inner Shell	e	-307.1	-452	-579	-59.35	-285.9	-473.2	-579	293.1
	f	-221	645.2	-208.9	-59.35	649.2	-208.9	-225.1	874.3
Bolting Ring	g	-35.87	25.79	-133.6	0.187	25.79	-35.87	-133.6	159.4
	h	-12.02	10.42	-129	0.187	10.42	-12.02	-129	139.4
Primary Lid	i	-229.5	-119.2	-83.74	-72.18	-83.54	-83.74	-262.2	181.7
	j	296.4	-34.79	445.2	-6.201	445.2	296.5	-34.9	480.1
Secondary Lid	k	-433	0.659	-433	0	0.659	-433	-433	433.7
	l	408.7	13.33	408.7	0	408.7	408.7	-13.33	422.1

Notes:
(1) See Table 2-1 for load combinations.
(2) See Figure A2-44 for locations indicated in this table.

Table A2-31
Membrane Stresses in Various Components of the Cask
Hot Environment[1]

Component	Location[2]	Stress Components (psi) [3]				Principal Stresses (psi) [3]			S.I.[3] (psi)	S.I.[4] (psi)
		Normal Radial	Normal Axial	Norm Hoop	In-Plane	S_1	S_2	S_3		
Base Plate	A	73.65	-4	73.65	0	73.65	73.65	-4	77.67	99
Outer Shell	B	2541	180.5	995.7	766.7	2768	995.7	-46.67	2815	2,927
Inner Shell	C	-2443	1471	-684.8	-968.8	1698	-684.8	-2670	4368	4,500
Bolting Ring	D	187.4	-20.29	1144	-47.54	1144	197.7	-30.65	1175	1,224
Primary Lid	E	79.31	-197.9	98.58	-47.05	98.58	87.08	-205.7	304.2	341
Secondary Lid	F	-6.145	-1.624	-6.145	0	-1.624	-6.145	-6.145	4.521	8

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 2.4 psi internal pressure in the cask.
(4) Conservatively the stress intensities corresponding to 8.4 psi cask internal pressure have been added to the stress intensities of the previous column. The stress intensities for 8.4 psi internal pressure are obtained by multiplying the stress intensities of Table A2-37 by a factor of 8.4/10 = 0.84.

Table A2-32
Membrane Stresses in Various Components of the Cask
Hot Environment [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	-444.2	3.197	-444.2	0	3.197	-444.2	-444.2	447.4	732
	b	591.5	-11.24	591.5	0	591.5	591.5	-11.24	602.8	930
Outer Shell	c	-3151	2564	1178	766.7	2665	1778	-3252	5917	6,136
	d	1910	-2162	213.1	766.7	2050	213.1	-2302	4351	4,689
Inner Shell	E	-2456	-250.5	-1185	-968.9	114.7	-1185	-2822	2936	3,178
	F	-2430	3174	-185	-968.9	3337	-185	-2593	5930	6,227
Bolting Ring	G	-23.96	-298.3	1044	-47.54	1044	-15.96	-306.3	1350	1,434
	H	840.7	245.4	1245	-47.54	1245	844.4	241.6	1004	1,078
Primary Lid	i	-511	-281.5	-241.2	-95.13	-241.2	-247.1	-545.3	304.1	665
	j	669.6	-1143.	438.3	1.034	669.6	438.3	-1143.3	783.9	1,149
Secondary Lid	k	-220.8	2.811	-220.8	0	2.811	-220.8	-220.8	223.6	521
	l	208.5	-6.058	208.5	0	208.5	208.5	-6.058	214.6	504

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 2.4 psi internal pressure in the cask.
(4) Conservatively the stress intensities corresponding to 8.4 psi cask internal pressure have been added to the stress intensities of the previous column. The stress intensities for 8.4 psi internal pressure are obtained by multiplying the stress intensities of Table A2-37 by a factor of 8.4/10 = 0.84.

Table A2-33
Membrane Stresses in Various Components of the Cask
Increased External Pressure[1]

Component	Location[2]	Stress Components (psi)				Principal Stresses (psi)			
		Norm Radial	Norm Axial	Norm Hoop	In-Plane	S_1	S_2	S_3	S_4
Base Plate	A	-97.14	-7.081	-97.14	0	-7.081	-97.14	-97.14	90.06
Outer Shell	B	-196.9	64.7	-58.85	-0.0844	64.7	-58.85	-196.9	261.6
Inner Shell	C	-376.7	-20.06	-112.1	-45.42	-14.36	-112.1	-382.4	368
Bolting Ring	D	-129.5	-97.55	-646.1	22.8	-85.68	-141.3	-646.1	560.4
Primary Lid	E	52.95	-204.9	-235.3	3.245	52.99	-205	-235.3	288.3
Secondary Lid	F	8.261	-9.199	8.261	0	8.261	8.261	-9.199	17.46

Notes: (1) See Table 2-1 for load combinations.
(2) See Figure A2-45 for locations indicated in this table.

Table A2-34
Membrane Plus Bending Stresses in Various Components of Cask
Increased External Pressure [1]

Component	Location[2]	Stress Components (psi)				Principal Stresses (psi)			
		Normal Radial	Normal Axial	Norm Hoop	In-Plane	S_1	S_2	S_3	S.I.
Base Plate	a	374.9	-15.44	374.9	0	374.9	374.9	-15.44	390.3
	b	-569.2	1.276	-569.2	0	1.276	-569.2	-569.2	570.5
Outer Shell	c	48.94	-298.5	-137	-0.8444	48.94	-137	-298.5	347.5
	d	-163.5	421.6	19.34	-0.8444	421.6	19.34	-163.5	585.2
Inner Shell	e	-482.2	-1182	-491.5	-45.42	-479.2	-491.5	-1184	705.2
	f	-271.2	1129	267.4	-45.42	1130	267.4	-272.7	1403
Bolting Ring	g	33.04	-447.2	-771.8	22.8	34.12	-448.3	-771.8	805.9
	h	-122.1	236.5	-520.3	22.8	238	-123.6	-520.3	758.3
Primary Lid	i	-436.8	-262.9	-263.8	-10.93	-262.3	-263.8	-437.5	175.3
	j	542.7	-146.9	-206.7	17.42	543.2	-147.3	-206.7	749.9
Secondary Lid	L	548.6	-17.2	548.6	0	548.6	548.6	-17.2	565.8
	M	532.1	-1.202	-532.1	0	-1.202	-532.1	-532.1	530.9

Notes: (1) See Table 2-1 for load combinations.
(2) See Figure A2-44 for locations indicated in this table.

Table A2-35
Membrane Stresses in Various Components of 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

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] (psi)	S.I.[4] (psi)
		Normal Radial	Normal Axial	Normal Hoop	In-Plane Shear	S_1	S_2	S_3		
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

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 (psi)				Principal Stresses (psi)			
		NORMAL RADIAL	NORMAL AXIAL	NORM HOOP	IN-PLANE	S_1	S_2	S_3	S.I.
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

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

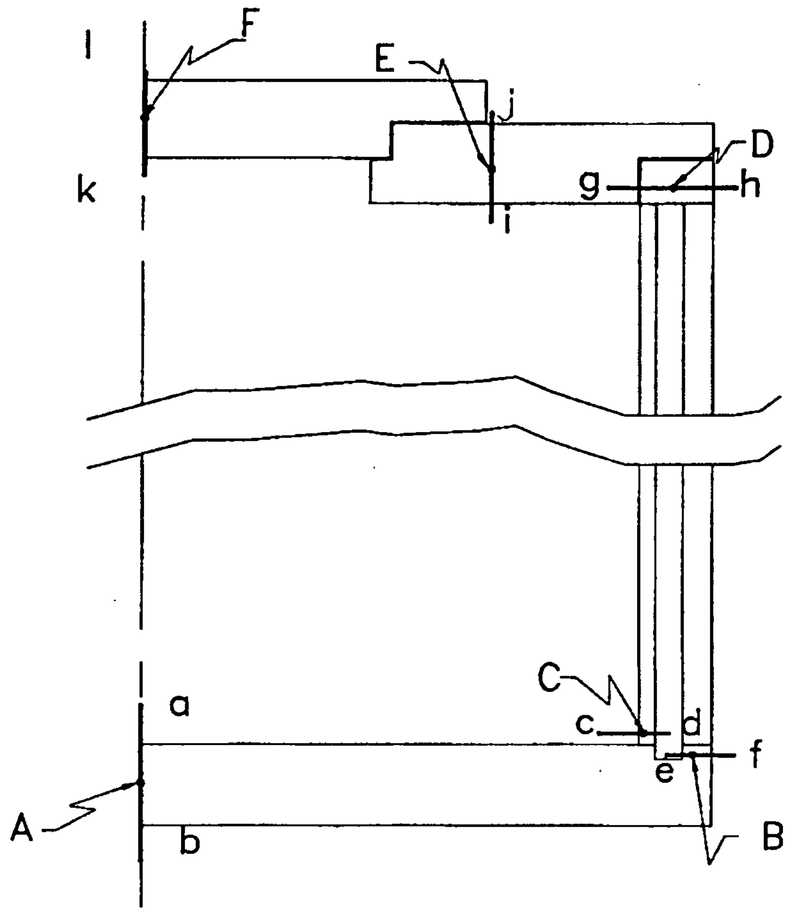

Figure A2-46
Locations of Stresses Indicated
in Tables A2-37 Through A2-40

Table A2-38
Membrane Plus Bending Stresses in Various Components of the Cask
Internal Pressure Of 10 psig(1)

Component	Location(2)	Stress Components (psi)				Principal Stresses (psi)			
		Normal Radial	Normal Axial	Norm Hoop	In-Plane	S_1	S_2	S_3	S.I.
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

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 (psi)				Principal Stresses (psi)			
		Normal Radial	Normal Axial	Norm Hoop	In-Plane	S_1	S_2	S_3	S.I.
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

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 (psi)				Principal Stresses (psi)			
		Normal Radial	Normal Axial	Norm Hoop	In-Plane	S_1	S_2	S_3	S.I.
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

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] (psi)
		Normal Radial	Normal Axial	Normal Hoop	In-Plane Shear	S_1	S_2	S_3	
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

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.

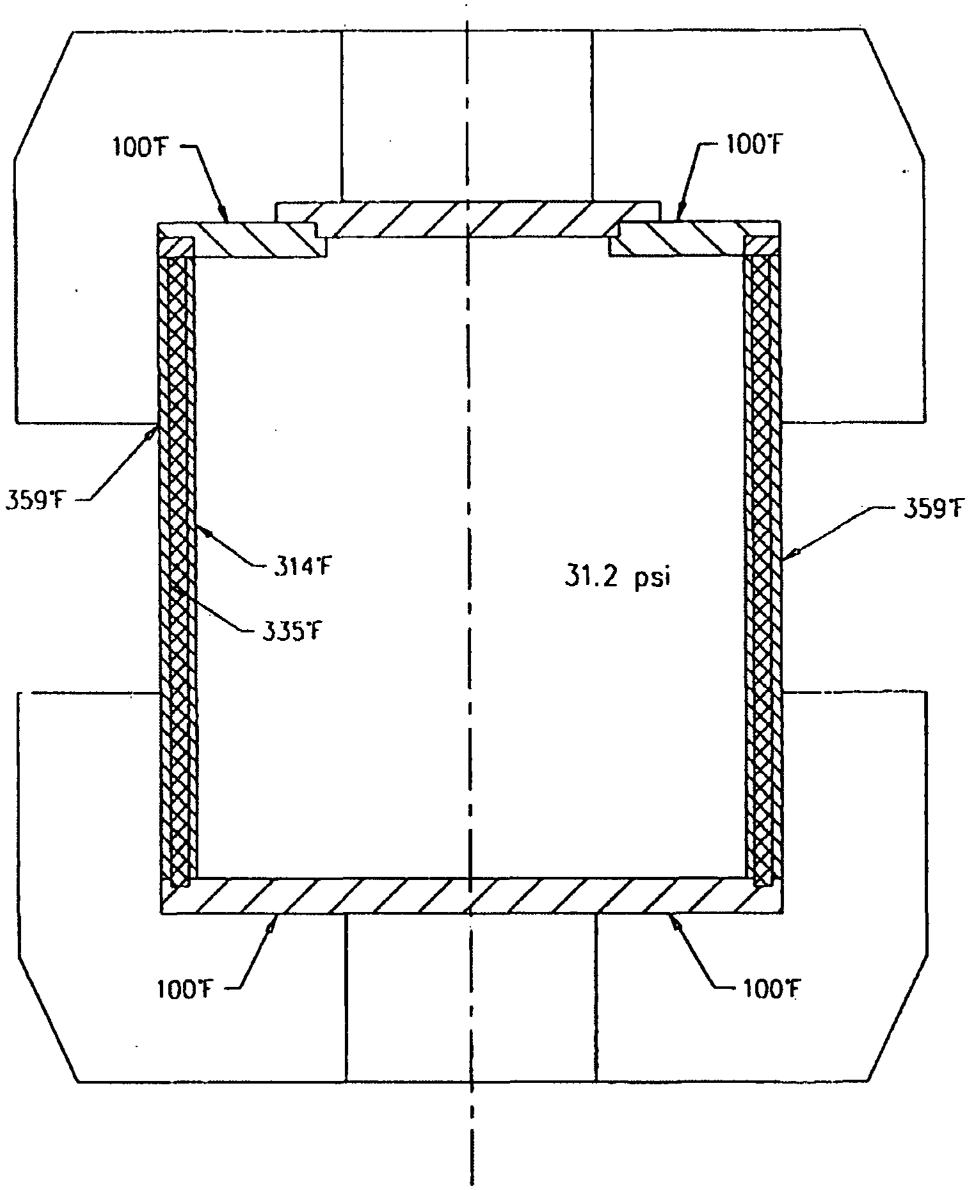

Figure A2-47
Fire Accident Temperature Distribution

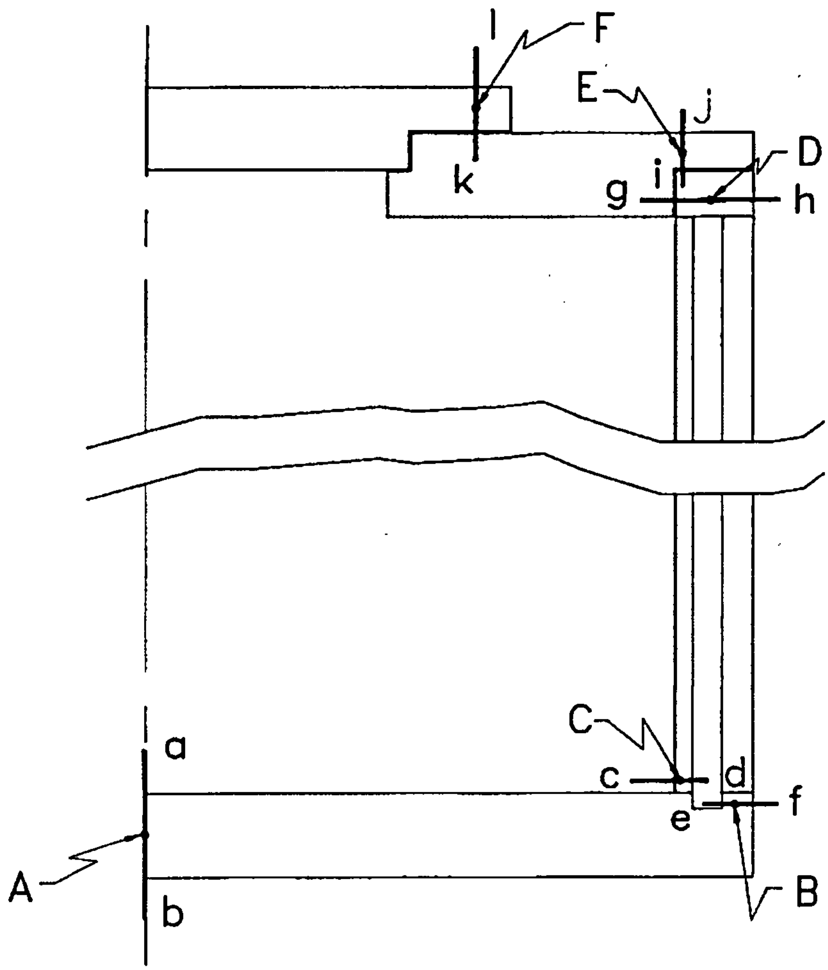

Figure A2-48
Fire Accident Locations of Stresses Indicated
Tables A2-41 and A2-42

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) (psi)
		Normal Radial	Normal Axial	Normal Hoop	In-Plane Shear	S_1	S_2	S_3	
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

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.
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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."
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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.

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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

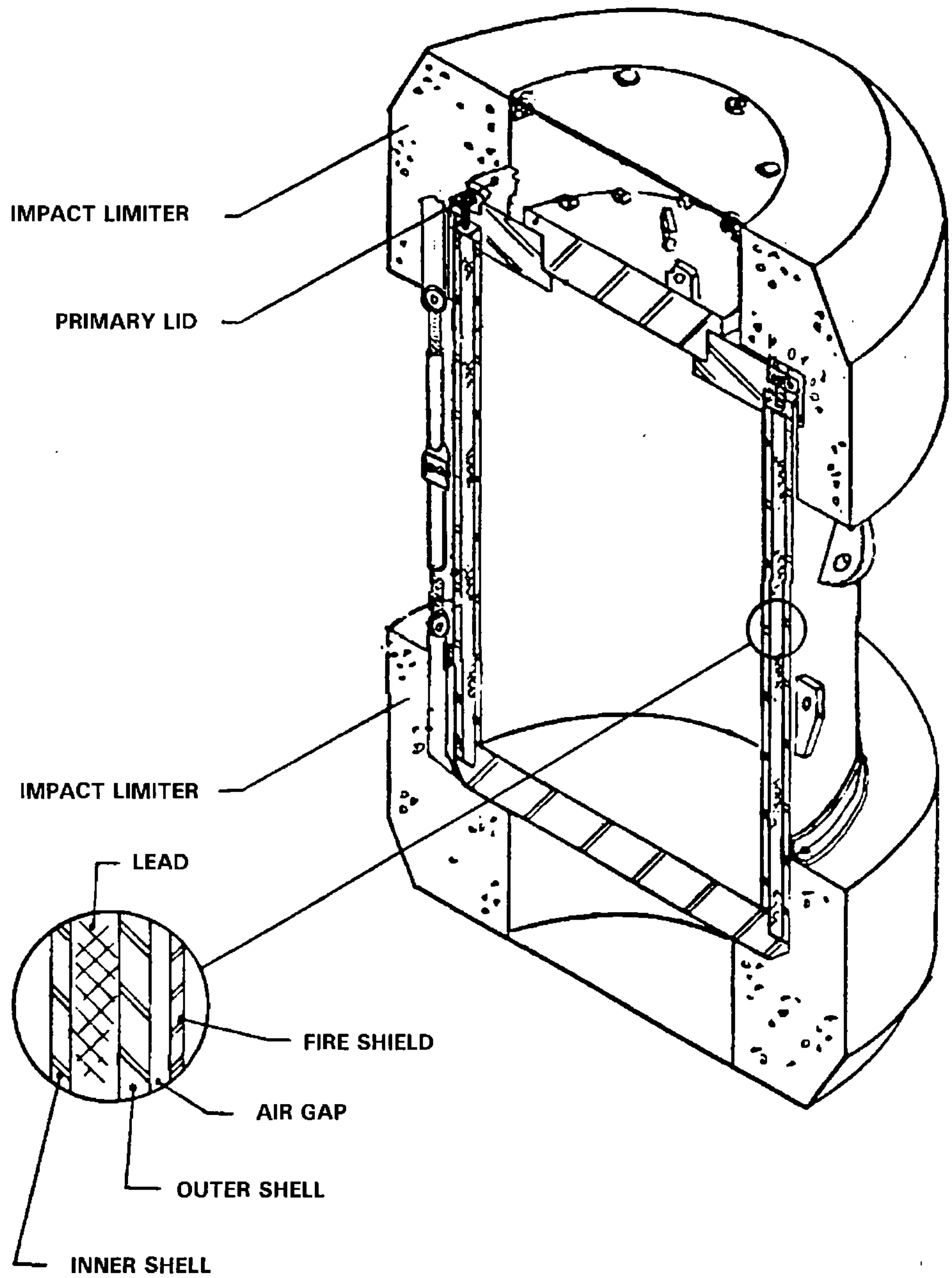

Figure 3.1
Location of Components Analyzed in Thermal Design

(Top thermal shield not shown)

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:
Specific Heat: BTU/lbm-F
Conductivity: BTU/hr-ft-F
Density: lbm/cu ft

References:
Stainless Steel Properties: Reference 1, Page 88
Carbon Steel Properties Reference 1, Page 83
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

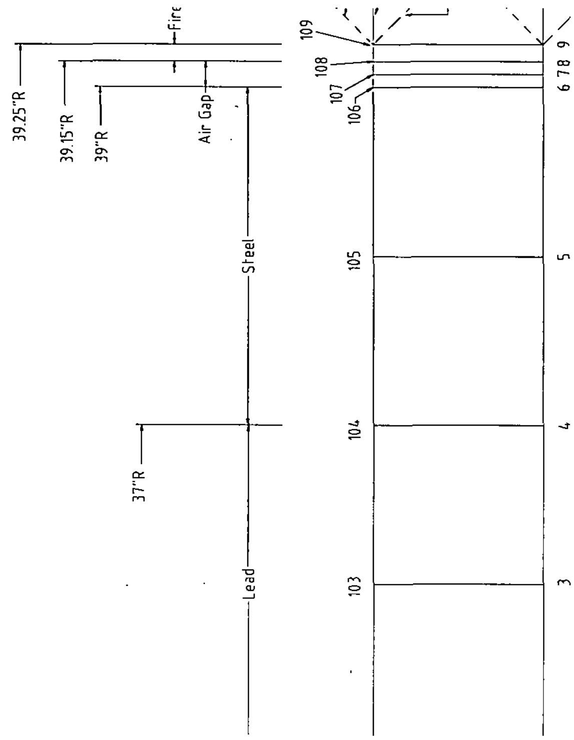

Figure 3.2
Node and Element Locations in the 10-160B Cask
Thermal Finite Element Model

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).

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

(Equation 3)

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).

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

(Equation 4)

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.

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

(Equation 5)

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 <u>Code of Federal Regulations</u> (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)

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

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

$$P_1 = 17.97 PSIA$$

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 Appendices 4.11.2 through 4.11.7.

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:

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

$$1\ W = 9.4804\times10^{-4}\ Btu/sec$$
$$1\ m\ = 39.37\ inch$$
$$1^\circ C\ = 1.8^\circ F$$

Therefore,

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

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

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

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 for the HAC fire test in Reference 12 using the finite element model of the secondary lid with the thermal shield shown in Figure 3-6. The time-history plot of the secondary lid seal temperature in Figure 3-7 shows that the peak temperature of the seal reaches 375°F shortly after the end of the 30 minute fire. Figure 3-8 shows the temperature contour plot of the secondary lid with the thermal-shield at the end of the 30 minute fire. As shown in Reference 12, the temperature at the location of the optional vent port seal reaches a peak of 308°F during the HAC fire transient. The temperature of the optional drain port seal is bounded the secondary lid seal since it is covered by the lower impact limiter, which provides insulation from the 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.

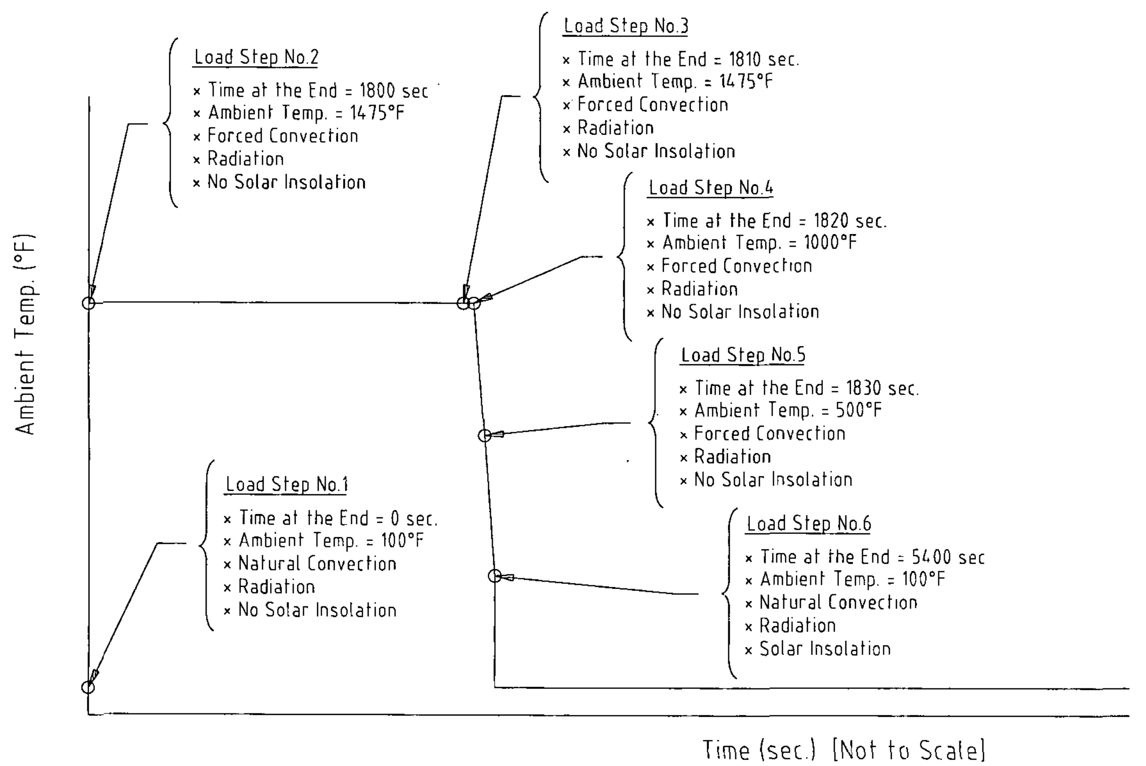

Figure 3.3
Transient Fire Analysis - Load Step and Boundary Conditions Schematic

Table 3.4
Summary of Maximum Hypothetical Accident Temperatures

	Maximum Calculated Temp.			Maximum
Component	Location	Time (hrs)	Value (°F)	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.

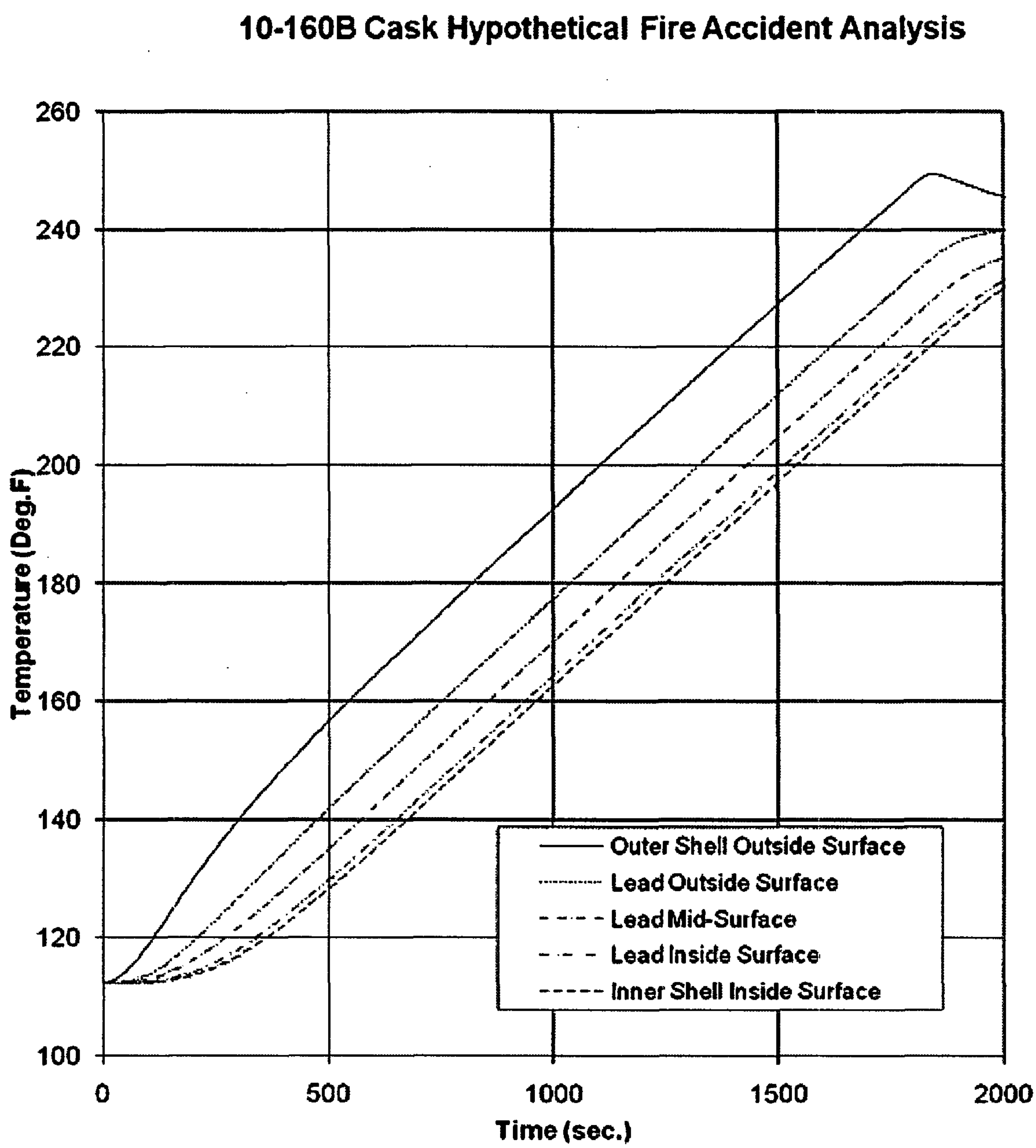

Figure 3.4
Hypothetical Accident - Fire Transient:
Temperature Versus Time

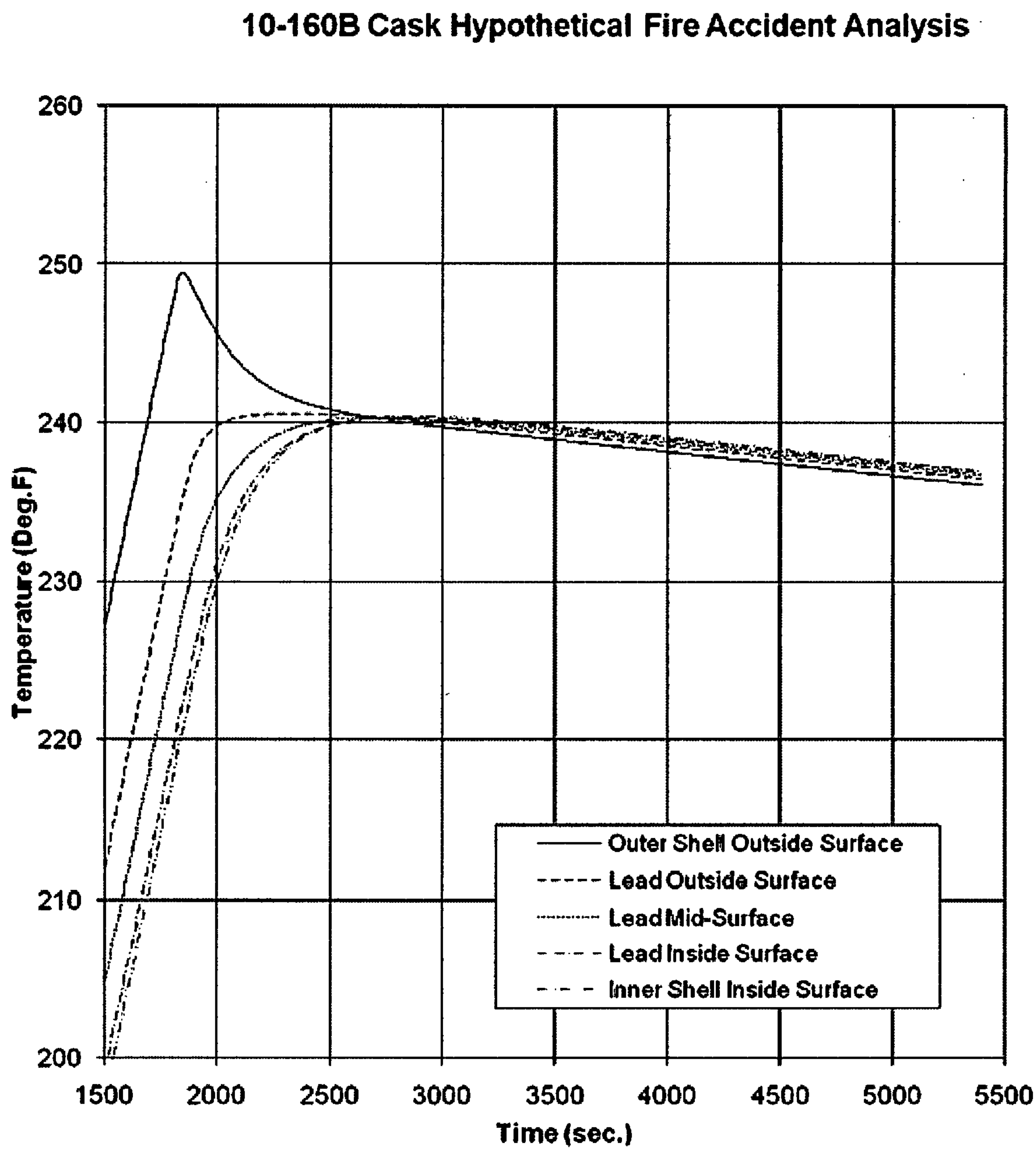

Figure 3.5
Hypothetical Accident - Cooldown:
Temperature Versus Time

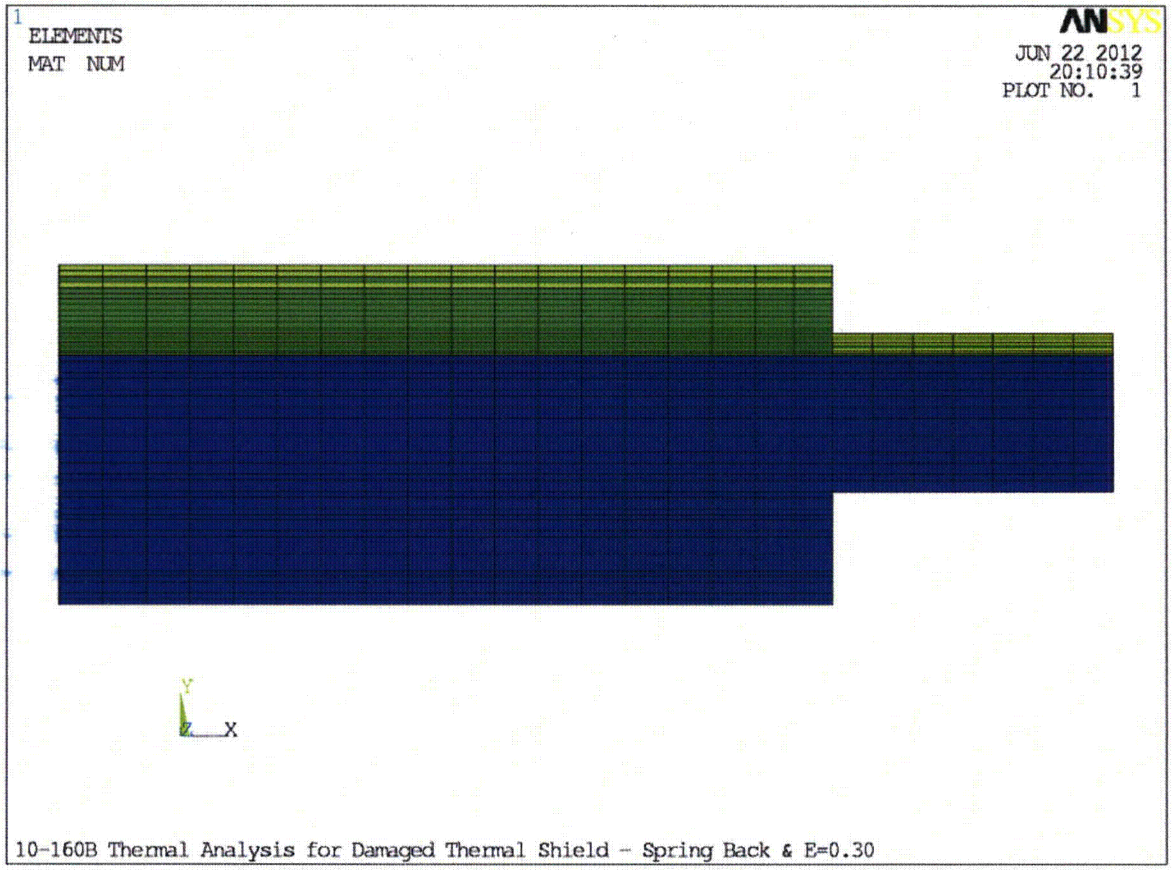

Figure 3.6
Finite Element Model of the Secondary Lid and the Thermal-Shield

(from Reference 12)

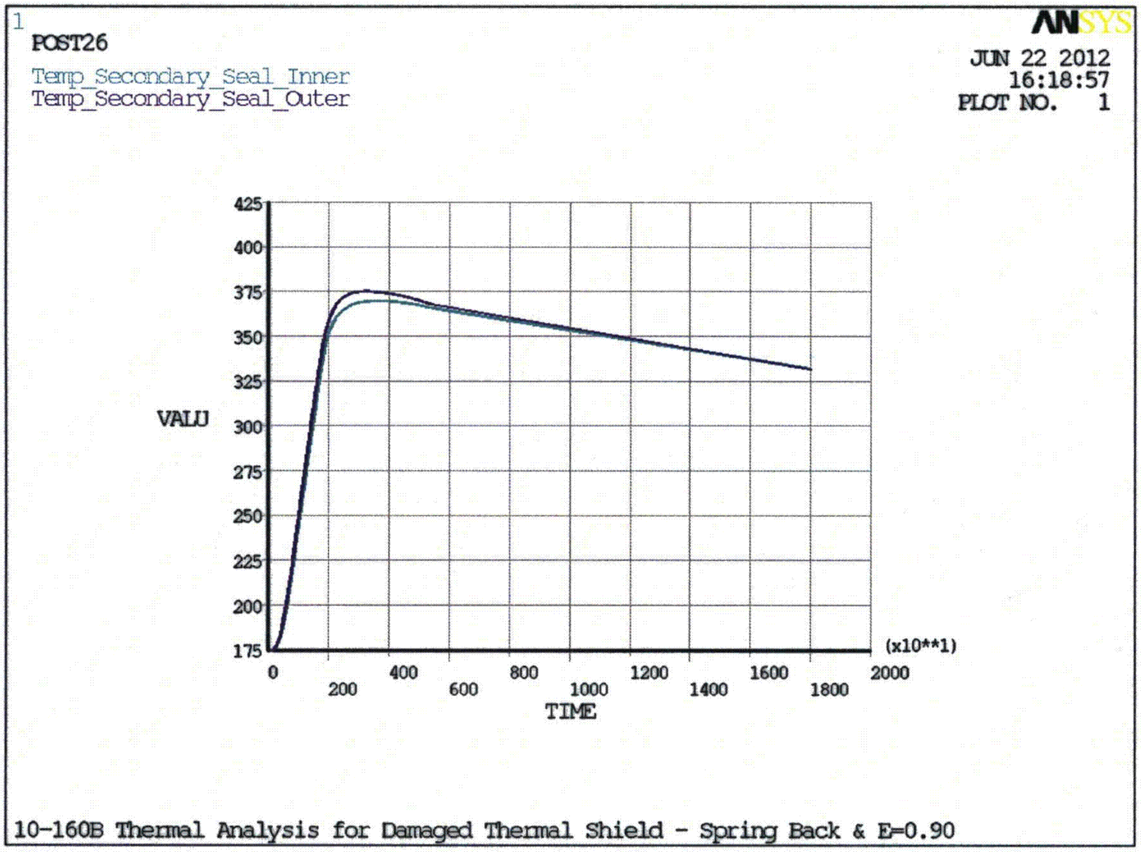

Figure 3.7
Seal Temperature Time-History Plot

(from Reference 12)

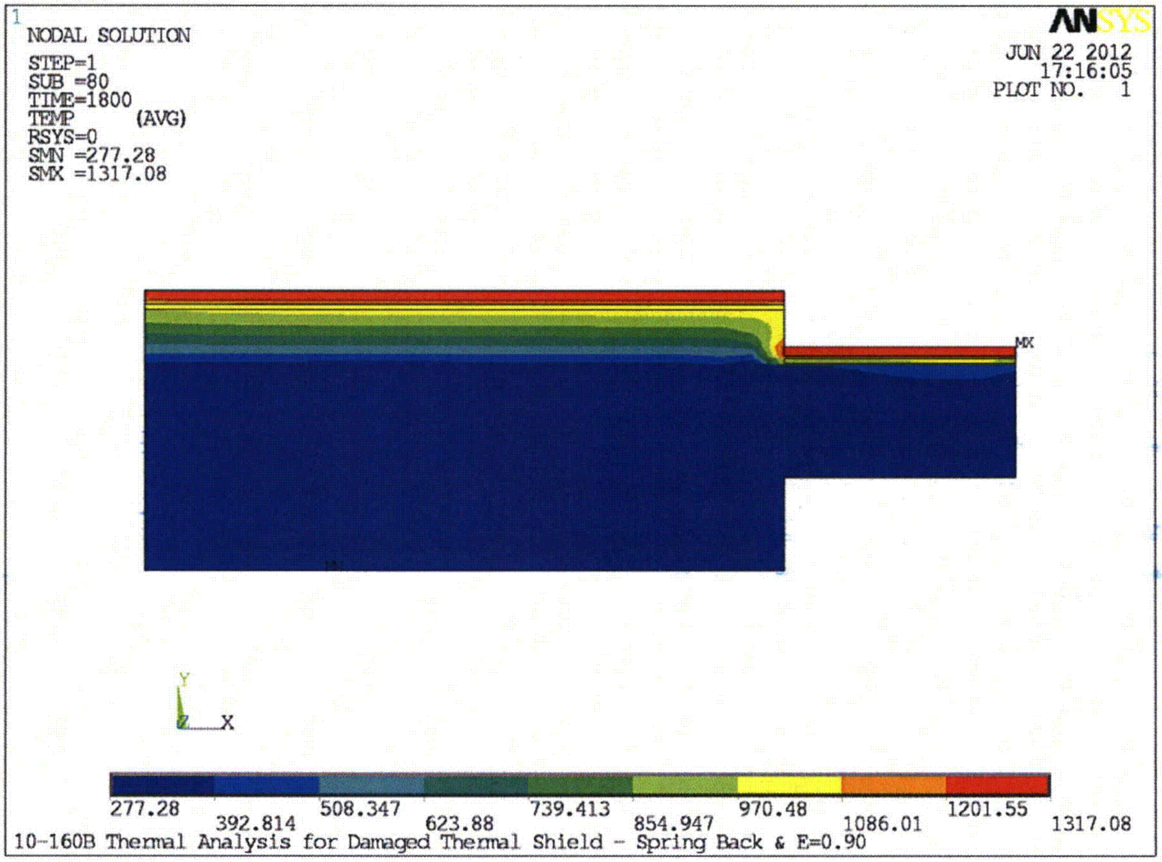

Figure 3.8
Temperature Contour Plot at the end of 30 Minute Fire

(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)

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

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

$$P_1 = 22.4 PSIA$$

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 Appendices 4.11.2 through 4.11.7) 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

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

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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.

4. CONTAINMENT

This chapter describes the containment configuration and test requirements for the 10-160B Cask. Both normal conditions of transport and hypothetical accident conditions are discussed.

4.1 CONTAINMENT BOUNDARY

4.1.1 CONTAINMENT VESSEL

The package containment vessel is defined as the inner shell of the shielded transport cask and the primary and secondary lids together with the associated o-ring seals and lid closure bolts. The inner shell of the cask, or containment vessel, consists of a right circular cylinder of 68 inches inner diameter and 77 inches inside height (nominal dimensions). The shell is fabricated of an outer shell of 2-inch thick steel plate, a 1 7/8 inch layer of lead, and an inner shell of 1 1/8 – inch thick steel. The cylindrical shell is attached at the base to a circular end plate construction with full penetration welds. The primary lid is attached to the cask body with 24, 1 ¾ inch 8 UN bolts. A secondary lid covers the 31 inch opening in the primary lid and is attached to the primary lid using 12, 1¾ inch 8 UN bolts. See Section 4.1.4 for closure details.

4.1.2 CONTAINMENT PENETRATIONS

There are two penetrations of the containment vessel. These are (1) an optional drain line, and (2) an optional cask vent port located in the secondary lid. The optional drain line is located at the cask base and consists of a ½ inch diameter hole drilled into the stainless steel cask bottom. The optional vent port penetrates the secondary lid into the main cask cavity. Both the vent and drain are sealed at the base of the exterior opening with an elastomer Parker Stat-o-Seal and a cap screw. The exterior openings are plugged by self-sealing Teflon-coated hex socket plugs.

4.1.3 WELDS

The containment vessel is fabricated from steel using full penetration welds.

4.1.4 CLOSURE AND SEALS

The primary lid closure consists of a two layer steel plate construction, stepped to fit over and within the top edge of the cylindrical body. The lid is supported at the perimeter of the cylindrical body by a 3.00-inch thick plate (bolt ring) welded to the top of the inner and outer cylindrical body walls. The lid confines two (2) solid, high temperature elastomer o-rings (Parker or equivalent) in machined grooves. Groove dimensions prevent over-compression of the o-rings by the lid closure bolt preload forces and hypothetical accident preload forces. The primary lid is attached to the cask body by 24 bolts. The primary lid is fitted with a secondary lid of similar construction attached with 12 bolts. The secondary lid is also sealed with two (2) solid, high temperature elastomer o-rings (Parker or equivalent) in machined grooves. Only the inner o-ring of each lid is part of the containment boundary.

The optional vent penetration, test ports, and drain penetrations are sealed as described in Section 4.1.2. The seal plugs in these penetrations are lockwired prior to each shipment. Table 4.1 gives the torque values for bolts and cap screws.

Table 4.1
Bolt and Cap Screw Torque Requirements

Location	Size	Torque Values +/- 10% (Lubricated)	
		In lb	Ft lb
Test Ports (2)	1/2 NPT	144	12
Primary Lid	1-3/4 inch, 8 UN	3600	300
Second Lid	1-3/4 inch, 8 UN	3600	300
Vent Port*	1/2 - 20 UNF	240	20
Drain Port*	1/2 - 20 UNF	240	20

*Optional - These ports may not be installed on cask.

4.2 CONTAINMENT REQUIREMENTS FOR NORMAL CONDITIONS OF TRANSPORT

4.2.1 LEAK TEST REQUIREMENTS

The 10-160B cask is designed, fabricated, and leak tested to preclude a release of radioactive material in excess of the limits prescribed in NRC Regulatory Guide 7.4, paragraph C and 10CFR71.51(a)(1). The limits on leakage during normal conditions of transport are defined by 10CFR71.51(a)(1).

The leak test procedure must be able to detect leaks of 2.57×10^{-6} ref-cm^3/sec (based on dry air at 25°C with a pressure differential of one atmosphere) to assure compliance with 10CFR71.51(a)(1). A description of the calculational procedure used to determine this value follows.

10CFR71.51(a)(1) states the containment requirements for normal conditions of transport as:

> ...no loss or dispersal of radioactive contents, as demonstrated to a sensitivity of 10^{-6} A_2 per hour, no significant increase in external radiation levels, and no substantial reduction in the effectiveness of the packaging;

ANSI N14.5-1997 (Reference 4) states that the permissible leak rate shall be determined by equation 1 (below):

(Equation 1) $$L = \frac{R}{C}$$

where:

L = permissible volumetric leak rate for the medium
R = package containment requirement (Ci/sec)
C = activity per unit volume of the medium that could escape from the containment system

In Section 3.4.4, it is noted that the saturated water vapor in equilibrium at 188 degrees-F and 12.2 psig could exist within the internal shipping containers (liners or drains). It is assumed that these conditions exist within the cask cavity. The containment must limit the leakage of this water vapor to that prescribed in ANSI N14.5. It is very conservative to assume that the concentration of nuclides in the free liquid is equal to that of the solids which comprise the vast majority of material being transported in the cask. This value is determined below:

$$C = \frac{\text{Total Curie Content of Vapor}}{\text{Minimum Void Volume in Cask Cavity}}$$

- Cask curie content = 3000 x A_2 or less
- Free water is limited to restriction of one-percent of solid volume
- Hence the curie content = 0.01 x 3000 A_2
- The minimum void volume occurs when the largest liner is shipped

(Equation 2) $$V\text{ (cask cavity)} = \frac{\pi}{4} \times 67.25^2 \times 75.75 = 269{,}064 \text{ in}^3$$

The largest liner will have at least ¾ inch of radial clearance and a 1½ inch of height difference, giving a volume,

(Equation 3) $$V\text{ (liner)} = \frac{\pi}{4} \times (67.25 - 2 \times 0.75)^2 \times (75.75 - 1.5) \text{ in}^3$$
$$= 252{,}103 \text{ in}^3$$

Void Volume = 269,064 – 252,103 = 16,961 in^3
= 16,961 in^3 x 16.4 cm^3/in^3
= 278,161 cm^3

Hence,

$$C = \frac{30A_2\ Ci}{278{,}161\ cm^3} = 1.08 \times 10^{-4}\ A_2\ Ci/cm^3$$

(Equation 4)

And,

(Equation 5)

$$Ln = \frac{Rn}{C} = \frac{2.78 \times 10^{-10} A_2\ Ci/sec}{1.08 \times 10^{-4}\ A_2\ Ci/cm^3} = 2.57 \times 10^{-6}\ cm^3/sec$$ Eqn. 3, Ref. 4

A leak rate at standard conditions will be calculated which is equivalent to a volumetric leak rate of 2.57×10^{-6} cm^3/sec.

Equations B.3, B.4,and B.5 are used to determine the diameter of hole that would give a leak rate of 2.57×10^{-6} cm^3/sec.

$$Lu = (Fc + Fm)(Pu - Pd)\left(\frac{Pa}{Pu}\right)$$ Eqn. B.5, Reference 4

$$Fm = \frac{3.81 \times 10^3 D^3 \sqrt{\frac{T}{M}}}{a\ Pa}$$ Eqn. B.4, Reference 4

$$Fc = \frac{2.49 \times 10^6 D^4}{a\ \mu}$$ Eqn. B.3, Reference 4

where:

L_u	=	upstream leakage rate, cm^3/sec
μ_{air}	=	0.0185cP
T	=	188°F = 360°K Section 3.4.4
P_u	=	12.2 psig = 1.83 atm
P_d	=	1.0 atm
P_a	=	(1.83 + 1.0)/2 = 1.42 atm
M_{water}	=	18 g/gmole
A	=	length of hole; assume 0.6 cm

Note: The molecular weight of air is 29 g/gmole; using the molecular weight of water here is conservative.

Substituting into Eqns. B.3, B.4, and B.5:

$$F_c = 1.98 \times 10^8 D^4$$

$F_m = 1.48 \times 10^4 D^3$

$$2.57x10^{-6} = (1.98x10^8 D^4 + 1.48x10^4 D^3)(2.05 - 1.0)\left(\frac{1.53}{2.05}\right)$$ Solve for D

$D = 3.54 \times 10^{-4}$ cm

Next, using Equation B.5 from Reference 4, determine the flow of air at standard conditions through a hole of this size. Where:

a = 0.6 cm

M_{air} = 29 g/gmole

μ_{air} = 0.0185 cP

P_u = 1.0 atm

P_d = 0.01 atm

P_a = (1.0 + 0.01)/2 = 0.505 atm

T = 298°K

Substituting into B.5:

$$L_{std} = 2.45 \times 10^{-6} \frac{\text{ref - cm}^3}{\text{sec}}$$

4.2.2 PRESSURIZATION OF THE CONTAINMENT VESSEL

Section 2.4.4 summarizes normal condition temperatures and pressures within the containment vessel. These pressures and associated temperatures are used to evaluate the integrity of the 10-160B package. None of these conditions reduce the effectiveness of the package containment.

4.2.3 COOLANT CONTAINMENT

Not applicable; there are no coolants in the 10-160B package.

4.2.4 COOLANT LOSS

Not applicable; there are no coolants in the 10-160B package.

4.3 CONTAINMENT REQUIREMENTS FOR HYPOTHETICAL ACCIDENT CONDITIONS

4.3.1 LEAK TEST REQUIREMENTS

Section 2.7 demonstrates that the 10-160B cask will maintain its containment capability throughout the hypothetical accident conditions. Fission gas products will not be carried within the cask so there can be no release of fission gases. The 10-160B cask is designed, fabricated, and leak tested to preclude a release of radioactive material in excess of the limits prescribed in NRC Regulatory Guide 7.4, paragraph C and 10CFR71.51(a)(2). The limits on leakage during normal conditions of transport are defined by 10CFR71.51(a)(2).

The leak test procedure which assures compliance with leakage during normal conditions of transport will also be sufficient to assure compliance during hypothetical accident conditions. A description follows of the calculational procedure which demonstrates that the maximum leakage requirement during normal conditions of transport is more stringent than the maximum leakage requirement during the hypothetical accident.

10CFR71.51(a)(2) states the containment requirements for the hypothetical accident conditions as:

> ... no escape of krypton-85 exceeding 10 A_2 in 1 week, no escape of other radioactive material exceeding a total amount A_2 in 1 week, and no external radiation dose rate exceeding 10 mSv/h (1 rem/h) at 1 m (40 in) from the external surface of the package.

Since the cask does not carry fission products or radioactive gases, only the A_2 per week requirement is limiting. A release of A_2 in one week is equivalent to the activity release rate, R_a, given by equation 9.

$$Ra = (A2/\text{week})(1\ \text{week}/168\ \text{hr})$$

(Equation 9) $$= 5.952 \times 10^{-3}\ A2/\text{hr}$$

In Section 3.5.4, it is noted that the saturated water vapor in equilibrium at 250 degrees-F and 34.7 psig could exist within the internal shipping containers (liners or drains). It is assumed that these conditions exist within the cask cavity. The containment must limit the leakage of this water vapor to that prescribed in ANSI N14.5. It is very conservative to assume that the concentration of nuclides in the free liquid is equal to that of the solids which comprise the vast majority of material being transported in the cask. This value is determined below:

$$C = \frac{\text{Total Curie Content of Vapor}}{\text{Minimum Void Volume in Cask Cavity}}$$

- Cask curie content = 3000 x A_2 or less
- Free water is limited to restriction of one-percent of solid volume
- Hence the curie content = 0.01 x 3000 A_2

- The minimum void volume occurs when the largest liner is shipped

(Equation 10) $$V(\text{cask cavity}) = \frac{\pi}{4} \times 67.25 \times 75.75 = 269{,}064$$

The largest liner will have at least ¾ inch of radial clearance and a 1½ inch of height difference, giving a volume

$$V(\text{liner}) = \frac{\pi}{4} \times (67.25 - 2 \times 0.75)^2 \times (75.75 - 1.5)\ \text{in}^3$$

(Equation 11) $$= 252{,}103\ \text{in}^3$$

Void Volume $= 269{,}064 - 252{,}103 = 16{,}961$
$= 16{,}961\ \text{in}^3 \times 16.4\ \text{cm}^3/\text{in}^3$
$= 278{,}161\ \text{cm}^3$

Hence,

(Equation 12) $$C = \frac{30 A_2\ \text{Ci}}{278{,}161\ \text{cm}^3} = 1.08 \times 10^{-4}\ A_2\ \text{Ci/cm}^3$$

The corresponding volumetric leak rate, L, is calculated by substituting C given by equation 12 and R_a given by equation 9 into equation 1. Equation 13 results from these substitutions.

(Equation 13) $$La = \frac{5.952 \times 10^{-3} A_2\ \text{Ci/hr}}{1.08 \times 10^{-4}\ A_2\ \text{Ci/cm}^3} \frac{1\ \text{hr}}{3600\ \text{sec}}$$

$$= 1.53 \times 10^{-2}\ \text{cm}^3/\text{sec}$$

The allowable leak rate during the hypothetical accident is larger than during the normal conditions of transport, 2.45×10^{-6} ref-cm^3/sec. Thus, the leak rate for normal conditions of transport is limiting and will determine the maximum permissible leak rate during tests.

4.4 DETERMINATION OF TEST CONDITIONS FOR PRESHIPMENT LEAK TEST

4.4.1 TEST METHOD

The preshipment leak test is performed using the Gas Pressure Drop Method as shown in A.5.1, Table A-1 of ANSI N14,5-1997. The Gas Pressure Drop test is conducted on the 10-160B by pressurizing the annulus between the O-rings on the primary and secondary lids with dry air or nitrogen. If vent and drain ports are installed, these are tested by pressurizing the ports with dry air or nitrogen.

As required by ANSI N14.5, the test is conducted by holding the test pressure on the component being tested for a prescribed period of time (calculated below) and monitoring for any detectable drop in pressure. ANSI N14.5 – 1997 states (Reference 4, Table 1) that the acceptance criteria for the preshipment leak test is a leakage rate that is either less than the reference air leakage rate, L_R, or no detected leakage when tested to a sensitivity of $1x10^{-3}$ ref-cm^3/sec. This section will show that the requirement of ANSI N14.5 is met by testing to a sensitivity of $1x10^{-3}$ ref-cm^3/sec when performing the Gas Pressure Drop test for 15 minutes (10 minutes for vent or drain lines).

The calculations in 4.4.2 and 4.4.3 below are performed assuming dry air is the test gas, although as indicated in the above paragraph and in Chapter 8, nitrogen may be used as well. If nitrogen is the test gas used, the calculations for the required charge time in 4.4.2 and 4.4.3 below are conservative. Since air is primarily nitrogen, the physical properties of the two gases are very close. However, because the molecular weight and viscosity of nitrogen are slightly less than air's, the pressure drop experienced during the required charge time using nitrogen as the test gas will be slightly greater than for air (Reference 8).

	molecular wt	Viscosity (cP)
air	29.0	.0185
nitrogen	28.01	.0173

4.4.2 DETERMINING REQUIRED CHARGE TIME FOR GAS PRESSURE DROP TEST

The preshipment leak test is performed by charging the annulus of the O-rings (of the vent and drain port) with air and holding the pressure for the prescribed time. Any pressure drop larger than the minimum detectable increment on the pressure measuring instrument shall be corrected. In this section the minimum hold time is determined.

The annulus between the O-rings is pressurized with air. The annulus is centered between O-rings and is 1/8" deep and 1/8" wide with a minimum inner diameter of 68-15/16". The minimum volume of the annulus is 55 cm^3.

The required hold time for the Gas Pressure Drop test is determined using Equation 15 below, which is Equation B.14 of ANSI N14.5-1997. The same hold time determined below will be used for both the primary and secondary lids. Since the volume of the secondary lid annulus is approximately 28 cm^3, the test sensitivity will be greater than the primary lid's.

(Equation 14) $$L_R = \frac{V\,T_s}{3600\,H P_s}\left[\frac{P_1}{T_1} - \frac{P_2}{T_2}\right]$$ Eqn B.14, Reference 4

where:

L_R = atm-cm^3/sec of air at standard conditions
V = gas volume in the test annulus cm^3
T_s = reference absolute temperature, 298°K
H = test duration, hours
P_1 = gas pressure in test item at start of test, atm, abs
P_2 = gas pressure in test item at end of test, atm, abs
P_s = standard pressure = 1 atm
T_1 = gas temperature in test item at start of test, °K

T_2 = gas temperature in test item at end of test, °K

4.4.3 REQUIRED HOLD TIME AT THE TEST PRESSURE

As discussed in Section 4.4.1 above, the maximum sensitivity for the preshipment leak test as prescribed in ANSI N14.5-1997 is 10^{-3} ref-cm^3/sec. Further, ANSI N14.5-1997 states that in cases where the test sensitivity has been established and the Gas Pressure Drop test is used, the maximum permitted leak rate is:

$L \leq S/2$ Equation B-17, Reference 4

Therefore the maximum permitted leak rate for the preshipment leak test is 5 x 10^{-4} ref-cm^3/sec. Substituting this in Eqn. B-17 above, determine the required hold time, where:

$V = 55 \text{ cm}^3$

$T_s = T_1 = T_2 = 298°K$

$P_1 - P_2$ = pressure instrument sensitivity = 0.1 psig

$$5x10^{-4} = \frac{(55\,\text{cm}^3)(298^o K)}{3600(H\,hr)(1\,\text{atm})}\left(\frac{0.007\,\text{atm}}{298^\circ K}\right)$$

Solve for H:

H = 0.214 hr = 12.8 min.

For conservatism, the test will be conducted for 15 minutes.

4.5 PERIODIC VERIFICATION LEAK RATE DETERMINATION USING R-12 TEST GAS

This section contains calculations to determine the periodic verification test measurement that is equivalent to the maximum permissible leak rate as determined using ANSI N14.5-1997 (Reference 4).

The purpose of this calculation is to determine the allowable leak rate using the R-12 halogen gas that may be used to perform the annual verification leak tests on the 10-160B cask.

4.5.1 INTRODUCTION

The text of this document is prepared using Mathcad, Version 6.0, software. Most conventions used in the text are the same as normal practice. A benefit of the Mathcad code is that is automatically carries all units with the variables used in the calculations. The code also allows output of variables in any form of the fundamental units (length, mass, time, etc.), allowing for automatic conversions between unit systems without the need for conversion factors. All Mathcad calculations in this Section 4.5 have been verified by hand calculations.

This calculation uses formulas presented in ANSI N14.5 - 1997.

4.5.2 DETECTOR SENSITIVITY CALCULATION – TEST CONDITIONS

This section determines the sensitivity necessary for a leak test performed with R-12 halogen gas. This test is performed using a halogen leak detector. A leak standard, traceable to NIST, is used to calibrate the leak detector to detect the maximum allowable test leak rates specified in Figure 4.3. The test is performed as follows: The annulus between the o-ring seals of the 10-160B primary and secondary lids will be evacuated to a minimum vacuum of 20"Hg, and then be pressurized to a minimum pressure of 25 psig with R-12 halogen gas. In section 4.2.1, it was determined that the maximum possible diameter hole in the cask O-ring (D_{max}) that would permit the standard leak rate ($L_{std} = 2.45 \times 10^{-6}$) is:

The maximum possible diameter of hole in the O-ring is:

$D_{max} = 3.54 \times 10^{-4}$ cm — From Section 4.2.1

$$L_{std}(D) = (F_c(D) + F_m(D) \cdot (P_u - P_d) \cdot \frac{P_a}{P_d}$$

Eqn. B5 – ANSI N14.5 - 1997

Determine the equivalent air/R12 mixture (L_{mix}) that would leak from D_{max} during a leak test. Assume the O-ring void is first evacuated to 20"Hg vacuum (9.92"Hg abs) and then pressurized to 25 psig (2.7 atm) with an air/R12 mixture.

$P_{mix} := 2.7 \cdot atm$

$P_{air} := 9.92 \cdot in\_Hg$

$P_{air} = 0.33 atm$

$P_{R12} := P_{mix} - P_{air}$

$P_{R12} = 2.37 atm$ $\quad P_d := 1.0 \cdot atm$

$P_a := \frac{P_{mix} + P_{air}}{2} \Rightarrow P_a = 1.85 atm$

$M_{R12} := 121 \cdot \frac{gm}{mole}$ — ANSI N14.5 – 1997

$\mu_{R12} := 0.0124 \cdot cP$ — ANSI N14.5 – 1997

$$M_{mix} := \frac{M_{R12} \cdot P_{R12} + M_{air} \cdot P_{air}}{P_{mix}}$$ Eqn. B7 - ANSI N14.5

$$\Rightarrow \quad M_{mix} = 109.7 \frac{gm}{mole}$$

$$\mu_{mix} := \frac{\mu_{air} \cdot P_{air} + \mu_{R12} \cdot P_{R12}}{P_{mix}}$$ Eqn. B8 – ANSI N14.5 - 1997

$$\Rightarrow \quad \mu_{mix} = 0.0131 cP$$

Determine L_{mix} as a function of temperature. Assume the viscosities of air and R12 do not change significantly over the range of temperatures evaluated:

$T := 273K, 278K .. 318K$ Temperature range for test: 32°F to 113°F

$$F_c := \frac{2.49 \cdot 10^6 \cdot D_{max}^4 \cdot cP \cdot std}{a \cdot \mu_{mix} \cdot sec \cdot atm}$$

then,

$$F_c = 4.84 \times 10^{-6} \frac{cm^3}{atm\,sec}$$

$$F_m(T) := \frac{3.81 \cdot 10^3 \cdot D_{max}^3 \cdot \sqrt{\frac{T}{M_{mix}}} \cdot cm \cdot gm^{0.5}}{a \cdot P_a \cdot K^{0.5} \cdot mole^{0.5} \cdot sec}$$

$$L_{mix}(T) := (F_c + F_m(T)) \cdot (P_{mix} - P_{air}) \cdot \frac{P_a}{P_{mix}}$$

The R-12 component of this leak rate can be determined by multiplying the leak rate of the mixture by the ratio of the R-12 partial pressure to the total pressure of the mix, as follows.

$$L_{R12}(T) := L_{mix}(T) \cdot \frac{P_{R12}}{P_{mix}}$$

Determine the equivalent mass flow rate for L_{R12} in oz/yr:

$$N(T) := \frac{P_{R12} \cdot V}{R_o \cdot T}$$ Ideal Gas Law

where,

$$R_o := \frac{82.05 \cdot cm^3 \cdot atm}{mole \cdot K}$$

This data can then be used to convert the volumetric leak rate for R-12 calculated above to a mass leak rate. By dividing N by V, the number of moles per unit volume can be multiplied by the molecular weight of the gas and the maximum allowable volumetric leak rate to determine the maximum allowable mass leak rate, as a function of test temperature as shown in the graph below. The conversion from grams per second to ounces per year is also shown below.

$$L(T) := L_{R12}(T) \cdot \frac{N(T)}{V} \cdot M_{R12} \cdot \frac{yr}{oz}$$

$\frac{gm}{sec} = 1.113 \times 10^6 \frac{oz}{yr}$ Conversion of gm/sec to oz/yr

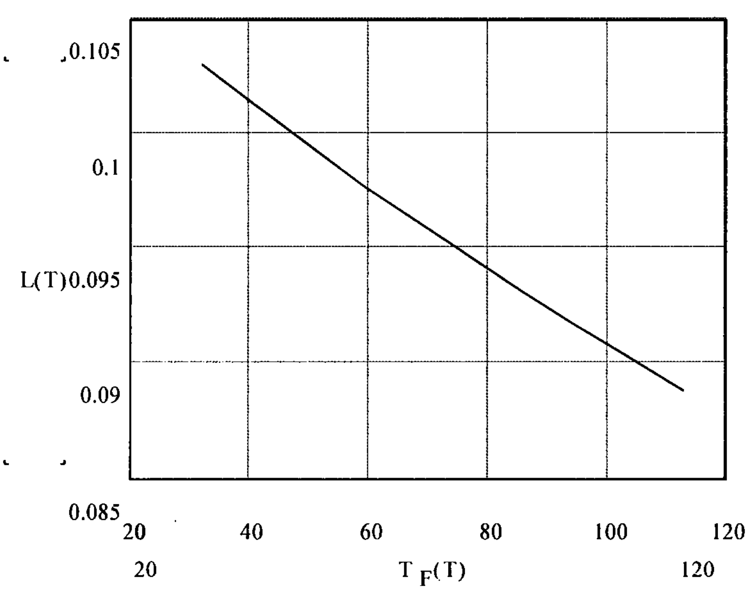

Figure 4.1
Allowable R-12 test leakage, oz/yr, versus test temperature, deg.F

The graph above can be used to determine the allowable leak rate based on the temperature at the time of the test. According to ANSI N14.5 methodology, the maximum allowable leak rate must be divided by 2 to determine the minimum sensitivity for the test. A graph of the required sensitivity in oz/yr is presented below:

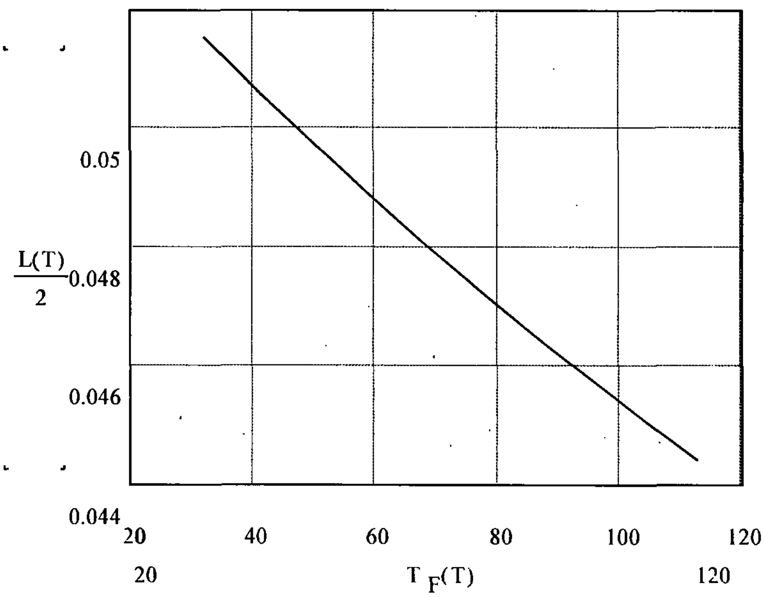

Figure 4.2
Allowable R-12 test leakage sensitivity, oz/yr, versus test temperature, deg.F

The values presented in Figure 4.4 should be used to determine the sensitivity to calibrate the leak detector prior to the test.

4.6 PERIODIC VERIFICATION LEAK RATE DETERMINATION USING HELIUM TEST GAS

This section contains calculations to determine the periodic verification test measurement that is equivalent to the maximum permissible leak rate as determined using ANSI N14.5-1997 (Reference 4).

4.6.1 INTRODUCTION

The purpose of this calculation is to determine the allowable leak rate using the Helium gas that may be used to perform the annual verification leak tests on the 10-160B cask.

4.6.2 DETECTOR SENSITIVITY – TEST CONDITIONS

In Section 4.2.1, it was determined that the maximum possible diameter hole in the cask O-ring (D_{max}) that would permit the standard leak rate ($L_{std} = 2.45 \times 10^{-6}$ ref- cm³/sec) is:

$D_{max} = 3.54 \times 10^{-4}$ cm From Section 4.2.1

Next, determine the equivalent air/He mixture (L_{mix}) that would leak from D_{max} during a leak test. Assume the O-ring void is pressurized to 25 psig (2.7 atm) with an air/He mixture.

$$P_{mix} := 2.7 \cdot atm$$

$$P_{air} := 1.0 \cdot atm$$

$$P_{He} := 1.7 \cdot atm$$

$$P_a := \frac{P_{mix} + P_{air}}{2}$$

$$P_a = 1.85 \cdot atm$$

$$M_{He} := 4.0 \cdot \frac{gm}{mole}$$ ANSI N14.5 - 1997

$$\mu_{He} := 0.0198 \cdot cP$$ ANSI N14.5 - 1997

$$M_{mix} := \frac{M_{He} \cdot P_{He} + M_{air} \cdot P_{air}}{P_{mix}}$$ Eqn. B7 - ANSI N14.5

$$\Rightarrow M_{mix} = 13.26 \cdot \frac{gm}{mole}$$

$$\mu_{mix} := \frac{\mu_{air} \cdot P_{air} + \mu_{He} \cdot P_{He}}{P_{mix}}$$ Eqn. B8 - ANSI N14.5

$\Rightarrow \mu_{mix} = 0.019 \cdot cP$

Determine L_{mix} as a function of temperature. Assume the viscosities of air and Helium do not change significantly over the range of temperatures evaluated:

$T := 273 \cdot K, 278 \cdot K .. 318 \cdot K$ Temperature range for test: 32°F to approx. 113°F

$$F_c := \frac{2.49 \cdot 10^6 \cdot D_{max}^4 \cdot cP \cdot std}{a \cdot \mu_{mix} \cdot sec \cdot atm}$$

$$F_m(T) := \frac{3.81 \cdot 10^3 \cdot D_{max}^3 \cdot \sqrt{\frac{T}{M_{mix}}} \cdot cm \cdot gm^{0.5}}{a \cdot P_a \cdot K^{0.5} \cdot mole^{0.5} \cdot sec}$$

$$L_{mix}(T) := \left(F_c + F_m(T)\right) \cdot \left(P_{mix} - P_{air}\right) \cdot \frac{P_a}{P_{mix}}$$

$$T_F(T) := \left[(T \cdot F - 273 \cdot K) \cdot \frac{9}{5 \cdot K} + 32 \right]$$

The Helium component of this leak rate can be determined by multiplying the leak rate of the mixture by the ratio of the Helium partial pressure to the total pressure of the mix, as follows.

$$L_{He}(T) := L_{mi}(T) \cdot \frac{P_{He}}{P_{mi}}$$

Determine the equivalent mass flow rate for L_{He} in oz/yr:

$$N(T) := \frac{P_{He} \cdot V}{R_o \cdot T}$$ Ideal Gas Law

where,

$$R_o := \frac{82.05 \cdot cm^3 \cdot atm}{moleK}$$

This data can then be used to convert the volumetric leak rate for Helium calculated above to a mass leak rate. By dividing N by V, the number of moles per unit volume can be multiplied by the molecular weight of the gas and the maximum allowable volumetric leak rate to determine the maximum allowable mass leak rate, as a function of test temperature as shown in the graph below. The conversion from grams per second to ounces per year is also shown below.

$$L(T) := L_{He}(T) \cdot \frac{N(T)}{V} \cdot M_{He} \cdot \frac{yr}{oz}$$

$$\frac{gm}{sec} = 1.113 \cdot 10^{6} \cdot \frac{oz}{yr}$$ Conversion of gm/sec to oz/yr

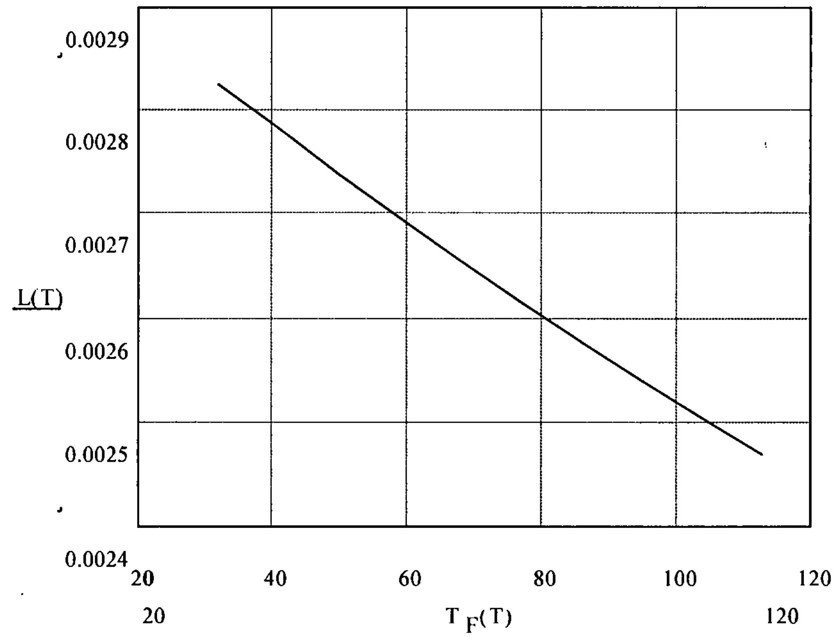

Figure 4.3
Allowable helium test leakage, oz/yr, versus test temperature, deg.F

The graph above can be used to determine the allowable leak rate based on the temperature at the time of the test. According to ANSI N14.5 methodology, the maximum allowable leak rate must be divided by 2 to determine the minimum sensitivity for the test. A graph of the required sensitivity in oz/yr is presented below:

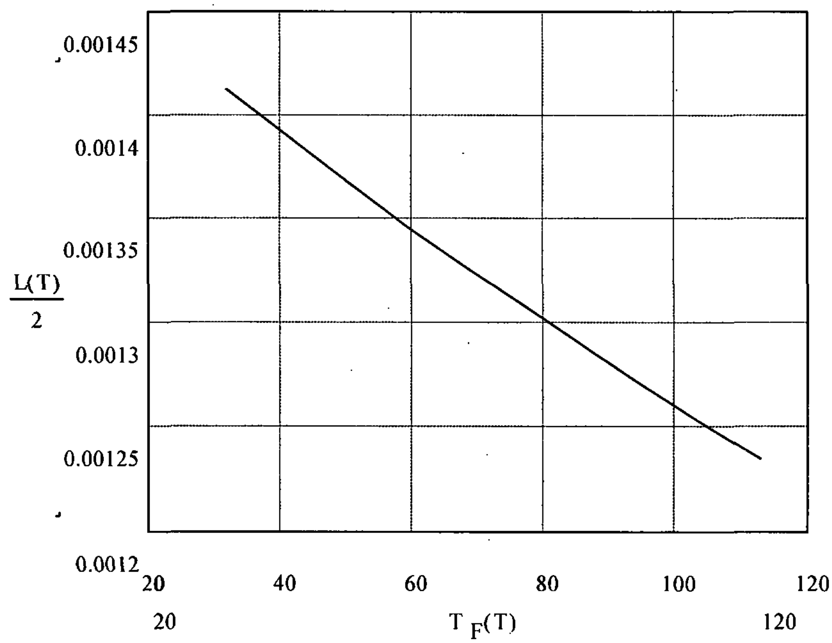

Figure 4.4
Allowable helium test leakage sensitivity, oz/yr, versus test temperature, deg.F

The values presented in Figure 4.8 should be used to determine the sensitivity to calibrate the leak detector prior to the test.

4.7 PERIODIC VERIFICATION LEAK RATE DETERMINATION USING R-134A TEST GAS

This section contains calculations to determine the periodic verification test measurement that is equivalent to the maximum permissible leak rate as determined using ANSI N14.5-1997 (Reference 8).

4.7.1 INTRODUCTION

The purpose of this calculation is to determine the allowable leak rate using the R-134a halogen gas that will be used as an alternative to perform the annual verification leak tests on the 10-160B cask. This halogen gas is now in widespread use as a replacement gas for R-12 in many industrial applications. Properties for R134a are included in Appendix 4.1.

4.7.2 DETECTOR SENSITIVITY CALCULATION - TEST CONDITIONS

This section determines the sensitivity necessary for a leak test performed with R-134a halogen gas. This test is performed using a halogen leak detector. A leak standard, traceable to NIST, is used to calibrate the leak detector to detect the maximum allowable test leak rates specified in Figure 4.11. The test is performed as follows: The annulus between the o-ring seals of the 10-160B primary and secondary lids will be evacuated to a minimum vacuum of 20"Hg, and then be pressurized to a minimum pressure of 25 psig with R-134a halogen gas. In section 4.2.1, it was determined that the maximum possible diameter hole in the cask O-ring (D_{max}) that would permit the standard leak rate ($L_{std} = 2.45 \times 10^{-6}$) is:

$D_{max} = 3.54 \times 10^{-4}$ cm

Next, determine the equivalent air/R134a mixture (L_{mix}) that would leak from D_{max} during a leak test. Assume the O-ring void is first evacuated to 20"Hg vacuum (9.92"Hg absolute) and then pressurized to 25 psig (2.7 atm) with an air/R134a mixture.

$P_{mix} := 2.7 \cdot atm$

$P_{air} := 9.92 \cdot in\_Hg$

$P_{air} = 0.33 atm$

$P_{R134a} := P_{mix} - P_{air}$

$P_{R134a} = 2.37 atm$ $\qquad P_d := 1.0 \cdot atm$

$$P_a := \frac{P_{mix} + P_{air}}{2}$$

$P_a = 1.85 atm$

The properties of R134a are given in the attached literature:

$$M_{R134a} := 102 \cdot \frac{gm}{mole}$$

$$\mu_{R134a} := 0.012 cP$$

$$M_{mix} := \frac{M_{R134a} \cdot P_{R134a} + M_{air} \cdot P_{air}}{P_{mix}}$$ Eqn. B7 - ANSI N14.5

$$\Rightarrow \quad M_{mix} = 93.04 \frac{gm}{mole}$$

$$\mu_{mix} := \frac{\mu_{air} \cdot P_{air} + \mu_{R134a} \cdot P_{R134a}}{P_{mix}}$$ Eqn. B8 - ANSI N14.5

$$\Rightarrow \quad \mu_{mix} = 0.013 cP$$

Determine L_{mix} as a function of temperature. Assume the viscosities of air and R134a do not change significantly over the range of temperatures evaluated:

$T := 273 \cdot K, 278 \cdot K .. 318 \cdot K$ Temperature range for test: $32^{O}F$ to $113^{O}F$

$$F_c := \frac{2.49 \cdot 10^6 \cdot D_{max}^4 \cdot cP \cdot ref}{a \cdot \mu_{mix} \cdot sec \cdot atm}$$

$$F_m(T) := \frac{3.81 \cdot 10^3 \cdot D_{max}^3 \cdot \sqrt{\frac{T}{M_{mix}}} \cdot cm \cdot gm^{0.5}}{a \cdot P_a \cdot K^{0.5} \cdot mole^{0.5} \cdot sec}$$

$$L_{mix}(T) := (F_c + F_m(T)) \cdot (P_{mix} - P_{air}) \cdot \frac{P_a}{P_{mix}}$$

$$T_F(T) := \left[(T \cdot F - 273 \cdot K) \cdot \frac{9}{5 \cdot K} + 32 \right]$$

The R-134a component of this leak rate can be determined by multiplying the leak rate of the mixture by the ratio of the R-134a partial pressure to the total pressure of the mix, as follows.

$$L_{R134a}(T) := L_{mix}(T) \cdot \frac{P_{R134a}}{P_{mix}}$$

Determine the equivalent mass flow rate for L_{R134a} in oz/yr, the measurement used by the detector:

$$N(T) := \frac{P_{R134a} \cdot V}{R_o \cdot T}$$ Ideal Gas Law

where,

$$R_o := \frac{82.05 \cdot cm^3 \cdot atm}{mole \cdot K}$$ Universal Gas Constant

This data can then be used to convert the volumetric leak rate for R-134a calculated above to a mass leak rate. By dividing N by V, the number of moles per unit volume can be multiplied by the molecular weight of the gas and the maximum allowable volumetric leak rate to determine the maximum allowable mass leak rate, as a function of test temperature as shown in the graph below. The conversion from grams per second to ounces per year is also shown below.

$$L(T) := L_{R134a}(T) \cdot \frac{N(T)}{V} \cdot M_{R134a} \cdot \frac{yr}{oz}$$

$$\frac{gm}{sec} = 1.113 \times 10^6 \frac{oz}{yr}$$ Conversion of gm/sec to oz/yr

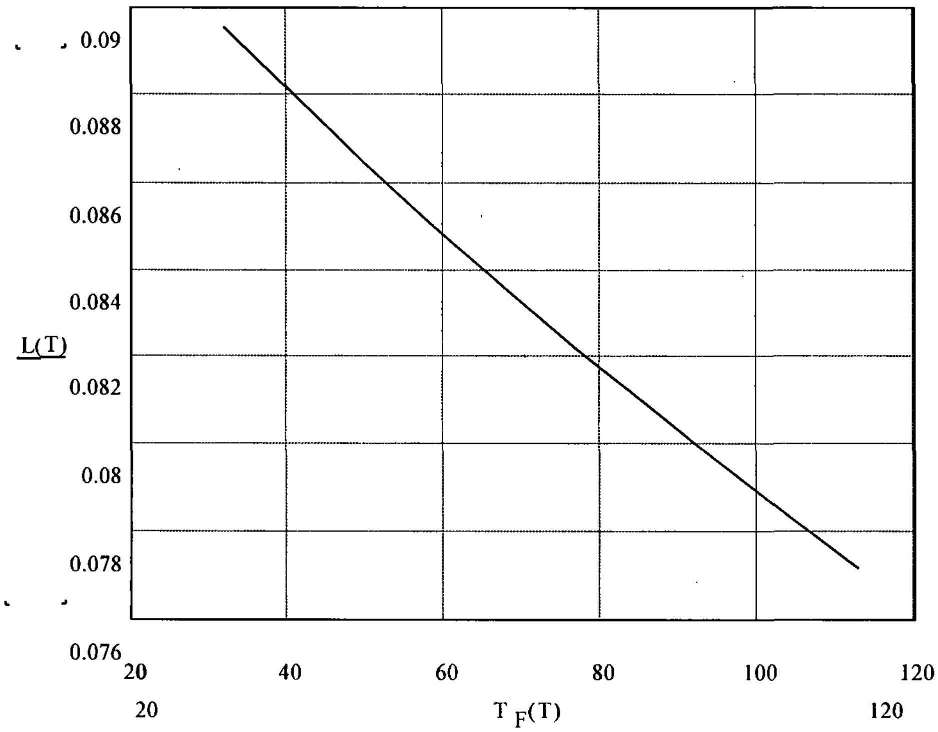

Figure 4.5
Allowable R134a test leakage, oz/yr, versus test temperature, deg.F

The graph above can be used to determine the allowable leak rate based on the temperature at the time of the test. According to ANSI N14.5 methodology, the maximum allowable leak rate must be divided by 2 to determine the minimum sensitivity for the test. A graph of the required sensitivity in oz/yr is presented below:

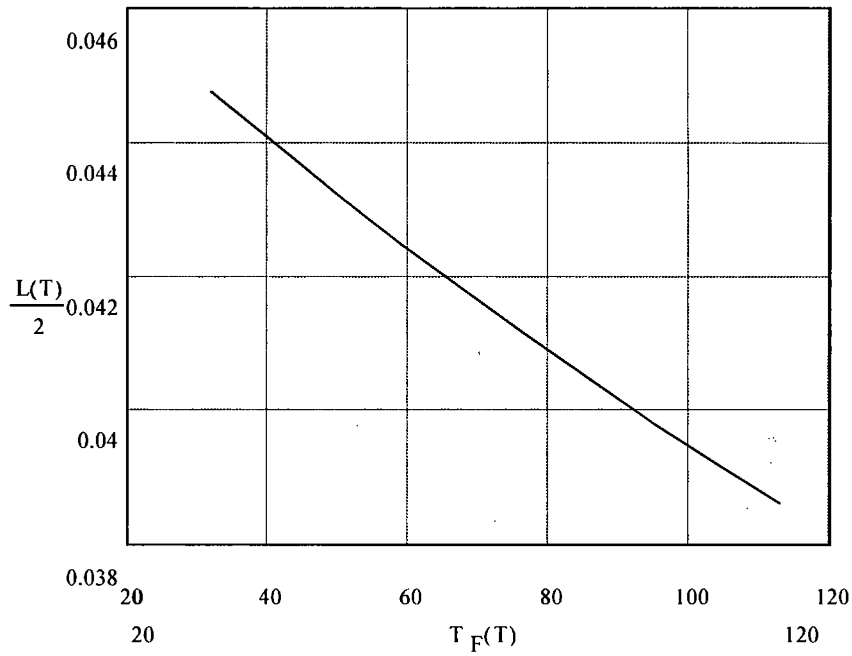

Figure 4.6
Allowable R134a test leakage sensitivity, oz/yr, versus test temperature, deg.F

The values presented in Figure 4.12 should be used to determine the sensitivity to calibrate the leak detector prior to the test.

4.8 COMBUSTIBLE GAS GENERATION SAFETY ASSURANCE

Assurance of safe shipment of vessels which may generate combustible gas is based on meeting the following criteria over the shipment period.

i) The quantity of hydrogen generated must be limited to a molar quantity that would be no more than 5% by volume at STP (or equivalent limits for other inflammable gases) of the secondary container gas void (i.e., no more than 0.063 gram moles/cubic foot, or

ii) The secondary container and the cask cavity (if required) must be inerted with a diluent to assure the oxygen, including that radiolytically generated, shall be limited to 5% by volume in those portions of the package which could have hydrogen greater than 5%. This criterion does not apply to TRU wastes, which shall be governed by the requirements of Appendice 4.11.2 through 4.11.7.

Criterion (i) essentially stipulates that the quantity of hydrogen shall be limited to 5% of the secondary container gas void at STP. This 5% hydrogen gas volume at standard conditions is equivalent to a hydrogen partial pressure of 0.735 psi or 0.063 gram moles/cubic foot. By actual experiment (Ref. 6), the produce an approximate 2.3 psi incremental pressure increase above a nominally atmospheric initial pressure. This is because 0.063 gram moles of hydrogen per cubic foot provides such a small source that the peak pressure rise resulting from ignition of this source is slight. (The pressure rise is independent of the total volume under test, i.e. the 0063 gram moles per cubic foot relationship to a 2.3 psi pressure rise is valid for one or many cubic feet of specimen volume). Methodology for demonstrating compliance with the 5% hydrogen concentration limit for TRU waste is described in Appendices 4.11.2 through 4.11.7. This incremental pressure rise is an inconsequential load on the cask structure.

(Ref. 7), Criteria (ii) is invoked to ensure that when a secondary container's hydrogen concentration potentially exceeds 5% volume, release of that hydrogen to the then existing total volume (secondary container void plus cask void) will not result in a total mixture of greater than 5% volume hydrogen in a greater than 5% oxygen atmosphere. Maintaining the oxygen concentration lower than five (5) volume % assures a nonflammable mixture.

4.9 PERIODIC VERIFICATION LEAK RATE DETERMINATION FOR LEAKTIGHT STATUS

4.9.1 INTRODUCTION

The purpose of this section is to describe the method for performing a periodic leak test to demonstrate meeting the leaktight criterion per ANSI N14.5-1997. This test method is only applicable to a 10-160B cask with butyl rubber o-rings and ethylene propylene seals.

4.9.2 TEST CONDITIONS

The test is performed with a mass spectrometer leak detector. The test is conducted on the 10-160B by evacuating the cask cavity to at least 90% vacuum then pressurizing the cask cavity with helium (+1 psig, -0 psig). The annulus between the o-rings is evacuated until the vacuum is sufficient to operate the helium mass spectrometer leak detector and the helium concentration in the annulus is monitored. The acceptance criterion is 1.0×10^{-7} atm-cm^3/sec of air (leaktight). The detector sensitivity must be less than or equal to 5.0×10^{-8} atm-cm^3/sec. Similar tests are performed on the vent and drain ports, if so equipped.

4.10 REFERENCES

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4.11 CHAPTER 4 APPENDICES

Appendix 4.11.1	Properties of R-134a
Appendix 4.11.2	TRU Waste Payload Control
Appendix 4.113.	Compliance Methodology For TRU Waste From Battelle Columbus Labarotories (BCL), West Jefforson, OH
Appendix 4.11.4	Compliance Methodology For TRU Waste From Missouri University Research Reactor (Murr), Columbia, MO
Appendix 4.11.5	Compliance Methodology For TRU Waste From Energytechnology Engineering Center (Etec)
Appendix 4.11.6	Compliance Methodology For TRU Waste From Lawrence Livermore National Laboratory (Llnl), Livermore, CA
Appendix 4.11.7	Compliance Methodology For TRU Waste From Idaho National Engineering And Environmental Laboratory (Ineel), Idaho Falls, ID

4.11.1 PROPERTIES OF R-134A

P134a

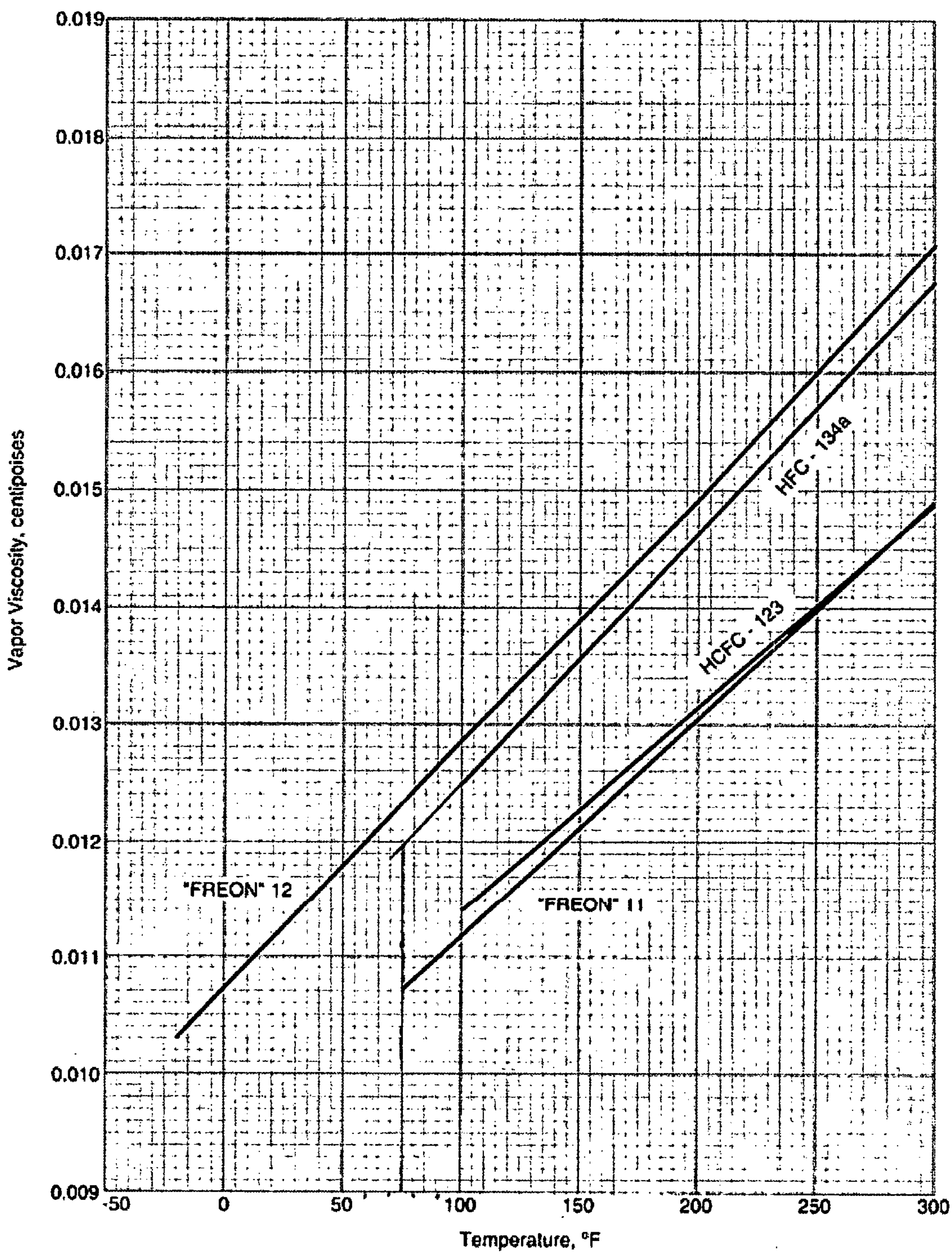
DuPont
Suva®
refrigerants

DuPont HFC-134a

Properties, Uses, Storage, and Handling

Suva® 134a refrigerant
Suva® 134a (Auto) refrigerant
Formacel® Z-4 foam expansion agent
Dymel® 134a aerosol propellant

Vapor Viscosity at Atmospheric Pressure



SUVA®

REFRIGERANTS

ART - 1

PRODUCT INFORMATION

Transport Properties of SUVA® Refrigerants:

SUVA® COLD - MP (HFC - 134a)
SUVA® TRANS - A/C (HFC - 134a)
SUVA® CENTRI - LP (HCFC - 123)

Viscosity
Thermal Conductivity
and
Heat Capacity
for the
Liquid and Vapor

DUPONT

Table 2
Physical Properties of HFC-134a

Physical Properties	Units	HFC-134a
Chemical Name	—	Ethane, 1,1,1,2-Tetrafluoro
Chemical Formula	—	CH_2FCF_3
Molecular Weight	—	102.03
Boiling Point at 1 atm (101.3 kPa or 1.013 bar)	°C °F	−26.1 −14.9
Freezing Point	°C °F	−103.3 −153.9
Critical Temperature	°C °F	101.1 213.9
Critical Pressure	kPa lb/in.^{2} abs	4060 588.9
Critical Volume	m^3/kg ft^3/lb	1.94×10^{-3} 0.031
Critical Density	kg/m^3 lb/ft^3	515.3 32.17
Density (Liquid) at 25°C (77°F)	kg/m^3 lb/ft^3	1206 75.28
Density (Saturated Vapor) at Boiling Point	kg/m^3 lb/ft^3	5.25 0.328
Heat Capacity (Liquid) at 25°C (77°F)	kJ/kg·K or Btu/(lb) (°F)	1.44 0.339
Heat Capacity (Vapor at Constant Pressure) at 25°C (77°F) and 1 atm (101.3 kPa or 1.013 bar)	kJ/kg·K or Btu/(lb) (°F)	0.852 0.204
Vapor Pressure at 25°C (77°F)	kPa bar psia	666.1 6.661 96.61
Heat of Vaporization at Boiling Point	kJ/kg Btu/lb	217.2 93.4
Thermal Conductivity at 25°C (77°F)		
Liquid	W/m·K Btu/hr·ft°F	0.0824 0.0478
Vapor at 1 atm (101.3 kPa or 1.013 bar)	W/m·K Btu/hr·ft°F	0.0145 0.00836
Viscosity at 25°C (77°F)		
Liquid	mPa·S (cP)	0.202
Vapor at 1 atm (101.3 kPa or 1.013 bar)	mPa·S (cP)	0.012
Solubility of HFC-134a in Water at 25°C (77°F) and 1 atm (101.3 kPa or 1.013 bar)	wt %	0.15
Solubility of Water in HFC-134a at 25°C (77°F)	wt %	0.11
Flammability Limits in Air at 1 atm (101.3 kPa or 1.013 bar)	vol %	None
Autoignition Temperature	°C °F	770 1418
Ozone Depletion Potential	—	0
Halocarbon Global Warming Potential (HGWP) (For CFC-11, HGWP = 1)	—	0.28
Global Warming Potential (GWP) (100 yr. ITH. For CO_2, GWP = 1)	—	1200
TSCA Inventory Status	—	Reported/Included
Toxicity AEL[a] (8- and 12-hr TWA)	ppm (v/v)	1000

[a] AEL (Acceptable Exposure Limit) is an airborne inhalation exposure limit established by DuPont that specifies time-weighted average concentrations to which nearly all workers may be repeatedly exposed without adverse effects.
Note: kPa is absolute pressure.

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4.11.2 TRU WASTE PAYLOAD CONTROL

1.0 INTRODUCTION

The purpose of this appendix is to identify the requirements for the control of remote handled transuranic (RH-TRU) and contact-handled transuranic (CH-TRU) waste, as defined by the U.S. Department of Energy (DOE) (Reference 12.1), as payload for transport in the 10-160B cask.

The payload parameters that are controlled in order to ensure safe transport of the TRU waste in the 10-160B cask are as follows:

- Restrictions on the physical and chemical form of CH-TRU and RH-TRU waste.
- Restrictions on payload materials to ensure chemical compatibility among all constituents in a particular 10-160B cask (including the parts of the cask that might be affected by the payload).
- Restrictions on the maximum pressure in the 10-160B cask during the transport period. (As a conservative analysis, the maximum pressure calculations are performed for a period of one year. Attachment C discusses the transport period.)
- Restrictions on the amount of potentially flammable gases that might be present or generated in the payload during the transport period.
- Restrictions on the layers of confinement for RH-TRU and CH-TRU waste materials in the waste containers packaged in the cask.
- Restrictions on the fissile material content for the cask.
- Restrictions on the hydrogen generation rates or the decay heat for the waste containers packaged in the cask.
- Restrictions on the weight for the loaded cask.

The methods for determining or measuring each restricted parameter, the factors influencing the parameter values, and the methods used by each shipping site for demonstrating compliance, are provided in the site-specific sub tier appendices. A payload container previously demonstrated to be in compliance with this appendix and subsequently shipped to another site remains acceptable for shipping provided the payload container has not been opened.

This appendix also includes the following as attachments:

- Description of the use of dose-dependent G values for TRU wastes (Attachment A)
- Chemical compatibility analysis for the TRU waste content codes (Attachment B).
- Shipping period for TRU waste in the 10-160B cask (Attachment C)

2.0 PURPOSE

2.1 Payload Parameters

The purpose of this appendix is to describe the payload requirements for RH-TRU and CH-TRU waste for transport in the 10-160B cask. Detailed descriptions of the site compliance methods associated with these requirements shall be provided in the site-specific sub tier appendices. Any and all assumptions used in the site compliance methods will be specified in the site-specific sub tier appendices

Sub tier appendices will be added, as necessary, to incorporate additional site-specific waste content codes that may be identified in the future. These appendices shall be submitted to the U.S. Nuclear Regulatory Commission (NRC) for review and approval, with shipments under additional codes authorized only after NRC approval.

Section 2.2 describes some typical methods of compliance available to show compliance with the individual payload parameter requirements. Section 3.0 describes the relationship between payload parameters and the classification of RH-TRU and CH-TRU materials into 10-160B cask payload content codes. Sections 4.0 through 11.0 discuss each payload parameter requirements for the 10-160B cask.

The payload parameters addressed in this document include:

- Physical form
- Chemical form and chemical properties
- Chemical compatibility
- Gas distribution and pressure buildup
- Payload container and contents configuration
- Isotopic characterization and fissile content
- Decay heat and hydrogen generation rates
- Weight.

2.2 Methods of Compliance

This section describes some typical methods that may be used to determine compliance with each payload parameter requirement and the controls imposed on the use of each method. Each shipping site shall select and implement a single compliance method, or a combination of methods, to ensure that the payload is compliant with each requirement and is qualified for shipment. These methods shall be documented in the site-specific sub tier appendices associated with this appendix.

A summary of typical methods of compliance that may be used for the 10-160B cask payload control is provided in the following sections.

2.2.1 Visual Examination

Visual examination at the time of waste generation may be used to qualify waste for transport. The operator(s) of a waste generating area shall visually examine the physical form of the waste according to site/equipment-specific procedures and remove all prohibited waste forms prior to its placement in the payload container. Observation of the waste generation process by an independent operator may be used as an independent verification of the compliance of the waste prior to closure of the payload container.

2.2.2 Visual Inspection

Visual inspection may be used to evaluate compliance with specific restrictions (e.g., visual inspection of payload container type, number of filters, etc.).

2.2.3 Radiography

Radiography may be used as an independent verification to qualify waste for transport. Radiography may be used to nondestructively examine the physical form of the waste, and to verify the absence of prohibited waste forms, after the payload container is closed.

2.2.4 Process Knowledge (Records and Database Information)

Process knowledge (PK) (also referred to as acceptable knowledge for the purposes of this document) refers to applying knowledge of the waste in light of the materials or processes used to generate the waste. PK is detailed information on the waste obtained from existing published or documented waste analysis data or studies conducted on wastes generated by processes similar to that which generated the waste. PK may include information on the physical, chemical, and radiological properties of the materials associated with the waste generation process(es), the fate of those materials during and subsequent to the process, and associated administrative controls. PK commonly includes detailed information on the waste obtained from existing waste analysis data, review of waste generating process(es), or detailed information relative to the properties of the waste that are known due to site-specific or process-specific factors (e.g., material accountability and tracking systems or waste management databases may supply information on waste isotopic composition or quantity of radionuclides, among other waste attributes). PK sources may include information collected by one or more of the compliance methods described in Sections 2.2.1 through 2.2.7.

Information obtained from existing site records and/or databases or knowledge of process may be used as a basis for reporting the absence of prohibited waste forms within waste containers. PK may also be used to show compliance with the physical and chemical form requirements and the payload container and contents requirements.

2.2.5 Administrative and Procurement Controls

Site-specific administrative and procurement controls may be used to show that the payload container contents are monitored and controlled, and to demonstrate the absence of prohibited items within waste containers.

2.2.6 Sampling Programs

Sampling programs may be used as an independent verification of compliance.

2.2.7 Measurement

Direct measurement or evaluation based on analysis using the direct measurement may be used to qualify waste (e.g., direct measurement of the weight or analysis of assay data to determine decay heat).

3.0 TRU WASTE PAYLOAD FOR 10-160B CASK

RH-TRU and CH-TRU waste is classified into content codes, which give a description of the RH-TRU and CH-TRU waste material in terms of processes generating the waste, the packaging methods used in the waste container(s), and the generating site. Content codes for the RH-TRU and CH-TRU waste to be shipped from each site are provided in the site-specific sub tier appendices to this appendix. Each content code provides a listing of all the payload parameters, their corresponding limits and restrictions, and the methods used by the site to meet these limits.

4.0 PHYSICAL FORM REQUIREMENTS

The physical form of waste comprising the 10-160B cask payload is restricted to solid or solidified materials in secondary containers. The total volume of residual liquid in a secondary container is restricted to less than 1% by volume. A secondary container is any container placed inside the primary container, the 10-160B cask. Secondary containers must be shored to prevent movement during accident conditions. Sharp or heavy objects in the waste shall be blocked, braced, or suitably packaged as necessary to provide puncture protection for the payload containers packaging these objects. Sealed containers greater than four liters in volume that do not have a known, measured, or calculated hydrogen release rate or resistance are prohibited.

5.0 CHEMICAL FORM AND CHEMICAL PROPERTIES

The chemical constituents allowed in a given content code determine the chemical properties of the waste. Specific requirements regarding the chemical form of the waste are as follows:

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

6.0 CHEMICAL COMPATIBILITY

Each content code has an associated chemical list based on PK information. Chemical constituents in a payload container assigned to a given content code shall conform to these chemical lists (included in each site-specific sub tier appendix). Chemicals or materials that are not listed are allowed in trace amounts (quantities less than one weight percent) in a payload container provided that the total quantity of trace chemicals or materials is restricted to less than five weight percent.

Chemical compatibility of the waste within itself and with the packaging shall ensure that chemical processes would not occur that might pose a threat to safe transport of the payload in the 10-160B Cask. The basis for evaluating the chemical compatibility shall be the U.S. Environmental Protection Agency (EPA) document, "A Method for Determining the Compatibility of Hazardous Wastes" (Reference 12.2). This method provides a systematic means of analyzing the chemical compatibility of specific combinations of chemical compounds and materials. Any incompatibilities between the payload and the packaging shall be evaluated separately if not covered by the EPA method.

As described in Attachment B to this appendix, the EPA method classifies individual chemical compounds, identified in the list of allowable chemicals and materials, into chemical groups and identifies the potential adverse reactions resulting from incompatible combinations of the groups. Attachment B presents the methodology and results for the chemical compatibility analyses performed on the list of allowable chemicals and materials associated with the TRU waste content codes expected to be shipped in the 10-160B Cask.

Chemicals and materials included on the content code chemical lists (in concentrations greater than one weight percent) shall be a subset of the list of allowable materials identified in Table B-1 of Attachment B to this appendix to demonstrate compliance with the compatibility requirement. The results of the compatibility analyses show that these content codes can be transported without any incompatibilities.

7.0 GAS DISTRIBUTION AND PRESSURE BUILDUP

Gas distribution and pressure buildup during transport of TRU waste in the 10-160B cask payload are restricted to the following limits:

- The gases generated in the payload must be controlled to prevent the occurrence of potentially flammable concentrations of gases within the payload confinement layers and the void volume of the inner vessel (IV) cavity. Specifically, hydrogen concentrations within the payload confinement layers are limited to 5 percent by volume during the shipping period (see Attachment C).
- The gases generated in the payload and released into the IV cavity must be controlled to maintain the pressure within the IV cavity below the acceptable packaging design limit of 31.2 pounds per square inch gauge (psig).

The primary mechanism for gas generation during TRU waste transportation in the 10-160B cask is by radiolysis of the waste materials. Gas generation from other mechanisms such as chemical, thermal, or biological activity is expected to be insignificant for the TRU waste payload. As discussed in Section 6.0, the chemicals and materials in the TRU waste are compatible and inert, and the restrictions of the materials that can be present in each content code precludes the occurrence of chemical reactions that can produce excessive gas. Gas generation from biological activity is expected to be insignificant given the transportation time, the nature of the waste (solid or solidified), and the environment of the payload (lack of nutrients, lack of water content, etc.). The temperatures of the payload, given the decay heat limits applicable, are expected to be below the normal usage range for the payload materials, resulting in very little potential for gas generation due to thermal decomposition.

8.0 PAYLOAD CONTAINER AND CONTENTS CONFIGURATION

Thirty-gallon and 55-gallon secondary containers may be used as payload containers in the 10-160B. The available volume of the cask cavity limits the number of payload containers that may be shipped at one time. In the case of 55-gallon drums, a maximum number of ten drums can be loaded into the 10-160B cask. Payload containers must have at least one filter vent. Filter vents shall be legibly marked to ensure both (1) identification of the supplier and (2) date of manufacture, lot number, or unique serial number. Typically, for purposes of radiological safety, TRU waste in the payload container may be packaged in one or more layers of confinement (plastic bags). Bags are closed with a twist and tape, fold and tape or heat-sealed closure. Heat-sealed bags may have a filter vent or be unvented.

Any drum or rigid polymer liner present inside a payload container shall have a filter vent or an opening that is equivalent to or larger than a 0.3-inch diameter hole before the container is transported in the 10-160B.

9.0 ISOTOPIC CHARACTERIZATION AND FISSILE CONTENT

9.1 Requirements

The 10-160B cask payload allows 325 FGE of fissile materials. Plutonium content in excess of 0.74 TBq (20 curies) per cask must be in solid form.

Compliance with the isotopic characterization and fissile content requirements involves the following steps:

- Determination of isotopic composition
- Determination of the quantity of radionuclides
- Calculation of the fissile mass and comparison with 325 FGE limit
- Calculation of plutonium content and confirmation of solid form if exceeding the 20 curie limit.

9.1.1 Isotopic Composition

The isotopic composition of the waste may be determined from direct measurements taken on the product material during the processing or post-process certification at each site, analysis of the waste, or from existing records and PK. The isotopic composition of the waste need not be determined by direct analysis or measurement of the waste unless PK is not available.

9.1.2 Quantity of Radionuclides

The quantity of the radionuclides in each payload container shall be estimated by either PK or direct measurement of the individual payload container, a summation of assay results from individual packages in a payload container, or a direct measurement on a representative sample of a waste stream (such as solidified inorganics). An assay refers to one of several radiation measurement techniques that determine the quantity of nuclear material in TRU wastes. Assay instruments detect and quantify the primary radiation (alpha, gamma, neutron) emanating from specific radionuclides, or a secondary radiation emitted from neutron interrogation techniques. The measured quantity of radiation is then used to calculate the quantity of other radionuclides. That calculation requires knowledge of the isotopic composition of the waste. Combinations of gamma spectroscopy and neutron measurements are often needed to calculate the quantity of nonfissile radionuclides.

9.1.3 Calculation of Fissile Mass

The calculation of the fissile mass shall be performed to demonstrate compliance with the 325 FGE limit using the values in Table 9.1.3.

Table 9.1.3 – Pu-239 Fissile Gram Equivalent, U-235 Fissile Equivalent Mass, Decay Heat, and Specific Activity of Selected Radionuclides

NUCLIDE	SPECIFIC ATOMIC NUMBER	Pu-239 FGE[1,2]	U-235 FEM[1,2,3]	DECAY HEAT[4] (W/g)	SPECIFIC ACTIVITY[5] (Ci/g)
U-233	92	9.00E-01	1.80E+00	2.84E-04	9.76E-03
U-235	92	6.43E-01	1.00E+00	6.04E-08	2.19E-06
Np-237	93	1.50E-02	3.00E-02	2.09E-05	7.13E-04
Pu-238	94	1.13E-01	2.25E-01	5.73E-01	1.73E+01
Pu-239	94	1.00E+00	2.00E+00	1.95E-03	6.29E-02
Pu-240	94	2.25E-02	4.50E-02	7.16E-03	2.30E-01
Pu-241	94	2.25E+00	4.50E+00	3.31E-03	1.04E+02
Pu-242	94	7.50E-03	1.50E-02	1.17E-04	3.97E-03
Am-241	95	1.87E-02	3.75E-02	1.16E-01	3.47E+00
Am-242m	95	3.46E+01	6.92E+01	4.32E-03	9.83E+00
Am-243	95	1.29E-02	2.57E-02	6.49E-03	2.02E-01
Cm-243	96	5.00E+00	1.00E+01	1.90E+00	5.22E+01
Cm-244	96	9.00E-02	1.80E-01	2.86E+00	8.18E+01
Cm-245	96	1.50E+01	3.00E+01	5.77E-03	1.74E-01
Cm-247	96	5.00E-01	1.00E+00	2.98E-06	9.38E-05
Cf-249	98	4.50E+01	9.00E+01	1.54E-01	4.14E+00
Cf-251	98	9.00E+01	1.80E+02	5.89E-02	1.60E+00

1 American National Standards Institute/American Nuclear Society (ANSI/ANS), 1981, "Nuclear Criticality Control of Special Actinide Elements," ANSI/ANS-8.15-1981, American National Standards Institute/American Nuclear Society, Washington, D.C.
2 American National Standards Institute/American Nuclear Society (ANSI/ANS), 1998, "Nuclear Criticality Safety in Operations with Fissionable Materials Outside Reactors," ANSI/ANS-8.1-1998, American National Standards Institute/American Nuclear Society, Washington, D.C.
3 American National Standards Institute/American Nuclear Society (ANSI/ANS), 1987, "Nuclear Criticality Control and Safety of Plutonium-Uranium Fuel Mixtures Outside Reactors," ANSI/ANS-8.12-1987, American National Standards Institute/American Nuclear Society, Washington, D.C.
4 International Commission on Radiological Protection, 1983. International Commission on Radiological Protection, 1983, "Radionuclide Transformations: Energy and Intensity of Emissions," Annals of the International Commission on Radiological Protection-38, Volumes 11-13, Pergamon Press, Oxford.
5Walker, F.W., Kiravac, G.J., and Rourke, F.M., 1983, Chart of the Nuclides, 13th Edition, Knolls Atomic Power Laboratories, Schenectady, NY.
Ci/g = Curies per gram.
W/g = Watts per gram.

9.1.4 Calculation of Plutonium Curies

The total plutonium (all plutonium isotopes) activity (curies) for each payload container shall be determined as described above and summed for the entire payload. If contents exceed 20 Ci, the plutonium waste form shall be confirmed as solid.

10.0 DECAY HEAT AND HYDROGEN GAS GENERATION RATES

10.1 Requirements

The hydrogen gas concentration shall not exceed five percent by volume in all void volumes within the 10-160B cask payload during the shipping period (see Attachment C). Payload containers of different content codes with different bounding G values and resistances may be assembled together as a payload, provided the decay heat limit and hydrogen gas generation rate limit for all payload containers within the payload is conservatively assumed to be the same as that of the payload container with the lowest decay heat limit and hydrogen gas generation rate limit.

10.2 Methodology of Ensuring Compliance with Flammable Gas Concentration Limits

As stated in Section 7, chemical, biological, and thermal gas generation mechanisms are expected to be insignificant in the 10-160B cask. In addition, potentially flammable VOCs are restricted to 500 ppm in the headspace of the 10-160B cask secondary containers (Section 5). Therefore, the only flammable gas of concern for transportation purposes is hydrogen. The concentration of hydrogen within any void volume in a layer of confinement of the payload or in the cask IV has been evaluated during the shipping period (see Attachment C).

Each content code shall have a unique and completely defined packaging configuration. Modeling the movement of hydrogen from the waste material to the payload voids, using the release rates of hydrogen through the various confinement layers, defines the relationship between generation rate and void concentration. This modeling allows determination of the maximum allowable hydrogen generation rate for a given content code to meet the 5% concentration limit. Based on hydrogen gas generation potential, quantified by hydrogen gas generation G values, the gas concentration limit can be converted to a decay heat limit. The maximum allowable hydrogen generation rates and decay heat limits for each site-specific content code shall be determined and reported in the site-specific payload compliance appendix (sub tier to this appendix). The modeling methodology for determining the hydrogen gas generation rate limit and the decay heat limit shall be presented in each site-specific payload compliance appendix. Conservative assumptions may be used in site-specific subtier appendices to introduce an additional margin of safety.

Parameters that govern the maximum allowable hydrogen generation rates and maximum allowable decay heat limits are listed below:

- Waste packaging configuration (i.e., the number and type of confinement layers).
- Release rates of hydrogen from each of these confinement layers.
- Void volume in the cask IV available for gas accumulation.

- Operating temperature and pressure for the payload in the 10-160B cask IV during the shipping period.
- Duration of the shipping period (see Attachment C).
- Hydrogen generation rates quantified by the G value of a waste material (the number of molecules of hydrogen produced per 100 eV of energy absorbed) (see Attachment A for description of dose-dependent G values and the Matrix Depletion Program).

10.3 Determination of Maximum Allowable Hydrogen Generation Rate

The modeling for determination of the maximum allowable generation rates is described below.

10.3.1 Input Parameters

The model parameters that must be quantified include the following:

Waste Packaging Configuration and Release Rates:

Packaging configurations are content code specific and will be documented in the sub-tier appendices. The bags, any rigid container with an opening or filter vent, and the drum filter vent all provide some resistance to the release of hydrogen from the container.

Pressure: The pressure is assumed to be isobaric and equal to one atmosphere. The mole fraction of hydrogen in each void volume would be smaller if pressurization is considered and would result in a greater maximum allowable hydrogen gas generation rate. Furthermore, the amount of hydrogen gas generated during the shipping period would be negligible compared to the quantity of air initially present at the time of sealing the 10-160B cask.

Temperature: The system temperature increases and decreases as the result of diurnal and seasonal variations in the environment (i.e, weather, solar radiation). Heat released from the radioactive components in the waste can also contribute to thermal input in the system.

The input parameters that can be described as a function of temperature are the release rate across the different confinement layers in the payload containers and the hydrogen G values for the waste streams. The resistance to the release of hydrogen is a function of temperature as documented in Appendix 6.9 of the CH-TRU Payload Appendices (Reference 12.3). The resistance generally decreases with increasing temperature and increases with decreasing temperature. The release rates across each confinement layer shall be defined at a specified temperature. The specified temperature shall be defined in terms of the expected operating temperature range. Since the release rates decrease with decreasing temperature, the use of the minimum expected operating temperature to calculate the lowest release rate will provide the maximum margin of safety when calculating the hydrogen gas generation rate or decay heat limit. Theoretically, the G value for a waste stream increases with increasing temperature (Reference 12.3). The G values at room temperature (i.e., 70°F) will be adjusted to the maximum expected operating temperature using the Arrhenius equation, unless it is demonstrated that the G values for the waste streams are not a function of temperature. The G values adjusted to reflect the maximum expected operating temperature would provide the maximum margin of safety in the calculated hydrogen gas generation rate or decay heat limits.

These are the important input parameters for determining the maximum allowable hydrogen generation rate limit. Other assumptions used in the mathematical analysis are included in Section 10.3.2.

10.3.2 Mathematical Analysis For Determining the Maximum Allowable Hydrogen Gas Generation Rates

At steady state, the flow rate of hydrogen across each of the confinement layers is equal to the same value and to the hydrogen generation rate. The maximum hydrogen concentration in a payload container with filter vents is reached at steady state. That is, a filter vented container with a hydrogen generation source has increasing concentrations of hydrogen with time until steady state conditions are reached. For the purpose of these calculations, it has been assumed that all payload containers are at steady state at the start of transport.

Once the drums are sealed inside the 10-160B cask IV, concentrations of hydrogen in the different layers increase due to the accumulation of hydrogen in the IV cavity. Some of the hydrogen generated during the transport period would accumulate in the payload containers, with the remainder being released into the cavity. For the purpose of these calculations, the mole fraction of hydrogen in a bag layer is set equal to the steady state value plus the mole fraction of hydrogen that has accumulated in the cavity. The IV cavity mole fraction of hydrogen is obtained by assuming that all of the hydrogen generated is released into the IV cavity. The maximum hydrogen concentration in the innermost layer is then limited to less than or equal to five (5) volume percent at the end of the shipping period by suitably choosing the gas generation rates. The maximum number of moles of hydrogen which can accumulate in the IV cavity is:

$$N_{gen} = (CG)(n_{gen})(t)$$

Where:

N_{gen} = total moles of hydrogen generated

CG = hydrogen gas generation rate per innermost layer of confinement (moles/sec)

n_{gen} = number of hydrogen generators (payload containers) in the 10-160B cask

t = shipping period duration, s

The maximum mole fraction of hydrogen in the 10-160B IV cavity is then equal to:

$$X_{fh} = (N_{gen}/N_{tg}) = \{N_{gen}/[P(V_{void})/RT]\}$$

Where:

X_{fh} = maximum mole fraction of hydrogen in the 10-160B IV cavity

N_{tg} = total moles of gas inside the 10-160B IV cavity

P = pressure inside the 10-160B, assumed to be constant at 1 atm (760 mm Hg), because the amount of gas generated is much less than the total amount of air originally in the cavity

V_{void} = void volume inside the 10-160B IV cavity (liters)

R = gas constant = 62.361 mm Hg-liter/mole-K

T = absolute temperature of air in the 10-160B IV cavity at the time of closure = 70°F
= 294K

The gas generation rate per innermost confinement layer that will yield a maximum hydrogen concentration of five (5) volume percent is then computed as the following:

$X_{inner} = X_{fh} + (CG)(R_{eff})$

Where:

X_{inner} = mole fraction of hydrogen in innermost confinement layer (a value of 0.05 has been used for this parameter since this is the maximum permissible concentration)

R_{eff} = the effective resistance to the release of hydrogen (sec/mole)

The effective resistance is computed by summing the individual confinement layer resistances. The resistance of a layer is equal to the reciprocal of the release rate from that layer. After substituting the first two equations into the third for X_{inner} and solving for the gas generation rate the following results:

$CG = (X_{inner})/\{R_{eff} + [(t)(n_{gen})/N_{tg}]\}$

where all terms are as defined previously.

10.4 Determination of Maximum Allowable Decay Limits for Content Codes

The maximum allowable decay heat limit for the CH-TRU waste content codes will be calculated assuming 100% deposition of the emitted energy into the waste within the drum. Specifically, the decay heat limit is calculated from the hydrogen gas generation rate and effective G-Value through the following expression:

$Q = [(CG)(N_A)/(G_{eff}\text{ molecules}/100\text{eV})][1.602\times10^{-19}\text{ watt-sec/eV}]$

Where:

CG = Hydrogen gas generation rate per innermost confinement layer in one drum (mol/sec).

Q = decay heat per innermost confinement layer (watts)

N_A = Avogadro's number = 6.023×10^{23} molecules/mole

Geff = G (hydrogen gas) = effective G value for flammable gas (molecules of hydrogenformed/100 electron volts [eV] emitted energy).

The maximum allowable decay heat limits for the RH-TRU waste content codes will be determined using the RadCalc Software (Reference 12.4). The current version of RadCalc is a Windows-compatible software program with applications in the packaging and transportation of radioactive materials. Its primary function is to calculate the generation of hydrogen gas by radiolytic production in the waste matrix of radioactive wastes. It contains a robust algorithm that determines the daughter products of selected radionuclides. The various functions in RadCalc can be used separately or together. The procedure is outlined below.

The first step in the evaluation of decay heat limits involves determining the activities of the radionuclides and daughters and the associated hydrogen gas generation rate at the time of sealing based on an initial isotopic ratio for the waste. The generation of hydrogen gas by radiolysis is a function of the energy absorbed by the waste. The second step in the evaluation of decay heat limits involves iterating on the total activity (decay heat limit) given the activity fractions from step one until the allowable hydrogen gas generation rate is obtained.

10.4.1 Databases and Input Parameters Used For Calculation of Maximum Allowable Decay Heat Limits

10.4.1.1 Radionuclide Databases

RadCalc uses radionuclide information, calculated gamma absorption fractions for selected container types, and G values to determine decay heat values. Radionuclide information is taken from FENDL/D-1.0 database (Reference 12.5). The following are a list of radionuclide parameters taken from FENDL/D-1.0 and the values they are used to calculate:

Radionuclide half-lives are used in calculating specific activity

Average heavy particle, beta-type radiation, and gamma radiation energies per disintegration are used in decay heat and hydrogen gas generation calculations

Discrete gamma energies and abundances are used in hydrogen gas generation calculations.

RadCalc uses the ORIGEN2 (Reference 12.6) database for decay calculations. The decay algorithms calculate the activity of the user specified source and daughter products over a specified period of time and the total number of disintegrations accumulated over this same time interval for each radionuclide. Parameters relevant to these calculations include atomic mass, atomic number, and state. These parameters are used for radionuclide identification and conversions. The decay constant and the branching ratios for decay modes are also used in the decay algorithms.

10.4.1.2 Gamma Absorption Fraction Input Parameters

RadCalc uses the total energy emitted by heavy particle and beta-type decay in calculating the volume of hydrogen produced. However, only a percent of gamma energy will be absorbed in the package and the waste. The absorbed gamma energy is a function of energy, waste density, material type, and geometry. The gamma energy absorbed by the waste is a function of the gamma emission strength, the quantity of gamma ray energy that is absorbed by collision with a waste particle, and the number of particles which interact with the gamma ray. Therefore, gamma energy absorption increases with increasing waste density. For a given waste density, a larger container will contain more particles, and therefore a higher percentage of the gamma ray energy would be absorbed than in a smaller container. The total cumulative absorbed dose for all nuclides and decay modes at time, t is evaluated as:

$$D_{total}(t) = \sum_{i=1}^{NR} AC_i/\lambda_i(0.82E_i^{\gamma} + E_i^{\beta} + E_i^{?} + E_i^{x})[1 - e^{-\lambda_i t}]$$

where,

$D_{total}(t)$ = Total cumulative absorbed dose at time, t (rad)
A = A proportionality constant equal to 1.84×10^{10} rad gram MeV^{-1} yr^{-1} Ci^{-1}
C_i = The specific activity of the "i"th nuclide in Curies/gram of waste
λ_i = The decay constant of the "i"th radionuclide (yr^{-1})
NR = Number of radionuclides
E_i^{γ} = λ energy in MeV of the "i"th radionuclide extracted from Flaherty et al. (Reference 12.11)
E_i^{β} = Average beta energy in MeV of the "i"th nuclide. The average beta energy is approximately one-third of the sum of the possible beta emissions multiplied by the relative abundance of each emission and were obtained from Flaherty et al. (Reference 12.7).
E_i^{x} = The absorbed secondary energy in MeV of the "i"th radionuclide. The secondary radiations result from the transition of a radionuclide from an excited state to the ground state and were obtained from Flaherty et al. (Reference 12.7).
$E_i^{?}$ = The absorbed gamma ray energy in MeV of the "i"th nuclide. The fraction of gamma energy that is absorbed by the waste is a function of the waste density and waste container geometry, and is evaluated for each radionuclide "i" as:
$E_i^{?}$ = $\sum_j n_{ij} f_{ij} E_{ij}^{?}$

where,

$\sum_j$ = the summation of the fractions of the gamma ray energies absorbed for all gamma emissions of the "i"th nuclide.
n_{ij} = the abundance of the "j"th gamma ray per decay of the "i"th nuclide
f_{ij} = the fraction of energy, of the "j"th gamma ray of the "i"th nuclide that is absorbed in the waste.
$E_{ij}^{?}$ = the energy in MeV, of the "j"th gamma ray of the "i"th nuclide.

RadCalc uses curve fits obtained from Flaherty et al. (Reference 12.7) and recalculated using the Monte Carlo N-Particle (MCNP) transport code (Reference 12.8) for ten containers, for obtaining the absorbed gamma dose.

The cask is not currently recognized by the RadCalc software. Therefore, another container with dimensions directly proportional to the cask was used in the calculations.

10.4.1.3 G Value Data

G values for TRU waste are content specific. G values are determined based on the bounding materials present in the payload. The G values at room temperature (i.e., 70°F) will be adjusted to the maximum expected operating temperature using the Arrhenius equation (unless data shows that the G values are temperature independent) in order to introduce a greater margin of safety in the calculated hydrogen gas generation rate or decay heat limits. The use of temperature-dependent and or dose-dependent G values for authorized content codes is discussed in the individual site-specific sub tier appendices. The methodology associated with the determination of dose-dependent G values pursuant to the Matrix Depletion Program is further discussed in Attachment A of this Appendix.

10.4.2 Input Parameters

The input parameters for the RadCalc software can be placed in three groups: (1) container data, (2) waste data, and (3) source data.

10.4.2.1 Container Data

RadCalc requires as input the following parameters associated with the container for which the maximum allowable decay heat limit is being calculated:

Container Type - The payload container for the waste material

Container Dates - Date of generation, date of sealing, and shipping period

Package Void Volume - void volume of the payload container.

A 6- by 6-foot liner with a volume equal to the cask is used to represent the payload container in the RadCalc input file as the RadCalc database does not include the cask. The package void volume for a 10-160B cask is 1938 liters as shown earlier.

10.4.2.2 Waste Data

RadCalc requires as input the following parameters associated with the waste for which the maximum allowable decay heat limit is being calculated:

Physical Form – liquid, solid, or gas

Waste Volume – volume of the waste, cm^3

Waste Mass – mass of the waste, g

G Value – G value of the waste, molecules per 100 eV

Liquids and gas wastes are prohibited in the 10-160B cask. The volume of the waste is determined based on the maximum number of 55-gallon drums that can be placed in the 10-160B cask. The waste volume in one drum is assumed to be 217 liters per drum (the external volume of a 55-gallon waste drum) and 2170 liters for 10 drums of waste in the cask. The waste volume is used by RadCalc, along with the waste mass, to determine the volume of hydrogen generated in the cask. The mass of the waste is calculated based on the assumed bulk density of the waste. The volume of hydrogen generated is a function of container waste density and geometry (Reference 12.7). The most conservative estimate of the volume of hydrogen (greatest volume) would occur at the highest possible bulk density of the waste. Appropriate density values for the RH-TRU content codes are discussed in the individual site-specific sub-tier appendices.

10.4.2.3 Source Data

RadCalc requires as input the following parameters associated with the source for which the maximum allowable decay heat limit is being calculated:

Isotopic Composition - List of radionuclides present in the waste

Activity - Reported activities of the listed radionuclides in curies or Becquerel.

10.4.3 Procedure For Determining Maximum Allowable Decay Heat Limits

The necessary inputs are provided to the code prior to initiating a run. A time period equivalent to the shipping period (Attachment C) is conservatively assumed between the date of beginning of decay and date of analysis. The model is run with the initial isotopic composition and activity and the corresponding hydrogen gas generation rate is obtained. It is compared with the maximum allowable hydrogen gas generation rate as obtained from Section 10.3, and the scaling factor is obtained by dividing the maximum allowable hydrogen gas generation rate by the RadCalc obtained rate. The isotopic composition is scaled by this differential factor. This is done on the basis of the assumption that the maximum decay heat occurs at the time of maximum activity that will result in the maximum hydrogen gas generation rate. The associated decay heat value will be the maximum decay heat limit as the decay heat limit shares a direct relationship with the hydrogen gas generation rate, independent of time.

10.5 Methodology for Compliance with Payload Assembly Requirements

Prior to shipping, the Transportation Certification Official at the shipping site (TCO) shall ensure that the 10-160B Cask payload consists of payload containers belonging to the same or equivalent content code. In the event that payload containers of different content codes with different bounding G values and resistances are assembled together in the 10-160B Cask, the TCO shall ensure that the decay heat and hydrogen gas generation rate for all payload containers within the payload are less than or equal to the limits associated with the payload container with the lowest decay heat limit and hydrogen gas generation rate limit.

11.0 WEIGHT

The weight limit for the contents of the loaded cask is 14,250 pounds.

12.0 REFERENCES

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Attachment A

Use of Dose-Dependent G Values for TRU Wastes

A.1.0 BACKGROUND

This attachment describes controlled studies and experiments that quantify the reduction in the rate of hydrogen gas generation (G value) over time based on the total dose received by the target matrix. Over time and with constant exposure to radiation, hydrogen is removed from the hydrogenous waste or packaging material (the matrix), thus decreasing the number of hydrogen bonds available for further radiolytic breakdown (the matrix is depleted). Therefore, when the alpha-generating source is dispersed in the target matrix, it will affect only that portion of the target material that is present in a small spherical volume surrounding the source particle. As the amount of available hydrogen is reduced over time, the effective G value decreases with increasing dose toward a value that is defined as the "dose-dependent G value." This phenomenon of matrix depletion has been studied and observed in previous studies (see Appendix 3.3 of the CH-TRU Payload Appendices [Reference A.7.1]). A formal study was recently undertaken to quantify dose-dependent G values under strictly controlled conditions and evaluate their applicability to transuranic (TRU) wastes (Reference A.7.2). This appendix summarizes the results of this study and derives dose-dependent G values for TRU waste materials, as applicable.

A.2.0 OVERVIEW OF THE MATRIX DEPLETION PROGRAM

The Matrix Depletion Program (MDP), established as a joint venture by the U.S. Department of Energy (DOE) National TRU Waste Program and the DOE Mixed Waste Focus Area, is comprised of the following elements:

1. Laboratory experiments for the assessment of effective G values as a function of dose for matrices expected in contact-handled (CH)-TRU wastes (polyethylene, polyvinyl chloride, cellulose, etc.), as well as an assessment of the impact of other variables (isotope, temperature, etc.) on the dose-dependent G values.

2. Measurements of effective G values and hydrogen concentrations in real waste and comparisons with dose-dependent G values.

3. Analysis to calculate effective G values from fundamental nuclear and molecular mechanisms.

A total of 60 one-liter test cylinders containing the simulated TRU waste materials were used, with two replicates for each test. Solid waste matrices (plastics and cellulose) were prepared by sprinkling the radioactive isotope powders over the matrix, folding the matrix over the contaminated surfaces, securing them, and placing them in test cylinders. Solidified waste matrices (cement) were mixed with a solution of dissolved plutonium oxide, water, and sodium hydroxide to adjust the pH. The test cylinders were connected to measurement devices that facilitated sampling of generated gases and quantifying the gas generation over time. The entire test apparatus was controlled by a personal computer through LABVIEW software.

All activities of the MDP were performed under a documented quality assurance (QA) program that specified the performance-based QA/quality control requirements for all aspects of the program (Reference A.7.3). The experiments under the MDP were designed using an U.S. Environmental Protection Agency established procedure to formulate data quality objectives.

QA objectives for the MDP were defined in terms of precision, accuracy, representativeness, completeness, and comparability. All data were validated and verified pursuant to the performance objectives of the program. The MDP was run for a duration of approximately three years.

A.3.0 RESULTS AND CONCLUSIONS FROM THE MDP

Results from the MDP are described in detail in the MDP final report (Reference A.7.2) and are summarized in Table A-1 in terms of the dose-dependent G values for each matrix tested.

For all matrices, these dose-dependent G values were achieved within a maximum dose of 0.006 watt*year (product of watts times years). For example, for a waste container with a watt loading of 0.1 watt, the dose-dependent G value shown in Table A-1 would be reached after 0.06 years or 22 days. The lower the watt loading, the longer it would take for the watt*year criteria to be satisfied and the dose-dependent G value to be applicable.

Table A-1. Experimental Dose-Dependent G Values

Matrix	Current Waste Material Type G Value	Number of Observations	Mean	Standard Deviation	95% Upper Tolerance Limit
Cement	1.3	202	0.25	0.18	0.58
Dry Cellulose	3.4	302	0.27	0.18	0.59
Polyethylene	3.4	186	0.23	0.22	0.64
Polyvinyl Chloride	3.4	99	0.14	0.19	0.50
Wet Cellulose	3.4	276	0.44	0.36	1.09

Source: Reference A.7.1.

The following conclusions can be drawn from the results of the MDP:

- Increasing dose (product of the decay heat loading and elapsed time) decreases the effective G value for hydrogen due to depletion of the matrix in the vicinity of the alpha-emitting radioactive source particle. The lower G value, called the "dose-dependent G value," is applicable after a dose of 0.006 watt*years.
- As with initial G values, the dose-dependent G values are a function of the waste matrix.
- Dose-dependent G values for wet cellulosics were higher than those for dry cellulosics because of the presence of water.
- The dose-dependent G values were independent of temperature based on testing performed at room temperature and at 140°F.
- Experiments performed with different particle sizes show that while initial G values could be higher for smaller particle sizes, the dose-dependent G values for all particle sizes tested are bounded by the values shown in Table A-1.
- Previous experiments that included agitation of cylinders similar to those used in the MDP indicated that agitation did not affect dose-dependent G values (See Section A.4.0).
- Isotopic composition did not have a significant impact on the dose-dependent G values based on experiments performed with two different isotopes of Pu (^{238}Pu and ^{239}Pu).

Data from actual CH-TRU waste containers at the Rocky Flats Environmental Technology Site and the Idaho National Engineering and Environmental Laboratory show that even when compared to the mean dose-dependent G values from the matrix depletion experiments, G values from real waste containers are lower. Theoretical analysis, using nuclear and molecular level mechanisms, also shows that hydrogen generation from radiolysis and matrix depletion is consistent with the experimental results from the MDP.

A.4.0 EFFECTS OF AGITATION ON DOSE-DEPENDENT G VALUES

The effects of agitation on dose-dependent G values have been evaluated by previous studies at both the laboratory-scale and drum-scale levels, and agitation has been found to have no impact on dose-dependent gas generation rates. Agitation could occur under transportation conditions but, as shown below, does not cause redistribution of the radionuclides to a nondepleted portion of the waste matrix and therefore does not cause an increase in the dose-dependent G values as shown in this section.

The earliest study of the effects of agitation on gas generation rates was performed by Zerwekh at the Los Alamos National Laboratory (LANL) in the late 1970s (Reference A.7.4). Zerwekh prepared an experimental array of 300-cm^3 stainless steel pressure cylinders, each loaded with 52.5 grams of a single or a combination of TRU waste matrix materials. Materials tested included cellulosics, polyethylene (PE) (low-density) bags, PE (high-density) drum liner material, and other typical TRU waste material. Net gas G values as a function of elapsed time were derived for each of the test cylinders and showed the characteristic decrease in G value with dose. Thorough mechanical shaking of two of the cylinders on two different occasions did not affect the rate of gas generation (Reference A.7.4).

In a second study, researchers at LANL retrieved six drums of ^{238}Pu contaminated waste from storage to study gas generation (Reference A.7.5). The wastes were contained in 30-gallon drums and consisted of either mixed cellulosic wastes or mixed combustible wastes. The drums ranged in age from four to ten years. Two of the drums containing mixed combustible wastes were tumbled end over end in a drum tumbler for four hours (Reference A.7.5). The researchers also reported G values for three drums of newly generated waste that were previously characterized. All six retrieved drums had measured G values that were lower than those measured for newly generated drums. The researchers concluded that the retrieved drums' effective hydrogen G values corroborate the matrix depletion observed for the laboratory-scale experiments in Reference A.7.4. Also, because of the vigorous nature of the agitation experienced by two of the four-year-old drums, the researchers concluded that radionuclide redistribution does not occur under transportation conditions (Reference A.7.5).

More recently, experiments on alpha radiolysis were conducted at LANL by Smith et al. (Reference A.7.6) to determine radionuclide loading limits for safe on-site storage of containers at LANL. Simulated TRU waste matrices in the form of cellulose (cheesecloth and computer paper) and PE (bottle and bag material forms) were contaminated with pre-weighed amounts of $^{238}PuO_2$ powder. The first PE experiment (referred to as PE test cylinder 1) used a PE bottle to allow any potential later redistribution of the radionuclide particles to fresh matrix surfaces. The radionuclide powder was poured into the bottle, which was sealed and gently rolled to allow contamination of the sides of the bottle. The bottle was returned to an upright position and the lid was punctured with an approximately 0.5-inch diameter hole to allow free movement of generated gas from the bottle to the test canister. It was noted that the $^{238}PuO_2$ powder adhered to the walls of the bottle and very little, if any, collected at the bottom. The remaining five test sample matrices were prepared by uniformly sprinkling the powder across a letter-sized sheet of the waste matrix, folding the sheet in toward the center from each end, and finally rolling each sheet into a cylindrical shape of about 2 by 4 inches. The six test matrices were placed inside six cylindrical, 2.06 liter stainless steel sealed canisters. Gas samples were extracted periodically and analyzed by mass spectrometry.

The first test canister for each waste material was subjected to vigorous dropping, rolling several times, and shaking on day 188 to simulate drum handling and transportation that could result in redistribution of the $^{238}PuO_2$ to fresh nondepleted portions of the waste matrix. Any agitation effects were expected to be most pronounced for the test canister containing the PE bottle in PE test cylinder 1, because some aggregation of the powder at the bottom of the bottle was expected. However, no change in the effective hydrogen G value was observed for either the cellulose or PE test canisters.

In summary, three separate studies have investigated the ability of agitation to redistribute radionuclide particles to nondepleted surfaces of TRU waste matrices. All three studies conclusively showed that the dose-dependent G values are not impacted by agitation during transportation. Application of dose-dependent effective G values is discussed in Section A.5.0.

A.5.0 APPLICATION OF DOSE-DEPENDENT G VALUES TO CH- and RH-TRU WASTES

Application to CH-TRU dose-dependent G values, based on the results of the MDP, are applicable to solid organic and solid inorganic CH-TRU waste material types. Solidified organic and inorganic solid wastes will be governed by the initial G values under all conditions because the solidified, aqueous nature of these waste forms, in theory, precludes observation of matrix depletion (as the matrix near the Pu is depleted, water can move to replace the depleted matrix). The watt*year criteria used to apply dose-dependent G values is twice the highest value recorded in the experiments. The dose-dependent G values chosen for the TRU waste materials are the 95% upper tolerance limit values shown in Table A-1. The application of dose-dependent G values to the waste types is as follows:

- Solid Inorganic Waste: Dose-dependent G value (H_2) for containers meeting a watt*year criteria of 0.012 is governed by assuming polyethylene as the packaging material, with a G value (H_2) of 0.64.
- Solid Organic Waste: Dose-dependent G value for containers meeting a watt*year criteria of 0.012 is governed by wet cellulosic materials in the waste, with a G value (H_2) of 1.09.

As can be seen from Table A-1, the above dose-dependent G values represent conservative values that are more than two times the mean value from the experiments.

The phenomenon of matrix depletion primarily stems from the nature of the waste matrix and the type of penetrating radiation; thus, if the waste matrix and radiation type are properly accounted for, G value results obtained for CH-TRU waste can be applicable to RH-TRU waste as well.

With respect to waste matrix, both CH- and RH-TRU waste are characterized by a large percentage of the materials shown in Table A-1. Thus, the required level of conservatism will be attained by assuming that the waste is comprised of the matrix with the greatest associated G value.

With respect to radiation type, both CH- and RH-TRU waste are characterized by large amounts of alpha and beta emitters; the primary difference between the two waste forms is the noticeable presence of gamma emitters in RH-TRU waste. Thus, while the G value for CH-TRU waste is dependent primarily on the emitted decay heat (since most or all of the alpha and beta radiation is absorbed by the waste matrix and contributes to hydrogen gas generation), the G value for RH-TRU waste is dependent on the actual fraction of the decay heat that is absorbed by the waste matrix.

Since the results of the MDP are applicable only to alpha and beta radiation, while gamma radiation effects were not quantified, G values for RH-TRU waste can be separated into those for alpha, beta, and gamma radiation and treated accordingly. Thus, RH-TRU waste G values for alpha and beta radiation can be treated as being dose-dependent and the lower "dose-dependent G value" used after a dose of 0.012 watt*years (twice the highest value recorded in the experiments), while G values for gamma radiation can conservatively be treated as not being dose-dependent and the initial G value used.

A.6.0 COMPLIANCE WITH WATT*YEAR CRITERIA

For RH-TRU waste, content codes using dose-dependent G values to obtain maximum allowable decay heat limits are required to comply with the watt*year criteria of 0.012 watt*years. Demonstration of compliance with the 0.012 watt*year criteria is carried out as follows:

1. Determine maximum allowable decay heat (Q) using the α and β dose-dependent G values and non-dose-dependent G values for γ radiation.

2. Determine decay heat limit that excludes the gamma radiation contribution (Q_{allow}) as a function of the maximum allowable hydrogen gas generation rate (Cg) and bounding G value for the content code as:

$$Q_{allow} = \frac{Cg \; * \; N_A \; * \; 1.602(10)^{-19} \; watt\text{-}\sec/eV}{G}$$

where,

Cg	=	Maximum allowable hydrogen gas generation rate limit obtained using the methodology described in site-specific sub tier appendices.
G	=	Bounding G value (molecules of hydrogen formed/100 electron volts [eV] emitted energy)
N_A	=	Avogadro's number (6.023×10^{23} molecules/mole).

3. Determine the Q_{allow}/Q ratio, which represents the minimum fraction of the total container decay heat that excludes the gamma radiation contribution.

$$Q_{watt*yr} = \frac{Q_{allow}}{Q} * Q_{actual}$$

4. Calculate the decay heat value for a container ($Q_{watt*yr}$) for watt*year compliance as:

   where, Q_{actual}, is the actual decay heat value for the container.

5. The watt*year for the payload is calculated as $Q_{watt*yr}$ times the elapsed time, and this value is compared to the 0.012 watt*year limit. The elapsed time is the time elapsed between the time of generation of the payload and the time of sealing of the payload.

A.7.0 REFERENCES

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Attachment B

Chemical Compatibility of
TRU Waste Content Codes

B.1.0 INTRODUCTION

This attachment describes the method used for demonstrating chemical compatibility in a given payload container, within a given waste stream/content code, and among content codes for the - 10-160B Cask payload. The chemical compatibility analyses cover normal conditions of transport as well as hypothetical accident conditions.

B.2.0 METHODOLOGY FOR CHEMICAL COMPATIBILITY ANALYSES

The chemical compatibility analysis was performed using the methods described in the EPA document "A Method for Determining the Compatibility of Hazardous Wastes" (Reference B.3.1).

Waste streams/content codes are classified as potentially chemically "incompatible" if the potential exists for any of the following reactions:

- explosion
- heat generation
- gas generation (flammable gases)
- pressure build up (nonflammable gases)
- toxic by-product generation
- fire
- violent polymerization
- solubilization of toxic substances.

Note: Solubilization of toxic substances and toxic byproduct generation are not directly a concern for transportation of waste in the 10-160B Cask payload but have been included for completeness.

Each generator and storage site has produced a comprehensive list of chemicals present in an approved content code. These chemical components are determined by examining the process technology, and by comprehensive analyses of the process knowledge. Under this system, all chemical inputs into the system are accounted for, even though all of these components may not be a final part of the waste. For example, generator sites might include both acids and bases in their lists, even though the two groups have been neutralized prior to placement in a payload container.

A list of chemicals/materials that may be present in TRU waste in concentrations greater than or equal to 1 percent by weight was compiled based on process knowledge from the potential waste shipping sites, as shown in Table B-1. The chemical compatibility analyses for the 10-160B Cask payload are then based on this table.

Although Table B-1 only identifies chemicals/materials in TRU waste in concentrations greater than or equal to 1 percent by weight, interactions involving compounds present in trace quantities (<1 percent by weight) do not pose an incompatibility problem for the following reasons:

- Most trace chemicals reported by the sites are in concentrations well below the trace limit of 1 weight percent.
- The trace chemicals are usually dispersed in the waste, which further dilutes concentrations of these materials.
- Total trace chemicals within a payload container are limited to less than 5 weight percent.
- Trace chemicals that might be incompatible with materials/chemicals in concentrations greater than or equal to 1 percent by weight would have reacted during the waste generating process prior to placement in payload containers.
- The waste is either solidified and immobilized (solidified materials) or present in bulk form as a solid (solid materials). In almost all cases, any possible reactions take place before the waste is generated in its final form.

Potential incompatibilities between the allowable materials/compounds listed in Table B-1 have been analyzed for the 10-160B payload. The analysis assigned EPA chemical reactivity group numbers and names to each allowable material. The reactivity group numbers were assigned based on information provided in Reference B.3.1. If the allowable material (or chemical) is a non-reactive inorganic material (not covered under the EPA reactivity group numbers), it was assigned a reactivity group number of "0" to reflect a complete analysis for all allowable materials (materials assigned a reactivity group number of "0" do not present a compatibility concern). The compiled list of allowable materials and assigned reactivity group numbers is provided in Attachment 1.0.

The list of allowable materials and assigned reactivity group numbers was sorted by reactivity group number and then condensed to form a list of the represented reactivity groups (Attachment 2.0).

Using the list of represented reactivity groups, a hazardous waste compatibility chart was generated. The chart, which is provided in Attachment 3.0, is a reduced version of the hazardous waste compatibility chart presented in Reference B.3.1. The chart summarizes the potential types of reactions possible between each of the reactivity groups represented in the list of allowable materials. The reaction codes and consequences of the reactions are specified for each combination of two reactivity groups.

Using the waste compatibility chart, a list of potential chemical incompatibilities in the TRU waste was generated. The list, which is presented in Attachment 4.0, also presents assessments of whether or not the reaction associated with each of the potential chemical incompatibilities will or will not occur. The results of the assessments indicated that no chemical incompatibilities will occur. Therefore, by precluding all potential incompatibilities, the chemicals/materials identified in Table B-1 are determined to be compatible for the 10-160B Cask payload.

Chemical lists provided for site-specific TRU waste content codes identified for shipment in the 10-160B Cask are a subset of Table B-1. Chemical incompatibilities therefore do not exist in and across these content codes. Only content codes with chemical lists that have been evaluated by this process and determined to be compatible shall be approved for shipment in the 10-160B Cask.

Table B-1 Table of Allowable Materials for TRU Waste[a]

Absorbent polymers, organic
Absorbents/adsorbents (e.g., Celite®, diatomaceous earth, diatomite, Florco®, Oil-Dri®, perlite, vermiculite)
Acids (inorganic and organic)
Alcohols (e.g., butanol, ethanol, isopropanol, methanol)
Alumina cement
Aquaset® products (for aqueous solutions)
Aqueous sludges or solutions
Asbestos
Ash (e.g., ash bottoms, fly ash, soot)
Asphalt
Bakelite® b
Batteries, dry (e.g., flashlight)
Caustics
Cellulose (e.g., Benelex®, cotton Conwed®, paper, rags, rayon, wood)
Cellulose acetate butyrate
Cellulose propionate
Ceramics (e.g., molds and crucibles)
Chlorinated polyether
Clays (e.g., bentonite)
Concrete
Detergent, solid (e.g., emulsifiers, surfactants)
Envirostone® (no organic emulsifiers allowed)
Esters (e.g., ethyl acetate, polyethylene glycol ester)
Ethers (e.g., ethyl ether)
Fiberglass (inorganic and organic)
Filter media (inorganic and organic)
Firebrick
Glass (e.g., borosilicate glass, labware, leaded glass, Raschig rings)
Graphite (e.g., molds and crucibles)
Greases, commercial brands
Grit
Halogenated organics (e.g., bromoform; carbon tetrachloride; chlorobenzene; chloroform; 1,1-dichloroethane; 1,2-dichloroethane; 1,1-dichloroethylene; cis-1,2-dichloroethylene; methylene chloride; 1,1,2,2-tetrachloroethane; tetrachloroethylene; 1,1,1-trichloroethane; 1,1,2-trichloroethane; trichloroethylene; 1,1,2-trichloro-1,2,2-trifluoroethane)
Heel (e.g., ash heel; soot heel; firebrick heel; sand, slag, and crucible heel)
Hydrocarbons, aliphatic (e.g., cyclohexane, n-paraffin hydrocarbons)
Hydrocarbons, aromatic (e.g., benzene; ethyl benzene; toluene; 1,2,4-trimethylbenzene; 1,3,5-trimethylbenzene; xylene)
Insulation (inorganic and organic)
Ketones (e.g., acetone, methyl ethyl ketone, methyl isobutyl ketone)
Leaded rubber (e.g., gloves, aprons, sheet material)
Leather
Magnesia cement (e.g., Ramcote® cement)
Magnesium alloy

Table B-1 Table of Allowable Materials for TRU Waste[a]

(Continued)

Metal hydroxides
Metal oxides (e.g., slag)
Metals (e.g., aluminum, cadmium, copper, steel, tantalum, tungsten, zinc)
Nitrates (e.g., ammonium nitrate, sodium nitrate)
Oil (e.g., petroleum, mineral)
Organophosphates (e.g., tributyl phosphate, dibutyl phosphate, monobutyl phosphite)
Paint, dry (e.g., floor/wall paint, ALARA)
Petroset® products (for aqueous solutions)
Plastics [e.g., polycarbonate, polyethylene, polymethyl methacrylate (Plexiglas®, Lucite®), polysulfone, polytetrafluoroethylene (Teflon®), polyvinyl acetate, polyvinyl chloride (PVC), polyvinylidene chloride (saran)]
Polyamides (nylon)
Polychlorotrifluoroethylene (e.g., Kel-F®)
Polyesters (e.g., Dacron®, Mylar®)
Polyethylene glycol (e.g., Carbowax®)
Polyimides
Polyphenyl methacrylate
Polypropylene (e.g., Ful-Flo® filters)
Polyurethane
Polyvinyl alcohol
Portland cement
Resins (e.g., aniline-formaldehyde, melamine-formaldehyde, organic resins, phenol-formaldehyde, phenolic resins, urea-formaldehyde)
Rubber, natural or synthetic [e.g., chlorosulfonated polyethylene (Hypalon®), ethylene-propylene rubber, EPDM, polybutadiene, polychloroprene (neoprene), polyisobutylene, polyisoprene, polystyrene, rubber hydrochloride (pliofilm®)]
Salts (e.g., calcium chloride, calcium fluoride, sodium chloride)
Sand/soil (inorganic and organic)
Trioctyl phosphine oxide
Water
Waxes, commercial brands
Other inorganic materials

[a]Other chemicals or materials not identified in this table are allowed provided that they meet the requirements for trace constituents (less than one weight percent of the payload container individually; less than five weight percent of the payload container combined). All materials in the final waste form must be inert (nonreactive), be in a nonreactive form, or have been rendered nonreactive.

[b]Bakelite is a trademark for materials that can be composed of several different polymers, including polyethylene, polypropylene, epoxy, phenolic, polystyrene, phenoxy, perylene, polysulfone, ethylene copolymers, ABS, acrylics, and vinyl resins and compounds.

B.3.0 REFERENCES

B.3.1 Hatayama, H. K., Chen, J.J., de Vera, E.R., Stephens, R.D., Storm, D.L., "A Method for Determining the Compatibility of Hazardous Wastes," EPA-600/2-80-076, EPA, Cincinnati, Ohio, 1980.

Attachment 1.0

Lists of Allowable Materials and
Associated Reactivity Groups

Lists of Allowable Materials and Associated Reactivity Groups		
Allowable Chemical/Material[a]	**Reactivity Group**[b]	
	Name	**Number**[c]
Absorbent polymers, organic	Combustible and flammable materials, miscellaneous	101
Absorbents/adsorbents (e.g., Celite®, diatomaceous earth, diatomite, Florco®, Oil-Dri®, perlite, vermiculite)	Other solidification materials and absorbents/adsorbents	0
Acids, inorganic	Acids, Mineral, Non-oxidizing	1
Acids, inorganic	Acids, Mineral, Oxidizing	2
Acids, organic	Acids, organic	3
Alcohols (e.g., butanol, ethanol, isopropanol, methanol)	Alcohols and Glycols	4
Alumina cement	Water reactive substance	107
Aquaset® products (for aqueous solutions)	Other solidification materials and absorbents/adsorbents	0
Aqueous sludges or solutions	Other solidification materials and absorbents/adsorbents	0
Asbestos	Other Inorganics (non-reactive)	0
Ash (e.g., ash bottoms, fly ash, soot)	Other Inorganics (non-reactive)	0
Asphalt	Combustible and flammable materials, miscellaneous	101
Bakelite®	Combustible and flammable materials, miscellaneous	101
Batteries, dry (e.g., flashlight)	Metals, alkali and alkaline earth, elemental and alloys	21
Caustics	Caustics	10
Cellulose (e.g., Benelex®, cotton Conwed®, paper, rags, rayon, wood)	Combustible and flammable materials, miscellaneous	101
Cellulose acetate butyrate	Polymerizable compounds	103
Cellulose propionate	Polymerizable compounds	103
Ceramics (e.g., molds and crucibles)	Other Inorganics (non-reactive)	0
Chlorinated polyether	Ethers	14
Clays (e.g., bentonite)	Other Inorganics (non-reactive)	0
Concrete	Other solidification materials and absorbents/adsorbents	0

Lists of Allowable Materials and Associated Reactivity Groups		
Allowable Chemical/Material[a]	**Reactivity Group[b]**	
	Name	**Number[c]**
Detergent, solid (e.g., emulsifiers, surfactants)	Esters	13
Detergent, solid (e.g., emulsifiers, surfactants)	Hydrocarbons, aromatic	16
Detergent, solid (e.g., emulsifiers, surfactants)	Hydrocarbons, aliphatic, unsaturated	28
Detergent, solid (e.g., emulsifiers, surfactants)	Organophosphates, phosphothioates, and phosphodithioates	32
Envirostone® (no organic emulsifiers allowed)	Other solidification materials and absorbents/adsorbents	0
Esters (e.g., ethyl acetate, polyethylene glycol ester)	Esters	13
Ethers (e.g., ethyl ether)	Ethers	14
Fiberglass, inorganic	Other Inorganics (non-reactive)	0
Fiberglass, organic	Combustible and flammable materials, miscellaneous	101
Filter media, inorganic	Other Inorganics (non-reactive)	0
Filter media, organic	Combustible and flammable materials, miscellaneous	101
Firebrick	Other Inorganics (non-reactive)	0
Glass (e.g., borosilicate glass, labware, leaded glass, Raschig rings)	Other Inorganics (non-reactive)	0
Graphite (e.g., molds and crucibles)	Other Inorganics (non-reactive)	0
Greases, commercial brands	Combustible and flammable materials, miscellaneous	101
Grit	Other Inorganics (non-reactive)	0
Halogenated organics (e.g., bromoform; carbon tetrachloride; chlorobenzene; chloroform; 1,1-dichloroethane; 1,2-dichloroethane; 1,1-dichloroethylene; cis-1,2-dichloroethylene; methylene chloride; 1,1,2,2-tetrachloroethane; tetrachloroethylene; 1,1,1-trichloroethane; 1,1,2-trichloroethane; trichloroethylene; 1,1,2-trichloro-1,2,2-trifluoroethane)	Halogenated Organics	17

Lists of Allowable Materials and Associated Reactivity Groups		
Allowable Chemical/Material[a]	**Reactivity Group**[b]	
	Name	**Number**[c]
Heel (e.g., ash heel; soot heel; firebrick heel; sand, slag, and crucible heel)	Other Inorganics (non-reactive)	0
Hydrocarbons, aliphatic (e.g., cyclohexane, n-paraffin hydrocarbons)	Hydrocarbon, aliphatic, unsaturated	28
Hydrocarbons, aliphatic (e.g., cyclohexane, n-paraffin hydrocarbons)	Hydrocarbon, aliphatic, saturated	29
Hydrocarbons, aromatic (e.g., benzene; ethyl benzene; toluene; 1,2,4-trimethylbenzene; 1,3,5-trimethylbenzene; xylene)	Hydrocarbons, aromatic	16
Insulation, inorganic	Other Inorganics (non-reactive)	0
Insulation, organic	Combustible and flammable materials, miscellaneous	101
Ketones (e.g., acetone, methyl ethyl ketone, methyl isobutyl ketone)	Ketones	19
Leaded rubber (e.g., gloves, aprons, sheet material)	Metals, Other elemental, and alloy, as sheets, rods, moldings, vapors, or sponges	23
Leaded rubber (e.g., gloves, aprons, sheet material)	Metals and metal compounds, toxic	24
Leaded rubber (e.g., gloves, aprons, sheet material)	Combustible and flammable materials, miscellaneous	101
Leather	Combustible and flammable materials, miscellaneous	101
Magnesia cement (e.g., Ramcote® cement)	Water reactive substance	107
Magnesium alloy	Metals, Other elemental, and alloy, as sheets, rods, moldings, vapors, or sponges	23
Metal hydroxides	Other Inorganics (non-reactive)	0
Metal oxides (e.g., slag)	Other Inorganics (non-reactive)	0
Metals (e.g., aluminum, cadmium, copper, steel, tantalum, tungsten, zinc)	Metals, alkali and alkaline earth, elemental	21
Metals (e.g., aluminum, cadmium, copper, steel, tantalum, tungsten, zinc)	Metals, Other elemental and alloy in the form of powders, vapors, or sponges	22

Lists of Allowable Materials and Associated Reactivity Groups		
Allowable Chemical/Material[a]	**Reactivity Group**[b]	
	Name	**Number**[c]
Metals (e.g., aluminum, cadmium, copper, steel, tantalum, tungsten, zinc)	Metals, Other elemental, and alloy, as sheets, rods, moldings, vapors, or sponges	23
Metals (e.g., aluminum, cadmium, copper, steel, tantalum, tungsten, zinc)	Metals and metal compounds, toxic	24
Metals (e.g., aluminum, cadmium, copper, steel, tantalum, tungsten, zinc)	Reducing agents, strong	105
Nitrates (e.g., ammonium nitrate, sodium nitrate)	Oxidizing Agents, Strong	104
Oil (e.g., petroleum, mineral)	Combustible and flammable materials, miscellaneous	101
Organophosphates (e.g., tributyl phosphate, dibutyl phosphate, monobutyl phosphite)	Organophosphates, phosphothioates, and phosphodithioates	32
Paint, dry (e.g., floor/wall paint, ALARA)	Combustible and flammable materials, miscellaneous	101
Petroset® products (for aqueous solutions)	Other solidification materials and absorbents/adsorbents	0
Plastics [e.g., polycarbonate, polyethylene, polymethyl methacrylate (Plexiglas®, Lucite®), polysulfone, polytetrafluoroethylene (Teflon®), polyvinyl acetate, polyvinyl chloride (PVC), polyvinylidene chloride (saran)]	Combustible and flammable materials, miscellaneous	101
Polyamides (nylon)	Amides	6
Polyamides (nylon)	Combustible and flammable materials, miscellaneous	101
Polychlorotrifluoroethylene (e.g., Kel-F®)	Combustible and flammable materials, miscellaneous	101
Polyesters (e.g., Dacron®, Mylar®)	Esters	13
Polyesters (e.g., Dacron®, Mylar®)	Combustible and flammable materials, miscellaneous	101
Polyethylene glycol (e.g., Carbowax®)	Alcohols and Glycols	4
Polyethylene glycol (e.g., Carbowax®)	Combustible and flammable materials, miscellaneous	101
Polyimides	Hydrocarbons, aromatic	16

Lists of Allowable Materials and Associated Reactivity Groups		
Allowable Chemical/Material[a]	Reactivity Group[b]	
	Name	Number[c]
Polyphenyl methacrylate	Combustible and flammable materials, miscellaneous	101
Polypropylene (e.g., Ful-Flo® filters)	Combustible and flammable materials, miscellaneous	101
Polyurethane	Combustible and flammable materials, miscellaneous	101
Polyvinyl alcohol	Alcohols and Glycols	4
Portland cement	Caustics	10
Portland cement	Water reactive substance	107
Resins (e.g., aniline-formaldehyde, melamine-formaldehyde, organic resins, phenol-formaldehyde, phenolic resins, urea-formaldehyde)	Aldehydes	5
Resins (e.g., aniline-formaldehyde, melamine-formaldehyde, organic resins, phenol-formaldehyde, phenolic resins, urea-formaldehyde)	Phenols and Creosols	31
Rubber, natural or synthetic [e.g., chlorosulfonated polyethylene (Hypalon®), ethylene-propylene rubber, EPDM, polybutadiene, polychloroprene (neoprene), polyisobutylene, polyisoprene, polystyrene, rubber hydrochloride (pliofilm®)]	Combustible and flammable materials, miscellaneous	101
Salts (e.g., calcium chloride, calcium fluoride, sodium chloride)	Other Inorganics (non-reactive)	0
Salts (e.g., calcium chloride, calcium fluoride, sodium chloride)	Fluorides, inorganic	15
Sand/soil, inorganic	Other Inorganics (non-reactive)	0
Sand/soil, organic	Combustible and flammable materials, miscellaneous	101
Trioctyl phosphine oxide	Organophosphates, phosphothioates, and phosphodithioates	32
Water	Water and Mixtures containing water	106

Lists of Allowable Materials and Associated Reactivity Groups		
Allowable Chemical/Material[a]	Reactivity Group[b]	
	Name	Number[c]
Waxes, commercial brands	Combustible and flammable materials, miscellaneous	101
Other inorganic materials	Other Inorganics (non-reactive)	0

[a]Chemicals in ***bold italic*** have been assigned to more than one reactivity group.
[b]Reactivity group from Hatayama, H.K., J. J. Chen, E.R. deVera, R.D. Stephens, and D.L. Storm, "A Method for Determining the Compatibility of Hazardous Wastes," EPA-600/2-80-076, U.S. Environmental Protection Agency, Cincinnati, Ohio, 1980.
[c]Non-reactive inorganic materials or chemicals are assigned a reactivity group number of "0."

Attachment 2.0

Lists of Unique Reactivity Group Numbers in Lists of Allowable Materials

List of Unique Reactivity Group Numbers in Lists of Allowable Materials		
Allowable Chemical/Material[a]	Reactivity Group[b]	
	Name	Number
Absorbents/adsorbents (e.g., Celite®, diatomaceous earth, diatomite, Florco®, Oil-Dri®, perlite, vermiculite)	Other solidification materials and absorbents/adsorbents	0
Acids, inorganic	Acids, Mineral, Non-oxidizing	1
Acids, inorganic	Acids, Mineral, Oxidizing	2
Acids, solid, organic	Acids, Organic	3
Polyethylene glycol (e.g., Carbowax®)	Alcohols and Glycols	4
Resins (e.g., aniline-formaldehyde, melamine-formaldehyde, organic resins, phenol-formaldehyde, phenolic resins, urea-formaldehyde)	Aldehydes	5
Polyamides (nylon)	Amides	6
Portland cement	Caustics	10
Esters (e.g., ethyl acetate, polyethylene glycol ester)	Esters	13
Ethers (e.g., ethyl ether)	Ethers	14
Salts (e.g., calcium chloride, calcium fluoride, sodium chloride)	Fluorides, inorganic	15
Hydrocarbons, aromatic (e.g., benzene; ethyl benzene; toluene; 1,2,4-trimethylbenzene; 1,3,5-trimethylbenzene; xylene)	Hydrocarbons, aromatic	16
Halogenated organics (e.g., bromoform; carbon tetrachloride; chlorobenzene; chloroform; 1,1-dichloroethane; 1,2-dichloroethane; 1,1-dichloroethylene; cis-1,2-dichloroethylene; methylene chloride; 1,1,2,2-tetrachloroethane; tetrachloroethylene; 1,1,1-trichloroethane; 1,1,2-trichloroethane; trichloroethylene; 1,1,2-trichloro-1,2,2-trifluoroethane)	Halogenated Organics	17
Ketones (e.g., acetone, methyl ethyl ketone, methyl isobutyl ketone)	Ketones	19
Batteries, dry (e.g., flashlight)	Metals, alkali and alkaline earth, elemental and alloys	21

List of Unique Reactivity Group Numbers in Lists of Allowable Materials		
Allowable Chemical/Material[a]	**Reactivity Group**[b]	
	Name	**Number**
Metals (e.g., aluminum, cadmium, copper, steel, tantalum, tungsten, zinc)	Metals, Other elemental and alloy in the form of powders, vapors, or sponges	22
Metals (e.g., aluminum, cadmium, copper, steel, tantalum, tungsten, zinc)	Metals, Other elemental, and alloy, as sheets, rods, moldings, vapors, or sponges	23
Leaded rubber (e.g., gloves, aprons, sheet material)	Metals and metal compounds, toxic	24
Hydrocarbons, aliphatic (e.g., cyclohexane, n-paraffin hydrocarbons)	Hydrocarbon, aliphatic, unsaturated	28
Hydrocarbons, aliphatic (e.g., cyclohexane, n-paraffin hydrocarbons)	Hydrocarbon, aliphatic, saturated	29
Resins (e.g., aniline-formaldehyde, melamine-formaldehyde, organic resins, phenol-formaldehyde, phenolic resins, urea-formaldehyde)	Phenols and Creosols	31
Organophosphates (e.g., tributyl phosphate, dibutyl phosphate, monobutyl phosphite)	Organophosphates, phosphothioates, and phosphodithioates	32
Asphalt	Combustible and flammable materials, miscellaneous	101
Cellulose acetate butyrate	Polymerizable compounds	103
Nitrates (e.g., ammonium nitrate, sodium nitrate)	Oxidizing Agents, Strong	104
Metals (e.g., aluminum, cadmium, copper, steel, tantalum, tungsten, zinc)	Reducing agents, strong	105
Aqueous solutions/water	Water and Mixtures containing water	106
Portland cement	Water reactive substances	107

[a]Chemicals in ***bold italic*** have been assigned to more than one reactivity group.
[b]Reactivity group from Hatayama, H.K., J.J. Chen, E.R. deVera, R.D. Stephens, and D.L. Storm, "A Method for Determining the Compatibility of Hazardous Wastes," EPA-600/2-80-076, U.S. Environmental Protection Agency, Cincinnati, Ohio, 1980.

Attachment 3.0

Waste Chemical Compatibility Chart

Hazardous Waste Chemical Compatibility Chart

Group No.	Reactivity Group Name	1	2	3	4	5	6	10	13	14	15	16	17	19	21	22	23	24	28	29	31	32	101	103	104	105	106	107
1	Acids, Mineral, Non-Oxidizing	1																										
2	Acids, Mineral, Oxidizing		2																									
3	Acids, Organic		G, H	3																								
4	Alcohols and Glycols	H	H, F	H, P	4																							
5	Aldehydes	H, P	H, F	H, P		5																						
6	Amides	H	H, GT				6																					
10	Caustics	H	H	H		H		10																				
13	Esters	H	H, F					H	13																			
14	Ethers	H	H, F							14																		
15	Fluorides, Inorganic	GT	GT	GT							15																	
16	Hydrocarbons, Aromatic		H, F									16																
17	Halogenated Organics	H, GT	H, GT, P					H, GF					17															
19	Ketones	H	H, F					H						19														
21	Metals, Alkali and Alkaline Earth, Elemental	GF, H, F	GF, H, F	GF, H, F	GF, H, F	GF, H, F	GF, H	GF, H	GF, H						21													
22	Metals, Other Elemental Alloys as Powders, Vapors, or Sponges	GF, H, F	GF, H, F	GF				GF, H					H, E			22												
23	Metals, Other Elemental Alloys as Sheets, Rods, Moldings, Etc.	GF, H, F	GF, H, F										H, F				23											
24	Metals and Metal Compounds, Toxic	S	S	S			S	S										24										
28	Hydrocarbons, Aliphatic, Unsaturated	H	H, F			H										H, E			28									
29	Hydrocarbons, Aliphatic, Saturated		H, F																	29								
31	Phenols and Cresols	H	H, F												GF, H						31							
32	Organophosphates, Phosphothioates, Phosphodithioates	GT, H	GT, H					H, E							H							32						
101	Combustible and Flammable Materials, Miscellaneous	H, G	GT, H, F												H, G, F								101					
103	Polymerizable Compounds	P, H	P, H	P, H				P, H							P, H	P, H	P, H	P, H			P, H			103				
104	Oxidizing Agents, Strong	GT, H		GT, H	H, F	H, F	GT, H, F		H, F	H, F		H, F	GT, H	H, F	H, F, E	H, F, E	H, F		H, F	H, F	H, F	GT, H, F	H, G, F	GT, H, F	104			
105	Reducing Agents, Strong	GF, H	GT, H, F	GF, H	GF, H, F	GF, H, F	GF, H		H, F				H, E	GF, H							GF, H	GF, GT	GF, H	GF, H, P	H, F, E	105		
106	Water and Mixtures Containing Water	H	H												GF, H	GF, H		S								GF, GT	106	
107	Water Reactive Substances	E	X	T	R	E	M		A	C	T	I	V	!	D	O		N	M	I	!	!						107
Reactivity Group No.		1	2	3	4	5	6	10	13	14	15	16	17	19	21	22	23	24	28	29	31	32	101	103	104	105	106	107

Reactivity Code	Consequence
E	Explosion
F	Fire
G	Innocuous and Non-Flammable Gas Generation
GF	Flammable Gas Generation
GT	Toxic Gas Generation
H	Heat Generation
P	Violent Polymerization
S	Solubilization of Toxic Substance

Source: Hatayama, H.K., J.J. Chen, E.R. deVera, R.D. Stephens, and D.L. Storm, "A Method for Determining the Compatibility of Hazardous Wastes" EPA-600/2-80-076, U.S. Environmental Protection Agency, Cincinnati, Ohio, 1980

Attachment 4.0

Potential Chemical Incompatibilities

Potential Chemical Incompatibilities			
Combination of Reactivity Groups		Reaction Result (A x B)	Explanation of Potential Incompatibility
Group A	Group B		
1	4	Heat Generation	Reaction will not occur – Acids are neutralized and solidified/immobilized prior to shipping
1	5	Heat Generation	Reaction will not occur – Acids are neutralized and solidified/immobilized prior to shipping
1	5	Violent Polymerization	Reaction will not occur – Acids are neutralized and solidified/immobilized prior to shipping
1	6	Heat Generation	Reaction will not occur – Acids are neutralized and solidified/immobilized prior to shipping
1	10	Heat Generation	Reaction will not occur – Acids are neutralized and solidified/immobilized prior to shipping; Bases/caustic materials are neutralized and solidified/immobilized prior to shipping
1	13	Heat Generation	Reaction will not occur – Acids are neutralized and solidified/immobilized prior to shipping
1	14	Heat Generation	Reaction will not occur – Acids are neutralized and solidified/immobilized prior to shipping
1	15	Toxic Gas Generation	Reaction will not occur – Acids are neutralized and solidified/immobilized prior to shipping
1	17	Heat Generation	Reaction will not occur – Acids are neutralized and solidified/immobilized prior to shipping
1	17	Toxic Gas Generation	Reaction will not occur – Acids are neutralized and solidified/immobilized prior to shipping
1	19	Heat Generation	Reaction will not occur – Acids are neutralized and solidified/immobilized prior to shipping
1	21	Flammable Gas Generation	Reaction will not occur – Acids are neutralized and solidified/immobilized prior to shipping
1	21	Heat Generation	Reaction will not occur – Acids are neutralized and solidified/immobilized prior to shipping
1	21	Fire	Reaction will not occur – Acids are neutralized and solidified/immobilized prior to shipping
1	22	Flammable Gas Generation	Reaction will not occur – Acids are neutralized and solidified/immobilized prior to shipping

Potential Chemical Incompatibilities			
Combination of Reactivity Groups		Reaction Result (A x B)	Explanation of Potential Incompatibility
Group A	Group B		
1	22	Heat Generation	Reaction will not occur – Acids are neutralized and solidified/immobilized prior to shipping
1	22	Fire	Reaction will not occur – Acids are neutralized and solidified/immobilized prior to shipping
1	23	Flammable Gas Generation	Reaction will not occur – Acids are neutralized and solidified/immobilized prior to shipping
1	23	Heat Generation	Reaction will not occur – Acids are neutralized and solidified/immobilized prior to shipping
1	23	Fire	Reaction will not occur – Acids are neutralized and solidified/immobilized prior to shipping
1	24	Solubilization of Toxic Substances	Reaction will not occur – Acids are neutralized and solidified/immobilized prior to shipping Additionally, any solubilization of toxic substances will not affect transportation of wastes.
1	28	Heat Generation	Reaction will not occur – Acids are neutralized and solidified/immobilized prior to shipping
1	31	Heat Generation	Reaction will not occur – Acids are neutralized and solidified/immobilized prior to shipping
1	32	Heat Generation	Reaction will not occur – Acids are neutralized and solidified/immobilized prior to shipping
1	32	Toxic Gas Generation	Reaction will not occur – Acids are neutralized and solidified/immobilized prior to shipping
1	101	Heat Generation	Reaction will not occur – Acids are neutralized and solidified/immobilized prior to shipping
1	101	Innocuous and Non-Flammable Gas Generation	Reaction will not occur – Acids are neutralized and solidified/immobilized prior to shipping
1	103	Violent Polymerization	Reaction will not occur – Acids are neutralized and solidified/immobilized prior to shipping
1	103	Heat Generation	Reaction will not occur – Acids are neutralized and solidified/immobilized prior to shipping

Potential Chemical Incompatibilities			
Combination of Reactivity Groups		**Reaction Result (A x B)**	**Explanation of Potential Incompatibility**
Group A	**Group B**		
1	104	Heat Generation	Reaction will not occur – Acids are neutralized and solidified/immobilized prior to shipping; oxidizing agents are reacted prior to being placed in the waste/shipped.
1	104	Toxic Gas Generation	Reaction will not occur – Acids are neutralized and solidified/immobilized prior to shipping; oxidizing agents are reacted prior to being placed in the waste/shipped.
1	105	Heat Generation	Reaction will not occur – Acids are neutralized and solidified/immobilized prior to shipping; reducing agents are reacted prior to being placed in the waste/shipped.
1	105	Flammable Gas Generation	Reaction will not occur – Acids are neutralized and solidified/immobilized prior to shipping; reducing agents are reacted prior to being placed in the waste/shipped.
1	106	Heat Generation	Reaction will not occur – Acids are neutralized and solidified/immobilized prior to shipping; free liquid content is limited to less than 1% of waste volume
1	107	Highly Reactive	Reaction will not occur – Acids are neutralized and solidified/immobilized prior to shipping; free liquid content is limited to less than 1% of waste volume; water reactive substances are reacted prior to being placed in the waste/shipped. Lime in Portland cement is most common water reactive substance expected in the waste. Portland cement is used as an absorbent and solidification agent for the wastes.
2	3	Innocuous and Non-Flammable Gas Generation	Reaction will not occur – Acids are neutralized and solidified/immobilized prior to shipping
2	3	Heat Generation	Reaction will not occur – Acids are neutralized and solidified/immobilized prior to shipping
2	4	Heat Generation	Reaction will not occur – Acids are neutralized and solidified/immobilized prior to shipping
2	4	Fire	Reaction will not occur – Acids are neutralized and solidified/immobilized prior to shipping

Potential Chemical Incompatibilities			
Combination of Reactivity Groups		Reaction Result (A x B)	Explanation of Potential Incompatibility
Group A	Group B		
2	5	Heat Generation	Reaction will not occur – Acids are neutralized and solidified/immobilized prior to shipping
2	5	Fire	Reaction will not occur – Acids are neutralized and solidified/immobilized prior to shipping
2	6	Heat Generation	Reaction will not occur – Acids are neutralized and solidified/immobilized prior to shipping
2	6	Toxic Gas Generation	Reaction will not occur – Acids are neutralized and solidified/immobilized prior to shipping
2	10	Heat Generation	Reaction will not occur – Acids are neutralized and solidified/immobilized prior to shipping; Bases/caustic materials are neutralized and solidified/immobilized prior to shipping
2	13	Heat Generation	Reaction will not occur – Acids are neutralized and solidified/immobilized prior to shipping
2	13	Fire	Reaction will not occur – Acids are neutralized and solidified/immobilized prior to shipping
2	14	Heat Generation	Reaction will not occur – Acids are neutralized and solidified/immobilized prior to shipping
2	14	Fire	Reaction will not occur – Acids are neutralized and solidified/immobilized prior to shipping
2	15	Toxic Gas Generation	Reaction will not occur – Acids are neutralized and solidified/immobilized prior to shipping
2	16	Heat Generation	Reaction will not occur – Acids are neutralized and solidified/immobilized prior to shipping
2	16	Fire	Reaction will not occur – Acids are neutralized and solidified/immobilized prior to shipping
2	17	Heat Generation	Reaction will not occur – Acids are neutralized and solidified/immobilized prior to shipping
2	17	Fire	Reaction will not occur – Acids are neutralized and solidified/immobilized prior to shipping
2	17	Toxic Gas Generation	Reaction will not occur – Acids are neutralized and solidified/immobilized prior to shipping
2	19	Heat Generation	Reaction will not occur – Acids are neutralized and solidified/immobilized prior to shipping

Potential Chemical Incompatibilities			
Combination of Reactivity Groups		Reaction Result (A x B)	Explanation of Potential Incompatibility
Group A	Group B		
2	19	Fire	Reaction will not occur – Acids are neutralized and solidified/immobilized prior to shipping
2	21	Flammable Gas Generation	Reaction will not occur – Acids are neutralized and solidified/immobilized prior to shipping
2	21	Heat Generation	Reaction will not occur – Acids are neutralized and solidified/immobilized prior to shipping
2	21	Fire	Reaction will not occur – Acids are neutralized and solidified/immobilized prior to shipping
2	22	Flammable Gas Generation	Reaction will not occur – Acids are neutralized and solidified/immobilized prior to shipping
2	22	Heat Generation	Reaction will not occur – Acids are neutralized and solidified/immobilized prior to shipping
2	22	Fire	Reaction will not occur – Acids are neutralized and solidified/immobilized prior to shipping
2	23	Flammable Gas Generation	Reaction will not occur – Acids are neutralized and solidified/immobilized prior to shipping
2	23	Heat Generation	Reaction will not occur – Acids are neutralized and solidified/immobilized prior to shipping
2	23	Fire	Reaction will not occur – Acids are neutralized and solidified/immobilized prior to shipping
2	24	Solubilization of Toxic Substances	Reaction will not occur – Acids are neutralized and solidified/immobilized prior to shipping Additionally, any solubilization of toxic substances will not affect transportation of wastes.
2	28	Heat Generation	Reaction will not occur – Acids are neutralized and solidified/immobilized prior to shipping
2	28	Fire	Reaction will not occur – Acids are neutralized and solidified/immobilized prior to shipping
2	29	Heat Generation	Reaction will not occur – Acids are neutralized and solidified/immobilized prior to shipping
2	29	Fire	Reaction will not occur – Acids are neutralized and solidified/immobilized prior to shipping
2	31	Heat Generation	Reaction will not occur – Acids are neutralized and solidified/immobilized prior to shipping

Potential Chemical Incompatibilities			
Combination of Reactivity Groups		Reaction Result (A x B)	Explanation of Potential Incompatibility
Group A	Group B		
2	31	Fire	Reaction will not occur – Acids are neutralized and solidified/immobilized prior to shipping
2	32	Heat Generation	Reaction will not occur – Acids are neutralized and solidified/immobilized prior to shipping
2	32	Toxic Gas Generation	Reaction will not occur – Acids are neutralized and solidified/immobilized prior to shipping
2	101	Heat Generation	Reaction will not occur – Acids are neutralized and solidified/immobilized prior to shipping
2	101	Fire	Reaction will not occur – Acids are neutralized and solidified/immobilized prior to shipping
2	101	Toxic Gas Generation	Reaction will not occur – Acids are neutralized and solidified/immobilized prior to shipping
2	103	Violent Polymerization	Reaction will not occur – Acids are neutralized and solidified/immobilized prior to shipping
2	103	Heat Generation	Reaction will not occur – Acids are neutralized and solidified/immobilized prior to shipping
2	105	Heat Generation	Reaction will not occur – Acids are neutralized and solidified/immobilized prior to shipping; reducing agents are reacted prior to being placed in the waste/shipped.
2	105	Fire	Reaction will not occur – Acids are neutralized and solidified/immobilized prior to shipping; reducing agents are reacted prior to being placed in the waste/shipped.
2	105	Toxic Gas Generation	Reaction will not occur – Acids are neutralized and solidified/immobilized prior to shipping; reducing agents are reacted prior to being placed in the waste/shipped.
2	106	Heat Generation	Reaction will not occur – Acids are neutralized and solidified/immobilized prior to shipping; free liquid content is limited to less than 1% of waste volume

Potential Chemical Incompatibilities			
Combination of Reactivity Groups		Reaction Result (A x B)	Explanation of Potential Incompatibility
Group A	Group B		
2	107	Highly Reactive	Reaction will not occur – Acids are neutralized and solidified/immobilized prior to shipping; free liquid content is limited to less than 1% of waste volume; water reactive substances are reacted prior to being placed in the waste/shipped. Lime in Portland cement is most common water reactive substance expected in the waste. Portland cement is used as an absorbent and solidification agent for the wastes.
3	4	Heat Generation	Reaction will not occur – Acids are neutralized and solidified/immobilized prior to shipping
3	4	Violent Polymerization	Reaction will not occur – Acids are neutralized and solidified/immobilized prior to shipping
3	5	Heat Generation	Reaction will not occur – Acids are neutralized and solidified/immobilized prior to shipping
3	5	Violent Polymerization	Reaction will not occur – Acids are neutralized and solidified/immobilized prior to shipping
3	10	Heat Generation	Reaction will not occur – Acids are neutralized and solidified/immobilized prior to shipping; Bases/caustic materials are neutralized and solidified/immobilized prior to shipping
3	15	Toxic Gas Generation	Reaction will not occur – Acids are neutralized and solidified/immobilized prior to shipping
3	21	Flammable Gas Generation	Reaction will not occur – Acids are neutralized and solidified/immobilized prior to shipping
3	21	Heat Generation	Reaction will not occur – Acids are neutralized and solidified/immobilized prior to shipping
3	21	Fire	Reaction will not occur – Acids are neutralized and solidified/immobilized prior to shipping
3	22	Flammable Gas Generation	Reaction will not occur – Acids are neutralized and solidified/immobilized prior to shipping
3	24	Solubilization of Toxic Substances	Reaction will not occur – Acids are neutralized and solidified/immobilized prior to shipping Additionally, any solubilization of toxic substances will not affect transportation of wastes.

Potential Chemical Incompatibilities			
Combination of Reactivity Groups		**Reaction Result (A x B)**	**Explanation of Potential Incompatibility**
Group A	**Group B**		
3	103	Violent Polymerization	Reaction will not occur – Acids are neutralized and solidified/immobilized prior to shipping
3	103	Heat Generation	Reaction will not occur – Acids are neutralized and solidified/immobilized prior to shipping
3	104	Heat Generation	Reaction will not occur – Acids are neutralized and solidified/immobilized prior to shipping; oxidizing agents are reacted prior to being placed in the waste/shipped.
3	104	Toxic Gas Generation	Reaction will not occur – Acids are neutralized and solidified/immobilized prior to shipping; oxidizing agents are reacted prior to being placed in the waste/shipped.
3	105	Heat Generation	Reaction will not occur – Acids are neutralized and solidified/immobilized prior to shipping; reducing agents are reacted prior to being placed in the waste/shipped.
3	105	Flammable Gas Generation	Reaction will not occur – Acids are neutralized and solidified/immobilized prior to shipping; reducing agents are reacted prior to being placed in the waste/shipped.
3	107	Highly Reactive	Reaction will not occur – Acids are neutralized and solidified/immobilized prior to shipping; free liquid content is limited to less than 1% of waste volume; water reactive substances are reacted prior to being placed in the waste/shipped. Lime in Portland cement is most common water reactive substance expected in the waste. Portland cement is used as an absorbent and solidification agent for the wastes.
4	21	Flammable Gas Generation	Reaction will not occur – Alcohols and Glycols are solidified/immobilized prior to shipping
4	21	Heat Generation	Reaction will not occur – Alcohols and Glycols are solidified/immobilized prior to shipping
4	21	Fire	Reaction will not occur – Alcohols and Glycols are solidified/immobilized prior to shipping

Potential Chemical Incompatibilities			
Combination of Reactivity Groups		Reaction Result (A x B)	Explanation of Potential Incompatibility
Group A	Group B		
4	104	Heat Generation	Reaction will not occur – Alcohols and Glycols are solidified/immobilized prior to shipping; oxidizing agents are reacted prior to being placed in the waste/shipped.
4	104	Fire	Reaction will not occur – Alcohols and Glycols are solidified/immobilized prior to shipping; oxidizing agents are reacted prior to being placed in the waste/shipped.
4	105	Heat Generation	Reaction will not occur – Alcohols and Glycols are solidified/immobilized prior to shipping; reducing agents are reacted prior to being placed in the waste/shipped.
4	105	Flammable Gas Generation	Reaction will not occur – Alcohols and Glycols are solidified/immobilized prior to shipping; reducing agents are reacted prior to being placed in the waste/shipped.
4	105	Fire	Reaction will not occur – Alcohols and Glycols are solidified/immobilized prior to shipping; reducing agents are reacted prior to being placed in the waste/shipped.
4	107	Highly Reactive	Reaction will not occur – Alcohols and Glycols are solidified/immobilized prior to shipping; free liquid content is limited to less than 1% of waste volume; water reactive substances are reacted prior to being placed in the waste/shipped. Lime in Portland cement is most common water reactive substance expected in the waste. Portland cement is used as an absorbent and solidification agent for the wastes.
5	10	Heat Generation	Reaction will not occur – Aldehydes are solidified/immobilized prior to shipping; bases/caustic materials are neutralized and solidified/immobilized prior to shipping
5	21	Flammable Gas Generation	Reaction will not occur – Aldehydes are solidified/immobilized prior to shipping
5	21	Heat Generation	Reaction will not occur – Aldehydes are solidified/immobilized prior to shipping
5	21	Fire	Reaction will not occur – Aldehydes are solidified/immobilized prior to shipping

Potential Chemical Incompatibilities			
Combination of Reactivity Groups		Reaction Result (A x B)	Explanation of Potential Incompatibility
Group A	Group B		
5	28	Heat Generation	Reaction will not occur – Aldehydes are solidified/immobilized prior to shipping
5	104	Heat Generation	Reaction will not occur – Aldehydes are solidified/immobilized prior to shipping; oxidizing agents are reacted prior to being placed in the waste/shipped.
5	104	Fire	Reaction will not occur – Aldehydes are solidified/immobilized prior to shipping; oxidizing agents are reacted prior to being placed in the waste/shipped.
5	105	Heat Generation	Reaction will not occur – Aldehydes are solidified/immobilized prior to shipping; reducing agents are reacted prior to being placed in the waste/shipped.
5	105	Flammable Gas Generation	Reaction will not occur – Aldehydes are solidified/immobilized prior to shipping; reducing agents are reacted prior to being placed in the waste/shipped.
5	105	Fire	Reaction will not occur – Aldehydes are solidified/immobilized prior to shipping; reducing agents are reacted prior to being placed in the waste/shipped.
5	107	Highly Reactive	Reaction will not occur – Aldehydes are solidified/immobilized prior to shipping; free liquid content is limited to less than 1% of waste volume; water reactive substances are reacted prior to being placed in the waste/shipped. Lime in Portland cement is most common water reactive substance expected in the waste. Portland cement is used as an absorbent and solidification agent for the wastes.
6	17	Heat Generation	Reaction will not occur – Amides are solidified/immobilized prior to shipping
6	17	Toxic Gas Generation	Reaction will not occur – Amides are solidified/immobilized prior to shipping
6	21	Flammable Gas Generation	Reaction will not occur – Amides are solidified/immobilized prior to shipping
6	21	Heat Generation	Reaction will not occur – Amides are solidified/immobilized prior to shipping

Potential Chemical Incompatibilities			
Combination of Reactivity Groups		Reaction Result (A x B)	Explanation of Potential Incompatibility
Group A	Group B		
6	24	Solubilization of Toxic Substances	Reaction will not occur – Amides are solidified/immobilized prior to shipping Additionally, any solubilization of toxic substances will not affect transportation of wastes.
6	104	Heat Generation	Reaction will not occur – Amides are solidified/immobilized prior to shipping; oxidizing agents are reacted prior to being placed in the waste/shipped.
6	104	Fire	Reaction will not occur – Amides are solidified/immobilized prior to shipping; oxidizing agents are reacted prior to being placed in the waste/shipped.
6	104	Toxic Gas Generation	Reaction will not occur – Amides are solidified/immobilized prior to shipping; oxidizing agents are reacted prior to being placed in the waste/shipped.
6	105	Heat Generation	Reaction will not occur – Amides are solidified/immobilized prior to shipping; reducing agents are reacted prior to being placed in the waste/shipped.
6	105	Flammable Gas Generation	Reaction will not occur – Amides are solidified/immobilized prior to shipping; reducing agents are reacted prior to being placed in the waste/shipped.
6	107	Highly Reactive	Reaction will not occur – Amides are solidified/immobilized prior to shipping; free liquid content is limited to less than 1% of waste volume; water reactive substances are reacted prior to being placed in the waste/shipped. Lime in Portland cement is most common water reactive substance expected in the waste. Portland cement is used as an absorbent and solidification agent for the wastes.
10	13	Heat Generation	Reaction will not occur – Caustics/bases are neutralized and solidified/immobilized prior to shipping
10	17	Heat Generation	Reaction will not occur – Caustics/bases are neutralized and solidified/immobilized prior to shipping

Potential Chemical Incompatibilities			
Combination of Reactivity Groups		Reaction Result (A x B)	Explanation of Potential Incompatibility
Group A	Group B		
10	19	Heat Generation	Reaction will not occur – Caustics/bases are neutralized and solidified/immobilized prior to shipping
10	21	Flammable Gas Generation	Reaction will not occur – Caustics/bases are neutralized and solidified/immobilized prior to shipping
10	21	Heat Generation	Reaction will not occur – Caustics/bases are neutralized and solidified/immobilized prior to shipping
10	22	Flammable Gas Generation	Reaction will not occur – Caustics/bases are neutralized and solidified/immobilized prior to shipping
10	22	Heat Generation	Reaction will not occur – Caustics/bases are neutralized and solidified/immobilized prior to shipping
10	23	Flammable Gas Generation	Reaction will not occur – Caustics/bases are neutralized and solidified/immobilized prior to shipping
10	23	Heat Generation	Reaction will not occur – Caustics/bases are neutralized and solidified/immobilized prior to shipping
10	24	Solubilization of Toxic Substances	Reaction will not occur – Caustics/bases are neutralized and solidified/immobilized prior to shipping; Additionally, any solubilization of toxic substances will not affect transportation of wastes.
10	32	Heat Generation	Reaction will not occur – Caustics/bases are neutralized and solidified/immobilized prior to shipping
10	32	Explosion	Reaction will not occur – Caustics/bases are neutralized and solidified/immobilized prior to shipping
10	103	Violent Polymerization	Reaction will not occur – Caustics/bases are neutralized and solidified/immobilized prior to shipping
10	103	Heat Generation	Reaction will not occur – Caustics/bases are neutralized and solidified/immobilized prior to shipping
10	107	Highly Reactive	Reaction will not occur – Caustics/bases are neutralized and solidified/immobilized prior to shipping; free liquid content is limited to less than 1% of waste volume; water reactive substances are reacted prior to being placed in the waste/shipped. Lime in Portland cement is most common water reactive substance expected in the waste. Portland cement is used as an absorbent and solidification agent for the wastes.

Potential Chemical Incompatibilities			
Combination of Reactivity Groups		Reaction Result (A x B)	Explanation of Potential Incompatibility
Group A	Group B		
13	21	Flammable Gas Generation	Reaction will not occur – Esters are solidified/immobilized prior to shipping
13	21	Heat Generation	Reaction will not occur – Esters are solidified/immobilized prior to shipping
13	104	Heat Generation	Reaction will not occur – Esters are solidified/immobilized prior to shipping; oxidizing agents are reacted prior to being placed in the waste/shipped.
13	104	Fire	Reaction will not occur – Esters are solidified/immobilized prior to shipping; oxidizing agents are reacted prior to being placed in the waste/shipped.
13	105	Heat Generation	Reaction will not occur – Esters are solidified/immobilized prior to shipping; reducing agents are reacted prior to being placed in the waste/shipped.
13	105	Fire	Reaction will not occur – Esters are solidified/immobilized prior to shipping; reducing agents are reacted prior to being placed in the waste/shipped.
13	107	Highly Reactive	Reaction will not occur – Esters are solidified/immobilized prior to shipping; free liquid content is limited to less than 1% of waste volume; water reactive substances are reacted prior to being placed in the waste/shipped. Lime in Portland cement is most common water reactive substance expected in the waste. Portland cement is used as an absorbent and solidification agent for the wastes.
14	104	Heat Generation	Reaction will not occur – Ethers are solidified / immobilized prior to shipping. Oxidizing agents are reacted prior to being placed in the waste/shipped.
14	104	Fire	Reaction will not occur – Ethers are solidified / immobilized prior to shipping. Oxidizing agents are reacted prior to being placed in the waste/shipped.

Potential Chemical Incompatibilities			
Combination of Reactivity Groups		Reaction Result (A x B)	Explanation of Potential Incompatibility
Group A	Group B		
14	107	Highly Reactive	Reaction will not occur – Ethers are solidified / immobilized prior to shipping. Free liquid content is limited to less than 1% of waste volume; water reactive substances are reacted prior to being placed in the waste/shipped. Lime in Portland cement is most common water reactive substance expected in the waste. Portland cement is used as an absorbent and solidification agent for the wastes.
15	107	Highly Reactive	Reaction will not occur – Salts are reacted during use and processing; Free liquid content is limited to less than 1% of waste volume; water reactive substances are reacted prior to being placed in the waste/shipped. Lime in Portland cement is most common water reactive substance expected in the waste. Portland cement is used as an absorbent and solidification agent for the wastes.
16	104	Heat Generation	Reaction will not occur – Aromatic hydrocarbons are solidified/immobilized prior to shipping. Oxidizing agents are reacted prior to being placed in the waste/shipped.
16	104	Fire	Reaction will not occur – Aromatic hydrocarbons are solidified/immobilized prior to shipping. Oxidizing agents are reacted prior to being placed in the waste/shipped.
16	107	Highly Reactive	Reaction will not occur – Aromatic hydrocarbons are solidified/immobilized prior to shipping. Free liquid content is limited to less than 1% of waste volume; water reactive substances are reacted prior to being placed in the waste/shipped. Lime in Portland cement is most common water reactive substance expected in the waste. Portland cement is used as an absorbent and solidification agent for the wastes.
17	21	Heat Generation	Reaction will not occur – Halogenated organics are solidified/immobilized prior to shipping

Potential Chemical Incompatibilities			
Combination of Reactivity Groups		Reaction Result (A x B)	Explanation of Potential Incompatibility
Group A	Group B		
17	21	Explosion	Reaction will not occur – Halogenated organics are solidified/immobilized prior to shipping
17	22	Heat Generation	Reaction will not occur – Halogenated organics are solidified/immobilized prior to shipping
17	22	Explosion	Reaction will not occur – Halogenated organics are solidified/immobilized prior to shipping
17	23	Heat Generation	Reaction will not occur – Halogenated organics are solidified/immobilized prior to shipping
17	23	Fire	Reaction will not occur – Halogenated organics are solidified/immobilized prior to shipping
17	104	Heat Generation	Reaction will not occur – Halogenated organics are solidified/immobilized prior to shipping; oxidizing agents are reacted prior to being placed in the waste/shipped.
17	104	Toxic Gas Generation	Reaction will not occur – Halogenated organics are solidified/immobilized prior to shipping; oxidizing agents are reacted prior to being placed in the waste/shipped.
17	105	Heat Generation	Reaction will not occur – Halogenated organics are solidified/immobilized prior to shipping; reducing agents are reacted prior to being placed in the waste/shipped.
17	105	Explosion	Reaction will not occur – Halogenated organics are solidified/immobilized prior to shipping; reducing agents are reacted prior to being placed in the waste/shipped.
17	107	Highly Reactive	Reaction will not occur – Halogenated organics are solidified/immobilized prior to shipping; free liquid content is limited to less than 1% of waste volume; water reactive substances are reacted prior to being placed in the waste/shipped. Lime in Portland cement is most common water reactive substance expected in the waste. Portland cement is used as an absorbent and solidification agent for the wastes.
19	21	Flammable Gas Generation	Reaction will not occur – Ketones are solidified/immobilized prior to shipping

Potential Chemical Incompatibilities

Combination of Reactivity Groups		**Reaction Result (A x B)**	**Explanation of Potential Incompatibility**
Group A	**Group B**		
19	21	Heat Generation	Reaction will not occur – Ketones are solidified/immobilized prior to shipping
19	104	Heat Generation	Reaction will not occur –Ketones are solidified/immobilized prior to shipping; oxidizing agents are reacted prior to being placed in the waste/shipped.
19	104	Fire	Reaction will not occur –Ketones are solidified/immobilized prior to shipping; oxidizing agents are reacted prior to being placed in the waste/shipped.
19	105	Flammable Gas Generation	Reaction will not occur –Ketones are solidified/immobilized prior to shipping; reducing agents are reacted prior to being placed in the waste/shipped.
19	105	Heat Generation	Reaction will not occur –Ketones are solidified/immobilized prior to shipping; reducing agents are reacted prior to being placed in the waste/shipped.
19	107	Highly Reactive	Reaction will not occur – Ketones are solidified/immobilized prior to shipping; free liquid content is limited to less than 1% of waste volume; water reactive substances are reacted prior to being placed in the waste/shipped. Lime in Portland cement is most common water reactive substance expected in the waste. Portland cement is used as an absorbent and solidification agent for the wastes.
21	31	Flammable Gas Generation	Reaction will not occur – Phenols and Creosols are solidified/immobilized prior to shipping; metals are typically in oxide form
21	31	Heat Generation	Reaction will not occur – Phenols and Creosols are solidified/immobilized prior to shipping; metals are typically in oxide form
21	32	Heat Generation	Reaction will not occur – Organophosphates are solidified/immobilized prior to shipping; metals are typically in oxide form

Potential Chemical Incompatibilities			
Combination of Reactivity Groups		**Reaction Result (A x B)**	**Explanation of Potential Incompatibility**
Group A	**Group B**		
21	101	Heat Generation	Reaction will not occur – Combustible materials are dry; free liquid content is limited to less than 1% of waste volume; metals are typically in oxide form
21	101	Innocuous and Non-Flammable Gas Generation	Reaction will not occur – Combustible materials are dry; free liquid content is limited to less than 1% of waste volume; metals are typically in oxide form
21	101	Fire	Reaction will not occur – Combustible materials are dry; free liquid content is limited to less than 1% of waste volume; metals are typically in oxide form
21	103	Violent Polymerization	Reaction will not occur – Polymerizable compounds are reacted or immobilized/solidified prior to shipping; metals are typically in oxide form
21	103	Heat Generation	Reaction will not occur – Polymerizable compounds are reacted or immobilized/solidified prior to shipping; metals are typically in oxide form
21	104	Heat Generation	Reaction will not occur –Oxidizing agents are reacted prior to being placed in the waste/shipped; metals are typically in oxide form
21	104	Fire	Reaction will not occur –Oxidizing agents are reacted prior to being placed in the waste/shipped; metals are typically in oxide form
21	104	Explosion	Reaction will not occur –Oxidizing agents are reacted prior to being placed in the waste/shipped; metals are typically in oxide form
21	106	Flammable Gas Generation	Reaction will not occur – Free liquids are limited to less than 1% of waste volume; metals are typically in oxide form.
21	106	Heat Generation	Reaction will not occur – Free liquids are limited to less than 1% of waste volume; metals are typically in oxide form.
21	107	Highly Reactive	Reaction will not occur – Metals are typically in oxide form; water reactive substances are reacted prior to being placed in the waste/shipped. Lime in Portland cement is most common water reactive substance expected in the waste. Portland cement is used as an absorbent and solidification agent for the wastes.

Potential Chemical Incompatibilities			
Combination of Reactivity Groups		Reaction Result (A x B)	Explanation of Potential Incompatibility
Group A	Group B		
22	28	Heat Generation	Reaction will not occur – Unsaturated aliphatic hydrocarbons are solidified/immobilized prior to shipping
22	28	Explosion	Reaction will not occur – Unsaturated aliphatic hydrocarbons are solidified/immobilized prior to shipping
22	103	Violent Polymerization	Reaction will not occur – Polymerizable compounds are reacted or immobilized/solidified prior to shipping
22	103	Heat Generation	Reaction will not occur – Polymerizable compounds are reacted or immobilized/solidified prior to shipping
22	104	Heat Generation	Reaction will not occur – Oxidizing agents are reacted prior to being placed in the waste/shipped
22	104	Fire	Reaction will not occur – Oxidizing agents are reacted prior to being placed in the waste/shipped
22	104	Explosion	Reaction will not occur – Oxidizing agents are reacted prior to being placed in the waste/shipped
22	106	Flammable Gas Generation	Reaction will not occur – Free liquids are limited to less than 1% of waste volume; water reactive metals are reacted prior to shipping
22	106	Heat Generation	Reaction will not occur – Free liquids are limited to less than 1% of waste volume; water reactive metals are reacted prior to shipping
22	107	Highly Reactive	Reaction will not occur –Water reactive substances are reacted prior to being placed in the waste/shipped. Lime in Portland cement is most common water reactive substance expected in the waste. Portland cement is used as an absorbent and solidification agent for the wastes.
23	103	Violent Polymerization	Reaction will not occur – Polymerizable compounds are reacted or immobilized/solidified prior to shipping
23	103	Heat Generation	Reaction will not occur – Polymerizable compounds are reacted or immobilized/solidified prior to shipping

Potential Chemical Incompatibilities			
Combination of Reactivity Groups		Reaction Result (A x B)	Explanation of Potential Incompatibility
Group A	Group B		
23	104	Heat Generation	Reaction will not occur – Oxidizing agents are reacted prior to being placed in the waste/shipped
23	104	Fire	Reaction will not occur – Oxidizing agents are reacted prior to being placed in the waste/shipped
23	107	Highly Reactive	Reaction will not occur –Water reactive substances are reacted prior to being placed in the waste/shipped. Lime in Portland cement is most common water reactive substance expected in the waste. Portland cement is used as an absorbent and solidification agent for the wastes.
24	103	Violent Polymerization	Reaction will not occur – Polymerizable compounds are reacted or immobilized/solidified prior to shipping
24	103	Heat Generation	Reaction will not occur – Polymerizable compounds are reacted or immobilized/solidified prior to shipping
24	106	Solubilization of Toxic Substances	Reaction will not occur – Free liquid content is limited to less than 1% of waste volume; Additionally, any solubilization of toxic substances will not affect transportation of wastes.
24	107	Highly Reactive	Reaction will not occur – Water reactive substances are reacted prior to being placed in the waste/shipped. Lime in Portland cement is most common water reactive substance expected in the waste. Portland cement is used as an absorbent and solidification agent for the wastes.
28	104	Heat Generation	Reaction will not occur – Unsaturated aliphatic hydrocarbons are immobilized/solidified prior to shipping; oxidizing agents are reacted prior to being placed in the waste/shipped
28	104	Fire	Reaction will not occur – Unsaturated aliphatic hydrocarbons are immobilized/solidified prior to shipping; oxidizing agents are reacted prior to being placed in the waste/shipped

Potential Chemical Incompatibilities

Combination of Reactivity Groups		**Reaction Result (A x B)**	**Explanation of Potential Incompatibility**
Group A	**Group B**		
28	107	Highly Reactive	Reaction will not occur – Unsaturated aliphatic hydrocarbons are immobilized/solidified prior to shipping; free liquid content is limited to less than 1% of waste volume; water reactive substances are reacted prior to being placed in the waste/shipped. Lime in Portland cement is most common water reactive substance expected in the waste. Portland cement is used as an absorbent and solidification agent for the wastes.
29	104	Heat Generation	Reaction will not occur – Saturated aliphatic hydrocarbons are immobilized/solidified prior to shipping; oxidizing agents are reacted prior to being placed in the waste/shipped
29	104	Fire	Reaction will not occur – Saturated aliphatic hydrocarbons are immobilized/solidified prior to shipping; oxidizing agents are reacted prior to being placed in the waste/shipped
29	107	Highly Reactive	Reaction will not occur – Saturated aliphatic hydrocarbons are immobilized/solidified prior to shipping; free liquid content is limited to less than 1% of waste volume; water reactive substances are reacted prior to being placed in the waste/shipped. Lime in Portland cement is most common water reactive substance expected in the waste. Portland cement is used as an absorbent and solidification agent for the wastes.
31	103	Violent Polymerization	Reaction will not occur – Polymerizable compounds are reacted or immobilized/solidified prior to shipping; phenols and creosols are immobilized/solidified prior to shipping
31	103	Heat Generation	Reaction will not occur – Polymerizable compounds are reacted or immobilized/solidified prior to shipping; phenols and creosols are immobilized/solidified prior to shipping

Potential Chemical Incompatibilities			
Combination of Reactivity Groups		Reaction Result (A x B)	Explanation of Potential Incompatibility
Group A	Group B		
31	104	Heat Generation	Reaction will not occur – Phenols and creosols are immobilized/solidified prior to shipping; oxidizing agents are reacted prior to being placed in the waste/shipped
31	104	Fire	Reaction will not occur – Phenols and creosols are immobilized/solidified prior to shipping; oxidizing agents are reacted prior to being placed in the waste/shipped
31	105	Flammable Gas Generation	Reaction will not occur – Phenols and creosols are immobilized/solidified prior to shipping; reducing agents are reacted prior to being placed in the waste/shipped
31	105	Heat Generation	Reaction will not occur – Phenols and creosols are immobilized/solidified prior to shipping; reducing agents are reacted prior to being placed in the waste/shipped
31	107	Highly Reactive	Reaction will not occur – Phenols and creosols are immobilized/solidified prior to shipping; free liquid content is limited to less than 1% of waste volume; water reactive substances are reacted prior to being placed in the waste/shipped. Lime in Portland cement is most common water reactive substance expected in the waste. Portland cement is used as an absorbent and solidification agent for the wastes.
32	104	Heat Generation	Reaction will not occur – Organophosphates are immobilized/solidified prior to shipping; oxidizing agents are reacted prior to being placed in the waste/shipped
32	104	Fire	Reaction will not occur – Organophosphates are immobilized/solidified prior to shipping; oxidizing agents are reacted prior to being placed in the waste/shipped
32	104	Toxic Gas Generation	Reaction will not occur – Organophosphates are immobilized/solidified prior to shipping; oxidizing agents are reacted prior to being placed in the waste/shipped

Potential Chemical Incompatibilities			
Combination of Reactivity Groups		**Reaction Result (A x B)**	**Explanation of Potential Incompatibility**
Group A	**Group B**		
32	105	Toxic Gas Generation	Reaction will not occur – Organophosphates are immobilized/solidified prior to shipping; reducing agents are reacted prior to being placed in the waste/shipped
32	105	Flammable Gas Generation	Reaction will not occur – Organophosphates are immobilized/solidified prior to shipping; reducing agents are reacted prior to being placed in the waste/shipped
32	105	Heat Generation	Reaction will not occur – Organophosphates are immobilized/solidified prior to shipping; reducing agents are reacted prior to being placed in the waste/shipped
32	107	Highly Reactive	Reaction will not occur – Organophosphates are immobilized/solidified prior to shipping; free liquid content is limited to less than 1% of waste volume; water reactive substances are reacted prior to being placed in the waste/shipped. Lime in Portland cement is most common water reactive substance expected in the waste. Portland cement is used as an absorbent and solidification agent for the wastes.
101	104	Heat Generation	Reaction will not occur – Combustible materials are dry; oxidizing agents are reacted prior to being placed in the waste/shipped
101	104	Fire	Reaction will not occur – Combustible materials are dry; oxidizing agents are reacted prior to being placed in the waste/shipped
101	104	Innocuous and Non-Flammable Gas Generation	Reaction will not occur – Combustible materials are dry; oxidizing agents are reacted prior to being placed in the waste/shipped
101	105	Flammable Gas Generation	Reaction will not occur – Combustible materials are dry; reducing agents are reacted prior to being placed in the waste/shipped
101	105	Heat Generation	Reaction will not occur – Combustible materials are dry; reducing agents are reacted prior to being placed in the waste/shipped

Potential Chemical Incompatibilities			
Combination of Reactivity Groups		Reaction Result (A x B)	Explanation of Potential Incompatibility
Group A	Group B		
101	107	Highly Reactive	Reaction will not occur – Combustible materials are dry; free liquid content is limited to less than 1% of waste volume; water reactive substances are reacted prior to being placed in the waste/shipped. Lime in Portland cement is most common water reactive substance expected in the waste. Portland cement is used as an absorbent and solidification agent for the wastes.
103	104	Heat Generation	Reaction will not occur – Polymerizable compounds are reacted or immobilized/solidified prior to shipping; oxidizing agents are reacted prior to being placed in the waste/shipped
103	104	Fire	Reaction will not occur – Polymerizable compounds are reacted or immobilized/solidified prior to shipping; oxidizing agents are reacted prior to being placed in the waste/shipped
103	104	Toxic Gas Generation	Reaction will not occur – Polymerizable compounds are reacted or immobilized/solidified prior to shipping; oxidizing agents are reacted prior to being placed in the waste/shipped
103	105	Heat Generation	Reaction will not occur – Polymerizable compounds are reacted or immobilized/solidified prior to shipping; reducing agents are reacted prior to being placed in the waste/shipped
103	105	Violent Polymerization	Reaction will not occur – Polymerizable compounds are reacted or immobilized/solidified prior to shipping; reducing agents are reacted prior to being placed in the waste/shipped
103	105	Flammable Gas Generation	Reaction will not occur – Polymerizable compounds are reacted or immobilized/solidified prior to shipping; reducing agents are reacted prior to being placed in the waste/shipped

Potential Chemical Incompatibilities			
Combination of Reactivity Groups		**Reaction Result (A x B)**	**Explanation of Potential Incompatibility**
Group A	**Group B**		
103	107	Highly Reactive	Reaction will not occur – Polymerizable compounds are reacted or immobilized/solidified prior to shipping; free liquid content is limited to less than 1% of waste volume; water reactive substances are reacted prior to being placed in the waste/shipped. Lime in Portland cement is most common water reactive substance expected in the waste. Portland cement is used as an absorbent and solidification agent for the wastes.
104	105	Heat Generation	Reaction will not occur – Oxidizing agents are reacted prior to being placed in the waste/shipped; reducing agents are reacted prior to being placed in the waste/shipped
104	105	Fire	Reaction will not occur – Oxidizing agents are reacted prior to being placed in the waste/shipped; reducing agents are reacted prior to being placed in the waste/shipped
104	105	Explosion	Reaction will not occur – Oxidizing agents are reacted prior to being placed in the waste/shipped; reducing agents are reacted prior to being placed in the waste/shipped
104	107	Highly Reactive	Reaction will not occur – Oxidizing agents are reacted prior to being placed in the waste/shipped; free liquid content is limited to less than 1% of waste volume; water reactive substances are reacted prior to being placed in the waste/shipped. Lime in Portland cement is most common water reactive substance expected in the waste. Portland cement is used as an absorbent and solidification agent for the wastes.
105	106	Flammable Gas Generation	Reaction will not occur – Reducing agents are reacted prior to being placed in the waste/shipped; free liquid content is limited to less than 1% of waste volume
105	106	Toxic Gas Generation	Reaction will not occur – Reducing agents are reacted prior to being placed in the waste/shipped; free liquid content is limited to less than 1% of waste volume

Potential Chemical Incompatibilities			
Combination of Reactivity Groups		Reaction Result (A x B)	Explanation of Potential Incompatibility
Group A	Group B		
105	107	Highly Reactive	Reaction will not occur – Reducing agents are reacted prior to being placed in the waste/shipped; free liquid content is limited to less than 1% of waste volume; water reactive substances are reacted prior to being placed in the waste/shipped. Lime in Portland cement is most common water reactive substance expected in the waste. Portland cement is used as an absorbent and solidification agent for the wastes.
106	107	Highly Reactive	Reaction will not occur – Free liquid content is limited to less than 1% of waste volume; water reactive substances are reacted prior to being placed in the waste/shipped. Lime in Portland cement is most common water reactive substance expected in the waste. Portland cement is used as an absorbent and solidification agent for the wastes.

Attachment C

Shipping Period for TRU Waste in the 10-160B Cask

C.1.0 INTRODUCTION

This Attachment presents the basis for the shipping period for TRU wastes from the time of cask closure until cask opening. This shipping period is used in the analysis of the gas generation in the 10-160B cask.

The 10-160B cask may be used to ship TRU waste from generator sites to the Waste Isolation Pilot Plant (WIPP) for disposal or between sites (e.g., from the Battelle West Jefferson, OH site to the U.S. Department of Energy [DOE] Hanford, WA site) for interim storage. While the shipments are in transit, a satellite tracking system will be operational to monitor progress and provide direct communication between the driver and the transport dispatcher.

C.2.0 EXPECTED SHIPPING PERIOD

The expected shipping period is the amount of time from the sealing of the cask at the loading facility until the opening of the cask at the unloading facility. It consists of: the time from cask sealing to the release of the transport unit from the loading facility, the expected transit time, and the time from arrival at the unloading facility until the cask is opened. For assessing the expected shipping period, it will be assumed that there are no delays.

C.2.1 Loading

The loading process from cask sealing to unit release includes health physics surveys, installing the upper impact limiter, and vehicle inspections. The time from cask sealing until the unit is released for travel has been accomplished in less than four (4) hours. To be conservative, a one-day (24 hour) duration will be assumed.

C.2.2 Transit

The longest route of prospective intersite shipments is from Savannah River, SC to Hanford, approximately 2800 miles. Shipments to WIPP are encompassed by this distance. All TRU shipments will be made with two drivers. Using two drivers, on an appropriate rotational schedule, the truck can travel for twenty-four (24) hours per day for up to seven days. Assuming an average speed of 45 mph, which includes time for vehicle inspections, fueling, meals, and driver relief, the duration of a 2800 mile trip is expected to be 62 hours. Again, to be conservative, the transit duration will be assumed to be three days (72 hours).

C.2.3 Unloading

The unloading process includes receipt survey and security checks, positioning of the trailer in the TRU waste unloading area, removal of the cask from the trailer to a transfer cart, positioning of the cask in the cask unloading room, and removal of the lid. This process has been accomplished in less than eight (8) hours. Again, to be conservative, the unloading duration will be assumed to be one day (24 hours).

C.2.4 Total

The total expected shipping period, with no delays, is less than 75 hours. For the purpose of this analysis, a conservative period of 5 days (120 hours) will be assumed.

C.3.0 SHIPPING DELAYS

The maximum shipping time will be assumed to be the sum of the expected shipping time and the time for delays which could extend the shipping time. These delays are: loading delays; transit delays due to weather or road closures, shipping vehicle accidents, mechanical delays, or driver illness; and unloading delays. Each of these delays are assessed below.

C.3.1 Loading Delays

There are a number of situations that could extend the time between cask sealing and truck release. These include: loading preceding a holiday weekend, problems with a leak test, and handling equipment failure. Both the leak test problem and the handling equipment failure should be resolvable by replacing or obtaining temporary equipment. Each of these situations is unlikely to cause more than a two day delay. The holiday weekend could cause a delay of three days, i.e., from Friday afternoon until Tuesday. It is very unlikely that more than two of the three loading delays could occur on the same shipment, so a total of five days seems a reasonably conservative assessment for a loading delay.

C.3.2 Transit Delays

Transit delays due to weather, e.g., a road closed due to snow, are unlikely to cause a delay of more than five days. A road closure due to a vehicle accident or a roadway or bridge failure would result in re-routing which could add up to two days to the transit time. A transit time delay due to weather or road closure will be assumed to be five days.

Transit delays due to an accident with the truck could cause a lengthy delay. Response time for notification and to take immediate corrective action is assumed to be one day. (The use of the on-board satellite communication system will facilitate an early response.) Accident mitigation may require transferring the cask to a different trailer using cranes and other heavy equipment. Mitigation is assumed to take five days for a total accident delay of six days.

Mechanical problems with the truck or trailer could also cause multi-day delays. Significant failures may require a replacement tractor or trailer. An appropriate response to a mechanical failure is assumed to take four days.

Driver illness could also cause transit delays. If a driver it too ill to continue, a replacement driver will be brought in. A two day delay is assessed for bringing in a replacement driver.

C.3.3 Unloading Delay

An unloading delay will occur if the truck arrives just before a holiday weekend. This could result in a four day delay. Additionally, a delay due to unloading equipment failure could occur. Repair of such equipment should not require more than four days. The unloading delay will be conservatively assumed to be five days. If an unanticipated situation occurs that would result in a much longer delay, the cask can be vented.

C.3.4 Total Delay

The total delay, i.e., the sum of the delay times for each of the delay types, is 27 days. This assumes that each type of delay occurs on the same shipment.

C.4.0 Maximum Shipping period

The maximum shipping period, as the sum of the expected shipping period and the total delay, is 32 days. This period assumes that each of the possible shipping delays occurs on the same shipment, a very unlikely occurrence. Further, for additional conservatism, the assumed maximum will be nearly doubled to 60 days. Thus, a 60 day shipping period will be the maximum used in analysis of gas generation in the sealed cask. A shorter, site-specific shipping period may be developed and included in the site-specific sub tier appendix, which contains the waste content codes for the site, that is submitted to the NRC for approval. This site-specific shipping period may be used in the gas generation analysis for the site's waste.

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4.11.3 COMPLIANCE METHODOLOGY FOR TRU WASTE FROM BATTELLE COLUMBUS LABAROTORIES (BCL), WEST JEFFERSON, OH

1.0 INTRODUCTION

This appendix presents the methods of preparation and characterization to qualify remote-handled (RH) transuranic (TRU) and contact-handled (CH) TRU waste, as defined by the U.S. Department of Energy (DOE) (Reference 12.1), as payload for transport in the 10-160B cask and to demonstrate that the TRU waste forms at Battelle Columbus Laboratories (BCL), described in this appendix, comply with the payload requirements. The methods for determining each restricted parameter, the factors influencing the parameter values, and the methods used by BCL for demonstrating compliance, are provided in the following sections.

This appendix also includes the following as attachments:

- Content codes BC 121A, BC 121B, BC 312A, BC 314A, BC 321A, BC 321B, and BC 322A (Attachment A)
- Chemical Lists for the above mentioned content codes (Attachment A)
- Methods for Determining Gas Generation Rates and Decay Heat Values (Attachment B).

2.0 PURPOSE

The purpose of this appendix is to describe the methods that shall be used to prepare and characterize the RH-TRU and CH-TRU waste belonging to BCL prior to transport in the 10-160B cask. This appendix is based on the format and requirements for TRU waste identified in Appendix 4.11.2. It incorporates acceptable methods applicable to the content codes listed in Table 3-1 of this appendix.

Section 3.0 describes the TRU waste payload. Sections 4.0 through 11.0 discuss each payload parameter and the BCL methods for demonstrating compliance with the cask payload requirements.

3.0 TRU WASTE PAYLOAD FOR 10-160B CASK

TRU waste is classified into content codes, which give a description of the RH-TRU and CH-TRU waste materials in terms of processes generating the waste, the packaging methods used in the waste container(s), and the generating site. Content codes for the RH-TRU and CH-TRU waste from BCL are provided in Attachment A and are listed in Table 3-1.

Table 3-1. BCL Content Codes

Content Code	**Waste Form Description**
BC 121A, BC 121B	CH-TRU Solid Organic Waste (D&D operations)
BC 312A	RH-TRU Solidified Organic Waste (R&D operations)
BC 314A	RH-TRU Cemented Inorganic Process Solids (R&D operations)
BC 321A	RH-TRU Solid Organic Waste (D&D operations)
BC 321B	RH-TRU Solid Organic Waste (Pool filters and resins)
BC 322A	RH-TRU Solid Inorganic Waste (R&D operations)

D&D = Decontamination and decommissioning.
R&D = Research and development.

The BCL has developed a formal TRU waste certification program that ensures the generation and packaging of waste under rigorous controls and documented procedures, in compliance with all governing regulations. In addition, complete documentation packages, along with quality assurance/quality control records, are generated for all payload containers. All TRU waste generated from the BCL will be packaged under a formal certification program (i.e., the BCL Decommissioning Project (BCLDP) TRU Waste Certification Program (WCP)). TRU waste generated from the BCL will comply with all transportation requirements using the following methods:

- Formally documented acceptable knowledge (AK)/process knowledge of the processes generating the waste
- Visual examination (VE), including audio/video surveillances of all packaging activities, conducted in accordance with approved procedures that ensure the absence of prohibited items and compliance with packaging requirements
- Data packages generated for all payload containers that document the contents and properties of the waste in the container
- Measurement of required parameters to ensure compliance with limits.

4.0 PHYSICAL FORM

4.1 Requirements

The physical form of waste comprising the 10-160B cask payload is restricted to solid or solidified materials in secondary containers. The total volume of residual liquid in a secondary container is restricted to less than 1% by volume. Secondary containers must be shored to prevent movement during accident conditions. Sharp or heavy objects in the waste shall be blocked, braced, or suitably packaged as necessary to provide puncture protection for the payload containers packaging these objects. Sealed containers greater than four liters in size are prohibited.

4.2 Methods of Compliance and Verification

All TRU waste from the BCLDP is newly packaged under procedures and plans that ensure compliance with transportation and other governing regulations. Pursuant to these procedures, compliance with the physical form requirements is ensured by documented AK and VE.

The BCL uses VE to verify the physical waste form descriptions documented as AK. As waste items are sorted, the BCL VE expert evaluates each waste item for consistency with the AK process description for the waste stream being packaged and determines and documents the physical form and description, and material type(s) and composition (percentage) of the item. The BCL AK expert independently reviews determinations made by the VE expert with respect to waste item assignments to waste streams as defined by the AK process descriptions during the AK confirmation process. AK discrepancy reports are generated with associated corrective actions, as necessary. The BCL also uses VE to ensure absence of prohibited items. As waste items are sorted, the BCL VE expert evaluates each waste item. As identified, any prohibited item is segregated for mitigation or other disposition and is not loaded into a waste container for shipment.

In addition to the generation of inventory loading records for each waste container, the VE documentation includes video/audio records. Video documentation of TRU waste packaging shall be performed at all times when TRU waste is being sorted and packaged under TC-OP-01.4 in the BCL hot cells using two cameras and two videocassette recorders. A microphone feed is provided to verify and verbally note the identification of the waste stream and the container. This process duplicates the information recorded in hardcopy form on the waste container loading record. When TRU waste packages are in the cell, but packaging is not being performed, motion/light sensitive recording equipment shall be left running, with a videocassette in place, to document any movement in the packaging area. This will be used to verify that all packaging was recorded and that no packaging was performed without the proper VE documentation.

The BCLDP TRU WCP will use AK and VE to verify that the liquid content of the payload container complies with the requirements. Packaging personnel shall restrict the presence of free liquids to the extent that is reasonably achievable by pouring, pumping, or aspirating. Free liquids encountered during packaging shall be absorbed. Any liquid in nontransparent inner containers, including pumps or mechanical equipment that may contain an oil reservoir that is not solidified, will be handled by assuming that the container is filled with liquid and the volume will be added to the total liquid documented for the payload container in evaluating compliance with the 1% (volume) limit on free liquids.

BCLDP TRU WCP personnel shall ensure compliance with the requirement associated with sharp or heavy objects through visual examination at the time of packaging as described in TC-OP-01.4, Segregation and Packaging of TRU Waste. BCLDP packaging operations include the practice of size reduction and the use of a 0.015-inch thick steel liner in the 55-gallon drums. Following size reduction, items with the potential to puncture the liner and drum are blocked, braced, or suitably packaged to ensure container integrity. Waste may alternatively be repackaged into 55-gallon drums lined with a rigid polyethylene liner.

BCLDP TRU WCP personnel shall ensure compliance with the requirement associated with sealed containers through visual examination at the time of packaging as described in TC-OP-01.4, Segregation and Packaging of TRU Waste. Sealed containers greater than 4 liters identified during the sorting process will be segregated for disposition and shall not be packaged for shipment.

As described in TC-AP-01.1, TRU Waste Data Package Generation, compliance with each of the restrictions on physical form shall be recorded in the payload container data package.

5.0 CHEMICAL FORM AND CHEMICAL PROPERTIES

5.1 Requirements

The chemical properties of the waste are determined by the chemical constituents allowed in a given content code. Specific requirements regarding the chemical form of the waste are as follows:

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

5.2 Methods of Compliance and Verification

Compliance with chemical form and chemical property restrictions is demonstrated through process knowledge or sampling programs, if required.

5.2.1 Pyrophoric Materials

Nonradioactive pyrophoric materials (e.g., organic peroxides, sodium metal, and chlorides) shall be segregated and not be packaged into payload containers. Radioactive pyrophoric material (e.g., metallic plutonium and americium), if present in the waste stream, shall be limited to less than 1 weight percent of the payload container. In accordance with TC-OP-01.4, Segregation and Packaging of TRU Waste, qualified BCLDP TRU WCP personnel shall use AK information in conjunction with VE, as described in Section 4.2, during waste generation and packaging to verify the absence of nonradioactive pyrophoric materials and compliance with the restriction on radioactive pyrophoric material (e.g., according to records of waste generation processes, nonradioactive pyrophoric materials have not been used). As described in TC-AP-01.1, TRU Waste Data Package Generation, the absence of nonradioactive pyrophorics and compliance with the restriction on radioactive pyrophoric material shall be recorded in the payload container data package. Any nonradioactive pyrophorics encountered during examination shall be segregated and shall not be shipped.

5.2.2 Explosives, Corrosives, and Compressed Gases

In accordance with TC-OP-01.4, Segregation and Packaging of TRU Waste, qualified BCLDP TRU WCP personnel shall use AK information in conjunction with VE, as described in

Section 4.2, during waste generation and packaging to verify the absence of explosives, corrosives, and compressed gases. Any unvented compressed gas canisters (including aerosol cans) identified during the packaging of wastes shall be segregated as described in TC-OP-01.4, Segregation and Packaging of TRU Waste. Acids and bases, if found, shall be neutralized. The absence of explosives, unvented compressed gas canisters, and corrosives shall be documented in the payload container data packages by BCLDP TRU WCP personnel as described in TC-AP-01.1, TRU Waste Data Package Generation.

5.2.3 Flammable VOCs

All TRU waste from the BCL is from research and development or decontamination and decommissioning related activities and will be packaged with the generation of complete data packages. The BCL wastes are not expected to have flammable VOCs based on the content codes, the waste packaging process (sorted and repackaged into drums as individual items, which minimizes the introduction of potentially flammable VOCs into the drums), and the lack of a source for potentially flammable VOCs.

6.0 CHEMICAL COMPATIBILITY

6.1 Requirements

Each content code has an associated chemical list (Attachment A) based on AK information. Chemical constituents in a payload container assigned to a given content code shall conform to these approved chemical lists. Chemicals/materials that are not listed are allowed in trace amounts (quantities less than 1 weight percent) in a payload container provided that the total quantity of trace chemicals/materials is restricted to less than 5 weight percent.

Chemical compatibility of a waste with its packaging ensures that chemical reactions will not occur that might pose a threat to the safe transport of a payload in the 10-160B cask.

6.2 Methods of Compliance and Verification

Attachment B of Appendix 4.11.2 presents the methodology and results for the chemical compatibility analyses performed for the list of allowable chemicals/materials associated with the TRU waste content codes expected to be shipped in the 10-160B cask. The results of these chemical compatibility analyses show that these content codes can be transported without any incompatibilities.

The chemicals present in the BCL content codes conform to the list of allowable materials in Attachment B of Appendix 4.11.2 and thereby meet the chemical compatibility requirements. Qualified BCLDP TRU WCP personnel shall document the presence of any chemicals identified during the waste characterization process in the payload container data packages. TC-OP-01.4, Segregation and Packaging of TRU Waste, includes instructions for comparing chemicals noted in the payload container data packages against the chemicals listed in the appropriate content code to ensure the contents of payload containers are compatible.

7.0 GAS DISTRIBUTION AND PRESSURE BUILDUP

7.1 Requirements

Gas distribution and pressure buildup during transport of TRU waste in the 10-160B cask payload are restricted to the following limits:

- The gases generated in the payload must be controlled to prevent the occurrence of potentially flammable concentrations of gases within the payload confinement layers and the void volume of the inner vessel (IV) cavity. Specifically, hydrogen concentrations within the payload confinement layers are limited to 5 percent by volume during a maximum 60-day shipping period (see Attachment C of Appendix 4.11.2).
- The gases generated in the payload and released into the IV cavity must be controlled to maintain the pressure within the IV cavity below the acceptable packaging design limit of 31.2 pounds per square inch gauge (psig).

7.2 Methods of Compliance and Verification

Compliance with the 10-160B cask design pressure limit for each BCL content code is analyzed by assuming that all gases generated are released into the IV cavity and by including the contributions from thermal expansion of gases and vapor pressure of atmospheric water.

Table 7-1 shows that the pressure increase during a period of 365 days is below the design pressure limit of 31.2 psig for all the BCL content codes.

Table 7-1. Maximum Pressure Increase Over 365-Day Shipping Period

Content Code	G_{eff} (RT)[a]	Void Volume (Liters)	Activation Energy (kcal/mole)	Decay Heat Limit per Cask (Watts)	G_{eff}[b]	P_{max}[c] (psig)
BC 121A	8.1	1938	2.1	2.26	14.19	31.13
BC 121B	8.1	1938	2.1	2.26	14.19	31.13
BC 312A[d]	--	--	--	--	--	--
BC 314A	0.72	1938	0	7.23	0.72	12.02
BC 321A	8.1	1938	2.1	1.96	14.19	28.10
BC 321B	8.1/2.1[e]	1938	2.1	2.03	4.65	15.03
BC 322A	0.024	1938	0	217	0.024	12.02

a G value for net gas (molecules per 100 eV) at room temperature (70°F).
b Effective G value (molecules per 100 eV) at maximum operating temperature of 168°F calculated using the Arrhenius equation for which activation energy is an input.
c Maximum pressure.
d This code consists of solidified organics; compliance with pressure limits will be shown by testing.
e BC 321B reports 12% cellulosics and 80% resins (remainder being inorganic material) and is reflected in the calculation of the temperature-corrected Geff.

Compliance with the restrictions on flammable gas concentration is discussed in Section 10.0.

8.0 PAYLOAD CONTAINER AND CONTENTS CONFIGURATION

8.1 Requirements

Fifty-five-gallon drums are authorized payload containers in a 10-160B cask. Up to ten 55-gallon drums of TRU waste may be packaged in the cask. Each 55-gallon drum to be packaged in the cask must have a minimum of one filter vent. The minimum filter vent specifications for the 55-gallon drums and drum liners used to package waste inside the drums are provided in Table 8-1.

The test methods used to determine the compliance of filter vents with the performance-based requirements of flow rate, efficiency, and hydrogen diffusivity shall be directed by procedures under a quality assurance program.

Filter vents shall be legibly marked to ensure both (1) identification of the supplier and (2) date of manufacture, lot number, or unique serial number.

Table 8-1. Minimum Filter Vent Specifications

Container/Filter Type	Filter Specification			
	Number of Vents Required per Container	Flow Rate (ml/min of air, STP, at 1 inch of water)[a]	Efficiency (percent)	Hydrogen Diffusivity (mol/s/mol fraction at 25°C)
Drum Filter	1	35	99.5	3.70E-6
Drum Liner Filter	1	35	NA[b]	3.70E-6

[a] Filters tested at a different pressure gradient shall have a proportional flow rate (e.g., 35 ml/min at 1 inch of water = 1 L/min at 1 psi).

[b] Filters installed in containers that are overpacked are exempt from the efficiency requirement as the drum must exhibit a ≥99.5 percent efficiency.

NA = Not applicable.

The rigid polyethylene liner, if present, in a payload container shall be punctured with a 1-inch diameter hole before the container is transported in the 10-160B.

8.2 Methods of Compliance and Verification

Procured filter vents at BCL shall be inspected as directed by QD-AP-04.1, Documentation and Control of Purchased Items and Services, to verify compliance with the applicable filter vent specifications specified in the purchase requisition (i.e., visual inspection of certificate of conformance serial numbers to actual filter vents and inspection of filters for physical damage). Under WA-OP-006, Procurement and Inspection of Packagings for Hazardous Materials Shipments, payload containers and liners, if present, shall be visually inspected to ensure that they have been fitted with the required number of filter vents or required hole diameter as specified above. Nonconforming filter vents shall be segregated in accordance with

QD-AP-15.1, Nonconformance Reporting for Activities, Items and Materials. As described in TC-OP-01.4, Segregation and Packaging of TRU Waste, qualified BCLDP TRU WCP personnel also shall visually inspect payload containers during packaging to ensure that each has been fitted with the correct type and number of filter vents.

Prior to transport, payload container filter vents shall be visually inspected by the Transportation Certification Official (TCO) for damage or defect. If a defect is identified, a nonconformance report shall be issued in accordance with QD-AP-15.1, Nonconformance Reporting for Activities, Items and Materials, and the payload container shall be returned for repackaging or overpacking prior to certification.

9.0 ISOTOPIC CHARACTERIZATION AND FISSILE CONTENT

9.1 Requirements

The 10-160B cask payload allows 325 FGE of fissile materials. Plutonium content in excess of 0.74 TBq (20 curies) per cask must be in solid form.

9.2 Methods of Compliance and Verification

BCLDP TRU WCP personnel will calculate the fissile or fissionable radionuclide content of the payload container as Pu-239 (plutonium-239) fissile gram equivalents (FGE) and as plutonium curies as described in DD-98-04, Waste Characterization, Classification and Shipping Support Technical Basis Document, and TC-AP-01.2, Calculations Using Radioassay Data. These calculations are based on the waste generation source and configuration, which establishes the initial radionuclide compositions based on location and initial use. As described in DD-98-04, Waste Characterization, Classification and Shipping Support Technical Basis Document, assay of samples and dose rate measurements, along with the appropriate isotopic composition, are used to determine the isotopic inventory. The TCO shall evaluate the compliance of the total FGE value and the plutonium curies of payload containers with the maximum limits.

It should be noted that BCLDP accountability records indicate no more than approximately 50 grams of fissile material is dispersed throughout the BCL West Jefferson North facility in low isotopic enrichments (Reference 12.2). Therefore, the drum loading of fissile material will be much lower.

10.0 DECAY HEAT AND HYDROGEN GAS GENERATION RATES

This section describes the logic and methodology used in evaluating payload characteristics that meet the hydrogen gas concentration requirement for each of the content codes for the BCL TRU wastes described in this section.

10.1 Requirements

The hydrogen gas concentration shall not exceed 5% by volume in all void volumes within the 10-160B cask payload during a 60-day shipping period. A 10-160B cask payload must be assembled of payload containers belonging to the same content code. Payload containers of different content codes with different bounding G values and resistances may be assembled together as a payload, provided the decay heat limit and hydrogen gas generation rate limit for all payload containers within the payload is conservatively assumed to be the same as that of the payload container with the lowest decay heat limit and hydrogen gas generation rate limit.

10.2 Methodology of Ensuring Compliance with Flammable Gas Concentration Limits

As stated in Appendix 4.11.2, chemical, biological, and thermal gas generation mechanisms are insignificant in the 10-160B cask. In addition, as shown in Section 5.1 of Appendix 4.11.2, potentially flammable VOCs are restricted to 500 ppm in the headspace of the 10-160B cask secondary containers. Therefore, the only flammable gas of concern for transportation purposes is hydrogen. The concentration of hydrogen within any void volume in a layer of confinement of the payload or in the cask IV has been evaluated during a 60-day shipping period (see Attachment C of Appendix 4.11.2).

Attachment A provides the TRU waste content codes for the BCL TRU wastes that are included in the authorized payload for the 10-160B cask. Each content code has a unique and completely defined packaging configuration. Modeling the movement of hydrogen from the waste material to the payload voids, using the release rates of hydrogen through the various confinement layers, defines the relationship between generation rate and void concentration. This modeling allows determination of the maximum allowable hydrogen generation rate for a given content code to meet the 5% concentration limit, as detailed in Section 10.3. Based on hydrogen gas generation potential, quantified by hydrogen gas generation G values, the gas concentration limit can be converted to a decay heat limit, as detailed in Section 10.4. The maximum allowable hydrogen generation rates and decay heat limits for the TRU content codes for BCL wastes are listed in Table 10-1 (see Attachment A of Appendix 4.11.2 for a description of the Matrix Depletion Program and dose-dependent G values).

Content Code	Maximum Allowable Hydrogen Gas Generation Rate, mole/second/ drum	Maximum Allowable Hydrogen Gas Generation Rate, moles/second/ cask	Maximum Allowable Decay Heat Limit, Watts/Drum (Dose <= 0.012 watt*year)	Maximum Allowable Decay Heat Limit, Watts/Cask (Dose <= 0.012 watt*yr)	Maximum Allowable Decay Heat Limit, Watts/Drum (Dose > 0.012 watt*year)	Maximum Allowable Decay Heat Limit, Watts/Cask (Dose > 0.012 watt*year)
BC 121A	3.944E-8	3.944E-7	0.081	0.81	0.238	2.26[a]
BC 121B	4.745E-8	4.745E-7	0.101	1.01	0.298	2.26[a]
BC 312A	3.429E-8	3.429E-7	–[b]	–[b]	–[b]	–[b]
BC 314A	3.429E-8	3.429E-7	0.723	7.23	0.723	7.23
BC 321A	3.429E-8	3.429E-7	0.096	0.96	0.196	1.96
BC 321B	3.429E-8	3.429E-7	0.181	1.81	0.203	2.03
BC 322A	3.429E-8	3.429E-8	21.7	217	21.7	217

[a] Constrained by total decay heat that will comply with design pressure limit (see Table 7-1).
[b] No decay heat limit or activity limit due to unknown G value.

10.3 Determination of Maximum Allowable Hydrogen Generation Rates for Content Codes

The maximum allowable hydrogen generation rates were determined using the modeling methodology described in Appendix 4.11.2 and the following input parameters.

Waste Packaging Configuration and Release Rates: Each content code has a unique packaging configuration that is completely defined. The waste described by content codes BC 312A, BC 314A, BC 321A, and BC 322A will be placed directly into a 55-gallon drum lined with a steel liner. The waste described by content code BC 321B will also be placed directly into a 55-gallon drum that may be lined with a steel liner or a polyethylene liner. The waste described by content codes BC 121A and BC 121B will be placed into a 55-gallon drum that may be lined with a polyethylene liner. Ten drums will then be placed into the 10-160B cask. Release rates of hydrogen through the drum filters and drum liner filters have been quantified, and are summarized in Table 10-2. Note that, if used, the polyethylene liner in content codes BC 121A and BC 121B is punctured with a 1-inch diameter hole. For BC 321B if a rigid polyethylene liner is used the release rate associated with liner lid hole is conservatively assumed to be the same as that of the steel liner filter. These are based on release rates obtained for filters (Reference 12.3) at room temperatures. The release rates used in the calculations are the minimum measured values in each case.

Table 10-2. Release Rates of Hydrogen

Content Code	Confinement Layer	Release Rate (mol/sec/mol fraction)	
		T = 233K	T = 348.6K
BC 121A	Polyethylene Liner	5.20×10^{-4}	5.66×10^{-4}
	Drum Filter	2.46×10^{-6}	4.98×10^{-6}
BC 121B	Liner bag	4.67×10^{-6}	4.67×10^{-6} [a]
	Polyethylene liner	5.20×10^{-4}	5.66×10^{-4}
	Drum filter	2.46×10^{-6}	4.98×10^{-6}
BC 312A	Drum Liner Filter	2.46×10^{-6}	4.98×10^{-6}
	Drum Filter	2.46×10^{-6}	4.98×10^{-6}
BC 314A	Drum Liner Filter	2.46×10^{-6}	4.98×10^{-6}
	Drum Filter	2.46×10^{-6}	4.98×10^{-6}
BC 321A	Drum Liner Filter	2.46×10^{-6}	4.98×10^{-6}
	Drum Filter	2.46×10^{-6}	4.98×10^{-6}
BC 321B	Drum Liner Filter	2.46×10^{-6}	4.98×10^{-6}
	Drum Filter	2.46×10^{-6}	4.98×10^{-6}
BC 322A	Drum Liner Filter	2.46×10^{-6}	4.98×10^{-6}
	Drum Filter	2.46×10^{-6}	4.98×10^{-6}

[a] This is the minimum measured value and is applicable to all temperatures.

The release rates in Table 10-2 are shown for two different temperatures. The temperature dependence of these release rates is discussed later in this section.

Void Volume in the 10-160B IV: The cask will have a payload of 10 drums and a drum carriage. The interior volume of the cask, V_{cask}, is 4438 liters. The volume occupied by the drum carriage, $V_{carriage}$, is 143.2 liters. The external volume of a single drum, V_{drum}, is 235.7 liters. The void volume within the cask is calculated as:

$$V_{V,cask} = V_{cask} - V_{carriage} - 10\, V_{drum}$$

$$V_{V,cask} = 4438 \text{ liters} - 143.2 \text{ liters} - 10\,(235.7 \text{ liters})$$

$$V_{V,cask} = 1938 \text{ liters}$$

Pressure: The pressure is assumed to be isobaric and equal to one atmosphere. The mole fraction of hydrogen in each void volume would be smaller if pressurization is considered and would result in a greater maximum allowable hydrogen gas generation rate. Furthermore, the amount of hydrogen gas generated during a 60-day shipping period would be negligible compared to the quantity of air initially present at the time of sealing the 10-160B cask.

Temperature: The input parameter affected by temperature is the release rate through the different confinement layers in the payload containers and the G values for hydrogen. Release rates increase with increasing temperature (Reference 12.4). Therefore, the minimum release rates would be those at the lowest operating temperature. These are the release rates indicated in Table 10-2 for 233K. The minimum decay heat limits are determined by the ratio of the release rates and the G values. In other words, the higher the release rates, the higher the decay heat limit; the higher the G value, the lower the decay heat limit. The dependence of G values on temperature is documented in Section 10.4. For determining the decay heat limit, the temperature that yielded the minimum decay heat limit for each content code was used as the input parameter.

In summary, the temperature dependence of the input parameters was accounted for in the calculation so that, in each case, the minimum possible limit (hydrogen generation rate or decay heat limit) was obtained. This provides an additional margin of safety in the analysis for each content code.

10.4 Determination of Maximum Allowable Decay Limits

The maximum allowable decay heat limits for the CH-TRU and RH-TRU waste content codes for BCL were calculated using the methodologies described in Appendix 4.11.2 and the content code-specific G values and waste data described below.

10.4.1 G Value Data

G values for TRU waste are content specific. G values are determined based on the bounding materials present in the payload. The following G values were used for each of the content codes based on the presence of the bounding materials. The G values at 70°F are adjusted to the maximum operating temperature of the 10-160B cask (168°F) using the Arrhenius equation. The maximum operating temperature yields the lowest decay heat limits for the operating temperature range of the 10-160B cask.

Table 10-3 summarizes the bounding G values for hydrogen and the activation energies for the G values for these different content codes at the temperature that provides the minimum decay heat limit. Materials determining these bounding G values are also listed in Table 10-3. These G values are further discussed by content code below.

Dose-dependent G values for the authorized content codes are provided in Table 10-4 at the temperature that provides the minimum decay heat limit (i.e., 348.6K, the maximum operating temperature). The methodology associated with the determination of dose-dependent G values pursuant to the Matrix Depletion Program is further discussed in Attachment A of Appendix 4.11.2.

BC 121A and BC 121B

These content codes represent solid organic debris consisting of various combustible and non-combustible items. The material present in this waste with the highest G value at the maximum operating temperature of the 10-160B cask (168°F) is cellulosics and is therefore considered as the bounding material. The G value for hydrogen associated with cellulosics is 3.2

molecules/100eV (at 70°F) if the attained dose is less than or equal to 0.012 watt*year. The dose dependent G value for cellulosics is 1.09 molecules/ 100 eV if the dose attained in the drum is greater than 0.012 watt*yr. The methodology associated with the determination of dose-dependent G values pursuant to the Matrix Depletion Program is further discussed in Attachment A of Appendix 4.11.2. The G values at 70°F are adjusted to the maximum operating temperature of the 10-160B cask (168°F) using the Arrhenius equation. The activation energy of the G value for cellulosics is 2.1 kcal/mole. Thus, at the maximum operating temperature of the 10-160B cask (168°F), the bounding hydrogen G values for cellulosics are 5.61 molecules/100 eV (dose ≤ 0.012 watt*year) and 1.91 molecules/100 eV (dose > 0.012 watt*year).

Table 10-3. Summary of Bounding G Values (Dose ≤ 0.012 watt*year)

Content Code	Waste Material	Maximum Hydrogen Gas G value at 70°F (molecules/ 100 eV)	Bounding Hydrogen Gas G Value (molecules/100 eV)			Activation Energy (kcal/mole)
			α-radiation	β-radiation	γ-radiation	
BC 121A	Cellulose	3.2	5.61			2.1
BC 121B	Cellulose	3.2	5.61			2.1
BC 312A	Oils/Alcohol	-	-	-	-	-
BC 314A	30% Water	0.48	0.48	0.48	0.48	0
BC 321A	Cellulose	3.2	4.60	5.61	5.61	2.1
BC 321B	12% Cellulose + 80% Resins	1.74	2.51	3.06	3.06	2.1
BC 322A	1% Water	0.016	0.016	0.016	0.016	0

Table 10-4. Summary of Bounding G Values (Dose > 0.012 watt*year)

Content Code	Waste Material	Maximum Hydrogen Gas G value at 70°F (molecules/ 100 eV)	Bounding Hydrogen Gas G Value (molecules/100 eV)			
			α-radiation	β-radiation	γ-radiation	Activation Energy (kcal/mole)
BC 121A	Cellulose	1.09	1.91			2.1
BC 121B	Cellulose	1.09	1.91			2.1
BC 312A	Oils/Alcohol	-	-	-	-	-
BC 314A	30% Water	0.48	0.48	0.48	0.48	0
BC 321A	Cellulose	1.09	1.57	1.91	5.61	2.1
BC 321B	12% Cellulose + 80% Resins	1.74	2.15	2.62	3.06	2.1
BC 322A	1% Water	0.016	0.016	0.016	0.016	0

BC 312A

This content code represents solidified organics and does not have a defined G value.

BC 314A

This content code represents cemented inorganic process solids consisting of solidified cement slugs. It is assumed that water is the dominant hydrogen gas generating material in the waste form and will therefore be the bounding material. The G value for hydrogen from water is 1.6 molecules/100eV. It is also assumed that the moisture content of the waste is 30% and therefore the G value is 30% of the G value for water or 0.48 molecules/100eV (at all temperatures because the activation energy is 0 kcal/mole). There is no dose dependent G value for this content code per Attachment A of Appendix 4.11.2.

BC 321A

This content code represents solid organic debris consisting of various combustible and non-combustible items. The dominant material present in this waste is cellulosics (95%) and is therefore considered as the bounding material. The G value for hydrogen associated with cellulosics is 3.2 molecules/100eV (at 70°F) if the attained dose is less than or equal to 0.012 watt*year. The dose dependent G value for cellulosics is 1.09 molecules/100 eV if the dose attained in the drum is greater than 0.012 watt*yr. The methodology associated with the determination of dose-dependent G values pursuant to the Matrix Depletion Program is further discussed in Attachment A of Appendix 4.11.2. The G values at 70°F are adjusted to the maximum operating temperature of the 10-160B cask (168°F) using the Arrhenius equation. The activation energy of the G value for cellulosics is 2.1 kcal/mole. Thus, at the maximum operating temperature of the 10-160B cask (168°F), the bounding hydrogen G values for cellulosics are 5.61 molecules/100 eV (dose ≤ 0.012 watt*year) and 1.91 molecules/100 eV (dose > 0.012 watt*year).

BC 321B

This content code represents organic pool filter and resin waste consisting of ion exchange resins. The dominant material present in this waste is organic resins (80%). The waste also consists of cellulosics (12%). The effective G value for hydrogen for this content code is the sum of 80% of the G value for organic resins (1.7 molecules/100eV at 70°F) and 12% of the G value for cellulosics (3.2 molecules/100eV at 70°F), which is 1.74. G values for this content code at the maximum operating temperature (348.6K) are listed in Tables 10-3 and 10-4.

BC 322A

This content code represents waste consisting of glass, metal, and solidified and other inorganic materials. It is conservatively assumed that residual water is the dominant hydrogen gas generating material in this waste form and will therefore be the bounding material. The G value for hydrogen from water is 1.6 molecules/100eV. It is also assumed that the moisture content of the waste is 1% and therefore the G value is 1% of the G value for water, or 0.016 molecules/100eV (at all temperatures because the activation energy is 0 kcal/mole). There is no dose dependent G value for this content code per Attachment A of Appendix 4.11.2.

10.4.2 Waste Data

RadCalc requires as input the following parameters associated with the waste for which the maximum allowable decay heat limit is being calculated:

- Physical Form – liquid, solid, or gas
- Waste Volume – volume of the waste, cm^3
- Waste Mass – mass of the waste, g
- G Value – G value of the waste, molecules per 100 eV

Liquids and gas wastes are prohibited in the 10-160B cask. The volume of the waste is assumed to be 217 liters per drum (the external volume of the waste drum) and 2170 liters for 10 drums in the cask. The waste volume is used by RadCalc, along with the waste mass, to determine the volume of hydrogen generated in the cask. The mass of the waste is calculated based on the assumed bulk density of the waste. The volume of hydrogen generated is directly proportional to the mass of the waste, as discussed in Reference 12.5. The most conservative estimate of the volume of hydrogen (greatest volume) would occur at the highest possible bulk density of the waste. The waste bulk densities for content codes BC 321A and BC 321B are conservatively assumed to be 0.55 g/cm^3 and 0.36 g/cm^3, respectively. A conservative bounding waste bulk density of 1.5 g/cm^3, obtained from Reference 12.6, is used for content codes BC 314A and BC 322A, consisting of cement and metal scrap as bounding materials, respectively. Representative waste drum data for these content codes provide waste bulk densities well below the 1.5 g/cm^3 bounding bulk density used to calculate the decay heat limits. This mass of waste is calculated based on the total volume of the 10 waste drums (2170 liters).

10.4.3 Determining Decay Heats

Methods for demonstrating compliance of the BCL TRU waste with the decay heat and hydrogen gas generation rate limits are shown in Attachment B.

10.5 Methodology for Compliance with Payload Assembly Requirements

The TCO shall ensure that the 10-160B cask payload consists of payload containers belonging to the same content code. In the event that payload containers of different content codes with different bounding G values and resistances are assembled together in the 10-160B cask, the TCO shall ensure that the decay heat and hydrogen gas generation rate for all payload containers within the payload are less than or equal to the limits associated with the payload container with the lowest decay heat limit and hydrogen gas generation rate limit.

11.0 WEIGHT

11.1 Requirements

The weight limit for the contents of the loaded cask is 14,250 pounds.

11.2 Methods of Compliance and Verification

In accordance with TC-OP-01.4, Segregation and Packaging of TRU Waste, BCLDP shall weigh each payload container and contents on a calibrated scale to determine the total weight of the payload container. Based on the total measured weight of the individual payload containers, BCLDP shall calculate total assembly weight and evaluate compliance with the maximum loaded cask weight limit.

12.0 REFERENCES

12.1 U.S. Department of Energy (DOE), 2002, "Contact Handled-Transuranic Waste Acceptance Criteria for the Waste Isolation Pilot Plant," Rev. 0, *DOE/WIPP-02-3122*, U.S. Department of Energy, Carlsbad Field Office, Carlsbad, New Mexico.

12.2 Battelle Memorial Institute (BMI), 1993. Memorandum from W.J. Zielenbach to W.J. Madia, Subject: Case RSC-151, JN-1 Criticality System, Battelle Memorial Institute, Columbus, Ohio

12.3 Peterson, S.H., E.E. Smeltzer, and R.D. Shaw, 1990, "Determination of Flow and Hydrogen Diffusion Characteristics of Carbon Composite Filters Used at the Waste Isolation Pilot Plant," Westinghouse STC, Chemical and Process Development, Pittsburgh, Pennsylvania.

12.4 Connolly, M.J., S.M. Djordjevic, K.J. Liekhus, C.A. Loehr, and L.R. Spangler, 1998, "Position for Determining Gas Phase Volatile Organic Compound Concentration in Transuranic Waste Containers," *INEEL-95/0109*, Idaho National Engineering and Environmental Laboratory, Idaho Falls, Idaho.

12.5 Flaherty, J.E., A. Fujita, C.P. Deltete, and G.J. Quinn, 1986, "A Calculational Technique to Predict Combustible Gas Generation in Sealed Radioactive Waste Containers," *GEND 041*, EG&G Idaho, Inc., Idaho Falls, Idaho.

12.6 Perry, R.H., D.W. Green, and J.O. Maloney, 1984, *Perry's Chemical Engineers' Handbook*, 6th ed., McGraw-Hill Book Co., New York, New York.

Attachment A

Transuranic Content Codes and Chemical Lists

for Battelle Columbus Laboratories

CONTENT CODE: BC 121

CONTENT DESCRIPTION: Solid Organic Waste – CH-TRU Waste

WASTE DESCRIPTION: This waste consists of a variety of combustible and noncombustible items, and solidified organic and inorganic liquid wastes.

GENERATING SOURCES: This waste is generated from activities supporting the decontamination and decommissioning of Building JN-4 under the Battelle Columbus Laboratories Decommissioning Project (BCLDP).

WASTE FORM: The waste includes combustible items such as cloth and paper products, plastic, cardboard, rubber, wood, tubing, hoses, gloves, and filter waste (e.g., filters and filter housings). The waste includes noncombustible items such as crushed metal cans, scrap metal, piping, paint chips, hand tools, nuts, bolts, nails, Plexiglas, glass, and crucibles. The waste also includes solidified liquids, soil or dirt, and equipment such as vacuum cleaners.

WASTE PACKAGING: For content code BC 121A the waste is contained with one drum liner bag that is then placed inside a rigid polyethylene drum liner, which if present, is punctured with a 1-inch-diameter hole. Ten drums will then be placed into the 10-160B cask. For content code BC 121B waste will be placed directly into a 55-gallon drum with no layers of confinement. The drum may be lined with a rigid polyethylene liner punctured with a 1-inch diameter hole. Ten drums will then be placed into the 10-160B cask.

METHODS FOR DETERMINATION OF ISOTOPIC CHARACTERIZATION: The isotopic information required to demonstrate compliance with the limits on fissile content, decay heat, and curie content will be determined based on the waste generation source and configuration, which establishes the initial radionuclide compositions based on location and initial use. A combination of assay of samples and modeling the isotopic generation processes results in the establishment of a mixture that characterizes the waste in the content code and the majority of waste at the BCLDP. Using shipping package modeling, dose rate and weight measurements based on the mixture then allows the BCLDP to determine the isotopic inventory. As required, additional radioassay (e.g., confirming gamma spectrometry) will be performed.

FREE LIQUIDS: Liquid waste is prohibited in the drums except for residual amounts in well-drained containers. The total volume of residual liquid in a payload container shall be less than 1 volume percent of the payload container. Waste repackaging procedures ensure that free liquids are less than 1 volume percent of the payload container. Liquid waste will be solidified using Floor Dry. Absorbents such as Radsorb or diatomaceous earth will be added to any waste matrix that has the potential to dewater after packaging.

EXPLOSIVE/COMPRESSED GASES: Explosives and compressed gases in the payload containers are prohibited by waste packaging procedures. If present, pressurized cans (e.g., aerosol cans) shall be punctured and emptied prior to packaging.

PYROPHORICS: Nonradioactive pyrophorics (e.g., sodium potassium) in the payload containers are prohibited by waste packaging procedures. Waste packaging procedures shall ensure that all pyrophoric radioactive materials are present only in small residual amounts (less than 1 weight percent) in payload containers.

CORROSIVES: Corrosives are prohibited in the payload container. Acids and bases that are potentially corrosive shall be neutralized and rendered noncorrosive prior to being a part of the waste. The physical form of the waste and the waste generating procedures ensure that the waste is in a nonreactive form.

CHEMICAL COMPATIBILITY: A chemical compatibility study has been performed on this content code, and all waste is chemically compatible for materials in greater than trace (>1% by weight) quantities.

ADDITIONAL CRITERIA: Each drum is fitted with a minimum of one filter vent and the rigid liner, if present, is vented with 1.0-inch minimum diameter hole.

MAXIMUM ALLOWABLE HYDROGEN GENERATION RATES - OPTION 1: The maximum allowable hydrogen generation rate limits are summarized in the table below.

MAXIMUM ALLOWABLE DECAY HEAT LIMIT - OPTION 2: The maximum allowable decay heat limits are summarized in the table below.

Maximum Allowable Hydrogen Gas Generation Rates and Decay Heat Limits

Content Code	Maximum Allowable Hydrogen Gas Generation Rate, mole/second/drum	Maximum Allowable Hydrogen Gas Generation Rate, moles/second/cask	Maximum Allowable Decay Heat Limit, Watts/Drum (Dose <= 0.012 watt*year)	Maximum Allowable Decay Heat Limit, Watts/Cask (Dose <= 0.012 watt*yr)	Maximum Allowable Decay Heat Limit, Watts/Drum (Dose > 0.012 watt*year)	Maximum Allowable Decay Heat Limit, Watts/Cask (Dose > 0.012 watt*year)
BC 121A	3.944E-8	3.944E-7	0.081	0.81	0.238	2.26
BC 121B	4.745E-8	4.745E-7	0.101	1.01	0.298	2.26

BATTELLE COLUMBUS LABORATORIES CONTENT CODES BC 121A AND BC 121B

SOLID ORGANIC WASTE

MATERIALS AND CHEMICALS >1%

CARDBOARD
CELLULOSICS
CLOTH
CONCRETE
DIATOMACEOUS EARTH (FLOOR DRY)
DIRT
EQUIPMENT (including vacuum cleaner, motors, and dosimeter system)
FILTERS
GLASS
HYDRAULIC OIL, GLYCOLS, OILS, AND ALCOHOLS (including butanol, ethanol, and methanol)
METALS (including mercury, brass, lead shielding, lead shot, silver, stainless steel, aluminum, iron, copper beryllium, and zirconium)
OTHER INORGANICS
PAINT CHIPS (including barium, cadmium, chromium, and lead)
PAPER
PLASTER-OF-PARIS
PLASTIC
PLEXIGLAS
RADSORB
RUBBER
SOIL
WOOD

MATERIALS AND CHEMICALS <1%

ACIDS AND ACID SOLUTIONS

METALS (including lithium and sodium [reacted; dissolved in butyl alcohol])

SOLVENTS (including acetone, benzene, ethyl alcohol, butyl alcohol, methyl alcohol, ethyl benzene, toulene, hexane, methyl ethyl ketone, trichloroethylene, Marine Strip [contains methylene chloride])

WATER

CONTENT CODE: BC 312A

CONTENT DESCRIPTION: Solidified Organic Waste

WASTE DESCRIPTION: This waste consists of solidified organic and inorganic liquid wastes.

GENERATING SOURCES: This waste is generated during research and development activities conducted in Building JN-1.

WASTE FORM: The waste consists primarily of inorganic and organic liquids that have been solidified using Floor Dry. The inorganic liquids included acids and acid solutions, and elemental mercury. The organic liquids included hydraulic oil, waste water, sludge of sand and mixed fission products (dust, small fragments); small items such as tools may also be present; nonhalogenated organic liquids such as glycols, oils, and alcohols.

WASTE PACKAGING: The waste will be placed directly into a 55-gallon drum with no layers of confinement. The drum is lined with a steel liner. Ten drums will then be placed into the 10-160B cask.

METHODS FOR DETERMINATION OF ISOTOPIC CHARACTERIZATION: The isotopic information required to demonstrate compliance with the limits on fissile content, decay heat, and curie content will be determined based on the waste generation source and configuration, which establishes the initial radionuclide compositions based on location and initial use. A combination of assay of samples and modeling the isotopic generation processes results in the establishment of a mixture that characterizes the waste in the content code and the majority of waste at the BCLDP. Using shipping package modeling, dose rate and weight measurements based on the mixture then allows the BCLDP to determine the isotopic inventory. As required, additional radioassay (e.g., confirming gamma spectrometry) will be performed.

FREE LIQUIDS: Liquid waste is prohibited in the drums except for residual amounts in well-drained containers. The total volume of residual liquid in a payload container shall be less than 1 volume percent of the payload container. Waste packaging procedures ensure that free liquids are less than 1 volume percent of the payload container. Absorbents such as Radsorb or diatomaceous earth (e.g., Floor Dry) will be added to any waste matrix that has the potential to dewater after packaging.

EXPLOSIVE/COMPRESSED GASES: Explosives and compressed gases in the payload containers are prohibited by waste packaging procedures. If present, pressurized cans shall be punctured and emptied prior to packaging.

PYROPHORICS: Nonradioactive pyrophorics in the payload containers are prohibited by waste packaging procedures. Waste packaging procedures shall ensure that all pyrophoric radioactive materials are present only in small residual amounts (less than 1 weight percent) in payload containers.

CORROSIVES: Corrosives are prohibited in the payload container. Acids and bases that are potentially corrosive shall be neutralized and rendered noncorrosive prior to being a part of the waste. The physical form of the waste and the waste generating procedures ensure that the waste is in a nonreactive form.

CHEMICAL COMPATIBILITY: A chemical compatibility study has been performed on this content code, and all waste is chemically compatible for materials in greater than trace (>1% by weight) quantities.

ADDITIONAL CRITERIA: Each drum is fitted with a minimum of one filter vent. The steel liner is fitted with a filter with a hydrogen diffusivity of 3.7E-06 mole/second/mole fraction.

MAXIMUM ALLOWABLE HYDROGEN GENERATION RATES - OPTION 1: The maximum allowable hydrogen generation rate limit is 3.429E-08 moles per second per drum and 3.429E-07 moles per second per 10-160B cask.

MAXIMUM ALLOWABLE DECAY HEAT LIMIT - OPTION 2: There is no decay heat limit for this content code as no G values have been established. Waste cannot be transported under Option 2.

BATTELLE COLUMBUS LABORATORIES CONTENT CODE BC 312A

SOLIDIFIED ORGANIC WASTE

MATERIALS AND CHEMICALS >1%

DIATOMACEOUS EARTH (FLOOR DRY)

ACIDS AND ACID SOLUTIONS

MERCURY

HYDRAULIC OIL, GLYCOLS, OILS, AND ALCOHOLS

SAND

VERMICULITE

RADSORB

AQUA-SET/PETRO-SET

MATERIALS AND CHEMICALS <1%

METALS (including stainless steel, aluminum, iron, copper, lead, beryllium, and zirconium)

CONTENT CODE: BC 314A

CONTENT DESCRIPTION: Cemented Inorganic Process Solids

WASTE DESCRIPTION: This waste consists of slugs produced from dissolving fuel specimens in an acid solution that was then diluted several times and mixed with cement and water and allowed to solidify in foam cups.

GENERATING SOURCES: This waste is generated during repackaging of the waste materials generated from research and development activities conducted in Building JN-1.

WASTE FORM: The waste consists of slugs produced from dissolving fuel specimens in an acid solution which was then diluted several times and mixed with cement and water and allowed to solidify in foam cups. The slugs will contain limited amounts of radionuclides from fuel because of this dilution. The waste matrix will also include Floor Dry added during repackaging to absorb any water from condensation or dewatering.

WASTE PACKAGING: The waste will be placed directly into a 55-gallon drum with no layers of confinement. The drum is lined with a steel liner. Ten drums will then be placed into the 10-160B cask.

METHODS FOR DETERMINATION OF ISOTOPIC CHARACTERIZATION: The isotopic information required to demonstrate compliance with the limits on fissile content, decay heat, and curie content will be determined based on the waste generation source and configuration, which establishes the initial radionuclide compositions based on location and initial use. A combination of assay of samples and modeling of the isotopic generation process used in the establishment of a mixture that characterizes the waste in the content code and the majority of waste at the BCLDP. Using shipping package modeling, dose rate and weight measurements based on the mixture then allows the BCLDP to determine the isotopic inventory. As required, additional radioassay (e.g., confirming gamma spectroscopy) will be performed.

FREE LIQUIDS: Liquid waste is prohibited in the drums except for residual amounts in well-drained containers. The total volume of residual liquid in a payload container shall be less than 1volume percent of the payload container. Waste packaging procedures ensure that free liquids are less than 1 volume percent of the payload container. Absorbents such as diatomaceous earth will be added to any waste matrix that has the potential to dewater after packaging.

EXPLOSIVE/COMPRESSED GASES: Explosives and compressed gases in the payload containers are prohibited by waste packaging procedures. If present, pressurized cans shall be punctured and emptied prior to packaging.

PYROPHORICS: Nonradioactive pyrophorics in the payload containers are prohibited by waste packaging procedures. Waste packaging procedures shall ensure that all pyrophoric radioactive materials are present only in small residual amounts (less than 1 weight percent) in payload containers.

CORROSIVES: Corrosives are prohibited in the payload container. Acids and bases that are potentially corrosive shall be neutralized and rendered noncorrosive prior to being a part of the waste. The physical form of the waste and the waste generating procedures ensure that the waste is in a nonreactive form.

CHEMICAL COMPATIBILITY: A chemical compatibility study has been performed on this content code, and all waste is chemically compatible for materials in greater than trace (>1% by weight) quantities.

ADDITIONAL CRITERIA: Each drum is fitted with a minimum of one filter vent. The steel liner is fitted with a filter with a hydrogen diffusivity of 3.7E-06 mole/second/mole fraction.

MAXIMUM ALLOWABLE HYDROGEN GENERATION RATES - OPTION 1: The maximum allowable hydrogen generation rate limit is 3.429E-08 moles per second per drum and 3.429E-07 moles per second per 10-160B cask.

MAXIMUM ALLOWABLE DECAY HEAT LIMIT - OPTION 2: The maximum allowable decay heat limit is 0.723 watts per drum and 7.23 watts per 10-160B cask.

BATTELLE COLUMBUS LABORATORIES CONTENT CODE BC 314A

CEMENTED INORGANIC PROCESS SOLIDS

MATERIALS AND CHEMICALS >1%

DIATOMACEOUS EARTH (FLOOR DRY)

CEMENT SLUGS

MATERIALS AND CHEMICALS <1%

NITRIC ACID

WATER

CONTENT CODE: BC 321A

CONTENT DESCRIPTION: Solid Organic Waste

WASTE DESCRIPTION: This waste consists of a variety of combustible and noncombustible items.

GENERATING SOURCES: This waste is generated from activities supporting the decontamination and decommissioning of Building JN-1 under the Battelle Columbus Laboratories Decommissioning Project (BCLDP).

WASTE FORM: The waste may include combustible items such as cloth and paper products (e.g., from the cleanup of spills), rags, coveralls and booties, plastic, cardboard, rubber, wood, surgeons gloves, and Kimwipes. The waste may also include filter waste (e.g., dry box filters, HEPA filters, and filter cartridges); noncombustible Benelex and Plexiglas neutron shielding, blacktop, concrete, dirt, and sand; leaded gloves and aprons comprised of Hypalon rubber and lead oxide impregnated neoprene; and small amounts of metal waste. The waste may also include particulate and sludge-type organic process solids immobilized/solidified with Portland cement, vermiculite, Aqua-Set, or Petro-Set.

WASTE PACKAGING: The waste will be placed directly into a 55-gallon drum with no layers of confinement. The drum is lined with a steel liner. Ten drums will then be placed into the 10-160B cask.

METHODS FOR DETERMINATION OF ISOTOPIC CHARACTERIZATION: The isotopic information required to demonstrate compliance with the limits on fissile content, decay heat, and curie content will be determined based on the waste generation source and configuration, which establishes the initial radionuclide compositions based on location and initial use. A combination of assay of samples and modeling of the isotopic generation process, results in the establishment of a mixture that characterizes the waste in the content code and the majority of waste at the BCLDP. Using shipping package modeling, dose rate and weight measurement based on the mixture then allows the BCLDP to determine the isotopic inventory. As required, additional radioassay (e.g., confirming gamma spectroscopy) will be performed.

FREE LIQUIDS: Liquid waste is prohibited in the drums except for residual amounts in well-drained containers. The total volume of residual liquid in a payload container shall be less than 1 volume percent of the payload container. Waste packaging procedures ensure that free liquids are less than 1 volume percent of the payload container. Absorbents such as Radsorb or diatomaceous earth will be added to any waste matrix that has the potential to dewater after packaging.

EXPLOSIVE/COMPRESSED GASES: Explosives and compressed gases in the payload containers are prohibited by waste packaging procedures. If present, pressurized cans shall be punctured and emptied prior to packaging.

PYROPHORICS: Nonradioactive pyrophorics in the payload containers are prohibited by waste packaging procedures. Waste packaging procedures shall ensure that all pyrophoric radioactive materials are present only in small residual amounts (less than 1 weight percent) in payload containers.

CORROSIVES: Corrosives are prohibited in the payload container. Acids and bases that are potentially corrosive shall be neutralized and rendered noncorrosive prior to being a part of the waste. The physical form of the waste and the waste generating procedures ensure that the waste is in a nonreactive form.

CHEMICAL COMPATIBILITY: A chemical compatibility study has been performed on this content code, and all waste is chemically compatible for materials in greater than trace (>1% by weight) quantities.

ADDITIONAL CRITERIA: Each drum is fitted with a minimum of one filter vent. The steel liner is fitted with a filter with a hydrogen diffusivity of 3.7E-06 mole/second/mole fraction.

MAXIMUM ALLOWABLE HYDROGEN GENERATION RATES - OPTION 1: The maximum allowable hydrogen generation rate limit is 3.429E-08 moles per second per drum and 3.429E-07 moles per second per 10-160B cask.

MAXIMUM ALLOWABLE DECAY HEAT LIMIT - OPTION 2: The maximum allowable decay heat limit is 0.096 watts per drum and 0.96 watts per 10-160B cask if dose #0.012 watt*yr and 0.196 watts per drum and 1.96 watts per 10-160B cask if dose >0.012 watt*yr.

BATTELLE COLUMBUS LABORATORIES CONTENT CODE BC 321A

SOLID ORGANIC WASTE

MATERIALS AND CHEMICALS >1%

BLACKTOP (ASPHALT)
CELLULOSICS
RUBBER
DIATOMACEOUS EARTH (FLOOR DRY)
GLASS
IRON-BASED METAL/ALLOYS
PAPER
PLASTIC
RADSORB
CLOTH
CARDBOARD
WOOD
KIMWIPES
FILTERS
BENELEX
PLEXIGLAS
NEOPRENE
PORTLAND CEMENT
VERMICULITE
AQUA-SET/PETRO-SET
OTHER INORGANICS

MATERIALS AND CHEMICALS <1%

METALS (including aluminum, lead, zirconium, stainless steel, and carbon steel)
CONCRETE
SOIL

CONTENT CODE: BC 321B

CONTENT DESCRIPTION: Solid Organic Waste

WASTE DESCRIPTION: This waste consists of a variety of combustible and noncombustible items.

GENERATING SOURCES: This waste is generated during the change-out of resins in the Transfer/Storage Pool filtering system in Building JN-1 (Hot Cell Laboratory).

WASTE FORM: The waste may include filter waste (e.g., pool filters); nuclear grade resin, resin bags, paper, rubber gloves, Floor Dry bags, seals, hoses, valves, and clamps.

WASTE PACKAGING: The waste will be placed directly into a 55-gallon drum with no layers of confinement. The drum may be lined with a steel or polyethylene liner. Ten drums will then be placed into the 10-160B cask.

METHODS FOR DETERMINATION OF ISOTOPIC CHARACTERIZATION: The isotopic information required to demonstrate compliance with the limits on fissile content, decay heat, and curie content will be determined based on the waste generation source and configuration, which establishes the initial radionuclide compositions based on location and initial use. A combination of assay of samples and modeling the isotopic generation process results in the establishment of a mixture that characterizes the waste in the content code. Using shipping package modeling, dose rate and weight measurements based on the mixture then allows the BCLDP to determine the isotopic inventory. As required, additional radioassay (e.g., confirming gamma spectrometry) will be performed.

FREE LIQUIDS: Liquid waste is prohibited in the drums except for residual amounts in well-drained containers. The total volume of residual liquid in a payload container shall be less than 1 volume percent of the payload container. Waste packaging procedures ensure that free liquids are less than 1 volume percent of the payload container. Absorbents such as Radsorb or diatomaceous earth will be added to any waste matrix that has the potential to dewater after packaging.

EXPLOSIVE/COMPRESSED GASES: Explosives and compressed gases in the payload containers are prohibited by waste packaging procedures. If present, pressurized cans shall be punctured and emptied prior to packaging.

PYROPHORICS: Nonradioactive pyrophorics in the payload containers are prohibited by waste packaging procedures. Waste packaging procedures shall ensure that all pyrophoric radioactive materials are present only in small residual amounts (less than 1 weight percent) in payload containers.

CORROSIVES: Corrosives are prohibited in the payload container. Acids and bases that are potentially corrosive shall be neutralized and rendered noncorrosive prior to being a part of the waste. The physical form of the waste and the waste generating procedures ensure that the waste is in a nonreactive form.

CHEMICAL COMPATIBILITY: A chemical compatibility study has been performed on this content code, and all waste is chemically compatible for materials in greater than trace (>1% by weight) quantities.

ADDITIONAL CRITERIA: Each drum is fitted with a minimum of one filter vent, and the steel or polyethylene liner, if present, is either punctured or fitted with a filter with a hydrogen diffusivity of 3.7E-06 mole/second/mole fraction.

MAXIMUM ALLOWABLE HYDROGEN GENERATION RATES - OPTION 1: The maximum allowable hydrogen generation rate limit is 3.429E-08 moles per second per drum and 3.429E-07 moles per second per 10-160B cask.

MAXIMUM ALLOWABLE DECAY HEAT LIMIT - OPTION 2: The maximum allowable decay heat limit is 0.181 watts per drum and 1.81 watts per 10-160B cask if dose #0.012 watt*yr and 0.203 watts per drum and 2.03 watts per 10-160B cask if dose >0.012 watt*yr.

BATTELLE COLUMBUS LABORATORIES CONTENT CODE BC 321B

SOLID ORGANIC WASTE

MATERIALS AND CHEMICALS >1%

CELLULOSICS (≤12 weight %)

RUBBER

DIATOMACEOUS EARTH (FLOOR DRY)

ION EXCHANGE RESIN (≤80 weight %)

IRON-BASED METAL/ALLOYS

RADSORB

RESIN BAGS

FILTERS

OTHER INORGANICS

MATERIALS AND CHEMICALS <1%

METALS (including aluminum, lead, zirconium, stainless steel, and carbon steel)

CONTENT CODE: BC 322A

CONTENT DESCRIPTION: Solid Inorganic Waste

WASTE DESCRIPTION: This waste consists of a variety of glass and metal materials.

GENERATING SOURCES: This waste is generated during repackaging of the waste materials generated from research and development activities conducted in Building JN-1.

WASTE FORM: The waste consists primarily of glass and metal debris. Glass debris includes laboratory glassware, windows, leaded glass windows, and various glass apparatus. Metal items may include deteriorated berry cans, cable, wire, planchets, signs, valves, piping, strapping, tools, foils, sheeting, fixtures, equipment (e.g., pumps or motors that have had all oil or any other free liquids removed up to an allowance of 1%), hardware (e.g., nuts, bolts, brackets), specimen vials, fuel rod cladding, metallurgical mounts, and lead lined tubing. Metals of construction include stainless steel, aluminum, iron, copper, lead, beryllium, and zirconium.

WASTE PACKAGING: The waste will be placed directly into a 55-gallon drum with no layers of confinement. The drum is lined with a steel liner. Ten drums will then be placed into the 10-160B cask.

METHODS FOR DETERMINATION OF ISOTOPIC CHARACTERIZATION: The isotopic information required to demonstrate compliance with the limits on fissile content, decay heat, and curie content will be determined based on the waste generation source and configuration, which establishes the initial radionuclide compositions based on location and initial use. A combination of assay of samples and modeling of the isotopic generation process used in the establishment of a mixture that characterizes the waste in the content code and the majority of waste at the BCLDP. Using shipping package modeling, dose rate and weight measurements based on the mixture then allows the BCLDP to determine the isotopic inventory. As required, additional radioassay (e.g., confirming gamma spectroscopy) will be performed.

FREE LIQUIDS: Liquid waste is prohibited in the drums except for residual amounts in well-drained containers. The total volume of residual liquid in a payload container shall be less than 1 volume percent of the payload container. Waste packaging procedures ensure that free liquids are less than 1 volume percent of the payload container. Absorbents such as diatomaceous earth (e.g., Floor Dry) will be added to any waste matrix that has the potential to dewater after packaging.

EXPLOSIVE/COMPRESSED GASES: Explosives and compressed gases in the payload containers are prohibited by waste packaging procedures. If present, pressurized cans shall be punctured and emptied prior to packaging.

PYROPHORICS: Nonradioactive pyrophorics in the payload containers are prohibited by waste packaging procedures. Waste packaging procedures shall ensure that all pyrophoric radioactive materials are present only in small residual amounts (less than 1 weight percent) in payload containers.

CORROSIVES: Corrosives are prohibited in the payload container. Acids and bases that are potentially corrosive shall be neutralized and rendered noncorrosive prior to being a part of the waste. The physical form of the waste and the waste generating procedures ensure that the waste is in a nonreactive form.

CHEMICAL COMPATIBILITY: A chemical compatibility study has been performed on this content code, and all waste is chemically compatible for materials in greater than trace (>1% by weight) quantities.

ADDITIONAL CRITERIA: Each drum is fitted with a minimum of one filter vent. The steel liner is fitted with a filter with a hydrogen diffusivity of 3.7E-06 mole/second/mole fraction.

MAXIMUM ALLOWABLE HYDROGEN GENERATION RATES - OPTION 1: The maximum allowable hydrogen generation rate limit is 3.429E-08 moles per second per drum and 3.429E-07 moles per second per 10-160B cask.

MAXIMUM ALLOWABLE DECAY HEAT LIMIT - OPTION 2: The maximum allowable decay heat limit is 21.7 watts per drum and 217 watts per 10-160B cask.

BATTELLE COLUMBUS LABORATORIES CONTENT CODE BC 322A

SOLID INORGANIC WASTE

MATERIALS AND CHEMICALS >1%

CEMENT

DIATOMACEOUS EARTH (FLOOR DRY)

GLASS

METALS (including stainless steel, aluminum, iron, copper, lead, beryllium, and zirconium)

IRON-BASED METAL/ALLOYS

OTHER INORGANICS

MATERIALS AND CHEMICALS <1%

CARBON TETRACHLORIDE

1,1,1-TRICHLOROETHANE

TRICHLOROETHYLENE

Attachment B

Methodology for Determination of Decay Heats

and Hydrogen Gas Generation Rates for

Content Codes

for Battelle Columbus Laboratories

1.0 INTRODUCTION

All Battelle Columbus Laboratories Decommissioning Project (BCLDP) transuranic (TRU) waste to be transported in the 10-160B cask shall comply with the 5% (by volume) limit on hydrogen concentration during transport. If a bounding G value and decay heat limit have been established for the approved content code, compliance with the decay heat limit shall be evaluated pursuant to this attachment for the individual containers under the content code. If compliance with the decay heat limit cannot be demonstrated, the hydrogen generation rate of the container shall be determined as outlined in this attachment and compared to the hydrogen gas generation rate limit specified for that approved content code. If the container meets the limit, it is eligible for shipment if all other transportation requirements are met. If the container does not meet the limit, it cannot be shipped and shall be segregated for repackaging or other mitigation measures.

2.0 DECAY HEAT METHODOLOGY

This section describes the general features of nondestructive assay methods used in conjunction with acceptable knowledge by the BCLDP.

The overall methodology for the determination of the radioassay properties is described in DD-98-04, Waste Characterization, Classification, and Shipping Support Technical Basis Document and is summarized in Figure 1. Under the methodology, the isotopic content for an identified TRU waste stream is determined by a combination of (1) representative waste stream sample analyses, (2) conservative application of the Oak Ridge Isotope Generation and Depletion (ORIGEN2) code values for isotopes expected to be present, but not represented by the sample analyses, and (3) assessment of cesium (Cs)-137 content of a payload container based on external radiation field measurements and calculation of TRU isotopic content using a ratio of radionuclides based on known Cs-137 content. The determinations are verified on an approved, periodic basis by sample submission to the BCLDP Radioanalytical Laboratory for gamma and/or alpha spectroscopy. The results of the implementation of the DD-98-04 methodology provide the data inputs to the computer program (spreadsheet) used by the TRU Waste Transportation Certification Official to determine the parameters of interest for each payload container (including fissile grams equivalent and decay heat).

Since the gamma rays emitted by radionuclides can be readily detected and quantified by common measurement techniques, i.e., as a dose rate, emitted gamma are used to model the quantity of isotopes present in a standard waste stream. Verifying samples are analyzed for both gamma and alpha emitters. Because isotopes other than gamma emitters are known to be present, laboratory measurements of the isotopic distribution are combined with a computer-generated distribution of account for required isotopes, e.g., per U.S. Department of Transportation requirements. The measured isotopic distribution is based on laboratory analysis (alpha and gamma spectroscopy) of air, smear and material samples taken from throughout the accessible work areas of Building JN-1. Using the measured distribution as a base, the remaining isotopes are scaled according to the distribution generated by the ORIGEN2 computer code, which models the production and decay of fission and activation products of commercial nuclear power plant fuel. Commercial fuel best characterizes the overwhelming majority of the isotopes present, by isotope and relative ratio.

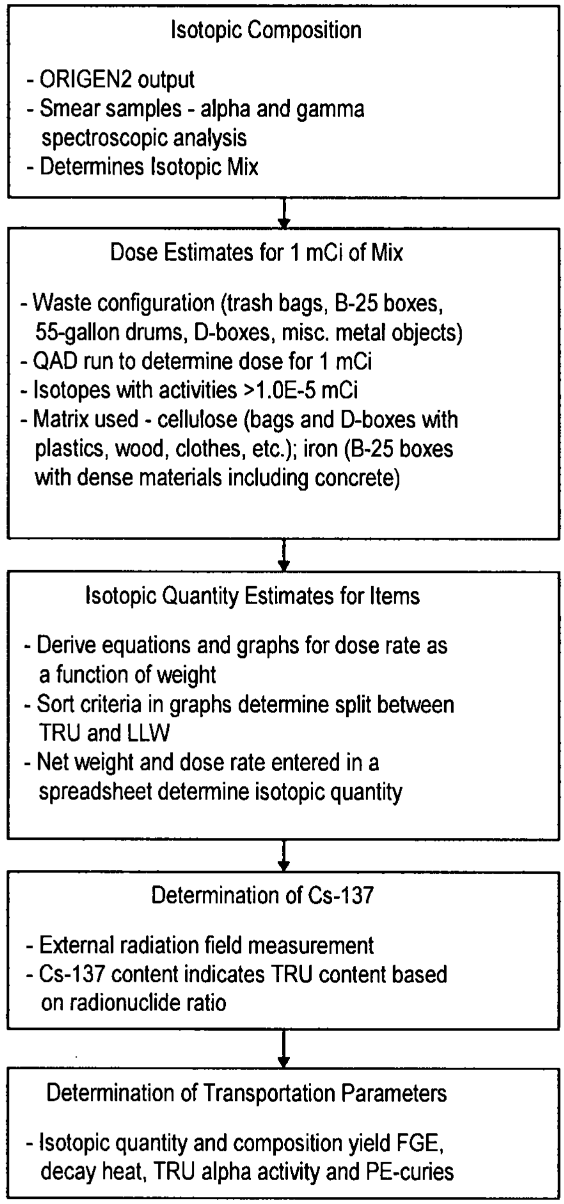

Figure 1
BCLDP Methodology for Determination
of Radioassay Properties for TRU Waste

The "JN standard isotopic mixture" used in the model is representative of the composition of the majority of radioactive waste generate in all areas of the BCL facility, except the pool. Waste from the pool is separately characterized based on sample results. In addition to the pool waste, other waste streams may be encountered that do not match the JN standard isotopic mix. In such cases, the newly characterized waste will be characterized based on specific analytical results (alpha and gamma spectroscopy).

A given quantity of the JN standard isotopic mixture is used as the radioactive material source with the QAD computer shielding code to generate external gamma ray interaction rates for various package and form weights. These interaction rates are used to generate interaction rates-to-weight conversion equations for each package and waste form. The equations are incorporated into spreadsheets so that activity content, in millicuries, for individual packages and waste forms can be calculated. Spreadsheets are also used to calculate TRU interaction rate levels, and plots of these values as a function of net container weight are provided for each container type to simplify field sorting and packaging.

Required QAD inputs include source and package dimensions including any shielding materials, and quantities of individual isotopes that make up the source (i.e., JN standard isotopic mixture). QAD calculations are performed for a range of representative weights for each package. Specific package models include field sort waste bag, metal case, IP-2 147-cubic-feet box, standard D-box, 55-gallon drum, and standard B-25 box models. The final packaging configuration for BCL TRU waste is the 55-gallon drum.

Waste matrices are modeled as either cellulose or iron. The cellulose matrix represents the varied composition of the bag and D-box models, which are composed of plastics, wood, cloth, etc., and are similar to cellulose in their electronic configuration. The iron matrix is used for the B-25 box and 55-gallon drum models, which include a range of more dense materials, including concrete. The choice of waste matrices is conservative as the physical properties of cellulose and iron relative to radiological parameters are well characterized. It is important to note that the representative weights for 55-gallon drum, for example, correspond to a density much less than the density of iron (7.86 g/cm^3), on the close order of less than 1.0 g/cm^3.

As detailed in DD-98-04, estimated uncertainties associated with the container weight, Cs-137 activity based on measurement of decay gammas emanating from the container, and estimation of inventories of other radionuclides and total transuranics based on measured or predicted ratios to Cs-137 activity have been factored into the determinations of an upper bounding uncertainty for the methodology.

The application of the ORIGEN2 code in the proposed BCLDP TRU Waste Certification Program methodology for determining radioassay properties for TRU wastes is conservative. In addition, associated measurement errors and assumptions have been conservatively estimated to determine a total error that is bounding for the methodology. The following subsection provides details on the application of the ORIGEN2 code for determining the radioassay properties.

Application of ORIGEN2 Code

The ORIGEN2 code (RSIC Code Package CCC-371) is used in the DD-98-04 methodology. Characterization of the JN standard isotopic distribution depended upon whether available data existed to permit estimation of the normalized activity ratio (to Cs-137 activity) for the isotopes of interest. Where sufficient data were available, a lognormal fit was used. Where insufficient data was available, the results of a series of ORIGEN2 software analyses were employed.

For Am-241, Cm-244, Co-60, Cs-134, Eu-154, Np-237, Pu-238, Pu-239/-240, Sb–125, Sr-90, U-234, and U-238, as many as 69 samples from the anticipated waste stream were available. A two-parameter (μ, σ) lognormal distribution was fitted to these data. The mean parameter (μ) estimated for each studied isotope represented its assumed normalized activity ratio (to Cs-137) in the standard isotopic distribution. The estimated spread parameter (σ) was used in considering the total uncertainty associated with the waste characterization.

For the isotopes of interest, the computer code ORIGEN2 was used to estimate their normalized activity ratio (to Cs-137). Specifically, values were assumed for enrichments, burn-up, and decay consistent with the processed used to generate the waste stream being classified. These values were then applied as parameters within the ORIGEN2 software, producing estimates of the activities of the various isotopes of interest.

Professional judgement consensus center, low, and high values were identified for each of these three parameters: enrichment, burn up, and decay. Taken together, these three values were meant to represent the central tendency and distribution (i.e., practical range) of the enrichment, burn up, and decay of potential waste streams. A deliberate choice was made to underestimate the decay time so as to make the resultant values conservative.

Twenty-seven iterations of ORIGEN2 software code would be required to consider each combination of these three values for each of three parameters (i.e., 33 = 27). Additional code runs would be necessary, moreover, to provide some measure of the uncertainty associated with the application of ORIGEN2 in estimating the normalized activity ratios of the remaining isotopes of interest. Latin Hypercube sampling is an alternative approach, allowing for effective integration of computer code but with fewer runs. In order to apply these values in the context of a Latin Hypercube design, an assumed distribution is required for each parameter considered in the design. Because the low and high values for each parameter were not symmetric in relation to the center value, a skewed distribution was selected. The lognormal represents a skewed distribution that can be readily applied without additional mathematical complication. The log-transformed center value was assumed to represent the distribution's log mean, and its log standard deviation was derived by averaging the deviations of the log-transformed low and high values from the log mean. Specifically, the average deviation was assumed to represent 1.645 (i.e., the 0.95 quantile of a standard normal distribution) times the log-standard deviation. Doing so is equivalent to assuming the low and high values represent, on average, a range from the 5th to the 95th percentile of the distribution.

In using the ORIGEN2 software code to characterize the normalized activity ratios for the isotopes without available data, the Latin Hypercube employed in the DD-98-04 methodology assumed that values for enrichment, burn up, and decay and software together represent a 'blackbox' estimation of normalized activity ratios. Using this approach, a series of replicate designs is applied. The mean result from each replicate design is considered when estimating the mean and variance in normalized activity.

Four replicates of a five-sample Latin Hypercube design were developed thereby providing 20 analysis runs. The distribution of each parameter was divided into five partitions of equal probability. Latin Hypercube sampling, then, insures that a random value of each partition is included in each of the five replicated designs, while minimizing the total number of required analysis runs.

The mean result across the 20 ORIGEN2 runs (or equivalently, the mean of the mean results determined for the four replicated designs) estimated for each studied isotope represents its assumed normalized activity ratio (to Cs-137) in the standard isotopic distribution. Though ORIGEN2 reports activities for all the isotopes of interest, only the results for those isotopes without sufficient available sample data are retained. The ORIGEN2 results and those based on available data are comparable. The estimated variance in mean result across the four replicate designs—a measure of the uncertainty associated with using the ORIGEN2 software to characterize isotope activity—is used in considering the total uncertainty associated with the waste characterization.

3.0 OBJECTIVES OF THE GAS GENERATION TESTING

The maximum allowable hydrogen gas generation rates for the TRU content codes for the BCLDP are provided in Table 10-1 of this appendix. Compliance with the hydrogen gas generation rate shall be demonstrated by testing. Compliance with the requirements of this test plan should be documented in site-specific procedures under a documented quality assurance program.

4.0 GAS GENERATION TEST METHODOLOGY

The following sections describe how compliance with the limit on the hydrogen gas generation rate will be implemented for each authorized content code for BCLDP.

Demonstration of Compliance With Hydrogen Gas Generation Limit

During the course of the testing, the headspace gas of the selected waste containers will be sampled and analyzed to determine the concentrations of hydrogen and other gases that are produced by radiolysis or present when the waste was packaged. Sampling lines that communicate with the headspace of the waste containers will be installed. Samples of the headspace gas will be withdrawn periodically and analyzed using a gas chromatograph and/or a mass spectrometer. The analytical results will be used to calculate the hydrogen gas generation rate. The measured hydrogen gas generation rate will be compared to the appropriate hydrogen gas generation limits for each content code to evaluate compliance with transportation requirements.

Because all layers of confinement in all the containers have been vented since the time of generation and the containers have been in a vented condition for a period of time, steady-state hydrogen concentrations exist within all void volumes inside a container. At steady-state conditions, the rate of gas generation by radiolysis equals the release rate of gas across each layer of confinement. The measured hydrogen gas concentration in the headspace gas will be used to calculate the hydrogen gas generation rate.

The hydrogen gas generation rate of the waste container is calculated from the measured hydrogen gas concentration using the following relationship:

$$C_g = X_H \text{ x } L_{CF}$$

where,

C_g = the hydrogen gas generation rate (mole/sec).

X_H = the measured concentration of hydrogen gas in the waste container headspace (mole fraction)

L_{CF} = diffusion characteristic of the waste container filter.

The rate shall be compared to the appropriate limit for the content code. The container shall be qualified for shipment only if the limit is met.

Another method may also be used when the final waste form is a solid monolith of evaporated/solidified inorganic wastes (BC 312A or 314A) that will be directly placed into drums. Process controls will be used to ensure homogeneity of the sludge. A small sample of the waste will be analyzed for its gas generation properties. The hydrogen gas generation rate for the drum can then be determined based on the mass of waste in the drum. For example, a sludge sample can be placed in a sealed test chamber of known volume. The concentration of hydrogen will be measured in the chamber after an elapsed period of time, and the following relationship will be used to calculate the hydrogen gas generation rate from the sample:

$$C_{g,\,sample} = \frac{X\,P\,V_{chamber}}{R\,T\,\Delta t}$$

where,

$C_{g,sample}$ = hydrogen gas generation rate from sample (mol/sec)

X = mole fraction hydrogen in the test chamber
P = absolute ambient pressure (atm)
$V_{chamber}$ = volume of the test chamber (L)
R = gas law constant (0.08206 atm L mol^{-1} K^{-1})
T = absolute ambient temperature (K)
Δt = elapsed time (sec).

The hydrogen gas generation rate will be calculated on a drum basis using the following relationship:

$$C_{g,drum} = C_{g,sample} \frac{m_{drum}}{m_{sample}}$$

where,

$C_{g,drum}$ = hydrogen gas generation rate in drum (mol/sec)
m_{drum} = mass of waste form in drum (g)
m_{sample} = mass of sample (g).

The actual drum hydrogen gas generation rate will be compared to the maximum allowable hydrogen generation rate limit in Table 10-1 of this appendix.

4.11.4 COMPLIANCE METHODOLOGY FOR TRU WASTE FROM MISSOURI UNIVERSITY RESEARCH REACTOR (MURR), COLUMBIA, MO

1.0 INTRODUCTION

This appendix presents how records and database information (process knowledge) have been used to qualify seven drums of Missouri University Research Reactor (MURR) contact-handled (CH) transuranic (TRU) waste as payload for transport in the 10-160B cask. The methods for determining each restricted parameter, the factors influencing the parameter values, and the methods used by MURR for demonstrating compliance, are provided in the following sections.

This appendix also includes the following as attachments:
- Content code MR 121A (Attachment A)
- Chemical Lists for the above mentioned content code (Attachment A)
- Methods for Determining Gas Generation Rates and Decay Heat Values and summary of drum compliance (Attachment B).

2.0 PURPOSE

The purpose of this appendix is to describe the process knowledge used to qualify the CH-TRU waste belonging to MURR prior to transport in the 10-160B cask. This appendix is based on the format and requirements for TRU waste identified in Appendix 4.11.2. It incorporates acceptable methods and process knowledge applicable to content code MR 121A described in this appendix.

Section 3.0 describes the TRU waste payload. Sections 4.0 through 11.0 discuss each payload parameter, and the process knowledge/methods employed to demonstrate compliance with the 10-160B cask payload requirements.

3.0 TRU WASTE PAYLOAD FOR 10-160B CASK

The content code for the CH-TRU waste from MURR (MR 121A—Solid Organic Waste) is provided in Attachment A. This content code refers to seven 55-gallon drums of solid organic waste from the MURR Transuranic Management by Pyropartitioning separation (TRUMP-S) program.

Complete documentation packages, along with quality assurance/quality control records, are generated for all payload containers as summarized in this appendix. TRU waste generated from the MURR will comply with all transportation requirements using the following methods:

- Formally documented acceptable knowledge (AK)/process knowledge of the processes generating the waste
- Data packages generated for all payload containers that document the contents and properties of the waste in the container including the absence of prohibited items and compliance with packaging requirements
- Measurement of required parameters to ensure compliance with limits.

4.0 PHYSICAL FORM

4.1 Requirements

The physical form of waste comprising the 10-160B cask payload is restricted to solid or solidified materials in secondary containers. The total volume of residual liquid in a secondary container is restricted to less than 1% by volume. Secondary containers must be shored to prevent movement during accident conditions. Sharp or heavy objects in the waste shall be blocked, braced, or suitably packaged as necessary to provide puncture protection for the payload containers packaging these objects. Sealed containers greater than four liters in size are prohibited.

4.2 Methods of Compliance and Verification

Compliance with the physical form requirements is determined by records and data base information (process knowledge). Laboratory archive records include a list of the contents of each bag of waste. A review of this inventory indicate that the physical form requirements have been met. There is no liquid waste. Any liquid waste remaining after an experiment or activity was evaporated prior to bagging out of the glove box as waste as documented in procedure TAM-32, "Treatment of Aqueous Residue" (Reference 12.1). Waste packaging records show that sharp and heavy objects have been packaged to provide puncture protection equivalent to Type A packaging requirements, and there are no sealed or pressurized containers in the waste.

5.0 CHEMICAL FORM AND CHEMICAL PROPERTIES

5.1 Requirements

The chemical properties of the waste are determined by the chemical constituents allowed in a given content code. Specific requirements regarding the chemical form of the waste are as follows:

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

5.2 Methods of Compliance and Verification

Compliance with the chemical form and chemical property restrictions is demonstrated through records and database information (process knowledge), chemical and physical inventory lists, and archived laboratory notebooks that describe process restrictions. No explosives were used in the experimental program. Lithium metal was the only non-radioactive pyrophoric used in the experiments. The excess lithium metal was oxidized in water, the solutions neutralized and evaporated to dryness. This solid was passed to the low-level waste stream. The plutonium and americium used in the TRUMP-S experimental program are contained in experimental residues in an oxidized state and are non-pyrophoric. Records indicate that no volatile organic materials were used in the experimental program and volatile organics are not present in the TRU waste. The chemical list for content code MR 121A is presented in Attachment A.

6.0 CHEMICAL COMPATIBILITY

6.1 Requirements

Each content code has an associated chemical list (Attachment A) based on AK information. Chemical constituents in a payload container assigned to a given content code shall conform to these approved chemical lists. Chemicals/materials that are not listed are allowed in trace amounts (quantities less than 1 weight percent) in a payload container provided that the total quantity of trace chemicals/materials is restricted to less than 5 percent (weight).

Chemical compatibility of a waste with its packaging ensures that chemical reactions will not occur that might pose a threat to the safe transport of a payload in the 10-160B cask.

6.2 Methods of Compliance and Verification

Attachment B of Appendix 4.11.2 presents the methodology and results for the chemical compatibility analyses performed for the list of allowable chemicals/materials associated with the TRU waste content codes expected to be shipped in the 10-160B cask. The results of these chemical compatibility analyses show that these content codes can be transported without any incompatibilities.

The chemicals present in MR 121A conform to the list of allowable materials in Attachment B of Appendix 4.11.2. Therefore, the waste meets the chemical compatibility requirements.

7.0 GAS DISTRIBUTION AND PRESSURE BUILDUP

7.1 Requirements

Gas distribution and pressure buildup during transport of TRU waste in the 10-160B cask payload are restricted to the following limits:

- The gases generated in the payload must be controlled to prevent the occurrence of potentially flammable concentrations of gases within the payload confinement layers and the void volume of the inner vessel (IV) cavity. Specifically, hydrogen concentrations within the payload confinement layers are limited to 5 percent by volume during a maximum 60-day shipping period (see Attachment C of Appendix 4.11.2).

- The gases generated in the payload and released into the IV cavity must be controlled to maintain the pressure within the IV cavity below the acceptable packaging design limit of 31.2 pounds per square inch gauge (psig).

7.2 Methods of Compliance and Verification

Compliance with the 10-160B cask design pressure limit for the MR 121A content code is analyzed by assuming that all gases generated are released into the IV cavity and by including the contributions from thermal expansion of gases and vapor pressure of atmospheric water.

Table 7-1 shows that the pressure increase during a period of 365 days is below the design pressure limit of 31.2 psig for MR 121A.

Table 7-1. Maximum Pressure Increase Over 365-Day Shipping Period

Content Code	G_{eff} (RT)[a]	Void Volume (Liters)	Activation Energy (kcal/mole)	Decay Heat Limit (Watts)	G_{eff}[b]	P_{max}[c] (psig)
MR 121A	8.1	1938	2.1	0.93	14.19	17.70

[a] G value for net gas (molecules per 100 eV) at room temperature (70°F).

[b] Effective G value (molecules per 100 eV) at maximum operating temperature of 168°F calculated using the Arrhenius equation for which activation energy is an input.

[c] Maximum pressure.

Compliance with the restrictions on flammable gas concentration is discussed in Section 10.0.

8.0 PAYLOAD CONTAINER AND CONTENTS CONFIGURATION

8.1 Requirements

Fifty-five-gallon drums are authorized payload containers in a 10-160B cask. Up to ten 55-gallon drums of TRU waste may be packaged in the cask. Each 55-gallon drum to be packaged in the cask must have a minimum of one filter vent. The minimum filter vent specifications for the seven 55-gallon drums of MR 121A are provided in Table 8-1.

Table 8-1. Minimum Filter Vent Specifications

Container/Filter Type	Filter Specification			
	Number of Vents Required per Container	Flow Rate (ml/min of air, STP, at 1 inch of water)[a]	Efficiency (percent)	Hydrogen Diffusivity (mol/s/mol fraction at 25°C)
Drum filter	1	35	99.5	3.70E-6
Filtered Bag	1	35	NA[b]	1.075E-5

[a] Filters tested at a different pressure gradient shall have a proportional flow rate (e.g., 35 ml/min at 1 inch of water = 1 L/min at 1 psi).

[b] Filters installed in containers that are overpacked are exempt from the efficiency requirement as the drum must exhibit a ≥99.5 percent efficiency.

NA = Not applicable.

Filter vents shall be legibly marked to ensure both (1) identification of the supplier and (2) date of manufacture, lot number, or unique serial number.

The rigid polyethylene liner, if present, in a payload container shall be punctured with a minimum of a 0.3-inch diameter hole before the container is transported in the 10-160B.

8.2 Methods of Compliance and Verification

Compliance with the payload container and contents configuration requirements is determined by visual examination, process knowledge and through procurement records. The MURR TRU waste is packaged within two layers of plastic, one inner plastic waste bag, and one filtered drum liner bag. The plastic bags are closed by the twist and tape method (i.e., not heat-sealed). The individual bags are placed in 55-gallon drums with a filter vent installed on each drum that meets the minimum filter vent specifications for the 55-gallon drums listed in Table 8-1. Procurement documents for the 55-gallon drums, lids, rigid liners, and filters are included in MURR archives indicating compliance with the requirements. Prior to transport, payload container filter vents shall be visually inspected for damage or defect. If a defect is identified, a nonconformance report shall be issued and the payload container shall be returned for repackaging/filter replacement prior to certification.

9.0 ISOTOPIC CHARACTERIZATION AND FISSILE CONTENT

9.1 Requirements

The 10-160B cask payload allows 325 FGE of fissile materials. Plutonium content in excess of 0.74 TBq (20 curies) per cask must be in solid form.

9.2 Methods of Compliance and Verification

The CH-TRU waste was generated over eight years using a total of 3.5627 grams of Neptunium-237, 1.4701 grams of Plutonium-239, 2.4125 grams of Americium-241 and 6.097 grams of depleted Uranium. Attachment B shows the gram loading of each drum. This is the total mass of each actinide assigned to MURR TRU waste. No other fissile materials were introduced into the waste. Small quantities of these materials were dispersed in the low-level waste, as well.

10.0 DECAY HEAT AND HYDROGEN GAS GENERATION RATES

This section describes the logic and methodology used in evaluating payload characteristics that meet the hydrogen gas concentration requirement for the MR 121A content code wastes described in this section.

10.1 Requirements

The hydrogen gas concentration shall not exceed 5% by volume in all void volumes within the 10-160B cask payload during a 60-day shipping period. A 10-160B cask payload must be assembled of payload containers belonging to the same content code. Payload containers of different content codes with different bounding G values and resistances may be assembled together as a payload, provided the decay heat limit and hydrogen gas generation rate limit for all payload containers within the payload is conservatively assumed to be the same as that of the payload container with the lowest decay heat limit and hydrogen gas generation rate limit.

10.2 Methodology of Ensuring Compliance with Flammable Gas Concentration Limits

As stated in Section 7.2 of Appendix 4.11.2, chemical, biological, and thermal gas generation mechanisms are insignificant in the 10-160B cask. In addition, as shown in Section 5.1 of Appendix 4.11.2, potentially flammable VOCs are restricted to 500 ppm in the headspace of the 10-160B cask secondary containers. Therefore, the only flammable gas of concern for transportation purposes is hydrogen. The concentration of hydrogen within any void volume in a layer of confinement of the payload or in the cask IV has been evaluated during a 60-day shipping period (see Attachment C of Appendix 4.11.2).

Attachment A provides the MR 121A content code authorized payload for the 10-160B cask. This content code has a unique and completely defined packaging configuration. Modeling the movement of hydrogen from the waste material to the payload voids, using the release rates of hydrogen through the various confinement layers, defines the relationship between generation rate and void concentration. This modeling allows determination of the maximum allowable hydrogen generation rate for the MR 121A content code to meet the 5% concentration limit, as detailed in Section 10.3. Based on hydrogen gas generation potential, quantified by hydrogen gas generation G values, the gas concentration limit can be converted to a decay heat limit, as detailed in Section 10.4. The maximum allowable hydrogen generation rate and decay heat limit for the MR 121A content code for MURR waste are listed in Table 10-1 (see Attachment A of Appendix 4.11.2 for a description of the Matrix Depletion Program and dose-dependent G values).

Table 10-1. Maximum Allowable Hydrogen Gas Generation Rate and Decay Heat Limit for MR 121A

Content Code	Maximum Allowable Hydrogen Gas Generation Rate, mole/second/ drum	Maximum Allowable Hydrogen Gas Generation Rate, moles/second/ cask	Maximum Allowable Decay Heat Limit, Watts/Drum (Dose <= 0.012 watt*year)	Maximum Allowable Decay Heat Limit, Watts/Cask (Dose <= 0.012 watt*yr)	Maximum Allowable Decay Heat Limit, Watts/Drum (Dose > 0.012 watt*year)	Maximum Allowable Decay Heat Limit, Watts/Cask (Dose > 0.012 watt*year)
MR121A	1.323E-8	1.323E-7	0.032	0.320	0.093	0.930

10.3 Determination of Maximum Allowable Hydrogen Generation Rate

The maximum allowable hydrogen generation rate was determined using the modeling methodology described in Appendix 4.11.2 and the following input parameters.

Waste Packaging Configuration and Release Rates: The waste described by content code MR 121A, is packaged within two layers of plastic, one plastic inner bag, and one filtered drum liner bag. The plastic bags are closed by the twist and tape method. The bags are placed inside a polyethylene rigid liner punctured with a minimum 0.3-inch diameter hole. The liner would then be placed directly into a 55-gallon drum with a filter vent installed on each drum meeting the minimum filter vent specifications for the 55-gallon drums listed in Table 8-1. The release rates in Table 10-2 are shown for two different temperatures (minimum and maximum operating temperature of the 10-160B) and are based on values for various waste packaging confinement layers documented in Appendices 3.6.9 and 3.6.12 of the TRUPACT-II SAR (Reference 12.2). The temperature dependence of these release rates is discussed later in this section.

Void Volume in the 10-160B IV: The cask will have a payload of 10 drums and a drum carriage. The interior volume of the cask, V_{cask}, is 4438 liters. The volume occupied by the drum carriage, $V_{carriage}$, is 143.2 liters. The external volume of a single drum, V_{drum}, is 235.7 liters. The void volume within the cask is calculated as:

$$V_{void} = V_{cask} - V_{carriage} - 10\ V_{drum}$$

$$V_{void} = 4{,}438\ liters - 143.2\ liters - 10\ (235.7\ liters)$$

$$V_{void} = 1{,}938\ liters$$

Table 10-2. Release Rates of Hydrogen Across Confinement Layers for MR 121A

Confinement Layer	Release Rate (mol/sec/mol fraction)	
	T = 233K	T = 348.6K
Plastic Inner Bag (twist-and-tape closure)	3.895×10^{-7}	5.58×10^{-7} [a]
Filtered Liner Bag (twist-and-tape closure)	7.156×10^{-6}	1.447×10^{-5} [b]
Rigid Polyethylene Drum Liner (0.3-inch diameter hole)	4.683×10^{-5}	5.09×10^{-5}
Drum Filter	2.46×10^{-6}	4.98×10^{-6}

[a] The value at 70°F is conservatively used.

[b] The value at -20°F is conservatively used.

Pressure: The pressure is assumed to be isobaric and equal to one atmosphere. The mole fraction of hydrogen in each void volume would be smaller if pressurization is considered and would result in a greater maximum allowable hydrogen gas generation rate. Furthermore, the amount of hydrogen gas generated during a 60-day shipping period would be negligible compared to the quantity of air initially present at the time of sealing the 10-160B cask.

Temperature: The input parameter affected by temperature is the release rate through the different confinement layers in the payload containers and the G values for hydrogen. Release rates increase with increasing temperature as documented in Appendix 3.6.12 of the TRUPACT-II SAR (Reference 12.2). Therefore, the minimum release rates would be those at the lowest operating temperature. These are the release rates indicated in Table 10-2 for 233K. The minimum decay heat limits are determined by the ratio of the release rates and the G values. In other words, the higher the release rates, the higher the decay heat limit; the higher the G value, the lower the decay heat limit. The dependence of G values on temperature is documented in

Section 10.4. For determining the decay heat limit, the temperature that yielded the minimum decay heat limit was used as the input parameter.

In summary, the temperature dependence of the input parameters was accounted for in the calculation so that, in each case, the minimum possible limit (hydrogen generation rate or decay heat limit) was obtained. This provides an additional margin of safety in the analysis.

10.4 Determination of Maximum Allowable Decay Limit

The maximum allowable decay heat limit for the CH-TRU waste content code, MR 121A, was calculated using the methodology described in Appendix 4.11.2 and the content code-specific G values described below.

G values are determined based on the bounding materials present in the payload. The maximum operating temperature yields the lowest decay heat limits for the operating temperature range of the 10-160B cask. This content code represents solid organic debris consisting of various combustible and non-combustible items. The material present in this waste with the highest G value at the maximum operating temperature of the 10-160B cask (168°F) is cellulosics and is therefore considered as the bounding material. The G value for hydrogen associated with cellulosics is 3.2 molecules/100eV (at 70°F) if the attained dose is less than or equal to 0.012 watt*year. The dose dependent G value for cellulosics is 1.09 molecules/100 eV if the dose attained in the drum is greater than 0.012 watt*yr. The methodology associated with the determination of dose-dependent G values pursuant to the Matrix Depletion Program is further discussed in Attachment A of Appendix 4.11.2. The G values at 70°F are adjusted to the maximum operating temperature of the 10-160B cask (168°F) using the Arrhenius equation. The activation energy of the G value for cellulosics is 2.1 kcal/mole. Thus, at the maximum operating temperature of the 10-160B cask (168°F), the bounding hydrogen G values for MR 121A are 5.61 molecules/100 eV (dose $\leq$ 0.012 watt*year) and 1.91 molecules/100 eV (dose > 0.012 watt*year).

Demonstration of compliance of the MURR TRU waste with the decay heat and hydrogen gas generation rate limits is shown in Attachment B.

Methodology for Compliance with Payload Assembly Requirements

The MURR TRU waste payload consists of 7 55-gallon drums of the same content code meeting the payload assembly requirements.

11.0 WEIGHT

11.1 Requirements

The weight limit for the contents of the loaded cask is 14,250 pounds.

11.2 Methods of Compliance and Verification

The total weight of the TRU waste is 175 pounds, which will be distributed among the seven drums. This does not include the weight of the drums themselves, lids and filter vents, and any other bracing material required inside the drum. Each drum will be weighed prior to shipping. Based on the total measured weight of the individual payload containers and the 3 dunnage drums needed to complete the 10-drum payload, the MURR shall calculate total assembly weight and evaluate compliance with the maximum cask payload weight limit.

12.0 REFERENCES

12.1 University of Missouri, "Treatment of Aqueous Residue," TAM-32, University of Missouri Research Reactor TRUMP-S Program, Columbia, Missouri.

12.2 U.S. Department of Energy (DOE), "Safety Analysis Report for the TRUPACT-II Shipping Package," and associated TRUPACT-II Authorized Methods for Payload Control (TRAMPAC) Current Revision, U.S. Department of Energy Carlsbad Field Office, Carlsbad, New Mexico.

Attachment A

MR 121A Transuranic Content Code and Chemical List

for Missouri University Research Reactor

CONTENT CODE: MR 121A

CONTENT DESCRIPTION: Solid Organic Waste – CH-TRU Waste

WASTE DESCRIPTION: This waste consists of a variety of combustible and noncombustible items.

GENERATING SOURCES: This waste is generated from activities supporting the Missouri University Research Reactor (MURR) Transuranic Management by Pyropartitioning Separation (TRUMP-S) program.

WASTE FORM: The waste consists of lab ware waste that includes glove box gloves, poly vials, glass laboratory apparatus, paper towels, tools, polyethylene bags, rubber gloves o-rings, wires, crucibles: all exposed to metallic actinides, salts containing actinides, or aqueous solutions containing actinides.

WASTE PACKAGING: The waste described by content code MR 121A, is packaged within two layers of plastic, one intact waste inner bag, and one filtered drum liner bag. The plastic bags are closed by the twist and tape method. The bags may be placed inside a rigid polyethylene liner punctured with a minimum 0.3-inch diameter hole. The liner would then be placed directly in a 55-gallon drum with a filter vent installed on each drum. Ten drums will then be placed into the 10-160B cask.

METHODS FOR DETERMINATION OF ISOTOPIC CHARACTERIZATION: The isotopic composition of the waste is determined from measurements taken on the product material during the processing at the site. The processing organizations transmit the isotopic composition information to the site waste certification organization. Therefore, the isotopic composition of the waste need not be determined by direct analysis or measurement of the waste unless process information is not available.

FREE LIQUIDS: Liquid waste is prohibited in the drums except for residual amounts in well-drained containers. The total volume of residual liquid in a payload container shall be less than 1 volume percent of the payload container. Waste packaging procedures ensure that free liquids are less than 1 volume percent of the payload container.

EXPLOSIVE/COMPRESSED GASES: Explosives and compressed gases in the payload containers are prohibited by waste packaging procedures.

PYROPHORICS: Lithium metal was the only non-radioactive pyrophoric used in the experiments. The excess lithium metal was oxidized in water, the solutions neutralized and evaporated to dryness. This solid was passed to the low-level waste stream. The plutonium and americium used in the TRUMP-S experimental program are contained in experimental residues in an oxidized state and are non-pyrophoric.

CORROSIVES: Corrosives are prohibited in the payload container. Acids and bases that are potentially corrosive shall be neutralized and rendered noncorrosive prior to being a part of the waste. The physical form of the waste and the waste generating procedures ensure that the waste is in a nonreactive form.

CHEMICAL COMPATIBILITY: A chemical compatibility study has been performed on this content code, and all waste is chemically compatible for materials in greater than trace (>1% by weight) quantities.

ADDITIONAL CRITERIA: Each drum is fitted with a minimum of one filter vent.

MAXIMUM ALLOWABLE HYDROGEN GENERATION RATES - OPTION 1: The maximum allowable hydrogen generation rate limit is 1.323E-08 moles per second per drum and 1.323E-07 moles per second per 10-160B cask.

MAXIMUM ALLOWABLE DECAY HEAT LIMIT - OPTION 2: The maximum allowable decay heat limit is 0.032 watts per drum and 0.32 watts per 10-160B cask if dose ≤ 0.012 watt*yr and 0.093 watts per drum and 0.93 watts per 10-160B cask if dose > 0.012 watt*yr.

MISSOURI UNIVERSITY RESEARCH REACTOR CONTENT CODE MR 121A

SOLID ORGANIC WASTE

MATERIALS AND CHEMICALS >1%

CARDBOARD

CELLULOSICS

CLOTH

CONCRETE

DIATOMACEOUS EARTH (FLOOR DRY)

DIRT

EQUIPMENT (including vacuum cleaner, motors, and dosimeter system)

FILTERS

GLASS

METALS (including mercury, brass, lead shielding, lead shot, silver, stainless steel, aluminum, iron, copper beryllium, and zirconium)

OTHER INORGANICS

PAINT CHIPS (including barium, cadmium, chromium, and lead)

PAPER

PLASTER-OF-PARIS

PLASTIC

PLEXIGLAS

RADSORB

RUBBER

SOIL

WOOD

Attachment B

Methodology for Determination of Decay Heats

and Hydrogen Gas Generation Rates for

MR 121A Content Code

for Missouri University Research Reactor

The mass of each isotope assigned to each of the seven drums of content code MR 121A is listed in Table B-1 below. These mass numbers are from the total mass of each isotope computed in this section. The numerical values of the decay heat in watts per gram for each isotope are from Table 3-1 of the TRUPACT-II TRAMPAC (Reference 12.2). The computed decay heat for each isotope and the total decay heat for each of the seven drums is given in Table B-1, below. U-238 is not included in the table because its contribution to the decay heat is insignificant.

Table B-1 Mass and Decay Heat per Isotope, by Drum

Isotope	Mass (g)	Decay Heat (watts/g)	Decay Heat (watts/isotope)
Drum No. 1			
Np-237	2.1706	2.09E-05	4.537E-05
Pu-239	0.2282	1.95E-03	4.450E-04
Am-241	0.3431	1. 16 E-0 1	3.980E-02
Drum Decay Heat (watts/Drum)			4.029E-02

Drum No. 2			
Np-237	0.0381	2.09E-05	7.963E-07
Pu-239	0.6725	1.95E-03	1.311 E-03
Am-241	0.2957	1.16E-01	3.430E-02
Drum Decay Heat (watts/Drum)			3.561 E-02

Drum No. 3			
Np-237	0.1191	2.09E-05	2.489E-06
Pu-239	0.1036	1.95E-03	2.020E-04
Am-241	0.3469	1.16E-01	4.024E-02
Drum Decay Heat (watts/Drum)			4.044E-02

Drum No. 4			
Np-237	0.0199	2.09E-05	4.159E-07
Pu-239	0.1702	1.95E-03	3.319E-04
Am-241	0.3474	1.16E-01	4.030E-02
Drum Decay Heat (watts/Drum)			4.063E-02

Drum No. 5			
Np-237	0.4979	2.09E-05	1.041E-05
Pu-239	0.1554	1.95E-03	3.030E-04
Am-241	0.3521	1.16E-01	4.084E-02
Drum Decay Heat (watts/Drum)			4.115E-02

Drum No. 6			
Np-237	0.443	2.09E-05	9.259E-06
Pu-239	0	1.95E-03	0.000E+00
Am-241	0.3527	1.16E-01	4.091E-02
Drum Decay Heat (watts/Drum)			4.092E-02

Drum No. 7			
Np-237	0.268	2.09E-05	5.601 E-06
Pu-239	0.1459	1.95E-03	2.845E-04
Am-241	0.3747	1.16E-01	4.347E-02
Drum Decay Heat (watts/Drum)			4.376E-02

Error Assignment for Decay Heat Calculation

It is required that an error be assigned to the calculated decay heat for each payload container and to the entire payload. The error in actinide mass assigned to each waste bag is the source of error in the decay heat calculation. The inventory controls on the special nuclear materials used in the TRUMP-S project are the following TAM Procedures.

- TAM-21 "Transfer of Actinides"
- TAM-23 "Inventory Control of Actinides"
- TAM-24 "Quality Assurance"
- TAM-25 "Mixed Actinide Inventory"

The analytical balance used in the experiments was capable of ± 0.1 mg precision. The balance was standardized to ± 1.0 mg before every transfer of actinides into the glove box. This procedure assured the performance of the balance during experiments. This balance was used to assign actinide mass to all experimental materials assigned to waste bags at the conclusion of each experiment. Using these procedures, the SNM inventory for the eight years of the project closed to within 0.0079 g for americium, 0.0038 g for plutonium and 0.0007 g for neptunium.

Based on these procedures and the SNM inventory record, it is conservative to assume that the mass of actinide in each bag is known to ±1.0 mg. If it is further assumed that all of the mass is americium, which has a significantly higher decay heat than the other actinides, the error in the decay heat calculation will be ±1.16 x 10-4 watt/bag. The maximum number of waste bags assigned to any drum is six, so the maximum error in the decay heat will be 6.96 x 10-4 watt/drum. Drum 7 has the highest decay heat, of 0.04376 watt; with an added error of 0.000696 watt, the maximum decay heat for any drum would be 0.044456 watt. It can be concluded that all drums are below the decay heat limit of 0.093 watt/drum if the dose > 0.012 watt*year. Since each drum is below the decay heat, including error in the decay heat calculation, the payload decay heat will also be below the payload decay heat limit. For the entire 10-160B payload assembly of seven drums of waste and three dunnage drums (see Section 11.0), the total 10-160B payload will have a decay heat value of 0.2828 watts (including error) and therefore is less than the payload assembly limit of 0.93 watts (computed as 10 drums at 0.093 watt per drum) if dose per drum > 0.012 watt*year.

4.11.5 COMPLIANCE METHODOLOGY FOR TRU WASTE FROM ENERGY TECHNOLOGY ENGINEERING CENTER (ETEC)

1.0 INTRODUCTION

This appendix presents acceptable methods of preparation and characterization to qualify drums of Energy Technology Engineering Center (ETEC) contact-handled (CH) transuranic (TRU) and remote-handled (RH) TRU waste, as defined by the U.S. Department of Energy (DOE) (Reference 12.1), as payload for transport in the 10-160B cask. The methods for determining or measuring each restricted parameter, the factors influencing the parameter values, and the methods used by ETEC for demonstrating compliance, are provided in the following sections.

This appendix also includes the following as attachments:

- Content codes ET 121A, ET 121B, ET 126A, ET 126B, ET 325A, ET 325B, and ET 326A (Attachment A)
- Chemical Lists for the above mentioned content codes (Attachment A).

2.0 PURPOSE

The purpose of this appendix is to describe the acceptable methods that shall be used to prepare and characterize the CH-TRU and RH-TRU waste belonging to ETEC in order to demonstrate compliance with the TRU waste payload requirements prior to transport in the 10-160B cask. This appendix is based on the format and requirements for TRU waste identified in Appendix 4.11.2 of the 10-160B cask Safety Analysis Report (SAR). It incorporates acceptable methods applicable to the content codes listed in Attachment A.

Section 3.0 describes the TRU waste payload for ETEC. Sections 4.0 through 11.0 discuss each payload parameter and the method(s) for demonstrating compliance with the 10-160B cask payload requirements being employed by ETEC.

3.0 TRU WASTE PAYLOAD FOR 10-160B CASK

The CH-TRU waste is classified into four content codes, ET 121A, ET 121B, ET 126A and ET 126B. The RH-TRU waste is classified into three content codes, ET 325A, ET 325B and ET 326A. These content codes describe the TRU waste materials in terms of processes generating the waste, the packaging methods used in the waste container(s), and the generating site. The ETEC content codes for the CH-TRU and RH-TRU waste from ETEC are provided in Attachment A.

ETEC has developed formal procedures that ensure the generation, packaging, and repackaging of waste under rigorous controls. To demonstrate compliance with the payload requirements, complete documentation packages, along with quality assurance/quality control records, are generated for all payload containers. TRU waste generated from the ETEC will comply with all transportation requirements using the following methods:

Formally documented acceptable knowledge (AK)/process knowledge of the processes generating and packaging the waste

- Data packages generated for all payload containers that document the contents and properties of the waste in the container
- Measurement of required parameters to ensure compliance with limits.

4.0 PHYSICAL FORM

4.1 Requirements

The physical form of waste comprising the 10-160B cask payload is restricted to solid or solidified materials in secondary containers. The total volume of residual liquid in a secondary container is restricted to less than 1% by volume. Secondary containers must be shored to prevent movement during accident conditions. Sharp or heavy objects in the waste shall be blocked, braced, or suitably packaged as necessary to provide puncture protection for the payload containers packaging these objects. Sealed containers greater than four liters in size are prohibited.

4.2 Methods of Compliance and Verification

The waste consists primarily of inorganic and organic debris, homogeneous material (fines) with a small organic component, and a small quantity of solidified oils. The oils were collected during decontamination and decommissioning activities and were solidified using Petroset-II during repackaging. The contents of each waste container were recorded on lot followers during packaging or repackaging according to approved procedures that precluded prohibited items. Unique numbers were used to identify the waste containers, their contents, and their associated lot followers, and to track post-packaging activities.

The contents of the ET 121A, ET 121B, ET 126A, ET 126B, ET 325A and ET 325B waste stream containers were verified using computed tomography (CT). One prohibited item was found and removed. Waste stream ET 326A is a remote-handled homogeneous waste, and randomly selected 1-gal cans from that waste stream were opened for content verification and sampling for radiological and chemical characterization.

5.0 CHEMICAL FORM AND CHEMICAL PROPERTIES

5.1 Requirements

The chemical properties of the waste are determined by the chemical constituents allowed in a given content code. Specific requirements regarding the chemical form of the waste are as follows:

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

5.2 Methods of Compliance and Verification

For repackaged waste, the contents of repackaged containers were closely examined during the repackaging process to ensure the absence of explosives, pyrophorics, compressed gases, and corrosives. CT results were used to verify the absence of prohibited items.

For containers not undergoing repackaging, the absence of explosives, pyrophorics, compressed gases, and corrosives was verified by analysis of CT results or random sampling (e.g., the 1 – gallon cans of drain line residue, a homogeneous waste).

Compliance with the 500 ppm limit on flammable VOCs is demonstrated through acceptable knowledge/process knowledge of the processes generating and packaging the waste. The debris waste streams (i.e. content codes ET 121A, ET 121B, ET 325A and ET 325B) have no VOC contributing contents. Solvents used in the solidification process of the solidified oil waste stream (i.e. content codes ET 126A and ET 126B) are locked up in the solidification medium and will not exceed the 500 ppm limit. VOC analyses were performed for a large, representative set of samples from the drain line residue waste streams (ET 326A) and no VOCs were detected.

6.0 CHEMICAL COMPATIBILITY

6.1 Requirements

Each content code has an associated chemical list (Attachment A) based on process knowledge. Chemical constituents in a payload container assigned to a given content code shall conform to these approved chemical lists. Chemicals/materials that are not listed are allowed in trace amounts (quantities less than 1 percent [weight]) in a payload container provided that the total quantity of trace chemicals/materials is restricted to less than 5 percent (weight).

Chemical compatibility of a waste with its packaging ensures that chemical reactions will not occur that might pose a threat to the safe transport of a payload in the 10-160B cask.

6.2 Methods of Compliance and Verification

Attachment B of Appendix 4.11.2 presents the methodology and results for the chemical compatibility analyses performed for the list of allowable chemicals/materials associated with the TRU waste content codes expected to be shipped in the 10-160B cask. The results of these chemical compatibility analyses show that these content codes can be transported without any incompatibilities. The chemicals present in the ETEC content codes conform to the list of allowable materials in Attachment B of Appendix 4.11.2. Therefore, the waste meets the chemical compatibility requirements.

7.0 GAS DISTRIBUTION AND PRESSURE BUILDUP

7.1 Requirements

Gas distribution and pressure buildup during transport of TRU waste in the 10-160B cask payload are restricted to the following limits:

- The gases generated in the payload must be controlled to prevent the occurrence of potentially flammable concentrations of gases within the payload confinement layers and the void volume of the inner vessel (IV) cavity. Specifically, hydrogen concentrations within the payload confinement layers are limited to 5 percent by volume during a maximum 60-day shipping period (see Attachment C of Appendix 4.11.2).
- The gases generated in the payload and released into the IV cavity must be controlled to maintain the pressure within the IV cavity below the acceptable packaging design limit of 31.2 pounds per square inch gauge (psig).

7.2 Methods of Compliance and Verification

Compliance with the 10-160B cask design pressure limit for the ETEC content codes is analyzed by assuming that all gases generated are released into the IV cavity and by including the contributions from thermal expansion of gases and vapor pressure of atmospheric water.

Table 7-1 shows that the pressure increase during a period of 365 days is below the design pressure limit of 31.2 psig for all the ETEC content codes.

Table 7-1. Maximum Pressure Increase Over 365-Day Shipping Period

Content Code	G_{eff} (RT)[a]	Void Volume (Liters)	Activation Energy (kcal/mole)	Decay Heat Limit (Watts)	G_{eff}[b]	P_{max}[c] (psig)
ET 121A	8.1	1938	2.1	0.57	14.19	14.07
ET 121B	8.1	1938	2.1	2.26	14.19	31.13
ET 126A	4.1	1938	0.8	0.21	5.08	9.08
ET 126B	4.1	1938	0.8	0.95	5.08	11.75
ET 325A	8.1	1938	2.1	1.07	14.19	19.12
ET 325B	8.1	1938	2.1	2.26	14.19	31.13
ET 326A	2.05	1938	0.8	5.91	2.54	18.99

[a] G value for net gas (molecules per 100 eV) at room temperature (70°F).
[b] Effective G value (molecules per 100 eV) at maximum operating temperature of 168°F calculated using the Arrhenius equation for which activation energy is an input.
[c] Maximum pressure.

Compliance with the restrictions on flammable gas concentration is discussed in Section 10.0.

8.0 PAYLOAD CONTAINER AND CONTENTS CONFIGURATION

8.1 Requirements

Fifty-five-gallon drums are authorized payload containers in a 10-160B cask. Up to ten 55-gallon drums of TRU waste may be packaged in the cask. Each 55-gallon drum to be packaged in the cask must have a minimum of one filter vent. The minimum filter vent specifications for the 55-gallon drums of ETEC waste are provided in Table 8-1.

The test methods used to determine the compliance of filter vents with the performance-based requirements of flow rate, efficiency, and hydrogen diffusivity shall be directed by procedures under a quality assurance program.

Filter vents shall be legibly marked to ensure both (1) identification of the supplier and (2) date of manufacture, lot number, or unique serial number.

Table 8-1. Minimum Filter Vent Specifications

Container Type	Filter Specification			
	Number of Vents Required per Container	**Flow Rate (ml/min of air, STP, at 1 inch of water)[a]**	**Efficiency (percent)**	**Hydrogen Diffusivity (mol/s/mol fraction at 25°C)**
Drum	1	35	99.5	3.70E-6
Filtered Bag	1	35	NA[b]	1.075E-5

[a] Filters tested at a different pressure gradient shall have a proportional flow rate (e.g., 35 ml/min at 1 inch of water = 1 L/min at 1 psi).

[b] Filters installed in containers that are overpacked are exempt from the efficiency requirement as the drum must exhibit a ≥ 99.5 percent efficiency.

The rigid polyethylene liner, if present, in a payload container shall be punctured with a minimum of a 0.3-inch diameter hole before the container is transported in the 10-160B.

8.2 Methods of Compliance and Verification

Compliance with the payload container and contents configuration requirements is determined by visual observation, process knowledge, procurement records, and repackaging activities that ensure compliance. For content codes ET 121A, and ET 126A the waste is packaged directly into two plastic inner bags closed by the twist and tape method and then placed into a 55-gallon drum. For content code ET 325A, the waste is packaged in up to two plastic inner bags. The first bag (if present) may be closed by the twist and tape method and the second bag is vented/filtered. For content codes ET 121B, ET 126B, and ET 325B, the waste is packaged directly into two plastic inner bags both of which are vented/filtered and then placed into a 55-gallon drum. The bags may be placed inside a rigid polyethylene liner punctured with a minimum 0.3 inch diameter hole. The liner would then be placed directly inside a 55-gallon drum with a filter vent installed on each drum. For ET 326A, the waste is packaged directly into 55-gallon drums or will be packaged in closed 1-gallon paint cans that may be placed in larger metal cans that allow free transport of gas. The larger metal cans may be placed inside a rigid polyethylene liner punctured with a minimum 0.3-inch diameter hole. The liner would then be placed directly inside a 55-gallon drum installed with a filter vent. The drums may be lined with thick annular concrete shields. Bottom and top concrete shields plus thick steel lids may also be used inside the drums. Inner containers greater than 4 liters in volume are punctured or vented to allow free gas release. Up to ten drums of waste will then be placed into the 10-160B cask.

The requirements for the rigid liner and filter vent shall be controlled administratively or by puncturing the lids during repackaging activities and visually inspecting them prior to drum closure.

9.0 ISOTOPIC CHARACTERIZATION AND FISSILE CONTENT

9.1 Requirements

The 10-160B cask payload allows 325 FGE of fissile materials. Plutonium content in excess of 0.74 TBq (20 curies) per cask must be in solid form.

9.2 Methods of Compliance and Verification

The isotopic composition of the waste is derived from several sources, using a number of different procedures, depending upon the waste stream generation process and available historical information. It is derived from historical counting data and survey information for waste from nuclear fuel development activities; from a combination of survey data, decay-plus-ingrowth analysis, and the known initial fuel composition for decladding waste from a single spent fuel source; and by extensive sampling and radiological analysis for other materials.

10.0 DECAY HEAT AND HYDROGEN GAS GENERATION RATES

This section describes the logic and methodology used in evaluating payload characteristics that meet the hydrogen gas concentration requirement for the ETEC content codes described in this section.

10.1 Requirements

The hydrogen gas concentration shall not exceed 5% by volume in all void volumes within the 10-160B cask payload during a 60-day shipping period. A 10-160B Cask payload must be assembled of payload containers belonging to the same content code. Payload containers of different content codes with different bounding G values and resistances may be assembled together as a payload, provided the decay heat limit and hydrogen gas generation rate limit for all payload containers within the payload is conservatively assumed to be the same as that of the payload container with the lowest decay heat limit and hydrogen gas generation rate limit.

10.2 Methodology of Ensuring Compliance with Flammable Gas Concentration Limits

As stated in Section 7.2 of Appendix 4.11.2, chemical, biological, and thermal gas generation mechanisms are insignificant for the ETEC waste streams in the 10-160B cask. In addition, as shown in Section 5.1 of Appendix 4.11.2, potentially flammable VOCs are restricted to 500 ppm in the headspace of the 10-160B cask secondary containers. Therefore, the only flammable gas of concern for transportation purposes is hydrogen. The concentration of hydrogen within any void volume in a layer of confinement of the payload or in the cask IV has been evaluated during a 60-day shipping period (see Attachment C of Appendix 4.11.2).

Attachment A provides the ETEC content codes authorized as payload for the 10-160B cask. Each content code has a unique and completely defined packaging configuration. Modeling the movement of hydrogen from the waste material to the payload voids, using the release rates of hydrogen through the various confinement layers, defines the relationship between generation rate and void concentration. This modeling allows determination of the maximum allowable hydrogen generation rate for the ETEC content codes to meet the 5% concentration limit, as detailed in Section 10.3. Based on hydrogen gas generation potential, quantified by hydrogen gas generation G values, the gas concentration limit can be converted to a decay heat limit, as detailed in Section 10.4. The maximum allowable hydrogen generation rate and decay heat limits for the ETEC content codes are listed in Table 10-1 (see Attachment A of Appendix 4.11.2 for a description of the Matrix Depletion Program and dose-dependent G values).

10.3 Determination of Maximum Allowable Hydrogen Generation Rate

The maximum allowable hydrogen generation rates were determined using the modeling methodology described in Appendix 4.11.2 and the following input parameters.

Waste Packaging Configuration and Release Rates: For content codes ET 121A, and ET 126A the waste is packaged directly into two plastic inner bags closed by the twist and tape method and then placed into a 55-gallon drum. For content code ET 325A, the waste is packaged in up to two plastic inner bags. The first bag (if present) may be closed by the twist and tape method and the second bag is vented/filtered. For content codes ET 121B, ET 126B, and ET 325B, the waste is packaged directly into two plastic inner bags both of which are vented/filtered and then placed into a 55-gallon drum. The bags may be placed inside a rigid polyethylene liner punctured with a minimum 0.3 inch diameter hole. The liner would then be placed directly inside a 55-gallon drum with a filter vent installed on each drum. For ET 326A the waste is packaged directly into 55-gallon drums or will be packaged in closed 1-gallon paint cans that may be placed in larger metal cans that allow free transport of gas. The larger metal cans may be placed inside a rigid polyethylene liner punctured with a minimum 0.3-inch diameter hole. The liner would then be placed directly inside a 55-gallon drum installed with a filter vent. The drums may be lined with thick annular concrete shields. Bottom and top concrete shields plus thick steel lids may also be used inside the drums. Inner containers greater than 4 liters in volume are punctured or vented to allow free gas release. Up to ten drums of waste will then be placed into the 10-160B cask.

Table 10-1. Maximum Allowable Hydrogen Gas Generation Rates, Decay Heat Limits, and Total Activity Limits

Content Code	Maximum Allowable Hydrogen Gas Generation Rate, mole/second/ drum	Maximum Allowable Hydrogen Gas Generation Rate, moles/second/ cask	Maximum Allowable Decay Heat Limit, Watts/ Drum (Dose <= 0.012 watt*year)	Maximum Allowable Decay Heat Limit, Watts/Cask (Dose <= 0.012 watt*yr)	Maximum Allowable Decay Heat Limit, Watts/ Drum (Dose > 0.012 watt*year)	Maximum Allowable Decay Heat Limit, Watts/ Cask (Dose > 0.012 watt*year)
ET 121A	8.054E-9	8.054E-8	0.019	0.19	0.057	0.57
ET 121B	3.697E-8	3.697E-7	0.086	0.86	0.252	2.26
ET 126A	8.054E-9	8.054E-8	0.021	0.21	0.021	0.21
ET 126B	3.697E-8	3.697E-8	0.095	0.95	0.095	0.95
ET 325A	1.323E-8	1.323E-7	0.038	0.38	0.107	1.07
ET 325B	3.697E-8	3.697E-7	0.104	1.04	0.290	2.26
ET 326A	4.659E-8	4.659E-7	0.239	2.39	0.591	5.91

The release rates in Table 10-2 are shown for two different temperatures (minimum and maximum operating temperature of the 10-160B) and are based on release rate values for various waste packaging confinement layers documented in Appendices 3.6.9 and 3.6.12 of the TRUPACT-II SAR (Reference 12.2). The temperature dependence of these release rates is discussed later in this section.

<u>Void Volume in the 10-160B IV</u>: The cask will have a payload of 10 drums and a drum carriage. The interior volume of the cask, V_{cask}, is 4438 liters. The volume occupied by the drum carriage, $V_{carriage}$, is 143.2 liters. The external volume of a single drum, V_{drum}, is 235.7 liters. The void volume within the cask is calculated as:

$$V_{void} = V_{cask} - V_{carriage} - 10\ V_{drum}$$

$$V_{void} = 4{,}438 \text{ liters} - 143.2 \text{ liters} - 10\ (235.7 \text{ liters})$$

$$V_{void} = 1{,}938 \text{ liters}$$

<u>Pressure</u>: The pressure is assumed to be isobaric and equal to one atmosphere. The mole fraction of hydrogen in each void volume would be smaller if pressurization is considered and would result in a greater maximum allowable hydrogen gas generation rate. Furthermore, the amount of hydrogen gas generated during a 60-day shipping period would be negligible compared to the quantity of air initially present at the time of sealing the 10-160B cask.

<u>Temperature</u>: The input parameter affected by temperature is the release rate through the different confinement layers in the payload containers and the G values for hydrogen. Release rates increase with increasing temperature as documented in Appendix 3.6.12 of the TRUPACT-

II SAR (Reference 12.2). Therefore, the minimum release rates would be those at the lowest operating temperature. These are the release rates indicated in Table 10-2 for 233K. The minimum decay heat limits are determined by the ratio of the release rates and the G values. In other words, the higher the release rates, the higher the decay heat limit; the higher the G value, the lower the decay heat limit. The dependence of G values on temperature is documented in Section 10.4. For determining the decay heat limit, the temperature that yielded the minimum decay heat limit was used as the input parameter.

In summary, the temperature dependence of the input parameters was accounted for in the calculation so that, in each case, the minimum possible limit (hydrogen generation rate or decay heat limit) was obtained. This provides an additional margin of safety in the analysis.

Table 10-2. Release Rates of Hydrogen Across Confinement Layers

Confinement Layer	Release Rate (mol/sec/mol fraction)	
	T = 233K	T = 348.6K
Plastic Inner Bag (twist-and-tape closure)	3.895×10^{-7}	5.58×10^{-7} [a]
Plastic Inner Bag (vented/filtered with a 1.075x10-5 mole/sec/mole fraction filter at 294 K)	7.156×10^{-6}	1.447×10^{-5}
Rigid Polyethylene Drum Liner (0.3-inch diameter hole)	4.695×10^{-5}	5.09×10^{-5}
Drum Filter	2.46×10^{-6}	4.98×10^{-6}

[a] The value at 70°F is conservatively used.

10.4 Determination of Maximum Allowable Decay Limits

The maximum allowable decay heat limits for the ETEC waste content codes were calculated using the methodology described in Appendix 4.11.2 and the content code-specific G values and waste data described below:

10.4.1 G Value Data

G values for TRU wastes are content specific. G values are determined based on the bounding materials present in the payload. The following G values were used for each of the content codes based on the presence of the bounding materials. The G values at 70°F are adjusted to the maximum operating temperature of the 10-160B cask (168°F) using the Arrhenius equation. The maximum operating temperature yields the lowest decay heat limits for the operating temperature range of the 10-160B cask.

Table 10-3 summarizes the bounding G values for hydrogen and the activation energies for the G values for these different content codes at the temperature that provides the minimum decay heat limit (i.e., 348.6K, the maximum operating temperature). Materials determining these bounding

G values are also listed in Table 10-3. These G values are further discussed by content code below.

Dose-dependent G values for the authorized content codes are provided in Table 10-4 at the temperature that provides the minimum decay heat limit (i.e., 348.6K, the maximum operating temperature). The methodology associated with the determination of dose-dependent G values pursuant to the Matrix Depletion Program is further discussed in Attachment A of Appendix 4.11.2.

Table 10-3. Summary of Bounding G Values (Dose ≤ 0.012 watt*year)

Content Code	Waste Material	Maximum Hydrogen Gas G Value at 70°F (molecules/100 eV)	Bounding Hydrogen Gas G Value (molecules/100 eV)			Activation Energy (kcal/mole)
			α-radiation	β-radiation	γ-radiation	
ET 121A ET 121B	Cellulose	3.2	5.61			2.1
ET 126A ET 126B	Polyethylene	4.1	5.08			0.8
ET 325A ET 325B	Cellulose	3.2	4.60	5.61	5.61	2.1
ET 326A	50% Polyethylene	2.05	2.08	2.54	2.54	0.8

Table 10-4. Summary of Bounding G Values (Dose > 0.012 watt*year)

Content Code	Waste Material	Maximum Hydrogen Gas G Value at 70°F (molecules/100 eV)	Bounding Hydrogen Gas G Value (molecules/100 eV)			Activation Energy (kcal/mole)
			α-radiation	β-radiation	γ-radiation	
ET 121A ET 121B	Cellulose	1.09	1.91			2.1
ET 126A ET 126B	Polyethylene	4.1	5.08			0.8
ET 325A ET 325B	Cellulose	1.09	1.566	1.91	5.61	2.1
ET 326A	50% Polyethylene	0.32	0.33	0.40	2.54	0.8

ET 121A, ET 121B

This content code represents solid organic debris consisting of various combustible and non-combustible items. The material present in this waste with the highest G value at the maximum operating temperature of the 10-160B cask (168°F) is cellulosics and is therefore considered as the bounding material for hydrogen and total gas. The G value for hydrogen associated with cellulosics is 3.2 molecules/100eV (at 70°F) if the attained dose is less than or equal to 0.012 watt*year. The dose dependent G value for cellulosics is 1.09 molecules/100 eV if the dose attained in the drum is greater than 0.012 watt*yr. The methodology associated with the determination of dose-dependent G values pursuant to the Matrix Depletion Program is further discussed in Attachment A of Appendix 4.11.2. The G values at 70°F are adjusted to the maximum operating temperature of the 10-160B cask (168°F) using the Arrhenius equation. The activation energy of the G value for cellulosics is 2.1 kcal/mole. Thus, at the maximum operating temperature of the 10-160B cask (168°F), the bounding hydrogen G values for cellulosics are 5.61 molecules/100 eV (dose ≤ 0.012 watt*year) and 1.91 molecules/100 eV (dose > 0.012 watt*year).

ET 126A, ET 126B

This content code represents Petroset-II-solidified oil, with some solid debris waste. All the materials in the Petroset-II and the oil/solvent mixture added to form the final waste form have hydrogen G-values less than polyethylene that is also present in greater than 1 weight percent in the waste. The maximum hydrogen G-value for mineral oils and machining oils in Appendix 3.6.8, Table 3.13-1 of the TRUPACT-II SAR (Ref **12.**__) is 2.8 molecules/100 eV. Thus, the G value for hydrogen associated with polyethylene of 4.1 molecules/100eV (at 70°F) is considered bounding for this content code. For this content code, the bounding G value is considered to be independent of the dose per Attachment A of Appendix 4.11.2.

ET 325A, ET 325B

This content code represents solid organic debris consisting of various combustible and non-combustible items. The material present in this waste with the highest G value at the maximum operating temperature of the 10-160B cask (168°F) is cellulosics and is therefore considered as the bounding material for hydrogen and total gas. The G value for hydrogen associated with cellulosics is 3.2 molecules/100eV (at 70°F) if the attained dose is less than or equal to 0.012 watt*year. The dose dependent G value for cellulosics is 1.09 molecules/100 eV if the dose attained in the drum is greater than 0.012 watt*yr. The methodology associated with the determination of dose-dependent G values pursuant to the Matrix Depletion Program is further discussed in Attachment A of Appendix 4.11.2. The G values at 70°F are adjusted to the maximum operating temperature of the 10-160B cask (168°F) using the Arrhenius equation. The activation energy of the G value for cellulosics is 2.1 kcal/mole. Thus, at the maximum operating temperature of the 10-160B cask (168°F), the bounding hydrogen G values for cellulosics are 5.61 molecules/100 eV (dose $\leq$ 0.012 watt*year) and 1.91 molecules/100 eV (dose > 0.012 watt*year).

ET 326A

The bounding G values for hydrogen and total gas for this content code are provided by polyethylene, which is used only as packaging material. These G values are derived from the information presented in Appendix 3.6.7 of the TRUPACT-II SAR (Reference 12.2). The allowable materials in this content code in concentrations of greater than 1 weight percent are provided in Attachment A. All of these materials conform with the bounding G values for this content code.

10.4.2 Waste Data

RadCalc requires as input the following parameters associated with the waste for which the maximum allowable decay heat limit is being calculated:

- Physical Form – liquid, solid, or gas
- Waste Volume – volume of the waste, cm^3
- Waste Mass – mass of the waste, g
- G Value – G value of the waste, molecules per 100 eV

Liquids and gas wastes are prohibited in the 10-160B cask. The volume of the waste is assumed to be 217 liters per drum (the external volume of the waste drum) and 2170 liters for 10 drums in the cask. The waste volume is used by RadCalc, along with the waste mass, to determine the volume of hydrogen generated in the cask. The mass of the waste is calculated based on the assumed bulk density of the waste. The volume of hydrogen generated is directly proportional to the mass of the waste, as discussed in Reference 12.3. The most conservative estimate of the volume of hydrogen (greatest volume) would occur at the highest possible bulk density of the waste.

For content codes ET 325A or ET 325B, the single drum of this content code has a gross weight of 268 pounds (122 kg) and the volume occupied by the drum and waste is assumed to be 55 gallons (208×10^3 cm^3). Thus, the bulk density of this content code is (122×10^3 g/ 208x103 cm^3) or 0.59 g/cm^3. A conservative bounding waste bulk density of 1.5 g/cm^3 (based on cement obtained from Reference 12.4), is used for content code ET 326A. Representative waste drum data for this content code provide waste bulk densities well below the 1.5 g/cm^3 bounding bulk density used to calculate the decay heat limits. The mass of waste in the 10-160B is calculated based on the total volume of the 10 waste drums (2170 liters).

10.4.3 Determining Decay Heats

Decay heat shall be determined by calculations using the isotopic inventory information for fissile and nonfissile TRU radionuclides and for any non-TRU radionuclides that may be present in the TRU waste drums as determined through the methods documented in Section 9.2. The decay heats of the drums shall be calculated by combining the isotopic inventory data and the calculated decay heat for each radionuclide. The calculated value of the decay heat for an individual drum and the decay heat error (if applicable) shall be recorded in the data package for an individual payload container. If the drum meets the drum limit for the content code, it is eligible for shipment if all other transportation requirements are met. If the drum does not meet the limit, it cannot be shipped and shall be segregated for repackaging or other mitigation measures. The total decay heat for the 10-160B Cask payload shall be determined by summing the decay heats of all drums making up the payload for the 10-160B Cask. The total decay heat error (if applicable) is calculated as the square root of the sum of the squares of the individual decay heat error values. The total shipment decay heat value (calculated value plus total error) shall be compared to the cask limit for decay heat. The site transportation certification official (TCO) shall evaluate the compliance of individual drums and the total of all drums with the maximum limits per drum and per cask.

5.2 Methodology for Compliance with Payload Assembly Requirements

The TCO shall ensure that the 10-160B Cask payload consists of payload containers belonging to the same content code. In the event that payload containers of different content codes with different bounding G values and resistances are assembled together in the 10-160B cask, the TCO shall ensure that the decay heat or hydrogen gas generation rate for each payload container within the payload is less than or equal to the container with the most restrictive limits.

11.0 WEIGHT

11.1 Requirements

The weight limit for the contents of the loaded cask is 14,250 pounds.

11.2 Methods of Compliance and Verification

Each 55-gallon drum will be weighed on a calibrated scale after it is filled and closed. When the payload data sheets are completed for the shipment, they will reflect the total weight of each drum. Based on the total measured weight of the individual payload containers, ETEC shall calculate total assembly weight and evaluate compliance with the contents of the loaded cask.

12.0 REFERENCES

12.1 U.S. Department of Energy (DOE), 2002, “Contact Handled-Transuranic Waste Acceptance Criteria for the Waste Isolation Pilot Plant,” Rev. 0, *DOE/WIPP-02-3122*, U.S. Department of Energy, Carlsbad Field Office, Carlsbad, New Mexico.

12.2 U.S. Department of Energy, "Safety Analysis Report for the TRUPACT-II Shipping Package," Current Revision, U.S. Department of Energy Carlsbad Field Office, Carlsbad, New Mexico.

12.3 Flaherty, J.E., A. Fujita, C.P. Deltete, and G.J. Quinn, 1986, “A Calculational Technique to Predict Combustible Gas Generation in Sealed Radioactive Waste Containers,” *GEND 041*, EG&G Idaho, Inc., Idaho Falls, Idaho.

12.4 Perry, R.H., D.W. Green, and J.O. Maloney, 1984, *Perry's Chemical Engineers' Handbook*, 6th ed., McGraw-Hill Book Co., New York, New York.

Attachment A

Transuranic Content Codes and Chemical Lists

For Energy Technology Engineering Center (ETEC)

CONTENT CODE: ET 121A, ET 121B

CONTENT DESCRIPTION: Solid Organic Waste

GENERATING SITE: Energy Technology Engineering Center (ETEC)

STORAGE SITE: ETEC

WASTE DESCRIPTION: This waste consists of a variety of combustible and noncombustible organic items.

GENERATING SOURCE(S): Solid organic and inorganic debris waste was generated during decontamination and decommissioning (D&D) operations at the former ETEC-associated Hot Laboratory.

WASTE FORM: The waste may include combustible items such as cloth and paper products (e.g., from the cleanup of spills), rags, coveralls and booties, plastic, cardboard, rubber, wood, surgeons gloves, and Kimwipes. The waste may also include filter waste, (e.g., dry box filters, HEPA filters, and filter cartridges); noncombustible Benelex and plexiglas neutron shielding, blacktop, concrete, dirt, and sand; leaded gloves and aprons comprised of Hypalon rubber and lead oxide impregnated neoprene; and small amounts of metal waste. This waste may also include particulate and sludge-type organic process solids immobilized/solidified with Portland cement, vermiculite, Aquaset, or Petroset.

WASTE PACKAGING:

ET 121A: The waste is packaged in up to two plastic inner bags that are closed by the twist and tape method. The bags may be placed inside a rigid polyethylene liner punctured with a minimum 0.3-inch diameter hole. The liner would then be placed directly inside a 55-gallon drum installed with a filter vent. Up to ten drums will then be placed into the 10-160B cask.

ET 121B: The waste is packaged in up to two vented/filtered plastic inner bags. The bags may be placed inside a rigid polyethylene liner punctured with a minimum 0.3-inch diameter hole. The liner would then be placed directly inside a 55-gallon drum installed with a filter vent. Up to ten drums will then be placed into the 10-160B cask.

METHODS FOR DETERMINATION OF ISOTOPIC CHARACTERIZATION: The required isotopic information to demonstrate compliance with the limits on fissile content, decay heat, and curie content will be determined based on acceptable knowledge, the radioassay of samples, or on total drum activity measurements, taken on the product material.

FREE LIQUIDS: Liquid waste is prohibited in the drums except for residual amounts in well-drained containers. The total volume of residual liquid in a payload container shall be less than 1 volume percent of the payload container. Waste packaging procedures ensure that free liquids are less than 1 volume percent of the payload container.

EXPLOSIVES/COMPRESSED GASES: Explosives and compressed gases in the payload containers are prohibited by waste packaging procedures.

PYROPHORICS: Nonradioactive pyrophorics in the payload containers are prohibited by waste packaging procedures. Waste packaging procedures shall ensure that all pyrophoric radioactive materials are present only in small residual amounts (less than 1 weight percent) in payload containers.

CORROSIVES: Corrosives are prohibited in the payload containers. Acids and bases that are potentially corrosive shall be neutralized and rendered noncorrosive prior to being a part of the waste. The physical form of the waste and the waste generating procedures ensure that the waste is in a nonreactive form.

CHEMICAL COMPATIBILITY: A chemical compatibility study has been performed on this content code, and all waste is chemically compatible for materials in greater than trace (>1% weight) quantities.

ADDITIONAL CRITERIA: Each drum is fitted with a minimum of one filter vent. Drum filters have a minimum hydrogen diffusivity of 3.7E-06 mole/second/mole fraction. If present, rigid liners in 55-gallon drums shall be punctured with a minimum 0.3-inch diameter hole for gas release.

MAXIMUM ALLOWABLE HYDROGEN GENERATION RATES - OPTION 1: The maximum allowable hydrogen generation rate limit for ET 121A is 8.054E-09 moles per second per drum and 8.054E-08 moles per second per 10-160B cask. The maximum allowable hydrogen generation rate limit for ET 121B is 3.697E-08 moles per second per drum and 3.697E-07 moles per second per 10-160B cask.

MAXIMUM ALLOWABLE DECAY HEAT LIMIT - OPTION 2: The maximum allowable decay heat limit for ET 121A is 0.019 watts per drum and 0.19 watts per 10-160B cask if dose ≤ 0.012 watt*yr and 0.057 watts per drum and 0.57 watts per 10-160B cask if dose > 0.012 watt*yr. The maximum allowable decay heat limit for ET 121B is 0.086 watts per drum and 0.86 watts per 10-160B cask if dose ≤ 0.012 watt*yr and 0.252 watts per drum and 2.26 watts per 10-160B cask if dose > 0.012 watt*yr.

ENERGY TECHNOLOGY ENGINEERING CENTER (ETEC)

CONTENT CODES ET 121A AND ET 121B

SOLID ORGANIC WASTE

MATERIALS AND CHEMICALS >1%

PLASTIC

PAPER

WOOD

CELLULOSICS

CLOTH

POLY-LINER

METAL

STAINLESS STEEL

STRIPPABLE PAINT

RUBBER

PAINT

PLEXIGLAS

VERMICULITE

MATERIALS AND CHEMICALS <1%

CLEANERS

OILS

SOLVENTS

SEALANT MATERIAL

CONTENT CODE: ET 126A, ET 126B

CONTENT DESCRIPTION: Solidified Organic Process Waste

GENERATING SITE: Energy Technology Engineering Center (ETEC)

STORAGE SITE: ETEC

WASTE DESCRIPTION: This waste consists of a variety of PETROSET-II solidified oil, with some debris waste on top.

GENERATING SOURCE(S): Waste was accumulated during the final cleanup of the NMDF and consisted primarily of oil and oil sludge that was removed from building and glove-box equipment.

WASTE FORM: In 1988, the oil was consolidated and solidified using Petroset-II in four new drums (B55-1 through B55-4). The repackaging and solidification process took place in the Hot Laboratory cells during the period of October to December, 1988.

WASTE PACKAGING:

ET 126A: The waste is packaged in up to two plastic inner bags that are closed by the twist and tape method. The bags may be placed inside a rigid polyethylene liner punctured with a minimum 0.3-inch diameter hole. The liner would then be placed directly inside a 55-gallon drum installed with a filter vent. Up to ten drums will then be placed into the 10-160B cask.

ET 126B: The waste is packaged in up to two vented/filtered plastic inner bags. The bags may be placed inside a rigid polyethylene liner punctured with a minimum 0.3-inch diameter hole. The liner would then be placed directly inside a 55-gallon drum installed with a filter vent. Up to ten drums will then be placed into the 10-160B cask.

METHODS FOR DETERMINATION OF ISOTOPIC CHARACTERIZATION: The required isotopic information to demonstrate compliance with the limits on fissile content, decay heat, and curie content will be determined based on acceptable knowledge, the radioassay of samples, or on total drum activity measurements, taken on the product material.

FREE LIQUIDS: Liquid waste is prohibited in the drums except for residual amounts in well-drained containers. The total volume of residual liquid in a payload container shall be less than 1 volume percent of the payload container. Waste packaging procedures ensure that free liquids are less than 1 volume percent of the payload container.

EXPLOSIVES/COMPRESSED GASES: Explosives and compressed gases in the payload containers are prohibited by waste packaging procedures.

PYROPHORICS: Nonradioactive pyrophorics in the payload containers are prohibited by waste packaging procedures. Waste packaging procedures shall ensure that all pyrophoric radioactive materials are present only in small residual amounts (less than 1 weight percent) in payload containers.

CORROSIVES: Corrosives are prohibited in the payload containers. The physical form of the waste and the waste generating procedures ensure that the waste is in a nonreactive form.

CHEMICAL COMPATIBILITY: A chemical compatibility study has been performed on this content code, and all waste is chemically compatible for materials in greater than trace (>1% weight) quantities.

ADDITIONAL CRITERIA: Each drum is fitted with a minimum of one filter vent. Drum filters have a minimum hydrogen diffusivity of 3.7E-06 mole/second/mole fraction. If present, rigid liners in 55-gallon drums shall be punctured with a minimum 0.3-inch diameter hole for gas release.

MAXIMUM ALLOWABLE HYDROGEN GENERATION RATES - OPTION 1: The maximum allowable hydrogen generation rate limit for ET 126A is 8.054E-09 moles per second per drum and 8.054E-08 moles per second per 10-160B cask. The maximum allowable hydrogen generation rate limit for ET 126B is 3.697E-08 moles per second per drum and 3.697E-07 moles per second per 10-160B cask.

MAXIMUM ALLOWABLE DECAY HEAT LIMIT - OPTION 2: The maximum allowable decay heat limit for ET 126A is 0.021 watts per drum and 0.21 watts per 10-160B cask for all dose values. The maximum allowable decay heat limit for ET 126B is 0.095 watts per drum and 0.95 watts per 10-160B cask for all dose values.

ENERGY TECHNOLOGY ENGINEERING CENTER (ETEC)

CONTENT CODES ET 126A AND ET 126B

SOLIDIFIED ORGANIC PROCESS WASTE

MATERIALS AND CHEMICALS >1%

PETROSET-II

AQUASET

PLASTIC

POLY-LINER

RUBBER GLOVES

VERMICULITE

METALS

SYNTHETIC RUBBER

DRY/ALARA PAINT

PAPER

VACUUM PUMP OILS (INCLUDING DC-704 OIL)

HYDRAULIC OILS (INCLUDING ENERPAC)

MATERIALS AND CHEMICALS <1%

CELLULOSICS

METALS

SYNTHETIC RUBBER

DRY/ALARA PAINT

ISOPROPANOL

FREON

CONTENT CODE: ET 325A, ET 325B

CONTENT DESCRIPTION: Solid Organic and Inorganic Waste

GENERATING SITE: Energy Technology Engineering Center (ETEC)

STORAGE SITE: ETEC

WASTE DESCRIPTION: This waste consists of Hot Laboratory debris including paper, plastic, metal and glass.

GENERATING SOURCE(S): Solid organic and inorganic debris waste was generated during decontamination and decommissioning (D&D) operations at the former ETEC-associated Hot Laboratory.

WASTE FORM: The debris waste consists of miscellaneous waste materials removed from the facility during D&D, including a small capped pipe that contains unirradiated plutonium oxide/uranium oxide pieces from ETEC's former Nuclear Materials Development Facility, canisters of paint chips surrounded by lead shielding, and a lead brick.

WASTE PACKAGING:

ET 325A: The waste is packaged in up to two plastic inner bags. The first bag (if present) may be closed by the twist and tape method and the second bag is vented/filtered. The bags may be placed inside a rigid polyethylene liner punctured with a minimum 0.3-inch diameter hole. The liner would then be placed directly inside a 55-gallon drum installed with a filter vent. Up to ten drums will then be placed into the 10-160B cask.

ET 325B: The waste is packaged in up to two vented/filtered plastic bags. The bags may be placed inside a rigid polyethylene liner punctured with a minimum 0.3-inch diameter hole. The liner would then be placed directly inside a 55-gallon drum installed with a filter vent. Up to ten drums will then be placed into the 10-160B cask.

METHODS FOR DETERMINATION OF ISOTOPIC CHARACTERIZATION: The required isotopic information to demonstrate compliance with the limits on fissile content, decay heat, and curie content will be determined based on acceptable knowledge, the radioassay of samples, or on total drum activity measurements, taken on the product material.

FREE LIQUIDS: Liquid waste, except for residual amounts in well-drained containers, is prohibited in the drums. The total volume of residual liquid in a payload container shall be less than 1 volume percent of the payload container. Waste packaging procedures ensure that free liquids are less than 1 volume percent of the payload container.

EXPLOSIVES/COMPRESSED GASES: Explosives and compressed gases in the payload containers are prohibited by waste packaging procedures. If present, pressurized cans shall be punctured and emptied prior to packaging.

PYROPHORICS: Nonradioactive pyrophorics in the payload containers are prohibited by waste packaging procedures. Process knowledge indicates that no non-radioactive pyrophoric material was generated in association with the waste. Waste packaging procedures shall ensure that all radioactive pyrophoric materials are present only in small residual amounts (less than 1 weight percent) in payload containers.

CORROSIVES: Corrosives are prohibited in the payload container. Acids and bases that are potentially corrosive shall be neutralized or rendered noncorrosive prior to being a part of the waste. The physical form of the waste and the waste generating procedures ensure that the waste is in a nonreactive form.

CHEMICAL COMPATIBILITY: A chemical compatibility study has been performed on this content code, and all waste is chemically compatible for materials in greater than trace (>1% by weight) quantities.

ADDITIONAL CRITERIA: Each drum is fitted with a minimum of one filter vent. Drum filters have a minimum hydrogen diffusivity of 3.7E-06 mole/second/mole fraction. If present, rigid liners in 55-gallon drums shall be punctured with a minimum 0.3-inch diameter hole for gas release.

MAXIMUM ALLOWABLE HYDROGEN GENERATION RATES - OPTION 1: The maximum allowable hydrogen generation rate limit for ET 325A is 1.323E-08 moles per second per drum and 1.323E-07 moles per second per 10-160B cask. The maximum allowable hydrogen generation rate limit for ET 325B is 3.697E-08 moles per second per drum and 3.697E-07 moles per second per 10-160B cask.

MAXIMUM ALLOWABLE DECAY HEAT LIMIT - OPTION 2: The maximum allowable decay heat limit for ET 325A is 0.038 watts per drum and 0.38 watts per 10-160B cask if dose ≤ 0.012 watt*yr and 0.107 watts per drum and 1.07 watts per 10-160B cask if dose > 0.012 watt*yr. The maximum allowable decay heat limit for ET 325B is 0.104 watts per drum and 1.04 watts per 10-160B cask if dose ≤ 0.012 watt*yr and 0.290 watts per drum and 2.26 watts per 10-160B cask if dose > 0.012 watt*yr.

ENERGY TECHNOLOGY ENGINEERING CENTER (ETEC)

CONTENT CODES ET 325A AND ET 325B

SOLID ORGANIC AND INORGANIC WASTE

MATERIALS AND CHEMICALS >1%

CLOTH

CONCRETE PARTICULATE

FILTERS

GLASS

METALS(e.g., aluminum, titanium, iron, copper, lead, tungsten, brass, steel and stainless steel, tantalum)

PuO/UO PIECES (unirradiated)

PAINT CHIPS (strippable paint)

PLASTIC

PAPER

VERMICULITE

WOOD

MATERIALS AND CHEMICALS <1%

CLEANERS

OILS

SOLVENTS

SEALANT MATERIAL

CONTENT CODE: ET 326A

CONTENT DESCRIPTION: Solidified Organic Process Waste

GENERATING SITE: Energy Technology Engineering Center (ETEC)

STORAGE SITE: ETEC

WASTE DESCRIPTION: This waste consists of drain line residue, including organic sludges and sludge-like materials, steel and concrete components.

GENERATING SOURCE(S): This waste is primarily dry fines and solidified sludge that were removed from the former ETEC-associated Hot Laboratory drain line system and drain tank during decontamination and decommissioning operations. The waste includes fines that are the result of cutting and grinding operations.

WASTE FORM: The waste consists of materials that were washed out of operational hot cells. The primary constituents are steel and fuel element fines (including TRU, fission products, and activated cladding residue) from declad grinding and cutting operations, sludge wastes, steel and concrete debris, sand, dirt, grinding materials, and concrete dust/particulate. The sludge wastes are, in part, the result of solidification or liquid absorption procedures using diatomaceous earth, fly ash, cement, or concrete.

WASTE PACKAGING: The waste is packaged directly into 55-gallon drums or will be packaged in closed 1-gallon paint cans that may be placed in larger metal cans that allow free transport of gas. The larger metal cans may be placed inside a rigid polyethylene liner punctured with a minimum 0.3-inch diameter hole. The liner would then be placed directly inside a 55-gallon drum installed with a filter vent. Ten drums will then be placed into the 10-160B cask. The drums may be lined with thick annular concrete shields. Bottom and top concrete shields plus thick steel lids may also be used inside the drums. Inner containers greater than 4 liters in volume are punctured or vented to allow free gas release. Up to ten drums will then be placed into the 10-160B cask.

METHODS FOR DETERMINATION OF ISOTOPIC CHARACTERIZATION: The required isotopic information to demonstrate compliance with the limits on fissile content, decay heat, and curie content will be determined based on acceptable knowledge, the radioassay of samples, and on total drum activity measurements taken on the product material during the processing at the site.

FREE LIQUIDS: Liquid waste, except for residual amounts in well-drained containers, is prohibited in the drums. The total volume of residual liquid in a payload container shall be less than 1 volume percent of the payload container. Site procedures for liquid absorption and solidification ensure that free liquids are less than 1 volume percent of the payload container.

EXPLOSIVES/COMPRESSED GASES: Explosives and compressed gases in the payload containers are prohibited by waste packaging procedures. If present, pressurized cans shall be punctured and emptied prior to packaging.

PYROPHORICS: Nonradioactive pyrophorics in the payload containers are prohibited by waste packaging procedures. Process knowledge indicates that no non-radioactive pyrophoric material was generated in association with waste. Waste packaging procedures shall ensure that all radioactive pyrophoric materials are present only in small residual amounts (less than 1 weight percent) in payload containers.

CORROSIVES: Corrosives are prohibited in the payload container. Acids and bases that are potentially corrosive shall be neutralized or rendered noncorrosive prior to being a part of the waste. The physical form of the waste and the waste generating procedures ensure that the waste is in a nonreactive form.

CHEMICAL COMPATIBILITY: A chemical compatibility study has been performed on this content code, and all waste is chemically compatible for materials in greater than trace (>1% by weight) quantities.

ADDITIONAL CRITERIA: Each drum is fitted with a minimum of one filter vent. Drum filters have a minimum hydrogen diffusivity of 3.7E-06 mole/second/mole fraction. Inner containers greater than 4 liters in volume are punctured or vented to allow free gas release. If present, rigid liners in 55-gallon drums shall be punctured with a minimum 0.3-inch diameter hole for gas release.

MAXIMUM ALLOWABLE HYDROGEN GENERATION RATES - OPTION 1: The maximum allowable hydrogen generation rate limit is 4.659E-08 moles per second per drum and 4.659E-07 moles per second per 10-160B cask.

MAXIMUM ALLOWABLE DECAY HEAT LIMIT - OPTION 2: The maximum allowable decay heat limit is 0.239 watts per drum and 2.39 watts per 10-160B cask if dose ≤ 0.012 watt*yr and 0.591 watts per drum and 5.91 watts per 10-160B cask if dose > 0.012 watt*yr.

ENERGY TECHNOLOGY ENGINEERING CENTER (ETEC) CONTENT CODE ET 326A

SOLIDIFIED ORGANIC PROCESS WASTE

MATERIALS AND CHEMICALS >1%

ABSORBENTS (diatomaceous earth, vermiculite, fly ash, cement, concrete)
CONCRETE AND CONCRETE DUST/PARTICULATE
DIRT
GLASS
GRINDING MATERIALS (carborundum, other carbides)
IRON OXIDES
METALS (including carbon steel [containers, weir boxes, grindings and shavings], aluminum, chromium, titanium, zinc, beryllium, iron, nickel, copper, mercury, tungsten, zirconium, cadmium, brass, stainless steel [primarily grindings and shavings], molybdenum, lead)
PAINT CHIPS
PLASTIC
SAND (silica and alumina based)

MATERIALS AND CHEMICALS <1%

ACETONE
ALCOHOL
ALCONOX
BIG ORANGE CLEANER
CALCIUM CARBONATE
CAUSTIC CLEANERS: Oakite, MX-12, Big K (potassium hydroxide)
DOWANOL
ELECTROPOLISH (phosphoric and sulfuric acid)
FOGPROOF
FREON
GRAPHITE
HYDROFLUORIC, NITRIC, HYDROCHLORIC, CITRIC, PERCHLORIC/OXALIC ACID
KEROSENE
OIL, MINERAL OIL, HYDRAULIC OIL, CUTTING OIL, SPRAY LUBRICANTS
PETROSET, AQUASET, EARTH-TITE
RADIAC WASH
SODIUM OXIDE
TRICHLOROETHYLENE
TURCO PRODUCTS (alkaline cleaners), DEFOAMING AGENTS
WINDEX
ZEP SPRAY
METAL-X

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4.11.6 COMPLIANCE METHODOLOGY FOR TRU WASTE FROM LAWRENCE LIVERMORE NATIONAL LABORATORY (LLNL), LIVERMORE, CA

1.0 INTRODUCTION

This appendix presents how acceptable knowledge including records and database information (process knowledge) is used to qualify six drums of contact-handled transuranic (CH-TRU) waste, as payload for transport in the 10-160B cask. The methods for determining each restricted parameter, the factors influencing the parameter values, and the methods used by LLNL for demonstrating compliance, are provided in the following sections.

This appendix also includes the following as attachments:

- Content code LL 116A (Attachment A)
- Chemical List for the above mentioned content code (Attachment A).

2.0 PURPOSE

The purpose of this appendix is to describe the methods and acceptable knowledge that shall be used to prepare and characterize the CH-TRU waste belonging to LLNL in order to demonstrate compliance with the TRU waste payload requirements prior to transport in the 10-160B cask. This appendix is based on the format and requirements for TRU waste identified in Appendix 4.11.2. It incorporates acceptable methods applicable to the content codes LL 116A and LL 116B of this appendix.

Section 3.0 describes the TRU waste payload. Sections 4.0 through 11.0 discuss each payload parameter and the acceptable knowledge, process knowledge, and methods employed to demonstrate compliance with the 10-160B cask payload requirements.

3.0 TRU WASTE PAYLOAD FOR 10-160B CASK

The six drums of CH-TRU waste from LLNL are currently classified into a single content code, LL 116, that describes CH-TRU waste material in terms of processes generating the waste, the packaging methods used in the waste container(s), and the generating site. Content code LL 116A represents the current packaging configuration of the six drums. The waste described in LL 116A may be repackaged to the packaging configuration described in content code LL 116B. The LL 116A and LL 116B content codes for the CH-TRU waste from LLNL are provided in Attachment A.

Several payload assembly/container filter options and associated requirements are presented for the LL 116A and LL 116B content codes. LL 116A represents the current packaging configuration of the six drums of LLNL waste to be shipped in the 10-160B cask. This configuration has three layers of plastic bagging (2 inner bags, 1 inner bag). The waste may require repackaging to meet the hydrogen gas generation rate or decay heat limits calculated for LL 116A. A second packaging configuration LL 116B (no plastic bag layers) is presented to represent repackaging the LLNL waste. LL 116B packaging configuration requires all inner and liner bags be breached. Methods of complying with the 10-160B requirements are presented for both packaging configurations. For LL 116B, repackaged waste, the outer waste containers (55-gallon drums) may be fitted with either a standard drum filter or a high diffusivity drum filter. Additionally, the payload may be shipped as a single shipment of 6 55-gallon waste drums with 4 open dunnage drums or may be shipped as multiple shipments of up to 3 55-gallon waste drums with 7 open dunnage drums in order to meet the hydrogen gas generation limits. The hydrogen gas generation rates and decay heat limits associated with these configurations are discussed in Section 10.0.

Complete documentation packages, along with quality assurance/quality control records, shall be generated for all payload containers. TRU waste generated from the LLNL will comply with all transportation requirements using the following methods:

- Formally documented acceptable knowledge (AK)/process knowledge of the processes generating the waste
- Data packages generated for all payload containers that document the contents and properties of the waste in the container including the absence of prohibited item and compliance with packaging requirements
- Measurement of required parameters to ensure compliance with limits.

4.0 PHYSICAL FORM

4.1 Requirements

The physical form of waste comprising the 10-160B cask payload is restricted to solid or solidified materials in secondary containers. The total volume of residual liquid in a secondary container is restricted to less than 1% by volume. Secondary containers must be shored to prevent movement during accident conditions. Sharp or heavy objects in the waste shall be blocked, braced, or suitably packaged as necessary to provide puncture protection for the payload containers packaging these objects. Sealed containers greater than four liters in size are prohibited.

4.2 Methods of Compliance and Verification

Compliance with the physical form requirements is determined by records and database information. The waste consists mostly of dry solid laboratory waste such as tissues, paper, assorted plastics, glassware, ceramics and metals. Portland cement or Aquaset was used to solidify water-based liquids; Envirostone or Petroset was used to solidify small amounts of solvents and oil-based liquids. LLNL has certified that the waste contains less than 1% by volume of free liquids.

LLNL personnel shall ensure compliance with the requirement associated with sharp or heavy objects through visual examination at the time of packaging and process knowledge (records and database information). Items with the potential to puncture the liner and drum are blocked, braced, or suitably packaged to ensure container integrity.

LLNL personnel shall ensure compliance with the requirement associated with sealed containers through visual examination at the time of packaging and process knowledge (records and database information).

Compliance with each of the restrictions on physical form shall be recorded in the payload container data package.

5.0 CHEMICAL FORM AND CHEMICAL PROPERTIES

5.1 Requirements

The chemical properties of the waste are determined by the chemical constituents allowed in a given content code. Specific requirements regarding the chemical form of the waste are as follows:

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

5.2 Methods of Compliance and Verification

Compliance with chemical form and chemical property restrictions is demonstrated through process knowledge or sampling programs, if required.

5.2.1 Pyrophoric Materials

LLNL has certified that the waste does not contain any pyrophorics.

5.2.2 Explosives, Corrosives, and Compressed Gases

LLNL has certified that the waste does not contain any explosives or compressed gases. LLNL procedures call for all aerosol cans to be punctured before placement in a TRU waste drum. LLNL has certified that the waste does not contain any corrosive materials. Any corrosive materials used during the production of the waste was neutralized prior to being emplaced in the waste containers.

5.2.3 Flammable VOCs

All TRU waste from the LLNL is from research and development and will be packaged with the generation of complete data packages. The LLNL will ensure that the total amount of potentially flammable VOCs present in the headspace of a secondary container is restricted to 500 ppm.

6.0 CHEMICAL COMPATIBILITY

6.1 Requirements

Each content code has an associated chemical list (Attachment A) based on AK information. Chemical constituents in a payload container assigned to a given content code shall conform to these approved chemical lists. Chemicals/materials that are not listed are allowed in trace amounts (quantities less than 1 weight percent) in a payload container provided that the total quantity of trace chemicals/materials is restricted to less than 5 weight percent.

Chemical compatibility of a waste with its packaging ensures that chemical reactions will not occur that might pose a threat to the safe transport of a payload in the 10-160B cask.

6.2 Methods of Compliance and Verification

Attachment B of Appendix 4.11.2 presents the methodology and results for the chemical compatibility analyses performed for the list of allowable chemicals/materials associated with the TRU waste content codes expected to be shipped in the 10-160B cask. The results of these chemical compatibility analyses show that these content codes can be transported without any incompatibilities.

The chemicals present in the LLNL content codes conform to the list of allowable materials in Attachment B of Appendix 4.11.2. Therefore the waste meets the chemical compatibility requirements.

7.0 GAS DISTRIBUTION AND PRESSURE BUILDUP

7.1 Requirements

Gas distribution and pressure buildup during transport of TRU waste in the 10-160B cask payload are restricted to the following limits:

- The gases generated in the payload must be controlled to prevent the occurrence of potentially flammable concentrations of gases within the payload confinement layers and the void volume of the inner vessel (IV) cavity. Specifically, hydrogen concentrations within the payload confinement layers are limited to 5 percent by volume during a maximum 60-day shipping period (see Attachment C of Appendix 4.11.2).

- The gases generated in the payload and released into the IV cavity must be controlled to maintain the pressure within the IV cavity below the acceptable packaging design limit of 31.2 pounds per square inch gauge (psig).

7.2 Methods of Compliance and Verification

Compliance with the 10-160B cask design pressure limit for the LLNL content codes and each payload assembly configuration is analyzed by assuming that all gases generated are released into the IV cavity and by including the contributions from thermal expansion of gases and vapor pressure of atmospheric water.

Table 7-1 shows that the pressure increase during a period of 365 days is below the design pressure limit of 31.2 psig for all waste shipment options of LLNL TRU waste.

Table 7-1. Maximum Pressure Increase Over 365-Day Shipping Period

Content Code and Configuration	G_{eff} (RT)[a]	Void Volume (Liters)	Activation Energy (kcal/mole)	Decay Heat Limit (Watts/cask)	G_{eff}[b]	P_{max}[c] (psig)
LL 116A	8.1	1938	2.1	0.354	14.19	11.89
LL 116B standard drum filter (3.7E-6 mole/sec/mole fraction) (6 waste drums per cask)	8.1	1938	2.1	2.26	14.19	31.13
LL 116B high diffusivity drum filter (1.85E-5 mole/sec/mole fraction) (6 waste drums per cask)	8.1	1938	2.1	2.26	14.19	31.13
LL 116B standard drum filter (3.7E-6 mole/sec/mole fraction) (3 waste drums per cask)	8.1	1938	2.1	2.26	14.19	31.13
LL 116B high diffusivity drum filter (1.85E-5 mole/sec/mole fraction) (3 waste drums per cask)	8.1	1938	2.1	2.26	14.19	31.13

a G value for net gas (molecules per 100 eV) at room temperature (70°F) (dose > 0.012 watt*year).

b Effective G value (molecules per 100 eV) at maximum operating temperature of 168°F calculated using the Arrhenius equation for which activation energy is an input.

c Maximum pressure.

Compliance with the restrictions on flammable gas concentration is discussed in Section 10.0.

8.0 PAYLOAD CONTAINER AND CONTENTS CONFIGURATION

8.1 Requirements

Fifty-five-gallon drums are authorized payload containers in a 10-160B cask. Up to ten 55-gallon drums of TRU waste may be packaged in the cask. Each 55-gallon drum to be packaged in the cask must have a minimum of one filter vent. The minimum filter vent specifications for the 55-gallon drums of LLNL waste are provided in Table 8-1.

Filter vents shall be legibly marked to ensure both (1) identification of the supplier and (2) date of manufacture, lot number, or unique serial number.

The rigid polyethylene liner, if present, in a payload container shall be punctured with a 0.3-inch diameter hole for content code LL 116A or with a 1-inch diameter hole for content code LL 116B before the container is transported in the 10-160B.

Table 8-1. Minimum Filter Vent Specifications

Container Filter Type	Filter Specification			
	Number of Vents Required per Container	Flow Rate (ml/min of air, STP, at 1 inch of water)[a]	Efficiency (percent)	Hydrogen Diffusivity (mol/s/mol fraction at 25°C)
Standard drum filter	1	35	99.5	3.70E-6
High diffusivity drum filter	1	35	99.5	1.85E-5

[a] Filters tested at a different pressure gradient shall have a proportional flow rate (e.g., 35 ml/min at 1 inch of water = 1 L/min at 1 psi).

8.2 Methods of Compliance and Verification

Compliance with the payload container and contents configuration requirements is determined by visual examination, process knowledge, and through procurement records.

Procured filter vents at LLNL shall be inspected to verify compliance with the applicable filter vent specifications specified in the purchase requisition (i.e., visual inspection of certificate of conformance, serial numbers to actual filter vents, and inspection of filters for physical damage). Nonconforming filter vents shall be segregated.

Prior to transport, payload container filter vents shall be visually inspected for damage or defect. If a defect is identified, a nonconformance report shall be issued, and the payload container shall be returned for repackaging or overpacking prior to certification.

The requirements for the rigid liner shall be met by procurement controls and site QA procedures. Venting of the lid of a liner (along with the minimum diameter of the hole in the liner) may be controlled administratively (i.e., buying only punctured liners) or by visual examination of the liner prior to closure.

Alternatively, radiography or sampling programs and existing records may be used to verify that the liner meets the requirements.

9.0 ISOTOPIC CHARACTERIZATION AND FISSILE CONTENT

9.1 Requirements

The 10-160B cask payload allows 325 FGE of fissile materials. Plutonium content in excess of 0.74 TBq (20 curies) per cask must be in solid form.

9.2 Methods of Compliance and Verification

LLNL assays drums in Building 332 using an SGS, or a combination of calorimetry and gamma counting. In Building 251, individual waste parcels are assayed using gamma spectrometry. Assay results are used to calculate plutonium content and decay heat (plus error). Some drums having a low level of activity are assayed with LLNL's High Sensitivity Neutron Instrument, located in Building 331. LLNL may use other instruments, such as active and passive neutron detectors, gamma spectrometers, or an active and passive computed tomography gamma scanner to meet the isotopic characterization and fissile content requirements. The site transportation certification official (TCO) shall evaluate the compliance of the fissile material mass and plutonium curies of payload containers with the maximum limits.

10.0 DECAY HEAT AND HYDROGEN GAS GENERATION RATES

This section describes the logic and methodology used in evaluating payload characteristics that meet the hydrogen gas concentration requirement for the LL 116A and LL 116B content codes for the LLNL CH-TRU wastes described in this section.

10.1 Requirements

The hydrogen gas concentration shall not exceed 5% by volume in all void volumes within the 10-160B cask payload during a 60-day shipping period. A 10-160B Cask payload must be assembled of payload containers belonging to the same content code. Payload containers of different content codes with different bounding G values and resistances may be assembled together as a payload, provided the decay heat limit and hydrogen gas generation rate limit for all payload containers within the payload is conservatively assumed to be the same as that of the payload container with the lowest decay heat limit and hydrogen gas generation rate limit.

10.2 Methodology of Ensuring Compliance with Flammable Gas Concentration Limits

As stated in Section 7.2, chemical, biological, and thermal gas generation mechanisms are insignificant in the 10-160B cask. In addition, as shown in Section 5.1, potentially flammable VOCs are restricted to 500 ppm in the headspace of the 10-160B cask secondary containers. Therefore, the only flammable gas of concern for transportation purposes is hydrogen. The concentration of hydrogen within any void volume in a layer of confinement of the payload or in the cask IV has been evaluated during a 60-day shipping period (see Attachment C of Appendix 4.11.2).

Attachment A provides the TRU waste content code for the LLNL TRU wastes that are included in the authorized payload for the 10-160B cask. This content code has a unique and completely defined packaging configuration. Modeling the movement of hydrogen from the waste material to the payload voids, using the release rates of hydrogen through the various confinement layers, defines the relationship between generation rate and void concentration. This modeling allows determination of the maximum allowable hydrogen generation rate for the LL 116A and LL 116B content codes to meet the 5% concentration limit, as detailed in Section 10.3. Based on hydrogen gas generation potential, quantified by hydrogen gas generation G values, the gas concentration limit can be converted to a decay heat limit, as detailed in Section 10.4. The maximum allowable hydrogen generation rates and decay heat limits for the LLNL content code for different payload assembly configurations are listed in Table 10-1 (see Attachment A of Appendix 4.11.2 for a description of the Matrix Depletion Program and dose-dependent G values).

10.3 Determination of Maximum Allowable Hydrogen Generation Rates for Content Codes

The maximum allowable hydrogen generation rates were determined using the modeling methodology described in Appendix 4.11.2 and the following input parameters.

Table 10-1. Maximum Allowable Hydrogen Gas Generation Rates and Decay Heat Limits

Content Code/ Payload Configuration	Maximum Allowable Hydrogen Gas Generation Rate, mole/second/drum	Maximum Allowable Hydrogen Gas Generation Rate, moles/second/cask	Maximum Allowable Decay Heat Limit, Watts/Drum (Dose <= 0.012 watt*year)	Maximum Allowable Decay Heat Limit, Watts/Cask (Dose <= 0.012 watt*yr)	Maximum Allowable Decay Heat Limit, Watts/Drum (Dose > 0.012 watt*year)	Maximum Allowable Decay Heat Limit, Watts/Cask (Dose > 0.012 watt*year)
LL 116A	8.268×10^{-9}	4.961×10^{-8}	0.020	0.120	0.059	0.354
LL 116B Standard drum filter (3.7×10^{-6} mole/sec/mole fraction) (6 waste drums per cask)	7.360×10^{-8}	4.416×10^{-7}	0.182	1.092	0.533	2.26
LL 116B High diffusivity drum filter (1.85×10^{-5} mole/sec/mole fraction) (6 waste drums per cask)	1.412×10^{-7}	8.472×10^{-7}	0.275	1.650	0.807	2.26
LL 116B Standard drum filter (3.7×10^{-6} mole/sec/mole fraction) (3 waste drums per cask)	9.635×10^{-8}	2.890×10^{-7}	0.275	0.825	0.807	2.26
LL 116B High diffusivity drum filter (1.85×10^{-5} mole/sec/mole fraction) (3 waste drums per cask)	2.581×10^{-7}	7.742×10^{-7}	0.564	1.692	1.656	2.26

(a) Other limits applicable to the cask (not related to gas generation) shall also be met.

Waste Packaging Configuration and Release Rates: LL 116A: The waste described by LL 116A is packaged in 2 inner bags and 1 liner bag. The waste is then placed into a 55-gallon drum that may be lined with a polyethylene liner with a minimum 0.3-inch diameter hole. Six drums of waste will comprise the payload for the 10-160B cask with the remainder being comprised of 55-gallon dunnage drums that allow free release of gas across the hole in the drum lid. Release rates of hydrogen through the drum filter, the drum polyethylene liner, the inner plastic bags, and the liner bags are summarized in Table 10-2.

LL 116B: The waste described by LL 116B assumes that the waste described in LL 116A has either been repackaged or that all inner plastic bag layers have been breached. The waste is placed into a 55-gallon drum that may be lined with a polyethylene liner with a minimum 1-inch diameter hole. Either three or six drums of waste will comprise the payload for the 10-160B cask with the remainder being comprised of 55-gallon dunnage drums that allow free release of gas across the hole in the drum lid. Release rates of hydrogen through the drum filters and drum polyethylene liner are summarized in Table 10-2.

The release rates in Table 10-2 are shown for two different temperatures (minimum and maximum operating temperature of the 10-160B) and are based on release rate values for various TRU waste packaging confinement layers documented in Appendices 3.6.9 and 3.6.12 of the TRUPACT-II SAR (Reference 12.1). The temperature dependence of these release rates is discussed later in this section.

Void Volume in the 10-160B Cask IV: The cask will have a payload of 10 drums and a drum carriage. The interior volume of the cask, V_{cask}, is 4438 liters. The volume occupied by the drum carriage, $V_{carriage}$, is 143.2 liters. The external volume of a single drum, V_{drum}, is 235.7 liters. The void volume within the cask is calculated as:

$$V_{V,cask} = V_{cask} - V_{carriage} - 10\ V_{drum} + n_{dunnage}\ (208\ \text{liters})$$

$$V_{V,cask} = 4438\ \text{liters} - 143.2\ \text{liters} - 10\ (235.7\ \text{liters}) + n_{dunnage}\ (208\ \text{liters})$$

$$V_{V,cask}\ 1938\ \text{liters} + n_{dunnage}\ (208\ \text{liters})$$

where,

$n_{dunnage}$ = number of 55-gallon dunnage drums

Pressure: The pressure is assumed to be isobaric and equal to one atmosphere. The mole fraction of hydrogen in each void volume would be smaller if pressurization is considered and would result in a greater maximum allowable hydrogen gas generation rate. Furthermore, the amount of hydrogen gas generated during a 60-day shipping period would be negligible compared to the quantity of air initially present at the time of sealing the 10-160B cask.

Temperature: The input parameter affected by temperature is the release rate through the different confinement layers in the payload containers and the G values for hydrogen. For the LL 116A waste content code, these are the release rates across plastic bags, the filter on the drum and the release rate across the 0.3-inch-diameter hole on the rigid polyethylene drum liner. For the LL 116B waste content code, these are the filters on the drums and the release rate across the 1-inch diameter hole on the rigid polyethylene drum liner. These release rates increase with increasing temperature as documented in Appendix 3.6.12 of the TRUPACT-II SAR (Reference 12.1). Therefore, the minimum release rates would be those at the lowest operating temperature. These are the release rates indicated in Table 10-2 for 233K. The minimum decay heat limits are determined by the ratio of the release rates and the G values. In other words, the higher the release rates, the higher the decay heat limit; the higher the G value, the lower the decay heat limit. The dependence of G values on temperature is documented in Section 10.4. For determining the decay heat limit, the temperature that yielded the minimum decay heat limit was used as the input parameter.

In summary, the temperature dependence of the input parameters was accounted for in the calculation so that, in each case, the minimum possible limit (hydrogen generation rate or decay heat limit) was obtained. This provides an additional margin of safety in the analysis for the LL 116A and LL 116B content codes.

Table 10-2. Release Rates of Hydrogen

Content Code Payload Configuration	Confinement Layer	Release Rate (mol/sec/mol fraction)	
		T = 233K	T = 348.6K
LL 116A	Drum filter	2.46×10^{-6}	4.98×10^{-6}
	Inner bag	3.895×10^{-7}	5.58×10^{-7} [a]
	Liner bag	4.67×10^{-6}	4.67×10^{-6} [b]
	Polyethylene Liner (0.3-inch hole)	4.695×10^{-5}	5.09×10^{-5}
LL 116B (3.7×10^{-6} mole/sec/mf drum filter)	Polyethylene Liner (1.0-inch hole)	5.20×10^{-4}	5.66×10^{-4}
	Standard Drum Filter	2.46×10^{-6}	4.98×10^{-6}
LL 116B (1.85×10^{-5} mole/sec/mf drum filter)	Polyethylene Liner (1.0-inch hole)	5.20×10^{-4}	5.66×10^{-4}
	High Diffusivity Drum Filter	1.23×10^{-5}	2.49×10^{-5}

(a) The value at 70°F is conservatively used.
(b) This is the minimum measured value and is applicable to all temperatures.

10.4 Determination of Maximum Allowable Decay Limits

The maximum allowable decay heat limits for the CH-TRU waste content codes, LL 116A and LL 116B, were calculated using the methodology described in Appendix 4.11.2 and the content-code specific G value described below.

G values are determined based on the bounding materials present in the payload. The maximum operating temperature yields the lowest decay heat limits for the operating temperature range of the 10-160B cask. Content codes LL 116A and LL 116B represent solid organic debris consisting of various combustible and non-combustible items. The material present in this waste with the highest G value at the maximum operating temperature of the 10-160B cask (168°F) is cellulosics and is therefore considered as the bounding material. The G value for hydrogen associated with cellulosics is 3.2 molecules/100eV (at 70°F) if the attained dose is less than or equal to 0.012 watt*year. The dose dependent G value for cellulosics is 1.09 molecules/100 eV if the dose attained in the drum is greater than 0.012 watt*yr. The methodology associated with the determination of dose-dependent G values pursuant to the Matrix Depletion Program is further discussed in Attachment A of Appendix 4.11.2. The G values at 70°F are adjusted to the maximum operating temperature of the 10-160B cask (168°F) using the Arrhenius equation. The activation energy of the G value for cellulosics is 2.1 kcal/mole. Thus, at the maximum operating temperature of the 10-160B cask (168°F), the bounding hydrogen G values for the LLNL content codes are 5.61 molecules/100 eV (dose $\leq$ 0.012 watt*year) and 1.91 molecules/100 eV (dose $>$ 0.012 watt*year).

10.5 Methodology for Compliance with Payload Assembly Requirements

LLNL assays drums in Building 332 using an SGS, or a combination of calorimetry and gamma counting. In Building 251, individual waste parcels are assayed using gamma spectrometry. Assay results are used to calculate the decay heat (plus error). Some drums having a low level of activity are assayed with LLNL's High Sensitivity Neutron Instrument, located in Building 331. LLNL may use other instruments, such as active and passive neutron detectors, gamma spectrometers, or an active and passive computed tomography gamma scanner to establish the decay heat of the drum. The TCO shall evaluate the compliance of individual drums and the total of all drums with the maximum limits per drum and per cask.

If compliance with the decay heat limit cannot be demonstrated, the hydrogen generation rate of the container shall be determined and compared to the hydrogen gas generation rate limit specified for the LL 116A content code. If the container meets the limit, it is eligible for shipment if all other transportation requirements are met. If the container does not meet the limit, it cannot be shipped and shall be segregated for repackaging or other mitigation measures.

Compliance with the hydrogen gas generation rate shall be demonstrated by testing. Compliance with the requirements of the test plan described below must be documented in procedures under a quality assurance program.

10.5.1 Gas Generation Test Methodology

The following describes how compliance with the limit on the hydrogen gas generation rate will be implemented for LLNL content codes.

Demonstration of Compliance With Hydrogen Gas Generation Limit

During the course of the testing, the headspace gas of the selected waste containers will be sampled and analyzed to determine the concentrations of hydrogen and other gases that are produced by radiolysis or present when the waste was packaged. Sampling lines that communicate with the headspace of the waste containers will be installed. Samples of the headspace gas will be withdrawn periodically and analyzed using a gas chromatograph and/or a mass spectrometer. The analytical results will be used to calculate the hydrogen gas generation rate. The measured hydrogen gas generation rate will be compared to the appropriate hydrogen gas generation limits to evaluate compliance with transportation requirements.

Because all layers of confinement in all the containers have been vented since the time of packaging and the containers have been in a vented condition for a period of time, steady-state hydrogen concentrations exist within all void volumes inside a container. At steady-state conditions, the rate of gas generation by radiolysis equals the release rate of gas across each layer of confinement. The measured hydrogen gas concentration in the headspace gas will be used to calculate the hydrogen gas generation rate.

$$C_g = X_H \times L_{CF}$$

The hydrogen gas generation rate of the waste container is calculated from the measured hydrogen gas concentration using the following relationship:

where,

C_g = the hydrogen gas generation rate (mole/sec)

X_H = the measured concentration of hydrogen gas in the waste container headspace (mole fraction)

L_{CF} = diffusion characteristic of the waste container filter.

The actual drum hydrogen gas generation rate will be compared to the maximum allowable hydrogen generation rate limit in Table 10-1 of this appendix. The container shall be qualified for shipment only if the limit is met.

The TCO shall ensure that the 10-160B cask payload consists of payload containers belonging to the same content code. In the event that payload containers of different content codes with different bounding G values and resistances are assembled together in the 10-160B cask, the TCO shall ensure that the decay heat and hydrogen gas generation rate for all payload containers within the payload are less than or equal to the limits associated with the payload container with the lowest decay heat limit and hydrogen gas generation rate limit.

11.0 WEIGHT

11.1 Requirements

The weight limit for the contents of the loaded cask is 14,250 pounds.

11.2 Methods of Compliance and Verification

The LLNL shall weigh each payload container and contents on a calibrated scale to determine the total weight of the payload container. Based on the total measured weight of the individual payload containers and the payload carriage, LLNL shall calculate total assembly weight and evaluate compliance with the maximum contents weight limit.

12.0 REFERENCES

12.1 U.S. Department of Energy (DOE), "Safety Analysis Report for the TRUPACT-II Shipping Package," and associated TRUPACT-II Authorized Methods for Payload Control (TRAMPAC) Current Revision, U.S. Department of Energy Carlsbad Field Office, Carlsbad, New Mexico.

Attachment A

Transuranic Content Code and Chemical List

for Lawrence Livermore National Laboratory (LLNL)

CONTENT CODE: LL 116

CONTENT DESCRIPTION: TRU Combustible Waste

GENERATING SITE: Lawrence Livermore National Laboratory (LLNL)

STORAGE SITE: LLNL.

WASTE DESCRIPTION: The waste consists of glovebox bagout waste, non-glovebox-line generated laboratory trash, some contaminated equipment and some sealed sources. The waste may occasionally include small quantities of solidified liquids, especially if it is mixed waste, but this is usually segregated.

GENERATING SOURCE: The waste originates from LLNL Building 251.

WASTE FORM: The waste consists mostly of dry solids such as tissues, paper, assorted plastics, glassware, ceramics, and metals. Portland cement or Aquaset is used to solidify water-based liquids; Envirostone or Petroset is used to solidify small amounts of solvents and oil-based liquids.

WASTE PACKAGING: Details of the waste packaging for each content code are presented in the following table:

WASTE PACKAGING DESCRIPTION TABLE

Code	Description*
LL 116A	The waste is placed in two plastic bags, then placed in a 55-gallon drum fitted with a vented high density polyethylene rigid liner, itself lined inside with a third large plastic bag. Bags and liners are either polyvinyl chloride or polyethylene. All bag closures are by twist-and-tape or fold-and-tape method.
LL 116B	The waste is placed directly in a 55-gallon drum fitted with a vented high density polyethylene rigid liner. Any inner plastic bag layers are either open or breached

METHODS FOR DETERMINATION OF ISOTOPIC CHARACTERIZATION: LLNL assays drums in Building 332 using an SGS, or a combination of calorimetry and gamma counting. In Building 251, individual waste parcels are assayed using gamma spectrometry. Assay results are used to calculate the decay heat (plus error). Some drums having a low level of activity are assayed with LLNL's High Sensitivity Neutron Instrument, located in Building 331. LLNL may use other instruments, such as active and passive neutron detectors, gamma spectrometers, or an active and passive computed tomography gamma scanner to establish the decay heat of the drum. The TCO shall evaluate the compliance of individual drums and the total of all drums with the maximum limits per drum and per cask.

FREE LIQUIDS: Liquids are solidified according to procedure and allowed to cure before final sealing of the drum. LLNL has certified that the waste contains less than 1% by volume of free liquids.

EXPLOSIVES/COMPRESSED GASES: LLNL has certified that the waste does not contain any explosives or compressed gases. LLNL procedures call for all aerosol cans to be punctured before placement in a TRU waste drum.

PYROPHORICS: LLNL has certified that the waste does not contain any pyrophorics.

CORROSIVES: LLNL has certified that the waste does not contain any corrosive materials.

CHEMICAL COMPATIBILITY: A chemical compatibility study has been performed on this content code, and all waste is chemically compatible for materials in greater than trace (>1% weight) quantities.

ADDITIONAL CRITERIA: Each drum is fitted with a minimum of one filter vent.

MAXIMUM ALLOWABLE HYDROGEN GENERATION RATES — OPTION 1: The maximum allowable hydrogen generation rates are listed in the table below for the various payload configurations.

MAXIMUM ALLOWABLE WATTAGE — OPTION 2: The maximum allowable decay heat limits are listed in the table below for the various payload configurations.

Maximum Allowable Hydrogen Generation Rates and Decay Heat Limits for LL 116A

Content Code/ Payload Configuration	Maximum Allowable Hydrogen Gas Generation Rate, mole/second/ drum	Maximum Allowable Hydrogen Gas Generation Rate, moles/second/ cask	Maximum Allowable Decay Heat Limit, Watts/Drum (Dose <= 0.012 watt*year)	Maximum Allowable Decay Heat Limit, Watts/Cask (Dose <= 0.012 watt*yr)	Maximum Allowable Decay Heat Limit, Watts/Drum (Dose > 0.012 watt*year)	Maximum Allowable Decay Heat Limit, Watts/Cask (Dose > 0.012 watt*year)
LL 116A $3.7x10^{-6}$ mole/sec/mole fraction drum filter (6 waste drums per cask)	$8.268x10^{-9}$	$4.961x10^{-8}$	0.020	0.120	0.059	0.354
LL 116B $3.7x10^{-6}$ mole/sec/mole fraction drum filter (6 waste drums per cask)	$7.360x10^{-8}$	$4.416x10^{-7}$	0.182	1.092	0.533	2.26
LL 116B $1.85x10^{-5}$ mole/sec/mole fraction drum filter (6 waste drums per cask)	$1.412x10^{-7}$	$8.472x10^{-7}$	0.275	1.650	0.807	2.26
LL 116B $3.7x10^{-6}$ mole/sec/mole fraction drum filter (3 waste drums per cask)	$9.635x10^{-8}$	$2.890x10^{-7}$	0.275	0.825	0.807	2.26
LL 116B $1.85x10^{-5}$ mole/sec/mole fraction drum filter (3 waste drums per cask)	$2.581x10^{-7}$	$7.742x10^{-7}$	0.564	1.692	1.656	2.26

LAWRENCE LIVERMORE NATIONAL LABORATORY
CONTENT CODE LL 116A and LL 116B
TRU COMBUSTIBLE WASTE
MATERIALS AND CHEMICALS >1%

CLOTH

GLASS, LABWARE

GRAPHITE (Molds and Crucibles)

METALS (including mercury, brass, lead shielding, lead shot, silver, stainless steel, aluminum, iron, copper beryllium, and zirconium)

PAPER

POLYETHYLENE

RUBBER

RUBBER GLOVES

SOLIDIFICATION AGENTS/ABSORBANTS (Portland Cement, Aquaset, Petroset, Envirostone)

STAINLESS STEEL

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4.11.7 COMPLIANCE METHODOLOGY FOR TRU WASTE FROM IDAHO NATIONAL ENGINEERING AND ENVIRONMENTAL LABORATORY (INEEL), IDAHO FALLS, ID

1.0 INTRODUCTION

This appendix presents the methods used to qualify approximately 620 drums of remote-handled (RH) transuranic (TRU) waste stored at Idaho National Engineering and Environmental Laboratory (INEEL) as payload for transport in the 10-160B cask. The methods for determining each restricted parameter, the factors influencing the parameter values, and the methods used by INEEL for demonstrating compliance, are provided in the following sections. This appendix also includes the following as attachment:

- Content codes ID 322A, 322B, 325A and 325B (Attachment A)
- Chemical lists for content codes ID 322A, 322B, 325A and 325B (Attachment A).

2.0 PURPOSE

The purpose of this appendix is to describe the methods used to qualify the RH-TRU waste stored at INEEL prior to transport in the 10-160B cask and is based on the format and requirements for TRU waste identified in Appendix 4.11.2. Acceptable methods and process knowledge applicable to content codes ID 322A, 322B, 325A, and ID 325B are described in this appendix. Process knowledge (PK) (also referred to as acceptable knowledge (AK) for the purposes of this document) refers to applying knowledge of the waste in light of the materials or processes used to generate the waste.

Section 3.0 describes the TRU waste payload. Sections 4.0 through 11.0 discuss each payload parameter and the methods employed to demonstrate compliance with the 10-160B cask payload requirements.

3.0 TRU WASTE PAYLOAD FOR 10-160B CASK

The content codes for the RH-TRU waste stored at INEEL (ID 322A and 322B - Solid Inorganic Waste and ID 325A and 325B - Solid Organic Waste) are provided in Attachment A. These content codes apply to approximately 620 30-gallon drums of waste at the INEEL from the destructive and non-destructive examination of radiological materials such as fuel pins, reactor structural materials, and targets in the Argonne National Laboratory-East (ANL-E) Alpha Gamma Hot Cell Facility (AGHCF) between 1971 and 1995.

Complete documentation packages along with quality assurance and quality control records are generated for all payload containers as summarized in this appendix. TRU waste shipped from the INEEL will comply with all transportation requirements using the following methods:

- Formally documented AK of the processes generating the waste, including data packages generated for payload containers that document the contents and properties of the waste in the container including the absence of prohibited items and compliance with packaging requirements

- Measurement of required parameters to ensure compliance with limits.

4.0 PHYSICAL FORM

4.1 Requirements

The physical form of waste comprising the 10-160B cask payload is restricted to solid or solidified materials in secondary containers. The total volume of residual liquid in a secondary container is restricted to less than 1% by volume. Secondary containers must be shored to prevent movement during accident conditions. Sharp or heavy objects in the waste shall be blocked, braced, or suitably packaged as necessary to provide puncture protection for the payload containers packaging these objects. Sealed containers (e.g., rigid plastic containers, plastic bags, metal containers) greater than four liters in volume that do not have a known, measured, or calculated hydrogen release rate or resistance are prohibited.

4.2 Methods of Compliance and Verification

Compliance with the physical form requirements will be determined using AK (i.e., records and data base information). AK documentation for drums containing waste described by content codes ID 322A, 322B, 325A, and ID 325B (Reference 12.1) indicates that the physical form requirements have been met. Liquid chemicals were neutralized, if necessary, and absorbed resulting in no free liquid. Waste packaging records show that sharp and heavy objects have been packaged to provide puncture protection equivalent to Type A packaging requirements and there are no pressurized containers in the waste. The calculated hydrogen release rate for heat-sealed confinement layers greater than four liters in volume that may be present in the payload container is listed in Section 10 of this appendix.

5.0 CHEMICAL FORM AND CHEMICAL PROPERTIES

5.1 Requirements

The chemical properties of the waste are determined by the chemical constituents allowed in a given content code. Specific requirements regarding the chemical form of the waste are as :

Explosives, nonradioactive pyrophorics, compressed gases, and corrosives are prohibited.

Pyrophoric radionuclides may be present only in residual amounts less than 1 weight percent.

The total amount of potentially flammable volatile organic compounds (VOCs) present in the headspace of a secondary container is restricted to 500 parts per million.

5.2 Methods of Compliance and Verification

PK documentation (Reference 12.1) details the compliance with the chemical form and chemical property restrictions. Explosives, pyrophorics, and compressed gases including aerosol cans were prohibited from RH-TRU waste containers. Sodium and sodium potassium (NaK) metal were rendered safe by controlled reaction with ethanol or butanol. The resulting product was absorbed on pelletized clay and evaporated to dryness prior to disposal. All potentially corrosive liquid chemicals were neutralized and absorbed prior to packaging; therefore, the waste would not be considered corrosive. All organic liquids were evaporated to dryness before packaging. The chemical lists for content codes ID 322A, 322B, 325A and ID 325B are presented in Attachment A.

6.0 CHEMICAL COMPATIBILITY

6.1 Requirements

Each content code has an associated chemical list (Attachment A) based on AK information. Chemical constituents in a payload container assigned to a given content code shall conform to these approved chemical lists. Chemicals and materials that are not listed are allowed in trace amounts (quantities less than one weight percent) in a payload container provided that the total quantity of trace chemicals or materials is restricted to less than five weight percent. Chemical compatibility of a waste with its packaging ensures that chemical reactions will not occur that might pose a threat to the safe transport of a payload in the 10-160B cask.

6.2 Methods of Compliance and Verification

Attachment B of Appendix 4.11.2 presents the methodology and results for the chemical compatibility analyses performed for the list of allowable chemicals and materials associated with the TRU waste content codes expected to be shipped in the 10-160B cask. The results of these chemical compatibility analyses show that these content codes can be transported without any incompatibilities. The chemicals present in ID 322A, 322B, 325A, and ID 325B conform to the list of allowable materials in Attachment B of Appendix 4.11.2. Therefore, the waste meets the chemical compatibility requirements.

7.0 GAS DISTRIBUTION AND PRESSURE BUILDUP

7.1 Requirements

Gas distribution and pressure buildup during transportation of TRU waste in the 10-160B cask payload are restricted to the following limits:

- The gases generated in the payload must be controlled to prevent the occurrence of potentially flammable concentrations of gases within the payload confinement layers and the void volume of the inner vessel (IV) cavity. Specifically, the hydrogen concentrations within the payload confinement layers are limited to five percent by volume during the shipping period (see Attachment C of Appendix 4.11.2).
- The gas generated in the payload and released into the IV cavity must be controlled to maintain the pressure within the IV cavity below the acceptable packaging design limit of 31.2 pounds per square inch (psig).

7.2 Methods of Compliance and Verification

Compliance with the 10-160B cask design pressure limit for each content code described in Attachment A is analyzed by assuming all gases generated are released into the IV cavity and by including the contributions from thermal expansion of gases and vapor pressure of atmospheric water. The maximum effective total gas G value is described by that of cellulose and is evaluated at the maximum operating temperature of 168°F using the Arrhenius equation given the room temperature G value and an activation energy is 2.1 kcal/gmol (Reference 12.2, Appendix 3.1). Table 7-1 shows that the pressure increase during a period of 365 days is below the design pressure limit of 31.2 psig for all content codes listed in Attachment A. Compliance with the restrictions on flammable gas concentration is discussed in Section 10.0.

Table 7-1 Maximum Pressure Increase In Cask IV Over 365-Day Shipping Period

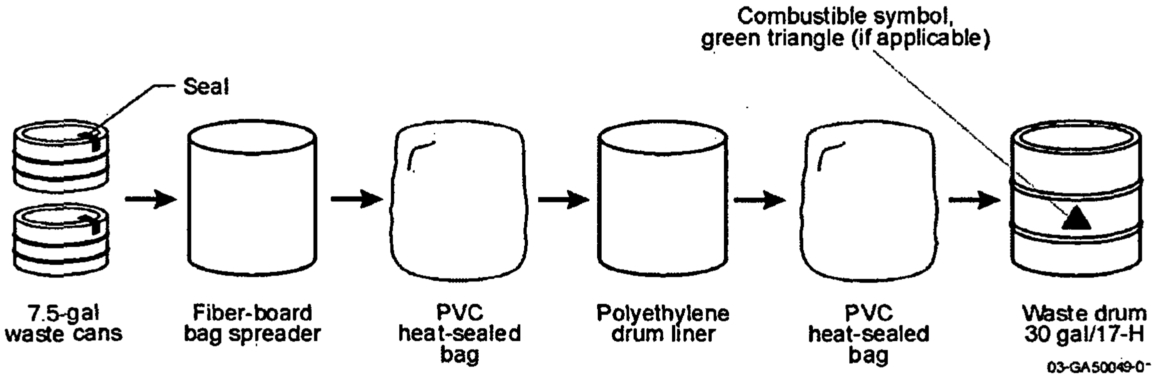
	No Matrix Depletion[a]			Matrix Depletion[b]		
Content Code	**Geff,, molecules per 100eV**	**Decay Heat Limit per Cask (W)[c]**	**ΔPtot (psig)**	**Geff,, molecules per 100eV**	**Decay Heat Limit per Cask (W)[c]**	**ΔPtot (psig)**
ID 322A	17.86	3.26e-1	12.2	14.19	1.17e-0	19.9
ID 322B	17.86	1.81e-0	31.1	14.19	2.28e-0	31.1
ID 325A	17.86	6.48e-2	8.9	14.19	2.35e-1	10.5
ID 325B	17.86	5.94e-1	15.7	14.19	2.06e-0	28.9

a. Geff @ 70°F: 10.2 molecules per 100 eV; Activation Energy: 2.1 kcal/mol (Ref. 12.2, Appx 3.2)
b. Geff @ 70°F: 8.1 molecules per 100 eV; Activation Energy: 2.1 kcal/mol (Ref. 12.2, Appx 3.2)
c. Ten waste drums per cask.

8.0 PAYLOAD CONTAINER AND CONTENTS CONFIGURATION

8.1 Requirements

Thirty-gallon and 55-gallon secondary containers may be used as payload containers in the 10-160B cask. Secondary containers must be shored to prevent movement during accident conditions. The available volume of the cask cavity limits the number of payload containers that may be shipped at one time. Up to ten 30-gallon or 55-gallon drums of TRU waste may be packaged in the cask. Payload containers and any sealed container liners greater than four liters in volume used to package waste inside the containers must have at least one filter vent with a minimum allowable hydrogen diffusivity listed in Table 8.1. A rigid polyethylene liner, if present in a payload container, shall have an opening that is equivalent to or larger than a 0.3-inch diameter hole (or equivalent filter vent) before the container is transported in the 10-160B. The typical waste packaging configuration is shown below.



The 7.5-gallon waste cans are not sealed containers because holes were drilled in the sides of the cans to allow a cable to be attached (Reference 12.1). The fiberboard bag spreader, which is situated between the waste cans and the PVC bag, is open on top. Neither the waste cans nor the fiberboard bag spreader inside the innermost PVC bag are considered confinement layers.

Sealed bags are closed with a twist-and-tape, fold-and-tape, or heat-sealed closure. Heat-sealed bags may have a filter vent or be unvented.

Table 8-1 Minimum Filter Vent Specifications

Container Filter Type	Minimum Flow Rate (mL/min air, STP, inch water)a	Efficiency (percent)	Hydrogen Diffusivity @ 25°C (mol/s/mol fraction)
Drum	35	99.9b	3.70e-6
Bag	35	---b	1.075e-5

a. Filters tested at a different pressure (other than 1 in water) shall have a proportional flow rate (Reference 12.3 , CH-TRAMPAC, Table 2.5-1).

b. Filters installed in payload containers that are overpacked in a drum are exempt from the efficiency requirement (Reference 12.3 , CH-TRAMPAC, Table 2.5-1).

8.2 Methods of Compliance and Verification

Compliance with the payload container and contents configuration requirements is determined by visual examination, process knowledge, and through procurement records. The methods used to determine the compliance of filter vents with the performance-based requirements of flow rate, efficiency, and hydrogen diffusivity shall be directed by procedures under a quality assurance program. Filter vents shall be legibly marked to ensure identification of the supplier as well as the date of manufacture, lot number, or unique serial number.

9.0 ISOTOPIC CHARACTERIZATION AND FISSILE CONTENT

9.1 Requirements

The 10-160B cask payload allows 325 FGE of fissile materials. Plutonium content in excess of 0.74 TBq (20 curies) per cask must be in solid form.

9.2 Methods of Compliance and Verification

Compliance with the isotopic characterization and fissile content requirements involves the following steps:

- Determination of the isotopic composition
- Determination of the quantity of radionuclides
- Calculation of the fissile mass and comparison with 10 CFR 71.15 limits
- Calculations of plutonium content and comparison with 20-curie limit.

9.2.1 Isotopic composition

The isotopic composition of the waste may be determined from direct measurements taken on the product material during processing or post-process certification at each site, analysis of the waste, or from existing records and AK. The isotopic composition of the waste need not be determined by direct analysis or measurement of the waste unless AK is not available.

9.2.2 Quantity of Radionuclides

The quantity of the radionuclides in each payload container shall be estimated by either AK or direct measurement of the individual payload containers, a summation of assay results from individual packages in a payload container, or a direct measurement on a representative sample of the quantity of nuclear material in TRU wastes. Assay instruments detect and quantify the primary radiation (alpha, gamma, and or neutron) emanating from specific radionuclides, or a secondary radiation emitted from neutron interrogation techniques. The measured quantity of radiation is then used to calculate the quantity of other radionuclides. That calculation requires knowledge of the isotopic composition of the waste. Combinations of gamma spectroscopy and neutron measurements are often needed to calculate the quantity of nonfissile radionuclides.

9.2.3 Calculation of Fissile Mass

The calculation of the fissile mass shall be performed to meet the 325 FGE requirement.

9.2.4 Calculation of Plutonium Curies

The total plutonium (all plutonium isotopes) activity (curies) for each payload container shall be determined as described above, summed for the entire payload and compared with the 20-curie waste form limit.

10. DECAY HEAT AND HYDROGEN GAS GENERATION RATES

10.1 Requirements

The hydrogen gas concentration shall not exceed 5% by volume in all void volumes within the 10-160B cask payload during the 60-day shipping period. Payload containers of different content codes with different bounding G values and resistances may be assembled together as a payload, provided the decay heat limit and hydrogen gas generation rate limit for all payload containers within the payload is conservatively assumed to be the same as that of the payload container with the lowest decay heat limit and hydrogen gas generation rate limit.

10.2 Methodology of Ensuring Compliance with Flammable Gas Limits

As stated in Section 7.2 of Appendix 4.11.2, chemical, biological, and thermal gas generation mechanisms are considered to be insignificant in the 10-160 cask. In addition, as shown in Section 5.1 of Appendix 4.11.2, potentially flammable VOCs are restricted to no more than 500 ppm in the headspace of the 10-160B cask secondary containers. Therefore, the only flammable gas of concern for transportation purposes is hydrogen. The hydrogen concentration within the void volumes of the payload confinement layers or the cask IV has been evaluated for a specified shipping period.

Attachment A of this appendix provides the TRU waste content codes for the INEEL RH TRU that are included in the authorized payload for the 10-160B cask. Each content code has a unique and completely defined packaging configuration. The movement of hydrogen from the waste material and across waste confinement layers to the payload voids can be modeled to determine the maximum allowable hydrogen gas generation rate to ensure the 5% by volume concentration is not exceeded in any of the void volumes inside the waste drums or 10-160B cask. Based on the hydrogen gas generation potential of the waste, quantified by hydrogen gas generation G values, the hydrogen gas generation limit can be expressed as an equivalent decay heat limit. The shippability of a waste drum regarding flammable gases can be determined by comparing its decay heat to the content code-specific decay heat limit listed in Table 10-1. If the decay heat limit is exceeded, the hydrogen gas generation rate in the waste drum can be calculated based on measured hydrogen concentration in the waste drum or a container in which the waste drum is placed, as detailed in Section 10.5.

Table 10-1 Maximum allowable hydrogen gas generation rates and decay heat limits.

Content Code	Hydrogen Gas Generation Rate Limit per Drum (mol/s)	Hydrogen Gas Generation Rate Limit per Cask (mol/s)	Decay Heat Limit per Drum, W (Dose ≤ 0.012 W-yr)	Decay Heat Limit per Cask,W (Dose ≤ 0.012 W-yr)	Decay Heat Limit per Drum, W (Dose > 0.012 W-yr)	Decay Heat Limit per Cask,W (Dose > 0.012 W-yr)
ID 322A	3.61e-9	3.61e-8	3.26e-2	3.26e-1	1.17e-1	1.17e-0
ID 322B	3.28e-8	3.28e-7	2.97e-1	1.81e-0	1.02e-0	2.28e-0
ID 325A	3.61e-9	3.61e-8	6.48e-3	6.48e-2	2.35e-2	2.35e-1
ID 325B	3.28e-8	3.28e-7	5.94e-2	5.94e-1	2.06e-1	2.06e-0

10.3 Determination of Maximum Allowable Hydrogen Generation Rates

The modeling methodology for determining the maximum allowable hydrogen gas generation rate limits is presented in this section. Parameters that impact the maximum allowable hydrogen gas generation rate limit are:

- Waste packaging configuration (i.e., the number and type of confinement layers)
- Release rates of hydrogen from each confinement layer
- Void volume in the cask IV available for gas accumulation
- Operating temperature and pressure for the payload in the 10-160B cask IV during the shipping period
- Duration of the shipping period

Waste Packaging Configuration:

ID 322A, ID 325A: The waste is packaged in two 7.5-gallon metal cans, a fiber drum pouch spreader, an inner polyvinyl chloride (PVC) pouch, a polyethylene drum liner, an outer PVC pouch, and a 17H 30-gallon drum with a high-efficiency particulate air (HEPA) filter vent or an opening in the drum lid. The PVC pouches are heat-sealed.

ID 322B, ID 325B: The waste is packaged in two 7.5-gallon metal cans, a fiber drum pouch spreader, an inner PVC pouch with a HEPA filter vent, a polyethylene drum liner, an outer PVC pouch with a HEPA filter vent, and a 17H 30-gallon drum with a HEPA filter vent or an opening in the drum lid.

Two shipping scenarios are considered:

1. The 30-gallon waste drums are placed directly in the 10-160B cask.

2. Each 30-gallon drum is placed directly in a 55-gallon drum with a filter vent installed on each drum. Ten drums will then be placed into the 10-160B cask.

In defining the hydrogen gas generation limits, the second shipping scenario bounds the first scenario; thus, this waste packaging configuration is used to define the maximum allowable hydrogen generation rates.

Release Rates from Confinement Layers:

The hydrogen release rate across a heat-sealed polymer bag (RR) is a function of hydrogen permeability, ρ, across the PVC bag, the permeable surface area (Ap), bag thickness (xp), and gas concentration at standard temperature and pressure (STP) (Reference 12.2, Appendix 6.13). Specifically,

$$RR = \frac{\rho A_p P_g}{x_p} \frac{mole}{22{,}400 cm^3 (STP)}$$

Where

RR	release rate of hydrogen (mole H_2/s/mole fraction H_2
ρ	hydrogen permeability, cm^3(STP) cm^{-1} (cm Hg)$^{-1}$ s^{-1}
Ap	permeable surface area, cm^2
Pg	gas pressure, cm Hg
xp	bag thickness, cm

The temperature dependence of gas permeability across a polymer can be defined by an Arrhenius equation:

$$\rho = \rho_0 \exp\left(\frac{-E_a}{RT}\right)$$

where Ea is the activation energy (kcal) associated with gas permeability, R is the gas constant defined as 1.987e-3 kcal/(mol K), and T is absolute gas temperature (K). For a hydrogen permeability for polyvinyl chloride of 3.6e-10 cm^3(STP) cm^{-1} (cm Hg)$^{-1}$ s^{-1} at 77°F (298.2 K) (Reference 12.2, Appendix 6.13) with an activation energy of 1.9 kcal/mole, the constant ρ0 can be defined to 8.89e-9 cm^3 (STP) cm^{-1} (cm Hg)$^{-1}$ s^{-1}. The effect of temperature of the hydrogen release rate is demonstrated below.

Void Volume in the 10-160B cask IV: The minimum void volume in the cask when filled with the maximum number of ten (10) 55-gallon waste drums is estimated to be 1,938 L (Appendix 4.11.5).

Permeable Surface Area and Thickness of PVC Confinement Layers: The minimum permeable surface area inside the 30-gallon waste drum was calculated based on the waste drum configuration described in Reference 12.1. The permeable surface area of a PVC confinement layer is defined by its minimum height and diameter. The maximum outside diameters of the 7.5-

gallon steels cans and polyethylene drum liner is 15 in (38.1 cm) and 18 in (45.7 cm), respectively. The 30-gallon drum has a useable height of 28 in (71.1 cm). The diameters of the inner and outer PVC confinement layers are assumed to be 16 in (40.6 cm) and 17 cm (43.2 cm), respectively. Because of the presence of a fiberboard pouch spreader and polyethylene liner, the heights of the inner and outer PVC confinement layers are assumed to be 26 in (66.0 cm) and 27 in (68.6 cm), respectively. The dimensions of the inner confinement layer, assumed to be that of a cylinder, are used to define the surface of both PVC confinement layers. The surface area along the side and top of the cylinder defined the total surface area. The permeable area of each PVC layer was calculated to be 9,700 cm2 and its thickness is 20 mils (0.0508 cm).

Pressure: The pressure is assumed to be isobaric and equal to one atmosphere. The mole fraction of hydrogen in each void volume would be smaller if pressurization is considered and would result in a greater maximum allowable hydrogen gas generation rate. Furthermore, the amount of hydrogen gas generated during the shipping would be negligible compared to the quantity of air initially present at the time of closure of the 10-160B cask.

Temperature: In order to account for effect of temperature on gas permeability across a PVC confinement layer, an average gas permeability is defined over the operating temperature range. The maximum and minimum operating temperatures in the 10-160B cask have been assumed to be 168°F (348.7 K) and -40°F (233.2 K), respectively. In order to provide an additional margin of safety, an average hydrogen permeability, ρavg, was determined over the lower temperature range of 77°F (298.2 K) and -40°F (233.2 K).

$$\rho_{avg} = \frac{\int_{233.2K}^{298.2K} \rho_0 \exp\left(\frac{-E_a}{RT}\right) dT}{\int_{233.2K}^{298.2K} dT}$$

The average hydrogen permeability equals 2.46e-10 cm^3 (STP) cm^{-1} $(cm\ Hg)^{-1}$ s^{-1}, which is equivalent to maintaining a constant temperature of 20°F (266.5 K).

Temperature-corrected hydrogen diffusivity values across filter vents (D*) used on drums and in heat-sealed bags were calculated at 20°F (266.5 K). The gas diffusivity across a filter vent at an absolute temperature T2 can be defined in terms of the hydrogen diffusivity across the same filter vent at a known absolute temperature T1(Reference 12.2, Appendix 6.9)

$$D^*_{T_2} = D^*_{T_1}\left(\frac{T_2}{T_1}\right)^{1.75}$$

The release rates across confinement layers used in the analysis are listed in Table 10-2.

Table 10-2. Hydrogen Release Rates Across Confinement Layers

Content Codes	Confinement Layer	Release Rate (mol/s/mol fraction)	
		T = 266.5 K	T = 298.2 K
ID 322A ID 325A	55-gal Drum Filter Vent	3.04e-6	3.70e-6
	30-gal Drum Filter Vent	3.04e-6	3.70e-6
	Each Heat-Sealed Bag	1.59e-7	2.33e-7
ID 322B ID 325B	55-gal Drum Filter Vent	3.04e-6	3.70e-6
	30-gal Drum Filter Vent	3.04e-6	3.70e-6
	Each Heat-Sealed Bag w/Filter Vent	8.99e-6	1.10e-5

10.4 Determination of Maximum Allowable Decay Heat Limits

The maximum allowable decay heat limits for content codes ID 322A, ID 322B, ID 325A, and ID 325B were calculated using the modeling methodology described in Section 10.4 of Appendix 4.11.2 and the content-code specific G values described below.

The gas-generation potential of a waste stream depends on the waste composition as well as the type of radiation that strikes the waste material. The radiation-specific effective G-values for each waste stream are calculated based on the maximum G-value for organic waste and the relative fraction of organic waste in the waste stream (Reference 12.2, Appendix 3.2). Waste streams designated to contain inorganic (noncombustible) or organic (combustible) solid waste contain at least 80% of the designated material (Reference 12.1). In calculating a G value for drums containing organic waste (ID 325A and ID 325B) , the drums are conservatively assumed to contain 100% combustible, hydrogenous material. Drums containing inorganic waste (ID 322A and ID 322B), the drums are assumed to contain a maximum of 20% hydrogenous material.

For waste drums in which the total dose has not exceed 0.012 W-yr, the maximum G value is based on cellulose and is determined at the maximum temperature (168°F) described by an Arrhenius equation (Reference 12.2, Appendix 3.1). Its G value at room temperature is 3.2 molecules per 100 eV with an activation energy of 2.1 kcal/mol. The maximum G value associated with solid organic waste is that of wet cellulose, which at room temperature is 1.09 molecules per 100 eV. Since matrix-depleted G values show no variation with temperature (Appendix 4.11.2, Attachment A), no temperature correction of these G values are made. Effective G values used to calculate decay heat limits are summarized in Table 10-3.

Table 10-3. Effective G-values by radiation type and content code.

	Content Code			
	ID 325A, ID 325B		ID 322A, ID 322B	
Radiation Type	No Matrix Depletion	Matrix Depletion	No Matrix Depletion	Matrix Depletion
Alpha	5.61	1.09	1.12	0.22
Beta	5.61	1.09	1.12	0.22
Gamma	5.61	5.61	1.12	1.12

G-value units: molecules per 100eV absorbed energy

10.5 Methodology for Compliance with Payload Assembly Requirements

10.5.1. Gas Generation Test Methodology

A waste drum in which its decay heat exceeds the maximum allowable decay heat limit can be shipped if the hydrogen gas generation in the waste drum can be demonstrated to be less than the maximum allowable hydrogen generation limit listed in Table 10-1 of this appendix. During the interim between drum retrieval and drum shipment, gas sample can be collected directly from the waste drum or from the container in which the vented waste drum is packaged. The measured hydrogen concentration can be related to the generation rate in the waste drum. Material balance equations are defined for different sampling scenarios from: (1) a vented 30-gallon waste drum; (2) a vented 55-gallon waste drum; or (3) a vented overpack container.

Direct Measurement of Hydrogen in Waste Drum

Vented waste drums in storage for over nine years are assumed to be at steady state. If a gas sample is collected directly from a waste drum, the gas generation rate is assumed to equal the hydrogen release rate across the filter vent:

$$C_g = X_{HS,H_2} D^*_{H_2}$$

where

Cg	hydrogen gas generation rate, mol/s
XHS,H2	hydrogen mole fraction in drum headspace
D*H2	hydrogen diffusivity of drum filter vent, mol/s/mol fraction

The actual hydrogen concentration in a previously unvented waste drum asymptotically approaches its steady-state value with increasing vent time. If the hydrogen concentration from a newly vented drum is greater than the steady-state concentration, it will result in a higher (more conservative) calculated hydrogen gas generation rate.

Waste Drum Inside a Vented Waste Container

In cases where a vented waste drum (wd) is placed in a vented waste container (wc), a gas sample can be collected from the waste container headspace. The hydrogen concentration in the waste container headspace is determined by solving the following material balance equations:

$$\frac{dX_{wd}}{dt} = \frac{C_g}{N_{wd}} - \frac{RR^*_{wd}}{N_{wd}}(X_{wd} - X_{wc})$$

$$\frac{dX_{wc}}{dt} = \frac{RR^*_{wd}}{N_{wc}}(X_{wd} - X_{wc}) - \frac{RR^*_{wc}}{N_{wc}} X_{wc}$$

where

X hydrogen mole fraction in the innermost confinement layer of waste drum (wd) or container (wc)
RR* hydrogen release rate across all confinement layers in waste drum or container
N total moles gas in waste drum (wd) or container (wc)

In the case of the waste drum, there are multiple confinement layers defined by the heat-sealed bags and drum filter vent. The hydrogen release rate across multiple confinement layers is defined as the inverse of the sum of the effective hydrogen resistance , Reff, across each confinement layer.

$$RR^* = \left[\sum_i R_{eff,i}\right]^{-1}$$

In the waste container, the hydrogen release rate is defined solely by that of its filter vent, which is the inverse of the hydrogen diffusivity across the filter vent. The total moles, N, in any volume (V) is defined by the ideal gas law:

$$N = \frac{PV}{RT}$$

where

P' gas pressure, atm
V gas volume, liter (L)
R' gas constant = 0.08206 atm l/(mol K)

The two differential equations above are identical in form to differential equations describing flammable gas generation in a container with two void volumes (Reference 12.2, Appendix 3.10). The analytical solution for these equations are described by Equations (5) through (9) in Reference 12.2, Appendix 3.10 and can be used to define the solutions to the differential equations. The resulting solution defines the relationship between the measured hydrogen concentration in the waste container at time t and the hydrogen gas generation rate. The value of hydrogen gas generation rate in the waste drum can be iterated in the equation defining hydrogen concentration in the waste container headspace until the calculated hydrogen concentration equals the measured value in the waste container headspace.

The initial hydrogen concentration in the waste container, Xwc(0), is zero. It is assumed that the vented waste drum is at steady state when placed inside the waste container. In this case, the initial hydrogen concentration in the waste drum is defined as:

$$X_{wd}(0) = \frac{C_g}{RR^*_{wd}}$$

The steady-state case bounds the situation when the hydrogen concentration in the newly vented waste drum may exceed its steady-state concentration. In this case, the hydrogen release rate will be greater than that in the steady-state case. This means hydrogen accumulation in the waste container headspace will occur more quickly, resulting in a calculated hydrogen generate rate greater than would be calculated in the case of the waste drum at steady state.

Waste Drum Inside Two Waste Containers

In the case where a waste drum is placed inside two consecutive vented waste containers, a gas sample can be collected from the headspace of the outer vented waste container. The material balance equations that describe hydrogen accumulation in the waste drum (wd), an inner waste container (iwc), and an outer waste container (owc), respectively, are:

$$\frac{dX_{wd}}{dt} = \frac{C_g}{N_{wd}} - \frac{RR^*_{wd}}{N_{wd}}(X_{wd} - X_{iwc})$$

$$\frac{dX_{iwc}}{dt} = \frac{RR^*_{wd}}{N_{iwc}}(X_{wd} - X_{iwc}) - \frac{RR^*_{iwc}}{N_{iwc}}(X_{iwc} - X_{owc})$$

$$\frac{dX_{owc}}{dt} = \frac{RR^*_{iwc}}{N_{owc}}(X_{iwc} - X_{owc}) - \frac{RR^*_{owc}}{N_{owc}}X_{owc}$$

At time zero, the waste drum is assumed to have been at steady state when placed inside the waste containers; therefore, Xwd(0) = Cg/RR*wd. The initial values, Xiwc(0) and Xowc(0) equal zero. At time t, the hydrogen concentration in the outer waste container headspace, Xowc, is measured.

The three differential equations above are identical in form to differential equations describing flammable gas generation for a container with three void volumes (Reference 12.2, Appendix 3.10). The analytical solution for these equations are described by Equations (16) through (34) in Reference 12.2 (Appendix 3.10) and can be used to determine the hydrogen gas generation rate based on the measured hydrogen concentration in the outer waste container headspace at time t. The value of hydrogen gas generation rate can be iterated in the equation defining hydrogen concentration in the outer waste container headspace until the calculated hydrogen concentration equals the measured value.

It is assumed that the vented waste drum is at steady state when placed inside the two waste containers. In this case, the initial hydrogen concentration in the waste drum is defined by same equation as in the case of waste in one waste container. As in the case of a waste drum inside one waste container, the steady state case bounds the situation when the hydrogen concentration in the newly vented waste drum may exceed its steady-state concentration.

11.0 WEIGHT

11.1 Requirements

The weight limit for the contents of the loaded cask is 14,250 pounds.

11.2 Methods of Compliance and Verification

The INEEL shall weigh each payload container and contents on a calibrated scale to determine the total weight of the payload container. Based on the total measured weight of the individual payload containers and the payload carriage, INEEL shall calculate total assembly weight and evaluate compliance with maximum contents weight limit.

12.0 REFERENCES

12.1 IT Corporation, "AK Documentation Report for INEEL-Stored Remote-Handled Transuranic Waste from Argonne National Laboratory-East," Revision 0, July 2003, IT Corporation, Albuquerque, New Mexico.

12.2 U. S. Department of Energy (DOE), CH-TRU Payload Appendices, Current Revision, U.S. Department of Energy Carlsbad Field Office, Carlsbad, New Mexico.

12.3 U. S. Department of Energy (DOE), Contact-Handled Transuranic Waste Authorized Methods for Payload Control (CH-TRAMPAC), Current Revision, U.S. Department of Energy Carlsbad Field Office, Carlsbad, New Mexico.

Attachment A

Transuranic Content Codes and Chemical Lists

for Idaho National Engineering and Environmental Laboratory

CONTENT CODE: ID 322A, ID 322B

CONTENT DESCRIPTION: Solid Inorganic Waste

WASTE DESCRIPTION: This waste consists primarily of a variety of inorganic debris.

GENERATING SOURCES: This waste is generated at the Argonne National Laboratory-East (ANL-E) Alpha Gamma Hot Cell Facility (AGHCF) between November 1971 and November 1995 during the processing of irradiated and unirradiated fuel pins from various reactor programs at ANL-W [Experimental Breeder Reactor-II (EBR-II)] and other U.S. Department of Energy (DOE) reactors, such as the New Production Reactor at the Savannah River Site (SRS). The AGHCF is a hot cell complex that includes office space, shielded gloveboxes, a hot cell under nitrogen atmosphere with work stations for remote manipulation of materials, and a Decontamination/Repair Area (DRA).

WASTE FORM: The waste consists of ferrous metals, including carbon and stainless steel and cast iron; nonferrous metals, including aluminum, brass, bronze, copper, lead, and tin; glass bottles, tubing, beakers, and plates; ceramic firebrick; porcelain (insulators); quartz; Vycor; boron nitride; and "passivated chemicals" absorbed in clay. Waste was contaminated primarily with fissile materials, MFP, and activation products. The predominant radionuclides are: Pu-239, Pu-240, Pu-241, Am-241, U-235, U-238, Cs-137, Ba-137m, Sr-90, Y-90, Co-60, and Fe-55.

WASTE PACKAGING:

ID 322A: The waste is packaged in two 7.5-gallon metal cans, a fiber drum pouch spreader, an inner PVC pouch, a polyethylene drum liner, an outer PVC pouch, and a 17H 30-gallon drum with a filter vent or an opening in the drum lid. The PVC pouches are heat-sealed. The inner PVC pouch is placed inside a rigid polyethylene liner without a lid. The liner and its contents are then heat-sealed inside the outer PVC pouch.

ID 322B: The waste is packaged in two 7.5-gallon metal cans, a fiber drum pouch spreader, an inner PVC pouch with a HEPA filter vent, a polyethylene drum liner, an outer PVC pouch with a filter vent, and a 17H 30-gallon drum with a filter vent or an opening in the drum lid. The inner PVC pouch is placed inside a rigid polyethylene liner without a lid. The liner and its contents are then heat-sealed inside the outer PVC pouch.

In addition, the 30-gallon drum may be placed within a vented 55-gallon waste drum.

METHODS FOR DETERMINATION OF ISOTOPIC CHARACTERIZATION: The isotopic composition of the waste is determined from process loss calculations and fission product calculations and was recorded on the associated forms or in data management systems. Therefore, the isotopic composition of the waste need not be determined by direct analysis or measurement of the waste unless process information is not available.

FREE LIQUIDS: Liquid waste is prohibited in the drums except for residual amounts in well-drained containers. The total volume of residual liquid in a payload container shall be less than

1 volume percent of the payload container. Waste packaging procedures ensure that free liquids are less than 1 volume percent of the payload container.

EXPLOSIVE/COMPRESSED GASES: Explosives and compressed gases in the payload containers are prohibited by waste packaging procedures.

PYROPHORICS: Sodium and NaK were passivated with alcohol and the alcohol absorbed into pelletized clay and evaporated. Other pyrophorics such as Zircalloy were sorted to segregate from WIPP waste containers.

CORROSIVES: Corrosives are prohibited in the payload container. Etchant solutions were neutralized and absorbed in pelletized clay rendering the solution noncorrosive prior to being a part of the waste. The physical form of the waste and the waste generating procedures ensure that the waste is in a nonreactive form.

CHEMICAL COMPATIBILITY: A chemical compatibility study has been performed on this content code, and all waste is chemically compatible for materials in greater than trace (>1% by weight) quantities.

ADDITIONAL CRITERIA: The sum of the hydrogen diffusivity of all drum filter vents per drum lid (30-gallon or 55-gallon), if present, is equal to or greater than 3.70e-06 mol/s/mol fraction at 25°C. The drum lid opening, if present, has an equivalent diameter equal to or greater than 0.3 in. Each bag filter vent, if present, has a minimum hydrogen diffusivity of 1.075e-05 mol/s/mol fraction at 25°C.

MAXIMUM ALLOWABLE HYDROGEN GENERATION RATES - OPTION 1: For ID 322A, the maximum allowable hydrogen generation rate limit is 3.61E-09 moles per second per drum and 3.61E-08 moles per second per 10-160B cask. For ID 322B, the maximum allowable hydrogen generation rate limit is 3.28E-08 moles per second per drum and 3.28E-07 moles per second per 10-160B cask.

MAXIMUM ALLOWABLE DECAY HEAT LIMIT - OPTION 2: For ID 322A, the maximum allowable decay heat limit is 3.26e-02 watts per drum and 3.26e-01 watts per 10-160B cask if the total dose is less than or equal to 0.012 watt-yr and 1.17e-01 watts per drum and 1.17 watts per 10-160B cask if the total dose is greater than 0.012 watt-yr. For ID 322B, the maximum allowable decay heat limit is 2.97e-01 watts per drum and 1.81 watts per 10-160B cask if the total dose is less than or equal to 0.012 watt-yr and 1.02 watts per drum and 2.28 watts per 10-160B cask if the total dose is greater than 0.012 watt-yr.

IDAHO NATIONAL ENGINEERING AND ENVIRONMENTAL LABORATORY
CONTENT CODE ID 322A
SOLID INORGANIC WASTE
MATERIALS AND CHEMICALS >1%

Aluminum
boron nitride
Brass
brick
Ceramic firebrick
Clay, pelletized
concrete
Ferrous metals (including carbon and stainless steels, cast iron)
Glass
HEPA FILTERS
Nonferrous metals (including aluminum, barium, brass, bronze, cadmium, chromium, copper, lead, mercury, selenium, and tin)
Organic debris ($\leq$ 20 volume %)
porcelain
quartz
STEEL
Vycor

MATERIALS AND CHEMICALS <1%

Toluene

CONTENT CODE: ID 325A, ID 325B

CONTENT DESCRIPTION: Solid Organic Waste

WASTE DESCRIPTION: This waste consists primarily of a variety of combustible debris.

GENERATING SOURCES: This waste is generated at the Argonne National Laboratory-East (ANL-E) Alpha Gamma Hot Cell Facility (AGHCF) between November 1971 and November 1995 during the processing of irradiated and unirradiated fuel pins from various reactor programs at ANL-W [Experimental Breeder Reactor-II (EBR-II)] and other U.S. Department of Energy (DOE) reactors, such as the New Production Reactor at the Savannah River Site (SRS). The AGHCF is a hot cell complex that includes office space, shielded gloveboxes, a hot cell under nitrogen atmosphere with workstations for remote manipulation of materials, and a Decontamination/Repair Area (DRA).

WASTE FORM: The waste consists of neoprene gloves and O-rings, polyethylene and polypropylene bottles; plastic tubing (including PVC, polyethylene, rubber, and styrene butadiene); PVC, polyurethane, and polyethylene bagging pouches; silicone and Teflon O-rings; paper products; cotton and synthetic rags; polyethylene and PVC sheeting; wood products (including masonite); neoprene, koroseal, and rubber gaskets; and a variety of plastics and cellulosics. Waste was contaminated primarily with fissile materials, mixed fission products (MFP), and activation products. The predominant radionuclides are: plutonium (Pu)-239, Pu-240, Pu-241, americium (Am)-241, uranium (U)-235, U-238, cesium (Cs)-137, barium (Ba)-137m, strontium (Sr)-90, yttrium (Y)-90, cobalt (Co)-60, and iron (Fe)-55.

WASTE PACKAGING:

ID 325A: The waste is packaged in two 7.5-gallon metal cans, a fiber drum pouch spreader, an inner PVC pouch, a polyethylene drum liner, an outer PVC pouch, and a 17H 30-gallon drum with a filter vent or an opening in the drum lid. The PVC pouches are heat-sealed. The inner PVC pouch is placed inside a rigid polyethylene liner without a lid. The liner and its contents are then heat-sealed inside the outer PVC pouch.

ID 325B: The waste is packaged in two 7.5-gallon metal cans, a fiber drum pouch spreader, an inner PVC pouch with a HEPA filter vent, a polyethylene drum liner, an outer PVC pouch with a filter vent, and a 17H 30-gallon drum with a filter vent or an opening in the drum lid. The inner PVC pouch is placed inside a rigid polyethylene liner without a lid. The liner and its contents are then heat-sealed inside the outer PVC pouch.

In addition, the 30-gallon drum may be placed within a vented 55-gallon waste drum.

METHODS FOR DETERMINATION OF ISOTOPIC CHARACTERIZATION: The isotopic composition of the waste is determined from process loss calculations and fission product calculations and was recorded on the associated forms or in data management systems. Therefore, the isotopic composition of the waste need not be determined by direct analysis or measurement of the waste unless process information is not available.

FREE LIQUIDS: Liquid waste is prohibited in the drums except for residual amounts in well-drained containers. The total volume of residual liquid in a payload container shall be less than 1 volume percent of the payload container. Waste packaging procedures ensure that free liquids are less than 1 volume percent of the payload container.

EXPLOSIVE/COMPRESSED GASES: Explosives and compressed gases in the payload containers are prohibited by waste packaging procedures.

PYROPHORICS: Sodium and NaK were passivated with alcohol and the alcohol absorbed into pelletized clay and evaporated. Other pyrophorics such as Zircalloy were sorted to segregate from WIPP waste containers.

CORROSIVES: Corrosives are prohibited in the payload container. Etchant solutions were neutralized and absorbed in pelletized clay rendering the solution noncorrosive prior to being a part of the waste. The physical form of the waste and the waste generating procedures ensure that the waste is in a noncreative form.

CHEMICAL COMPATIBILITY: A chemical compatibility study has been performed on this content code, and all waste is chemically compatible for materials in greater than trace (>1% by weight) quantities.

ADDITIONAL CRITERIA: The sum of the hydrogen diffusivity of all drum filter vents per drum lid (30-gallon or 55-gallon), if present, is equal to or greater than 3.70e-06 mol/s/mol fraction at 25°C. The drum lid opening, if present, has an equivalent diameter equal to or greater than 0.3 in. Each bag filter vent, if present, has a minimum hydrogen diffusivity of 1.075e-05 mol/s/mol fraction.

MAXIMUM ALLOWABLE HYDROGEN GENERATION RATES - OPTION 1: For ID 325A, the maximum allowable hydrogen generation rate limit is 3.61E-09 moles per second per drum and 3.61E-08 moles per second per 10-160B cask. For ID 325B, the maximum allowable hydrogen generation rate limit is 3.28E-08 moles per second per drum and 3.28E-07 moles per second per 10-160B cask.

MAXIMUM ALLOWABLE DECAY HEAT LIMIT - OPTION 2: For ID 325A, the maximum allowable decay heat limit is 6.48e-03 watts per drum and 6.48e-02 watts per 10-160B cask if the total dose is less than or equal to 0.012 watt-yr and 2.35e-02 watts per drum and 2.35e-01 watts per 10-160B cask if the total dose is greater than 0.012 watt-yr. For ID 325B, the maximum allowable decay heat limit is 5.94e-02 watts per drum and 5.94e-01 watts per 10-160B cask if the total dose is less than or equal to 0.012 watt-yr and 2.06e-01 watts per drum and 2.06 watts per 10-160B cask if the total dose is greater than 0.012 watt-yr.

**IDAHO NATIONAL ENGINEERING AND ENVIRONMENTAL LABORATORY
CONTENT CODE ID 325A
SOLID ORGANIC WASTE
MATERIALS AND CHEMICALS >1%**

cellulosics
clay, pelletized
Cotton
inorganic debris (including power cords, ≤ 20 volume %)
koroseal
Neoprene
plastic
polyethylene
polypropylene
PVC
Polyurethane
Paper
rubber
Silicone
styrene butadiene
synthetic rags
Teflon
wood (including masonite)

MATERIALS AND CHEMICALS <1%

Toluene

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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 18c).

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 Side
Condition	Side	Top/Bottom	Side	Top/Bottom	
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)

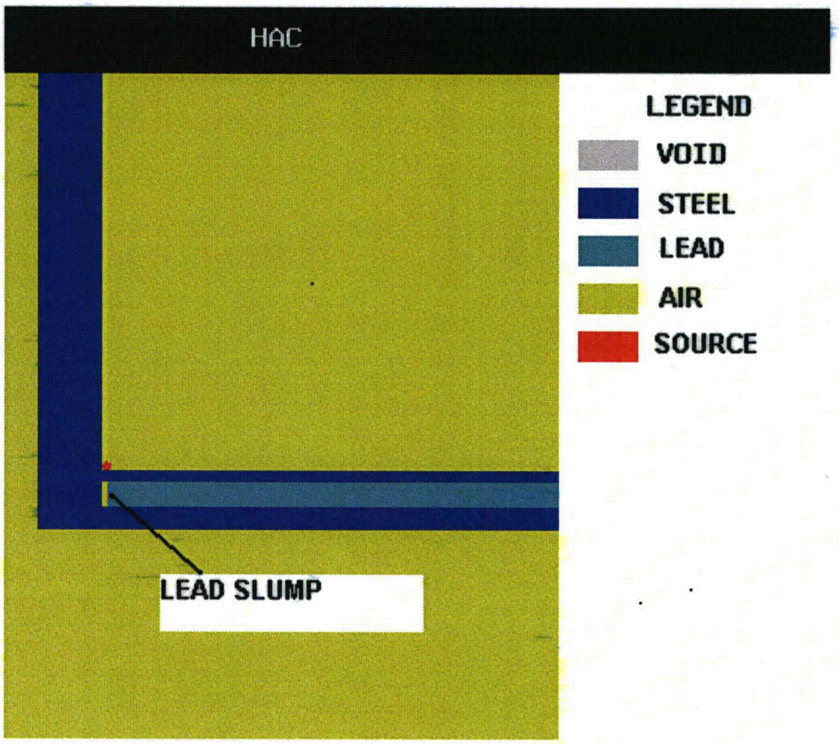
The walls of the 10-160B cask, 1.125" inner and 2" outer steel walls with a 1.875" lead layer between, are modeled as cylindrical shells around the cavity cylinder. The base and lid of the cask is a 5.5" steel plate. Impact limiters are conservatively ignored. This geometry is shown in Figure 5.1. In 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 (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	7.5	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 (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[13]; 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.

[13] The maximum allowable payload weight was changed to 14,250 lbs. when the top thermal shield was added. The distributed source calculation described here was performed to size some of the MCNP model source regions in the various density runs for the density factors in Figure 5.4. The impact of the weight change is small (-1.7%), resulting in a very small volume change in some of the source regions (radii changes on the order of 1-sqrt(.983)=0.9%, which is small compared to the conservative effects of neglecting the secondary containers.

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

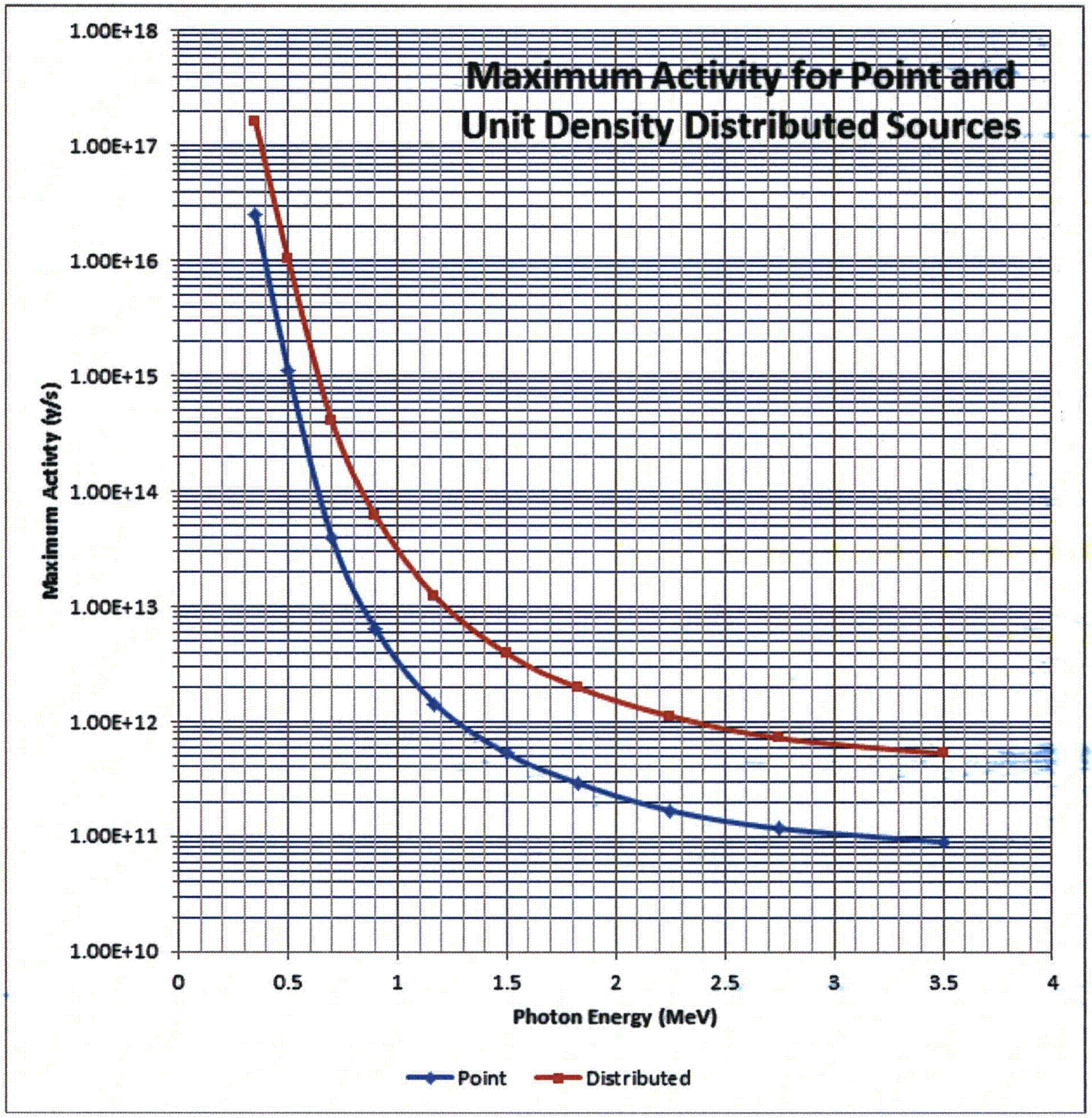
Results of the maximum activity calculations for the distributed unit density source are given in Table 5.7

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

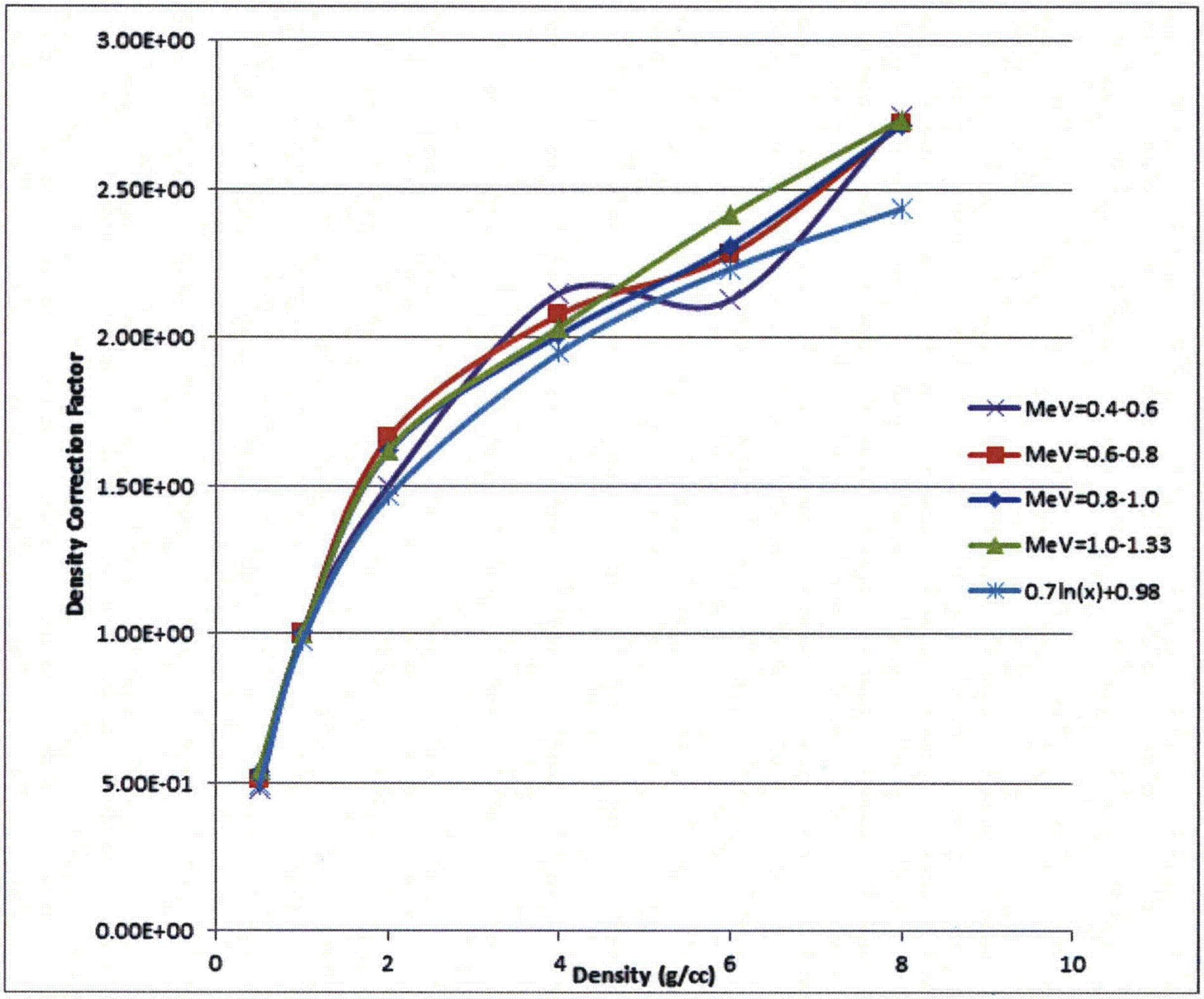
The cask activity limits for a point source and a unit density distributed source are plotted in Figure 5.3. The mid-point group energy values are used for plotting purposes.

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 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
 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
```

5.8.3 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 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
 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
```

5.8.5 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 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
 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
```

5.8.7 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
```

6. CRITICALITY EVALUATION

6.1 DESCRIPTION OF CRITICALITY DESIGN

This criticality safety evaluation supports shipment of up to ten TRU waste drums per 10-160B Cask. This criticality safety evaluation establishes a general payload for the 10-160B Cask. The maximum fissile mass limit for the 10-160B Cask is 325 fissile-gram-equivalent (FGE). The waste drums will be filled with manually compacted waste (i.e., not machine compacted) containing a maximum of 1% by weight of special reflectors.

6.1.1 DESIGN FEATURES

The Model 10-160B packaging consists of a lead and steel containment vessel which provides the necessary shielding for the various radioactive payloads. (Refer to Section 1.2.3 for packaging contents.) Tests and analysis performed and documented within chapters 2.0 and 3.0 have demonstrated the ability of the containment vessel to maintain its shielding integrity under normal conditions of transport.

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.

The important criticality control features are the containment vessel (CV) and the payload restrictions. The CV provides confinement of the payload during normal conditions of transport (NCT) and hypothetical accident conditions (HAC). The payload restrictions ensure that the analysis basis assumptions used in the criticality evaluation regarding the form and content of the payload are maintained. Any user of the package must have a Quality Assurance program that meets 10 CFR 71 Subpart H requirements.

Figures 6-1 and 6-2 present representative views of a single 10-160B Cask with ten 55-gallon drums for a normal as-loaded configuration.

6.1.2 SUMMARY TABLE OF CRITICALITY EVALUATION

Table 6.1 summarizes the results of the criticality evaluation for single packages and arrays of packages for the conditions defined in 10 CFR 71.55 and 71.59. These results indicate that the 10-160B Cask with any of the payloads described in Section 6.2 remains safely subcritical under NCT and HAC even with the extremely conservative assumptions used in the analysis.

6.1.3 CRITICALITY SAFETY INDEX

As shown in Table 6.1, the maximum calculated k_{eff} value is 0.93873 (Case f022flat02) for an infinite array of fully flooded 10-160B Casks containing an optimally moderated sphere with 325 g of Pu-239. This is below the k_{eff} limit of 0.94 after allowing for bias and uncertainties. Because an infinite array of casks is safely subcritical, N equals infinity and the CSI is zero.

Table 6.1. Summary of Criticality Safety Evaluation Results.

Single Package Results [10 CFR 71.55(b), (d), (e)]	
Package calculated to be subcritical under conditions for maximum reactivity	Maximum k_{eff}[a] = 0.93252, σ = 0.00020 (case f033)
Most reactive configuration	Compact sphere containing 325 g of Pu^{239} homogenized with 25% by volume of CH_2 and 1% by weight of Be based on CH_2 and Pu^{239} with the remaining volume filled with H_2O
Moderation for most reactive configuration	Cask flooded
Reflection for most reactive configuration (package materials and/or 30 cm water)	30 cm water around the cask
Array Results	
NCT array [10 CFR 71.59(a)(1)]	Maximum k_{eff}[a] = 0.45328, σ = 0.00015 (case f369a)
Number of packages	Analyzed: infinite array (CSI = 0)
Most reactive fissile content	Compact sphere containing 325 g of Pu^{239} homogenized with 25% by volume of CH_2 and 1% by weight of Be based on CH_2 and Pu^{239}
Interstitial moderation	No interstitial moderation
Reflection surrounding array	No reflector since infinite array
HAC array [10 CFR 71.59(a)(2)]	Maximum k_{eff}[a] =0.93873, σ = 0.00020 (case f022flat02)
Number of packages	Analyzed: infinite array (CSI = 0)
Most reactive fissile content:	Compact sphere containing 325 g of Pu^{239} homogenized with 25% by volume of CH_2 and 1% by weight of Be based on CH_2 and Pu^{239} with the remaining volume filled with H_2O
Interstitial moderation	0.001 g/cm^3 water interstitial moderation
Reflection surrounding array	No reflector since infinite array

[a] The effective criticality limit for this evaluation is $k_{eff} < 0.94$ which accounts for bias and uncertainties (see Section 6.8).

6.2 FISSILE MATERIAL CONTENTS

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.

3) Miscellaneous radioactive solid waste materials.

4) TRU wastes are limited as described in Appendices 4.11.2 through 4.11.7.

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.

The 10-160B payload is assumed to be 10 drums considered to be nominally 55 gals (208 Liters) for a total of 550 gal (2080 Liters) and conservatively assumed to contain 325 g of pure Pu^{239}.

The quantities of all fissile isotopes other than Pu^{239} present in the RH-TRU waste matrix may be converted to a FGE using the conversion factors outlined in the *Remote-Handling Transuranic Waste Authorization Methods for Payload Control* (RH-TRAMPAC) (Reference 6). Section 3.1.2 (page 3.1-5) of the RH-TRAMPAC discusses the derivation of the FGE conversion factors and justifies their use. In addition, the Pu^{239} is conservatively assumed to be contained within a sphere moderated and reflected by polyethylene (CH_2) with the total CH_2 comprising up to a maximum of 25% by volume of the 550 gallons. Beryllium is added as a special reflector/moderator with the total beryllium comprising up to a maximum of 1% by weight of the total masses of CH_2 and Pu^{239}.

There are no criticality controls on the isotopic composition of the plutonium. It is assumed, however, that the ^{240}Pu content exceeds the ^{241}Pu content. With this assumption, the fissile material is conservatively modeled as being 100% ^{239}Pu. The justification for this assumption is that the presence of ^{241}Pu content greater than ^{240}Pu content would require expensive isotopic enrichment. The vast majority of plutonium present in the world today meets this isotopic composition assumption. Note that of the plutonium nuclides that may be present, ^{241}Pu has the shortest half-life (14.4 years). It then decays to ^{241}Am, which shall be included in the plutonium mass. This is conservative because ^{241}Am is a parasitic neutron absorber in well moderated systems and, in unmoderated systems, requires a larger mass (~ 34 kg ^{241}Am) to achieve criticality than does ^{239}Pu (~ 5 kg ^{239}Pu). Thus counting ^{241}Am, present as a ^{241}Pu decay product, as ^{239}Pu is conservative.

The use of polyethylene as the bounding hydrogenous moderating material is justified in Section 6.2.1 of the *RH-TRU 72-B Safety Analysis Report, Revision 4, 2006* (Reference 7) which concludes that polyethylene is the most reactive moderator that could credibly moderate the transuranic waste in a pure form. A 25% volumetric packing fraction for polyethylene is used as a conservative value which is based on physical testing that bounds the packing fraction of polyethylene in manually compacted TRU waste of 13.36% (Reference 8).

This evaluation also addresses the addition of special reflectors in the waste matrix. Materials that can credibly provide better than 25% polyethylene/75% water equivalent reflection are termed "special reflectors" and are not authorized for shipment in quantities that exceed 1% by weight. Based on the studies of reflector material discussed in the *RH-TRU 72-B SAR* (Reference 7), Be, BeO, C, D2O, MgO, and depleted uranium (less than 0.72 wt% and greater than or equal to 0.3 wt% 235U) are the only materials considered special reflectors. Studies discussed in the *RH-TRU 72-B SAR* found that beryllium is the bounding special reflector as it provides the best reflection of the system and results in the highest k_{eff}.

For the NCT cases, the total amount of CH_2 is based on 25% by volume of 10 drums. The total amount of beryllium is based upon 1% by weight of the total mass of the CH_2 and the Pu^{239} in the 10 drums. The NCT configurations are assumed to not contain water. Therefore, the remaining volume not filled with polyethylene, Pu^{239} and beryllium is considered to be void. Densities are based upon smearing the materials with the void in the fissile sphere and the reflector.

For the NCT cases, the fissile sphere contains 325 g Pu^{239} uniformly distributed with 25% by volume of CH_2. Beryllium, added to the fissile sphere as a special reflector/moderator, is uniformly distributed throughout the sphere in the amount of 1% by mass of the total CH_2 and Pu^{239} mass. H/Pu ratios are postulated which determine the masses of CH_2 and beryllium in the fissile sphere for a given H/Pu ratio. The volume of the sphere is dependent upon the sum of the Pu^{239}, beryllium, polyethylene and void volumes. The various NCT fissile sphere compositions, densities and associated radii are presented in Table 6.2.

The remaining CH_2 (at 25% density) and beryllium not used in the fissile sphere are assumed to comprise a reflector completely surrounding the fissile sphere. The beryllium is uniformly distributed throughout the reflector volume in the amount of 1% by mass of the CH_2 mass. For the fissile sphere positioned in the centroid of the cask cavity, the reflector is a sphere. For the fissile sphere on the center floor or corner floor, the reflector occupies the same volume as the sphere but cylindrical in shape filling the lower portion of the cask. The reflector compositions are presented in Table 6.2 and representative views of the various NCT configurations are shown in Figures 6-3 through 6-5.

For the HAC cases, the total amount of CH_2 is based upon a maximum of 25% by volume of 10 drums. The total amount of beryllium is based upon a maximum of 1% by weight of the total mass of the CH_2 and the Pu^{239} in the 10 drums. The drums were considered to be nominally 55 gals (208 Liters) for a total of 550 gal (2080 Liters) for a 10 drum payload. The HAC configurations are assumed to contain water as required by 10 CFR 71.55(b). Therefore, any remaining volume not filled with polyethylene, Pu^{239} and beryllium is considered to be filled with water. Densities are based upon smearing the materials with the water in the fissile sphere and the reflector.

For the HAC cases, the fissile sphere is comprised of 325 g Pu^{239} uniformly distributed with the appropriate amounts of CH_2 and beryllium (as a special reflector/moderator) for the particular configuration. The remaining volume in the fissile sphere is filled with water. H/Pu ratios are postulated which determine the masses of CH_2 and beryllium in the fissile sphere for a given H/Pu ratio. The volume of the sphere is dependent upon the sum of the Pu^{239}, beryllium, polyethylene and water volumes. The various HAC fissile sphere compositions and associated radii are presented in Table 6.3. Modifications of certain compositions were made to examine the effect of less beryllium (0% and 0.5% by mass of total CH_2 and Pu^{239} mass) and by less polyethylene (20% by volume of the 10 drums). Representative views of the various HAC configurations are shown in Figures 6-6 through 6-9.

The HAC reflector contains the remaining CH_2 homogenized with sufficient H_2O to fill the remaining cask cavity volume. Beryllium is added to the reflector as a special reflector and is uniformly distributed throughout the volume in the amount of 1% by mass of the CH_2 mass. The fissile sphere is located in the cask centroid, on the center floor, corner floor or corner ceiling. The reflector compositions are presented in Table 6.3. Modifications of certain compositions were made to examine the effect of less beryllium (0% and 0.5% by mass of total CH_2 mass) and by less polyethylene (20% by volume of the 10 drums).

6.3 GENERAL CONSIDERATIONS

6.3.1 MODEL CONFIGURATION

Section 6.2 describes the fissile and reflector materials used in the criticality models.

Figures 6-1 and 6-2 present representative views of the normal condition 10-160B Cask with 10 drums. The radial and axial zone dimensions are shown in Table 6-4. The criticality model was developed using these dimensions and is essentially the same as the actual cask except that some details such as drain ports, lifting holes, and leak test ports are not included. The thermal barrier and impact limiter are also not included. These modeling simplifications will have a negligible impact on the criticality calculations and do not change the conclusions of the evaluation. A 12 inch water reflector region surrounds the cask.

The following additional assumptions are made in this evaluation.

1. The 10-160B is assumed to maintain its integrity under accident conditions; therefore, the cask model is based on nominal design dimensions and the payload is assumed to remain in the cask cavity under normal and accident conditions.
2. The fissile material is conservatively modeled as Pu^{239} with no credit taken for any neutron poisons that may be present such as Pu^{240} or Pu^{242}, the drums, or internal support structures.
3. The total volume of waste for the 10 drums was assumed to be 550 gallons (2080 Liters) based on a nominal drum capacity of 55 gallons. The moderating material is assumed to be bounded with polyethylene at a volume fraction of 25% of the total volume of waste. Because the analysis was done with optimum moderation and very conservative assumptions regarding the Pu, CH_2 and beryllium content and geometry, small variations in the drum volume due to design tolerances will have an insignificant impact on the overall results and will not change the conclusions of the analysis.

4. The maximum special reflecting material (beryllium) is 1% by weight in 550 gallons total volume of waste, i.e., 1% by weight of total mass of polyethylene and mass of plutonium.
5. Worse case NCT geometry is a sphere of fissile material. All plutonium is uniformly distributed within the sphere, as well as the polyethylene at a volume fraction of 25%. The beryllium is uniformly distributed within the sphere at 1% by weight of the total plutonium and polyethylene mass.
6. Worse case NCT reflector geometry contains the remaining polyethylene and beryllium. The reflector geometry is either a sphere surrounding the fissile material or a cylinder filling the bottom of the cask. In all cases, the polyethylene is at a packing fraction of 25% and the beryllium is uniformly distributed.
7. Worse case HAC geometry is a sphere of fissile material. All plutonium is uniformly distributed within the sphere, as well as the polyethylene (25%). The beryllium is uniformly distributed within the sphere at 1% by weight of the total plutonium and polyethylene mass. Water fills the remaining voids not filled by other materials.

Table 6.2. NCT Fissile Sphere and Reflector Compositions.

NCT Fissile Plus Moderator - 25% CH_2 Volume Fraction[b] - 1% Be Weight Fraction[c]

Material Identifier	H/Pu	Sphere Radius (cm)	Sphere Density (g/cm^3)	Mass Fractions[a]						
				Hydrogen		Beryllium	Carbon	Oxygen		Plutonium
				H^1	H^2	Be^9	C	O^{16}	O^{17}	Pu^{239}
m130	700	19.04676	0.244252	0.13564500	0.00004067	0.00990099	0.80844128	N/A	N/A	0.04597206
m131	800	19.913170	0.242853	0.13643688	0.00004091	0.00990099	0.81316084	N/A	N/A	0.04046038
m132	850	20.31945	0.242277	0.13676564	0.00004100	0.00990099	0.81512025	N/A	N/A	0.03817212
m133	900	20.71011	0.241765	0.13705920	0.00004109	0.00990099	0.81686988	N/A	N/A	0.03612883
m134	950	21.08656	0.241307	0.13732294	0.00004117	0.00990099	0.81844173	N/A	N/A	0.03429317
m135	1000	21.45002	0.240895	0.13756117	0.00004124	0.00990099	0.81986157	N/A	N/A	0.03263503
m136	1100	22.14214	0.240183	0.13797461	0.00004137	0.00990099	0.82232566	N/A	N/A	0.02975738
m137	1200	22.79349	0.239589	0.13832104	0.00004147	0.00990099	0.82439041	N/A	N/A	0.02734609
m138	1300	23.40961	0.239087	0.13861554	0.00004156	0.00990099	0.82614562	N/A	N/A	0.02529629
m139	1400	23.99489	0.238656	0.13886897	0.00004163	0.00990099	0.82765605	N/A	N/A	0.02353235
m140	1500	24.55294	0.238283	0.13908936	0.00004170	0.00990099	0.82896956	N/A	N/A	0.02199839
m141	1600	25.08671	0.237957	0.13928277	0.00004176	0.00990099	0.83012231	N/A	N/A	0.02065217
m142	1700	25.59869	0.237669	0.13945388	0.00004181	0.00990099	0.83114211	N/A	N/A	0.01946121
m143	1800	26.09097	0.237412	0.13960633	0.00004186	0.00990099	0.83205070	N/A	N/A	0.01840013

NCT Reflector - 25% CH_2 Volume Fraction[b] - 1% Be Weight Fraction[c]

Material Identifier	H/Pu	Sphere Radius (cm)	Reflector Density (g/cm^3)	Mass Fractions[a]						
				Hydrogen		Beryllium	Carbon	Oxygen		Plutonium
				H^1	H^2	Be^9	C	O^{16}	O^{17}	Pu^{239}
m160	N/A	79.21023	0.233058	0.142249921	4.26486E-05	0.00990099	0.847806441	N/A	N/A	N/A
m161	N/A	79.21023	0.233058	0.142249921	4.26486E-05	0.00990099	0.847806441	N/A	N/A	N/A
m162	N/A	79.21023	0.233058	0.142249921	4.26486E-05	0.00990099	0.847806441	N/A	N/A	N/A
m163	N/A	79.21023	0.233058	0.142249921	4.26486E-05	0.00990099	0.847806441	N/A	N/A	N/A
m164	N/A	79.21023	0.233058	0.142249921	4.26486E-05	0.00990099	0.847806441	N/A	N/A	N/A
m165	N/A	79.21023	0.233058	0.142249921	4.26486E-05	0.00990099	0.847806441	N/A	N/A	N/A
m166	N/A	79.21023	0.233058	0.142249921	4.26486E-05	0.00990099	0.847806441	N/A	N/A	N/A
m167	N/A	79.21023	0.233058	0.142249921	4.26486E-05	0.00990099	0.847806441	N/A	N/A	N/A
m168	N/A	79.21023	0.233058	0.142249921	4.26486E-05	0.00990099	0.847806441	N/A	N/A	N/A
m169	N/A	79.21023	0.233058	0.142249921	4.26486E-05	0.00990099	0.847806441	N/A	N/A	N/A
m170	N/A	79.21023	0.233058	0.142249921	4.26486E-05	0.00990099	0.847806441	N/A	N/A	N/A
m171	N/A	79.21023	0.233058	0.142249921	4.26486E-05	0.00990099	0.847806441	N/A	N/A	N/A
m172	N/A	79.21023	0.233058	0.142249921	4.26486E-05	0.00990099	0.847806441	N/A	N/A	N/A
m173	N/A	79.21023	0.233058	0.142249921	4.26486E-05	0.00990099	0.847806441	N/A	N/A	N/A

[a] Values derived assuming 19.7 g/cm^3 for Pu, 1.85 g/cm^3 for Be, 0.923 g/cm^3 for CH_2, and 1.0 g/cm^3 for H_2O.

[b] CH_2 volume fractions based on ten 55 gallon drums

[c] Be weight fraction based upon mass of CH_2 and Pu (fissile region only)

Table 6.3. HAC Fissile Sphere and Reflector Compositions.

HAC Fissile Plus Moderator

Material Identifier	H/Pu	CH_2[b] Volume Fraction	Be[c] Weight Fraction	Sphere Radius (cm)	Sphere Density (g/cm^3)	Mass Fractions[a] Hydrogen H^1	Hydrogen H^2	Beryllium Be^9	Carbon C	Oxygen O^{16}	Oxygen O^{17}	Plutonium Pu^{239}
m100	700	25%	1.0%	12.519999	1.019560	0.11441390	0.00003430	0.00264597	0.19336657	0.65049999	0.00026274	0.03877653
m101	800	25%	1.0%	13.088647	1.014851	0.11497677	0.00003447	0.00261028	0.19431786	0.65370021	0.00026404	0.03409638
m102	850	25%	1.0%	13.355327	1.012911	0.11521015	0.00003454	0.00259548	0.19471229	0.65502711	0.00026457	0.03215585
		25%	0.5%	13.352284	1.012326	0.11535548	0.00003459	0.00129870	0.19484164	0.65600821	0.00026497	0.03219641
		25%	0.0%	13.349243	1.011742	0.11550103	0.00003463	0.00000000	0.19497120	0.65699073	0.00026537	0.03223704
		20%	1.0%	13.393913	1.016274	0.11383931	0.00003413	0.00213088	0.15525677	0.69668428	0.00028140	0.03177324
m103	900	25%	1.0%	13.611761	1.011186	0.11541840	0.00003460	0.00258227	0.19506425	0.65621111	0.00026505	0.03042431
		25%	0.5%	13.608682	1.010604	0.11556323	0.00003465	0.00129208	0.19519253	0.65718959	0.00026545	0.03046248
		25%	0.0%	13.605605	1.010023	0.11570826	0.00003469	0.00000000	0.19532101	0.65816948	0.00026584	0.03050072
		20%	1.0%	13.651092	1.014565	0.11404263	0.00003419	0.00211700	0.15553406	0.69792857	0.00028190	0.03006165
m104	950	25%	1.0%	13.858882	1.009642	0.11560537	0.00003466	0.00257042	0.19538023	0.65727412	0.00026548	0.02886972
		25%	0.5%	13.855767	1.009063	0.11574973	0.00003470	0.00128613	0.19550755	0.65825023	0.00026587	0.02890577
		25%	0.0%	13.852654	1.008484	0.11589430	0.00003475	0.00000000	0.19563507	0.65922774	0.00026627	0.02894188
		20%	1.0%	13.898930	1.013035	0.11422516	0.00003425	0.00210454	0.15578300	0.69904565	0.00028235	0.02852505
m105	1000	25%	1.0%	14.097490	1.008253	0.11577416	0.00003471	0.00255972	0.19566550	0.65823377	0.00026587	0.02746628
		25%	0.5%	14.094340	1.007676	0.11591811	0.00003475	0.00128077	0.19579194	0.65920774	0.00026626	0.02750043
		25%	0.0%	14.091191	1.007100	0.11606226	0.00003480	0.00000000	0.19591858	0.66018308	0.00026665	0.02753463
		20%	1.0%	14.138232	1.011657	0.11438994	0.00003430	0.00209329	0.15600773	0.70005409	0.00028276	0.02713789
m106	1100	25%	1.0%	14.551873	1.005852	0.11606687	0.00003480	0.00254115	0.19616020	0.65989797	0.00026654	0.02503247

HAC Reflector

Material Identifier	H/Pu	CH_2[b] Volume Fraction	Be[c] Weight Fraction	Sphere Radius (cm)	Reflector Density (g/cm^3)	Mass Fractions[a] Hydrogen H^1	Hydrogen H^2	Beryllium Be^9	Carbon C	Oxygen O^{16}	Oxygen O^{17}	Plutonium Pu^{239}
m150	N/A	25%	1.0%	N/A	0.991734	0.11510979	0.00003451	0.00105738	0.09054180	0.79293624	0.00032027	N/A
m151	N/A	25%	1.0%	N/A	0.991737	0.11510879	0.00003451	0.00105705	0.09051365	0.79296572	0.00032029	N/A
m152	N/A	25%	1.0%	N/A	0.991738	0.11510828	0.00003451	0.00105689	0.09049956	0.79298046	0.00032029	N/A
		25%	0.5%	N/A	0.991497	0.11516820	0.00003453	0.00052857	0.09052169	0.79342654	0.00032047	N/A
		25%	0.0%	N/A	0.991256	0.11522815	0.00003455	0.00000000	0.09054382	0.79387283	0.00032065	N/A
		20%	1.0%	N/A	0.993391	0.11445521	0.00003432	0.00084408	0.07227755	0.81206084	0.00032800	N/A
m153	N/A	25%	1.0%	N/A	0.991739	0.11510778	0.00003451	0.00105672	0.09048548	0.79299521	0.00032030	N/A
		25%	0.5%	N/A	0.991498	0.11516769	0.00003453	0.00052849	0.09050760	0.79344121	0.00032048	N/A
		25%	0.0%	N/A	0.991257	0.11522763	0.00003455	0.00000000	0.09052974	0.79388743	0.00032066	N/A
		20%	1.0%	N/A	0.993392	0.11445480	0.00003432	0.00084395	0.07226622	0.81207270	0.00032800	N/A
m154	N/A	25%	1.0%	N/A	0.991740	0.11510727	0.00003451	0.00105656	0.09047139	0.79300997	0.00032030	N/A
		25%	0.5%	N/A	0.991500	0.11516717	0.00003453	0.00052841	0.09049351	0.79345589	0.00032048	N/A
		25%	0.0%	N/A	0.991259	0.11522711	0.00003455	0.00000000	0.09051565	0.79390203	0.00032066	N/A
		20%	1.0%	N/A	0.993393	0.11445440	0.00003432	0.00084382	0.07225489	0.81208457	0.00032801	N/A
m155	N/A	25%	1.0%	N/A	0.991742	0.11510677	0.00003451	0.00105639	0.09045730	0.79302472	0.00032031	N/A
		25%	0.5%	N/A	0.991501	0.11516666	0.00003453	0.00052833	0.09047942	0.79347057	0.00032049	N/A
		25%	0.0%	N/A	0.991260	0.11522658	0.00003455	0.00000000	0.09050156	0.79391664	0.00032067	N/A
		20%	1.0%	N/A	0.993394	0.11445399	0.00003431	0.00084369	0.07224356	0.81209644	0.00032801	N/A
m156	N/A	25%	1.0%	N/A	0.991744	0.11510576	0.00003451	0.00105606	0.09042910	0.79305425	0.00032032	N/A

[a] Values derived assuming 19.7 g/cm^3 for Pu, 1.85 g/cm^3 for Be, 0.923 g/cm^3 for CH_2, and 1.0 g/cm^3 for H_2O.

[b] CH_2 volume fractions based on ten 55 gallon drums

[c] Be weight fraction based upon mass of CH_2 and Pu (fissile region only)

8. Worse case HAC reflector geometry contains the remaining polyethylene and beryllium (1% by weight of the polyethylene) surrounding the fissile sphere. In addition, water is used to fill the space not filled by the polyethylene and beryllium. All three components (i.e., water, polyethylene and beryllium) are homogenously mixed and uniformly distributed throughout the remaining cask volume.
9. The criticality analyses were performed for fully reflected external conditions. Therefore, a 30.48 cm (12-in.) water reflector completely surrounding the cask is used in all single cask calculations for normal and accident conditions. This configuration is consistent with the requirements of 10 CFR 71.55(b)(3), which require full reflection, and a U.S. Nuclear Regulatory Commission recommendation that the thickness of the water reflector be at least 30 cm.

The previous paragraphs describe the assumptions used to analyze the 10-160B Cask. These assumptions provide the following conservative attributes, as required by 10 CFR 71.55.

1. Spherical fissile geometry for maximum reactivity
2. Optimum moderation, including special reflecting material (i.e., beryllium)
3. Full reflection
4. No credit for drums and internal drum support structure
5. Flooded for HAC

Figure 6-1. Representative Elevation View of a Single 10-160B Cask With Ten 55-gal Drums in the Cask Cavity (Normal (As-Loaded) Configuration).

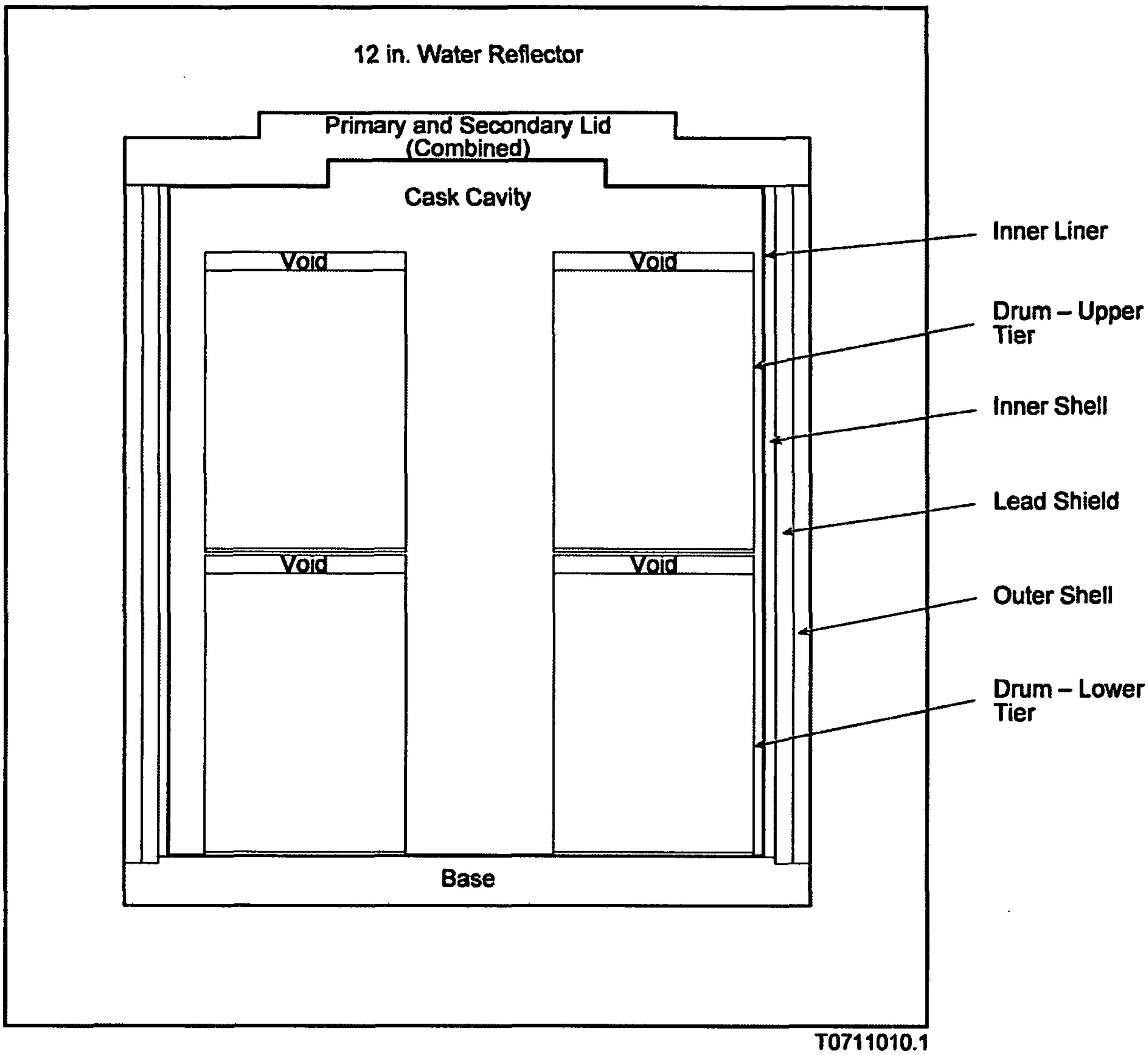


Figure 6-2. Representative Plan View of a Single 10-160B Cask With Ten 55-gal Drums in the Cask Cavity (Normal (As-Loaded) Configuration).

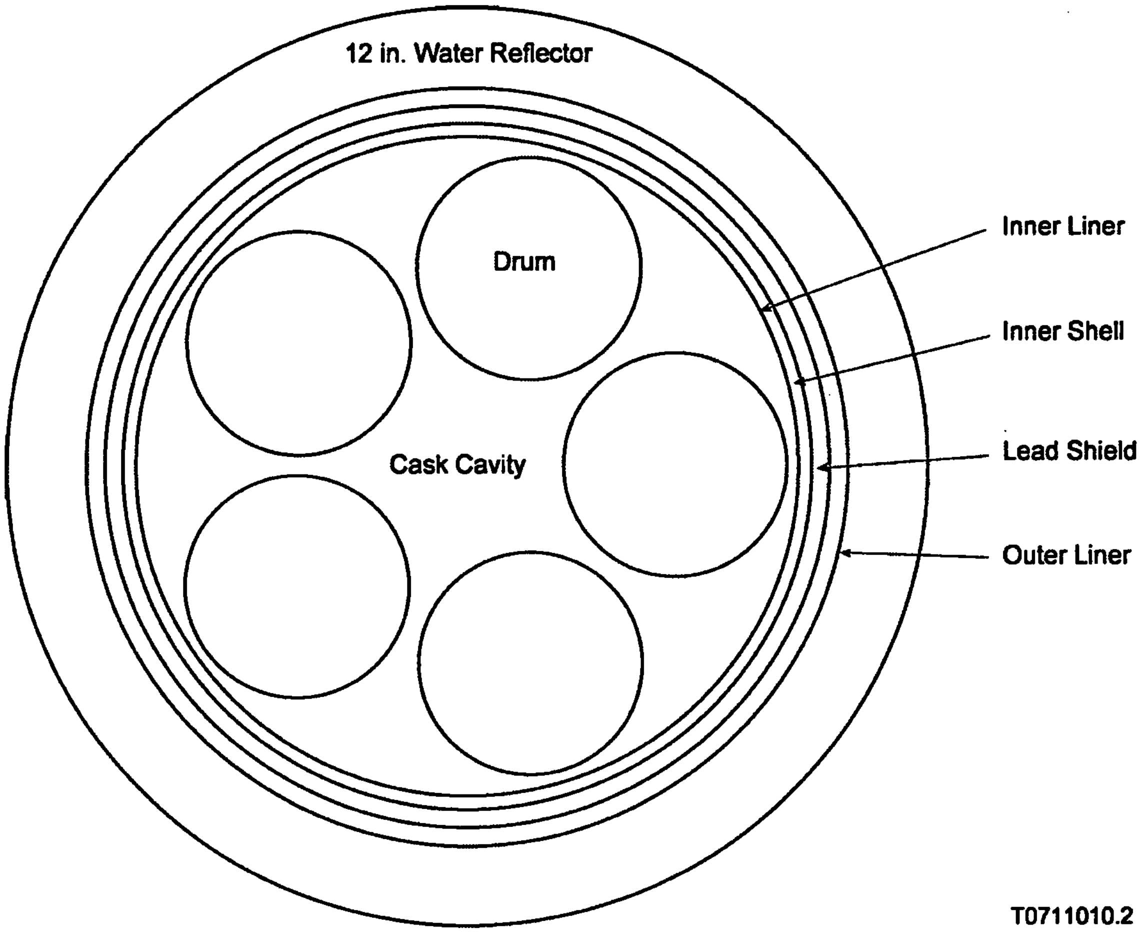


Figure 6-3. Elevation View of a Single 10-160B Cask with the Fissile and Reflector Regions for the NCT Centroid Case (Case f309).

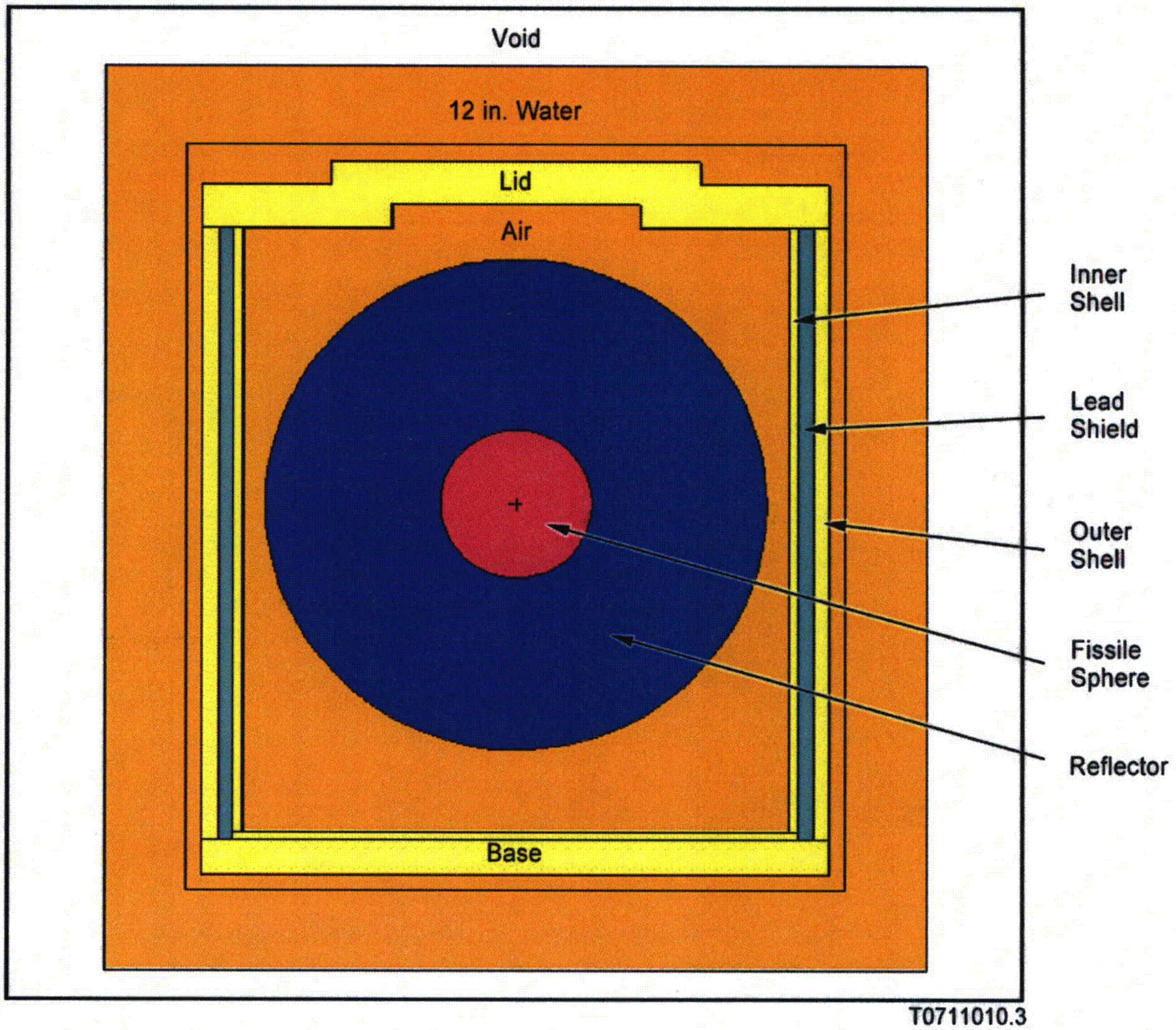


Figure 6-4. Elevation View of a Single 10-160B Cask with the Fissile and Reflector Regions for the NCT Base Center Case (Case f329).

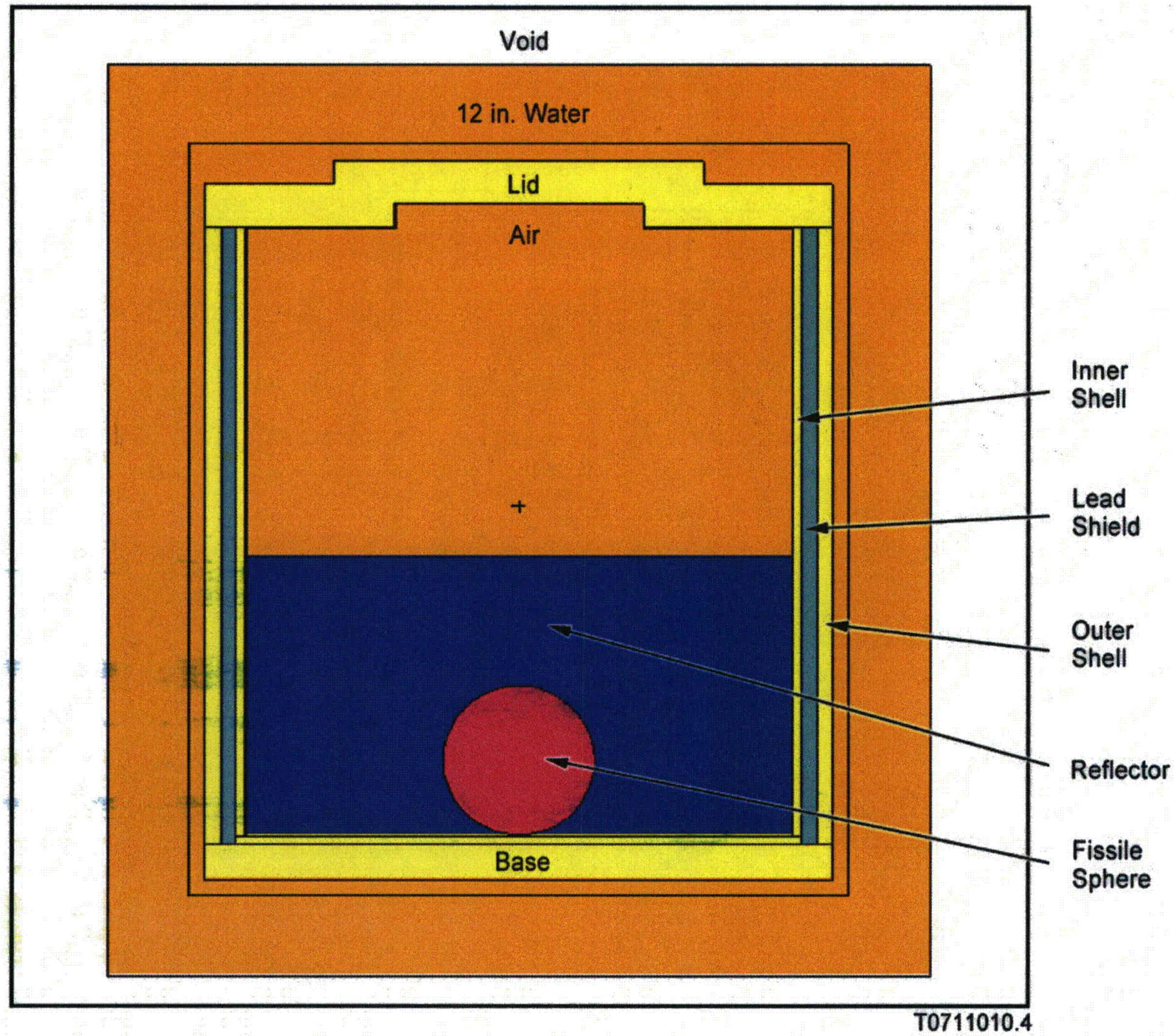


Figure 6-5. Elevation View of a Single 10-160B Cask with
the Fissile and Reflector Regions for the NCT Base Corner Case (Case f349).

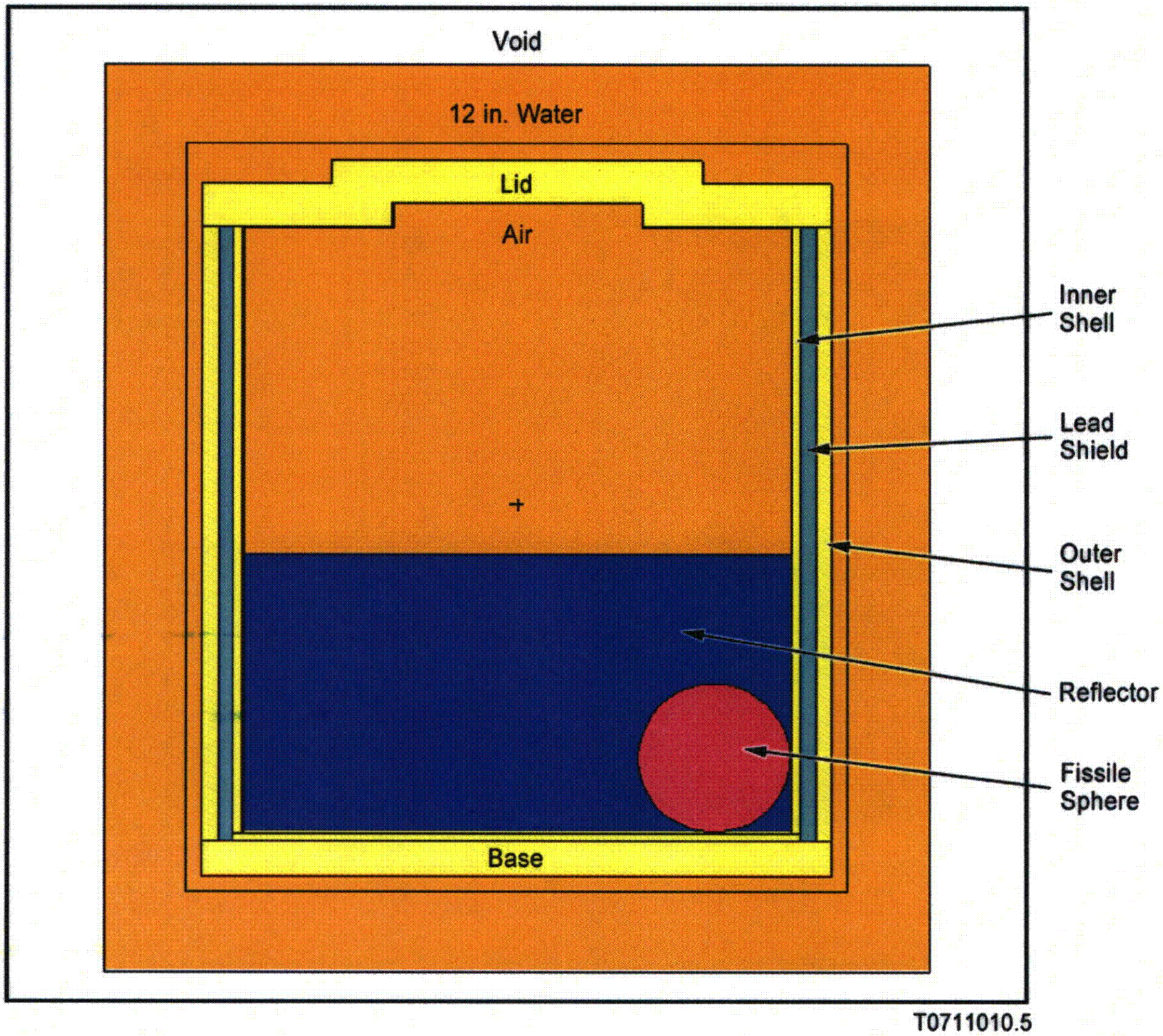


Figure 6-6. Elevation View of a Single 10-160B Cask with the Fissile and Reflector Regions for the HAC Centroid Case (Case f003).

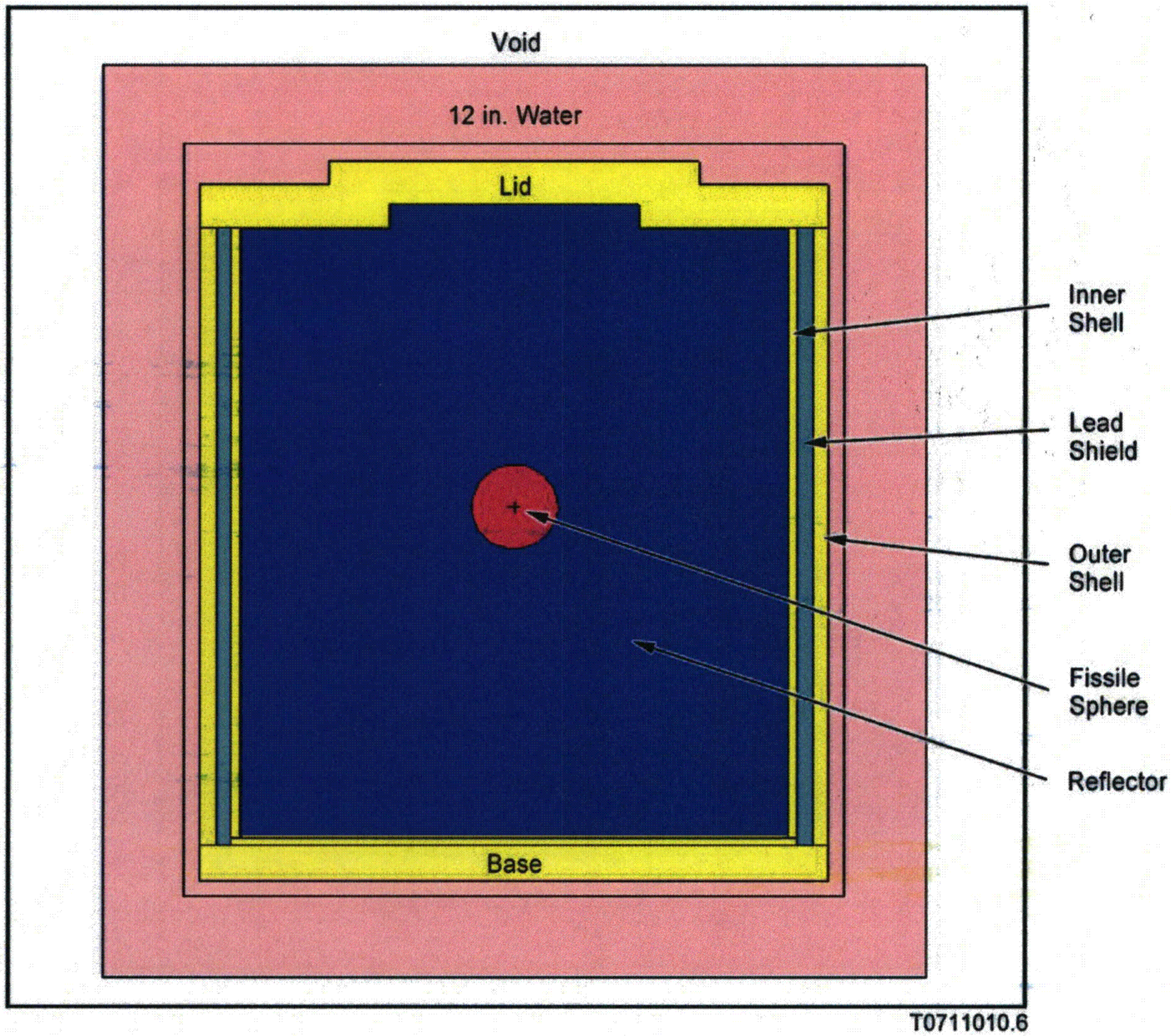


Figure 6-7. Elevation View of a Single 10-160B Cask with
the Fissile and Reflector Regions for the HAC Base Center Case (Case f013).

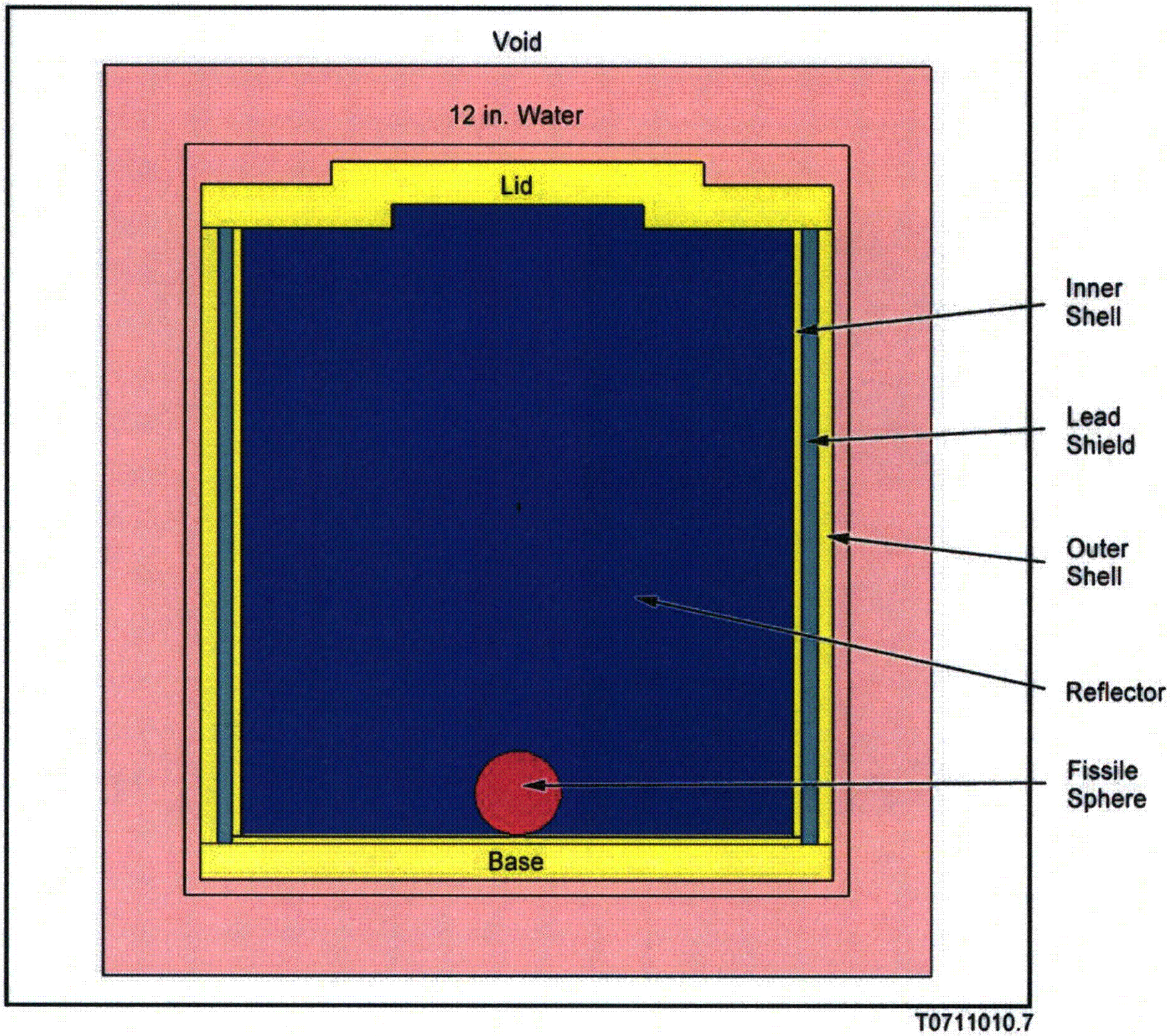


Figure 6-8. Elevation View of a Single 10-160B Cask with the Fissile and Reflector Regions for the HAC Base Corner Case (Case f023).

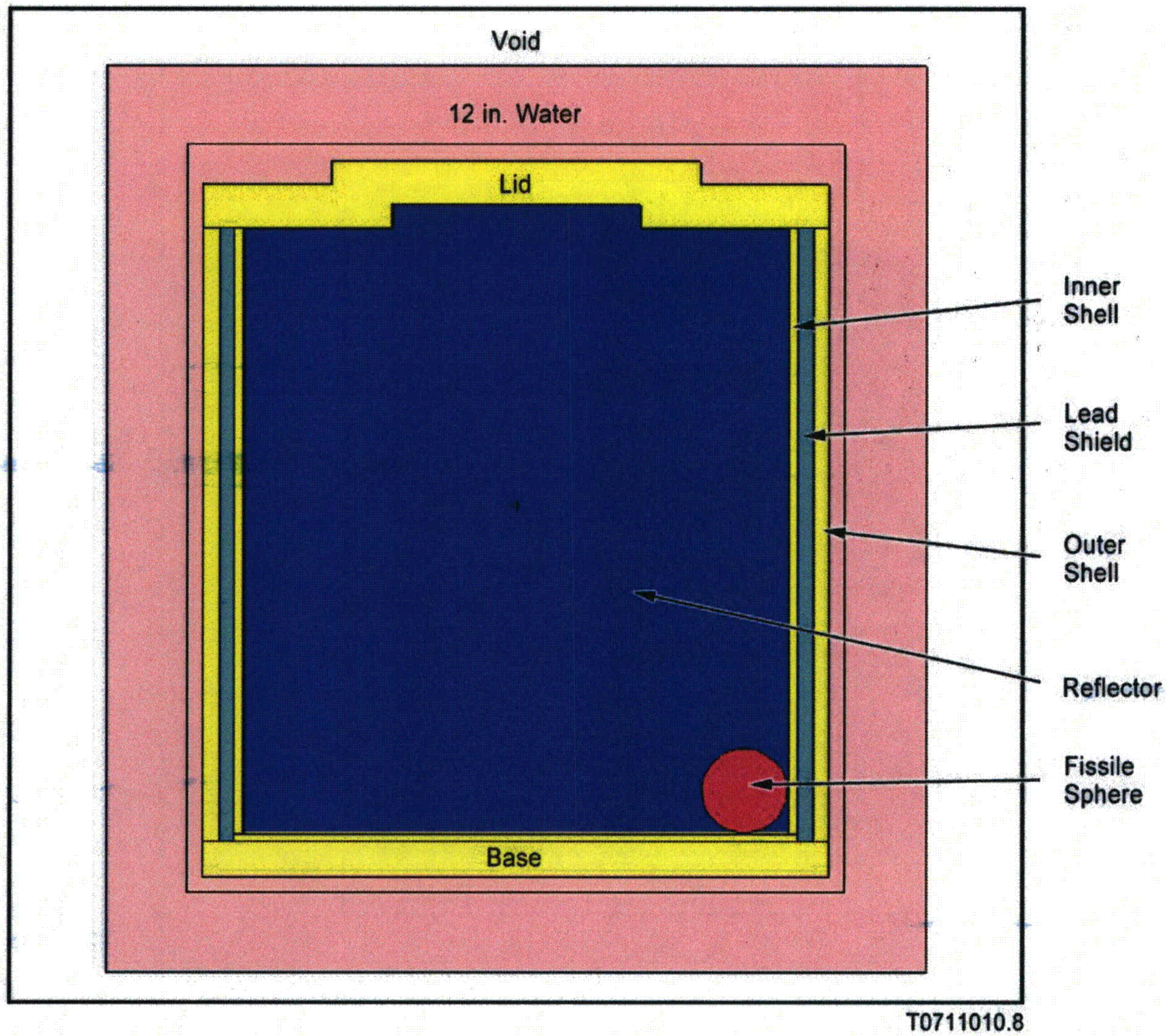


Figure 6-9. Elevation View of a Single 10-160B Cask with the Fissile and Reflector Regions for the HAC Lid Corner Case (Case f033).

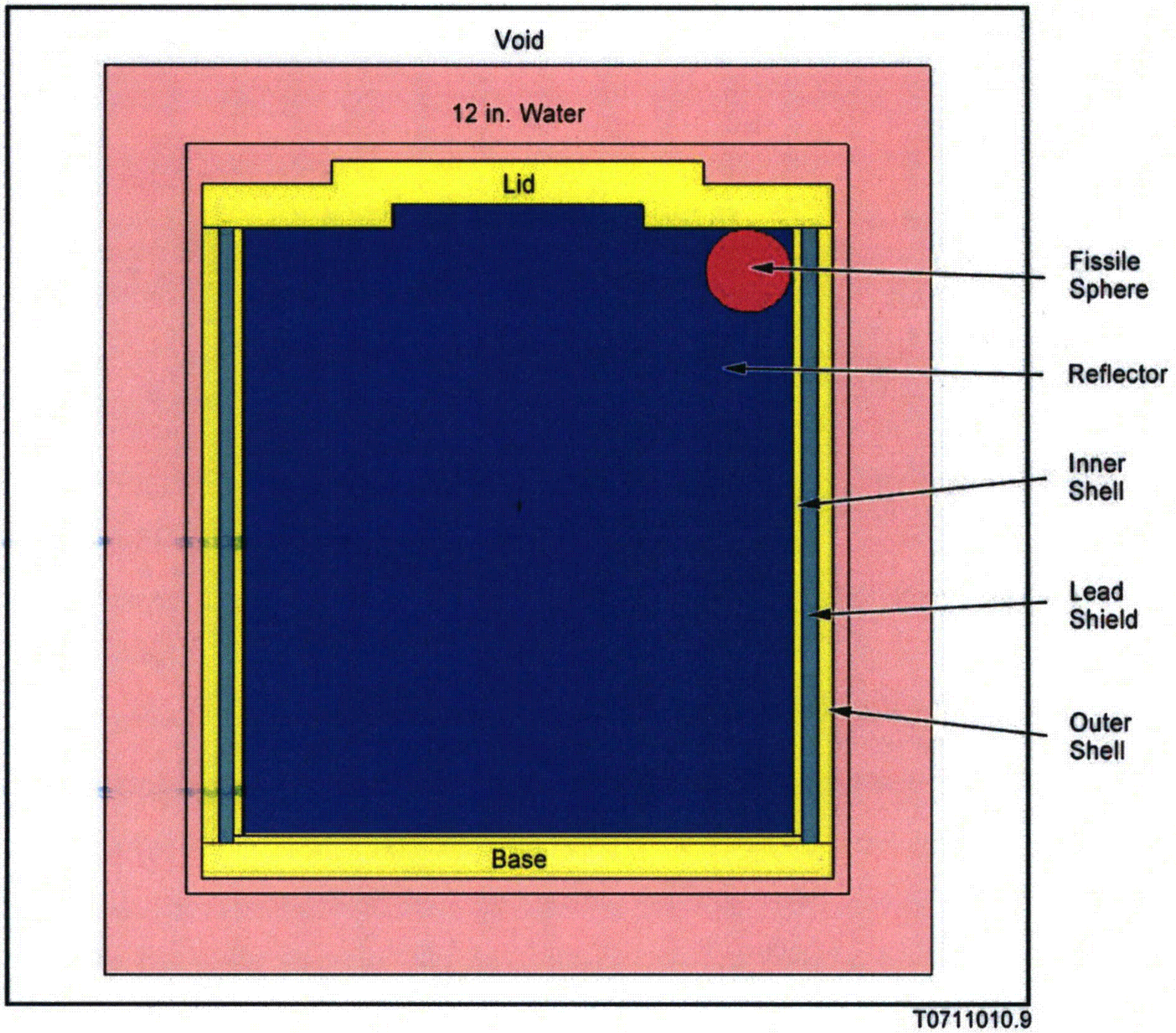


Table 6.4. Assumed Nominal Dimensions of the 10-160B Cask MCNP Criticality Model.

Zone (material)	Axial zone length		Zone outer radius		Zone radial thickness	
	in	cm	in	cm	in	cm
Cask Dimensions[a]						
Secondary Lid[b] (Carbon Steel)	5.5	13.970	23	58.420	23	58.420
Primary Lid[b] (Carbon Steel)	5.5	13.970	39	99.060	23.5	59.690
Cask cavity (void)	76.75	194.945	33.875	86.043	33.875	86.043
Inner liner[c] (SS 304)	77	195.580	34	86.360	0.125	0.318
Inner shell (Carbon Steel)	77	195.580	35.125	89.218	1.125	2.858
Lead shield (Lead)	78	198.120	37	93.980	1.875	4.763
Outer Shell (Carbon Steel)	78	198.120	39	99.060	2	5.080
Base (Carbon Steel)	5.5	13.970	39	99.060	39	99.060

[a] The bottom tapered edge of the cask is not modeled. Also, the impact limiter and thermal barrier are not included in the model. These modeling simplifications have negligible impact on the results.

[b] The primary and secondary lids are stepped. The dimensions listed in the table are the inner/outer-most dimensions.

[c] The inner lining is irregular in shape but essentially consists of 11 gage steel covering the entire cask inner cavity.

6.3.2 MATERIAL PROPERTIES

Table 6.5 shows the material compositions used in the MCNP models including the density of the material and the MCNP cross-sectional set name. Any changes in material properties under tests in 10 CFR 71.71 and 71.73, *Hypothetical Accident Conditions*, are minor and have a minimal impact on the results of this evaluation due to the conservative assumptions used to model the payload.

The $S(\alpha,\beta)$ cross-sections for hydrogen in the HAC regions were selected as light water (lwtr.60t) since the light water cross-sections provide a slightly higher reactivity than do the corresponding cross-sections for polyethylene.

Dry air was used for the NCT cases where the cask is dry. Air was assumed to only contain N_2 and O_2, thereby ignoring the trace amounts of Ar and other gases.

Table 6.5. Materials and Elemental Compositions Used to Perform the Criticality Analyses for the 10-160B Cask.

Item	Isotope Element	MCNP ZAID	Mass Fraction	Density (g/cm^3)
NCT Fissile	H^1	1001.66c	Table 6.2	Table 6.2
	H^2	1002.66c	Table 6.2	Table 6.2
	Be^9	4009.66c	Table 6.2	Table 6.2
	C	6000.66c	Table 6.2	Table 6.2
	Pu^{239}	94239.66c	Table 6.2	Table 6.2
	S(α,β)	poly.60t		
	S(α,β)	be.60t		
		Totals	1.00	Table 6.2
HAC Fissile	H^1	1001.66c	Table 6.3	Table 6.3
	H^2	1002.66c	Table 6.3	Table 6.3
	Be^9	4009.66c	Table 6.3	Table 6.3
	C	6000.66c	Table 6.3	Table 6.3
	O^{16}	8016.66c	Table 6.3	Table 6.3
	O^{17}	8017.66c	Table 6.3	Table 6.3
	Pu^{239}	94239.66c	Table 6.3	Table 6.3
	S(α,β)	lwtr.60t		
	S(α,β)	be.60t		
		Totals	1.00	Table 6.3
NCT Reflector	H^1	1001.66c	Table 6.2	Table 6.2
	H^2	1002.66c	Table 6.2	Table 6.2
	Be^9	4009.66c	Table 6.2	Table 6.2
	C	6000.66c	Table 6.2	Table 6.2
	Pu^{239}	94239.66c	Table 6.2	Table 6.2
	S(α,β)	poly.60t		
	S(α,β)	be.60t		
		Totals	1.00	Table 6.2
HAC Reflector	H^1	1001.66c	Table 6.3	Table 6.3
	H^2	1002.66c	Table 6.3	Table 6.3
	Be^9	4009.66c	Table 6.3	Table 6.3
	C	6000.66c	Table 6.3	Table 6.3
	O^{16}	8016.66c	Table 6.3	Table 6.3
	O^{17}	8017.66c	Table 6.3	Table 6.3
	Pu^{239}	94239.66c	Table 6.3	Table 6.3
	S(α,β)	lwtr.60t		
	S(α,β)	be.60t		
		Totals	1.00	Table 6.3
Air	N^{14}	7014.66c	0.761985	9.30E-04
	N^{15}	7015.66c	0.003015	3.68E-06
	O^{16}	8016.66c	0.234905	2.87E-04
	O^{17}	8017.66c	0.000095	1.16E-07
		Totals	1.00	0.00122

Item	Isotope Element	MCNP ZAID	Mass Fraction	Density (g/cm^3)
Carbon Steel	C	6000.66c	0.003000	0.023550
	Si^{28}	14028.66c	0.002572	0.020190
	Si^{29}	14029.66c	0.000135	0.001060
	Si^{30}	14030.66c	0.000092	0.000722
	P^{31}	15031.66c	0.000400	0.003140
	S	16000.66c	0.000500	0.003925
	Mn^{55}	25055.66c	0.010300	0.080855
	Fe^{54}	26054.66c	0.055383	0.434757
	Fe^{56}	26056.66c	0.901554	7.077199
	Fe^{57}	26057.66c	0.021193	0.166365
	Fe^{58}	26058.66c	0.002870	0.022530
	Cu^{63}	29063.66c	0.001370	0.010755
	Cu^{65}	29065.66c	0.000630	0.004946
		Totals	1.00	7.85
SS-304	C	6000.66c	0.000300	0.002409
	Cr^{50}	24050.66c	0.008345	0.067010
	Cr^{52}	24052.66c	0.167349	1.343812
	Cr^{53}	24053.66c	0.019341	0.155308
	Cr^{54}	24054.66c	0.004905	0.039387
	Mn^{55}	25055.66c	0.019994	0.160552
	Fe^{54}	26054.66c	0.038378	0.308175
	Fe^{56}	26056.66c	0.624743	5.016686
	Fe^{57}	26057.66c	0.014686	0.117929
	Fe^{58}	26058.66c	0.001989	0.015972
	Ni^{58}	28058.66c	0.067178	0.539439
	Ni^{60}	28060.66c	0.026768	0.214947
	Ni^{61}	28061.66c	0.001183	0.009499
	Ni^{62}	28062.66c	0.003834	0.030787
	Ni^{64}	28064.66c	0.001008	0.008094
		Totals	1.00	8.03
Lead	Pb	82000.50c	1.000000	11.34
		Totals	1.00	11.34
Water	H^1	1001.66c	0.111865	0.111865
	H^2	1002.66c	0.000034	3.35E-05
	O^{16}	8016.66c	0.887743	0.887743
	O^{17}	8017.66c	0.000359	0.000359
	S(α,β)	lwtr.60t		
		Totals	1.00	1.00

6.3.3 COMPUTER CODES AND CROSS-SECTIONAL LIBRARIES

The k_{eff} values are calculated using the computer program MCNP Version 5, Release 1.40[3]. The MCNP computer program has been approved for use with quality affecting analyses and is under configuration control in accordance with FSWO-QAP-001, *Quality Assurance Procedures*, QP 3-10, *Software Management*[2].

MCNP calculates k_{eff} using the Monte Carlo method from an arbitrary three-dimensional configuration using point wise continuous-energy cross-sectional data. Because of the statistical basis of this method, the results show an average k_{eff} value and a standard deviation, which represents the 1σ (68%) confidence interval. The MCNP criticality runs used 4,000 neutrons per generation with 3950 active generations. This results in a standard deviation of approximately 0.00025 or less for all calculations performed in this evaluation.

Table 6.5 shows the material compositions used in the MCNP models including the density of the material and the MCNP cross-sectional set name. The input for MCNP does not include an entry explicitly for the nuclear properties of materials; rather, it obtains this information automatically based on the particular library specified by the user for each of the isotopes and/or elements of the materials used in the model. The libraries are distributed with the code, and many libraries have been developed over the years by different entities for specific purposes. Although multiple libraries are available for the materials of this package and payload, the library based on Evaluated Nuclear Data Files VI (ENDF-VI) is used exclusively with the exception of elemental lead (Pb) that is not adequately addressed in ENDF-VI. (ENDF-VI has three of the four naturally occurring isotopes of Pb.) This library, named "endf60," is used because it represents the most recent available data from the centralized U.S. organization coordinating the establishment of nuclear data (the National Nuclear Data Center at Brookhaven National Laboratory). The Evaluated Nuclear Data Files V (ENDF-V) is used for elemental lead.

6.3.4 DEMONSTRATION OF MAXIMUM REACTIVITY

As mentioned in Section 6.3.1, the fissile material is conservatively configured as a compact sphere of fuel with varying amounts of hydrogenous materials. The optimal H/Pu ratio was determined by selecting the configuration with the maximum reactivity. This is the most reactive configuration consistent with a possible damaged condition and the chemical and physical form of the material. This configuration is extremely conservative and would not be expected to occur under NCT or HAC. However, considering the fact that no credit is taken for geometry control provided by the waste drums, this configuration conservatively meets the requirements of 10 CFR 71.55(b) and 71.55(e)(1). The HAC criticality analyses were performed assuming that water leaked into the cask cavity, filling all voids not occupied by the polyethylene, plutonium or beryllium materials.

In addition, maximum reactivity is assured by other features of the simulation. The inclusion of beryllium as a special moderating/reflecting material was demonstrated to increase reactivity. Credit was not taken for the presence of neutron absorbers in the cask payload volume, such as the metal drums and internal drum support structure, which would lower the reactivity.

The majority of the HAC cases had a 25% volume fraction of polyethylene and 1% by weight of beryllium as a special reflector. Four cases were run with the beryllium reduce to 0.5% and an additional four cases were run with beryllium eliminated. An additional four cases were run with the polyethylene reduced to 20% by volume. These cases establish that the 25% volume fraction of polyethylene and 1% by weight of beryllium were the most reactive configuration.

6.4 SINGLE PACKAGE EVALUATION

6.4.1 CONFIGURATION

The general requirements of 10 CFR 71.55(b) are that the package must be subcritical if water were to leak into the containment system so that, under the following conditions, maximum reactivity of the fissile material is attained:

1. Most reactive credible configuration consistent with the chemical and physical form of the material
2. Moderation by water to the most reactive credible extent
3. Close full reflection of the containment system by water on all sides or such greater reflection of the system as may additionally be provided by the surrounding material of the packaging.

The analysis assumes that water leaks into the cask cavity, and the waste drums are not present.

The criticality requirements of 10 CFR 71.55(e) for fissile material packages in accident conditions impose three conditions on the analysis. These conditions must be applied to a package that has undergone the tests specified in 10 CFR 71.73, which means that credit may be taken for the cask remaining leaktight during HAC. The conditions are as follows.

1. The fissile material is in the most reactive credible configuration consistent with the damaged condition of the package and the chemical and physical form of the contents.
2. Water moderation occurs to the most reactive credible extent consistent with the damaged condition of the package and the chemical and physical form of the contents.
3. There is full reflection by water on all sides as close as is consistent with the damaged condition of the package.

6.4.2 RESULTS

With the cask containment dry, the most reactive conditions occur when the quantity of fissile material is in a spherical form and most compact. Although the 10-160B Cask is designed to maintain the payload in the normal, as-loaded configuration shown in Figures 6-1 and 6-2, this evaluation does not take credit for the integrity of the waste drums. The most reactive configuration for this evaluation occurs when the plutonium, polyethylene, and beryllium form a sphere. Various H/Pu ratios are evaluated for the single cask. H/Pu ratio is associated with a given spherical diameter, assuming the material densities, as noted in Tables 6.2 (NCT) and 6.3 (HAC).

The results of the NCT analysis are shown in Figure 6-10 and summarized in Table 6.6. The most reactive NCT configuration was obtained with the fissile sphere in the base corner with water on the outside of the cask and an H/Pu ratio of 1400. The maximum K_{eff} is 0.42656.

The results of the HAC analysis are presented in Figure 6-11 and summarized in Table 6.7. The most reactive HAC configuration was obtained with the fissile sphere in the lid corner with an H/Pu ratio of 900. The maximum K_{eff} is 0.93252 and is below the limit of 0.94. Table 6.7 shows that there is a subcritical margin even if the fissile material is in the worst case configuration. Tables 6.6 and 6.7 summarize these results and demonstrate that all payload configurations meet the NCT and HAC criticality requirements of 10 CFR 71.55(b), (d), and (e).

In addition, Table 6.7 summarizes the results of the analyses that were preformed to examine the effect of less beryllium (0% and 0.5% by mass of total CH_2 and Pu^{239}) and less polyethylene (20% by volume of the 10 drums). The results (Cases f042 through f065) clearly show, by comparison with Case f033, that the most reactive configuration is for 25% by volume CH_2 and 1% by mass for beryllium.

Figure 6-10. Single Unit K_{eff} vs. H/Pu Ratio for NCT for Various Configurations

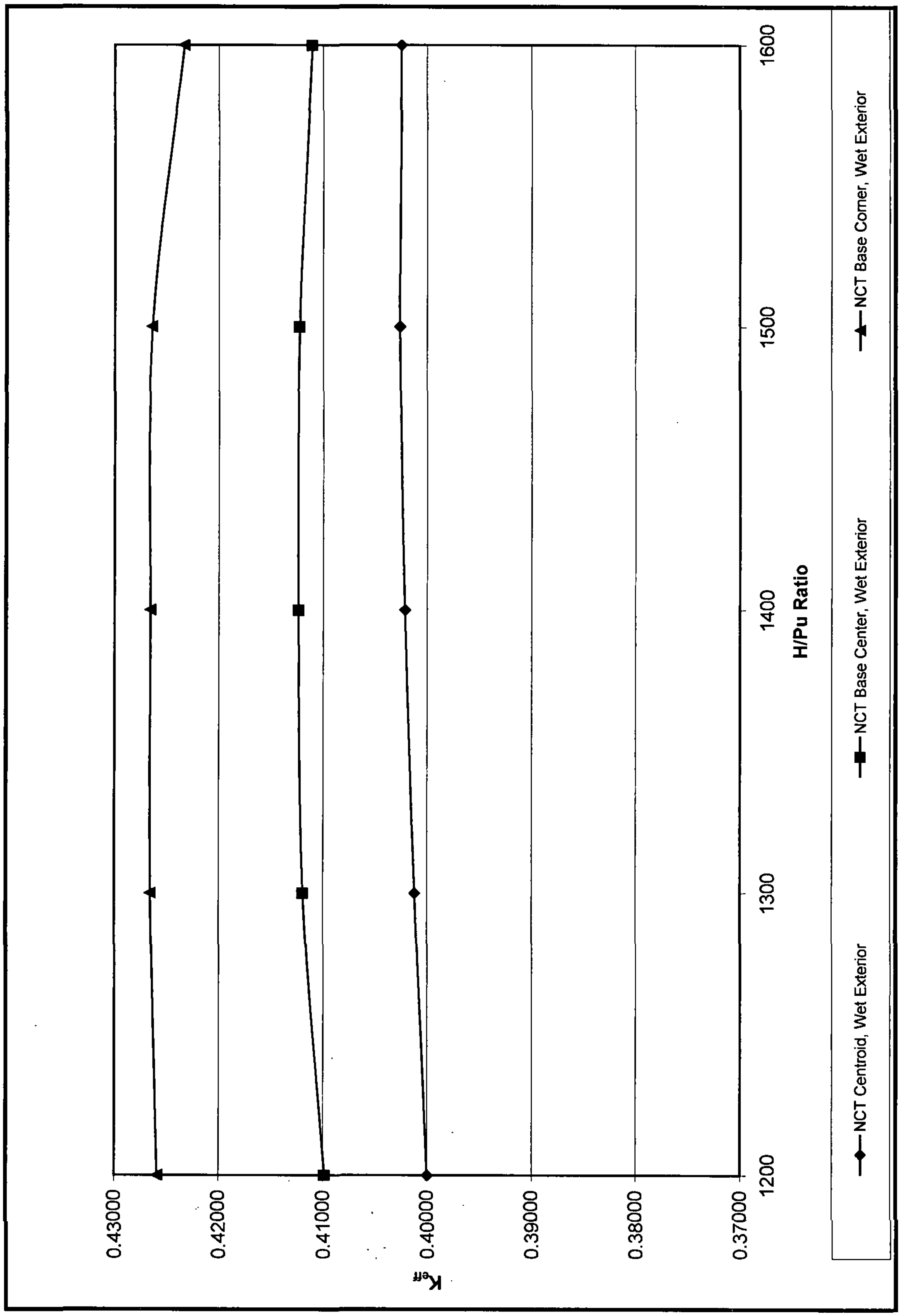


Table 6.6. Single Unit K_{eff} vs. H/Pu Ratio for NCT for Various Configurations

NCT 10-160B Single Cask					
Location	MCNP Case	H/Pu Ratio	K_{eff}	σ_{MCNP}	AEF[a] (eV)
NCT Centroid, Wet Exterior	f307	1200	0.40003	0.00015	0.0498
	f308	1300	0.40121	0.00015	0.0488
	f309	1400	0.40215	0.00014	0.0480
	f310	1500	0.40264	0.00014	0.0472
	f311	1600	0.40249	0.00015	0.0465
NCT Base Center, Wet Exterior	f327	1200	0.40987	0.00015	0.0508
	f328	1300	0.41195	0.00015	0.0497
	f329	1400	0.41236	0.00015	0.0488
	f330	1500	0.41228	0.00015	0.0480
	f331	1600	0.41108	0.00014	0.0473
NCT Base Corner, Wet Exterior	f367	1200	0.42589	0.00015	0.0519
	f368	1300	0.42655	0.00015	0.0507
	f369	1400	0.42656	0.00015	0.0497
	f370	1500	0.42641	0.00015	0.0489
	f371	1600	0.42334	0.00015	0.0481

[a] Energy corresponding to the average neutron lethargy causing fission (AEF)

Figure 6-11. Single Unit K_{eff} vs. H/Pu Ratio for HAC for Various Configurations

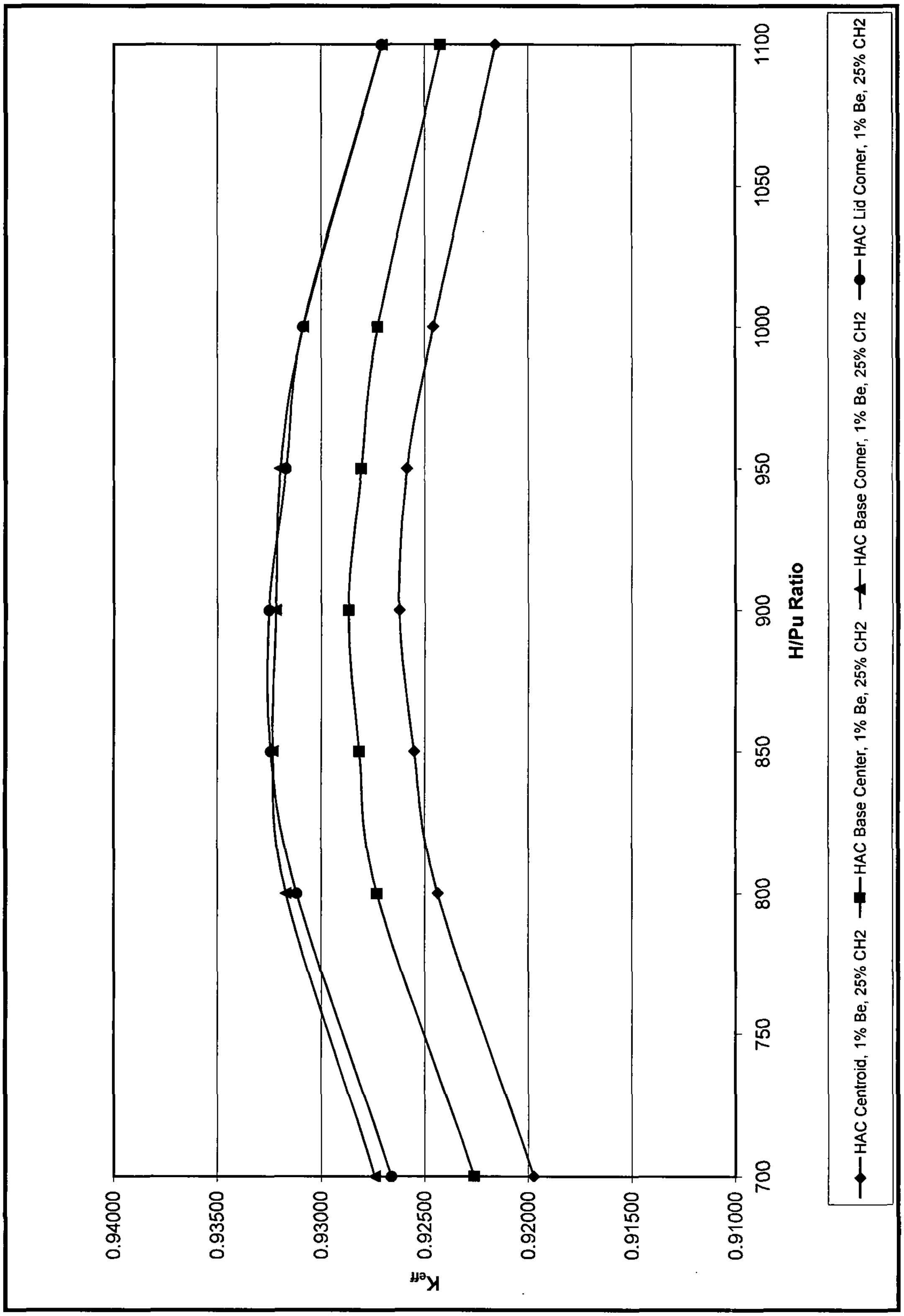


Table 6.7. Single Unit K_{eff} vs. H/Pu Ratio for HAC for Various Configurations

HAC 10-160B Single Cask					
Location	MCNP Case	H/Pu Ratio	K_{eff}	σ_{MCNP}	AEF[a] (eV)
HAC Centroid, 1% Be, 25% CH_2	f000	700	0.91975	0.00022	0.0586
	f001	800	0.92438	0.00020	0.0556
	f002	850	0.92552	0.00021	0.0543
	f003	900	0.92624	0.00020	0.0532
	f004	950	0.92586	0.00021	0.0522
	f005	1000	0.92458	0.00020	0.0513
	f006	1100	0.92158	0.00019	0.0498
HAC Base Center, 1% Be, 25% CH_2	f010	700	0.92261	0.00021	0.0590
	f011	800	0.92731	0.00020	0.0559
	f012	850	0.92816	0.00020	0.0546
	f013	900	0.92869	0.00021	0.0535
	f014	950	0.92806	0.00020	0.0525
	f015	1000	0.92726	0.00020	0.0515
	f016	1100	0.92424	0.00019	0.0499
HAC Base Corner, 1% Be, 25% CH_2	f020	700	0.92741	0.00021	0.0594
	f021	800	0.93169	0.00021	0.0562
	f022	850	0.93232	0.00020	0.0548
	f023	900	0.93219	0.00021	0.0537
	f024	950	0.93197	0.00020	0.0527
	f025	1000	0.93085	0.00020	0.0517
	f026	1100	0.92705	0.00020	0.0502
HAC Lid Corner, 1% Be, 25% CH_2	f030	700	0.92661	0.00021	0.0594
	f031	800	0.93118	0.00021	0.0562
	f032	850	0.93243	0.00020	0.0549
	f033	900	0.93252	0.00020	0.0537
	f034	950	0.93168	0.00020	0.0527
	f035	1000	0.93087	0.00020	0.0518
	f036	1100	0.92707	0.00019	0.0502
HAC Lid Corner, 0.5% Be, 25% CH_2	f042	850	0.93202	0.00020	0.0549
	f043	900	0.93213	0.00020	0.0537
	f044	950	0.93219	0.00020	0.0526
	f045	1000	0.93076	0.00020	0.0518
HAC Lid Corner, 0.0% Be, 25% CH_2	f052	850	0.93188	0.00021	0.0549
	f053	900	0.93199	0.00020	0.0536
	f054	950	0.93127	0.00020	0.0527
	f055	1000	0.93077	0.00020	0.0518
HAC Lid Corner, 1% Be, 20% CH_2	f062	850	0.92786	0.00020	0.0549
	f063	900	0.92859	0.00020	0.0538
	f064	950	0.92790	0.00020	0.0526
	f065	1000	0.92661	0.00019	0.0518

[a] Energy corresponding to the average neutron lethargy causing fission (AEF)

6.5 EVALUATION OF PACKAGE ARRAYS UNDER NCT

6.5.1 CONFIGURATION

The criticality requirements in 10 CFR 71.59(a) for arrays of fissile material packages in NCT require that 5 times N undamaged packages with nothing between the packages be subcritical, assuming packages are stacked together in any arrangement and with close full reflection on all sides of the array by water.

Normally, the array calculations begin with an infinite array model because, if the infinite array is adequately subcritical, no additional array calculations are necessary. If the infinite array is not shown to be safely subcritical, a finite array of packages is analyzed until an array size is found that is adequately subcritical. An infinite array of 10-160B Casks with the payloads described in Section 6.2 is adequately subcritical during NCT. Therefore, finite array cases are not necessary.

The MCNP model for the infinite array calculations is identical to the single-cask model except that the 30.5 cm (12-in.) water reflector is removed. Six reflective surfaces are added to form a tight-fitting hexagon around the cask and two reflective surfaces are placed at the top and bottom of the cask, as shown in Figure 6-12. The use of reflective surfaces around the side, top, and bottom simulates an infinite array of casks in the radial and axial directions. Two additional infinite array cases are run where the cask spacing is varied from 5 cm to 10 cm.

6.5.2 RESULTS

Table 6.8 summarizes the results of the NCT infinite array calculations. Because the k_{eff} values decrease slightly with increasing cask spacing (0.45328 for close-packed versus 0.44635 for 10 cm cask spacing), these cases indicate that there is some neutronic communication between the casks in the array when the containment is dry and there is no interspersed moderation. The results for the NCT array calculations indicate that an infinite array of 10-160B Casks loaded with any fissile configurations is safely subcritical with a maximum k_{eff} value of 0.45328 (case f369a).

Figure 6-12. Plan View of an Infinite Array of NCT 10-160B Casks (MCNP case f369a).

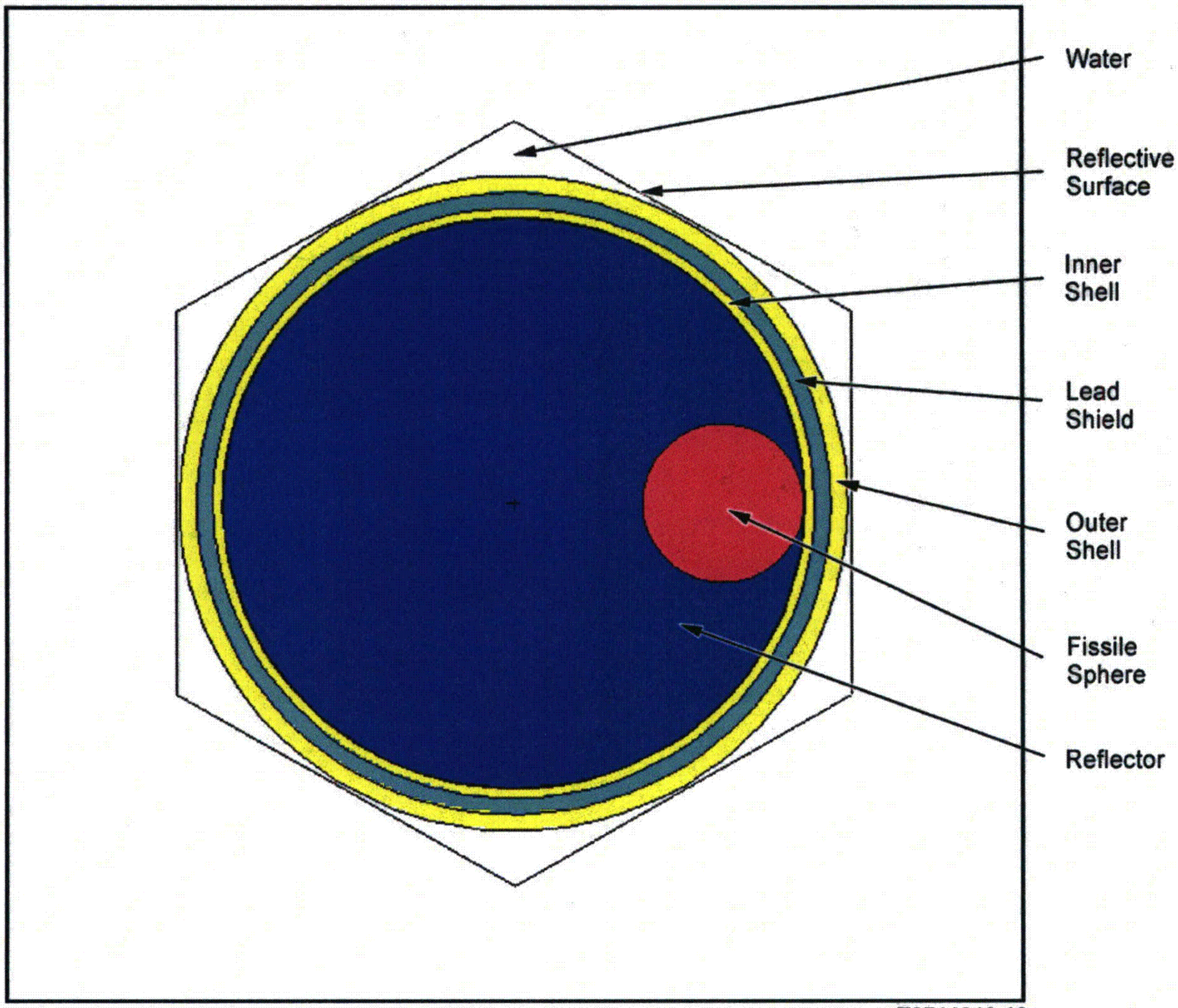


Table 6.8. Values of K_{eff} vs. Array Spacing for an Infinite Array of 10-160B Casks Under NCT.

NCT 10-160B Infinite Array					
Location	MCNP Case	Array Spacing	K_{eff}	σ_{MCNP}	AEF[a] (eV)
Base Corner	f369a	0.00	0.45328	0.00015	0.0495
	f369b	5.00	0.44946	0.00015	0.0496
	f369c	10.00	0.44635	0.00015	0.0496

[a] Energy corresponding to the average neutron lethargy causing fission (AEF)

6.6 EVALUATION OF PACKAGE ARRAYS UNDER HAC

6.6.1 CONFIGURATION

The criticality requirements of 10 CFR 71.59(a)(2), for arrays of fissile material packages under accident conditions require that 2 times N ($N \geq 0.5$) damaged packages be subcritical, assuming the packages are stacked together in any arrangement, with close full reflection on all sides of the array by water, and with optimum interspersed hydrogenous moderation. Although the 10-160B Cask remains sealed under the accident-condition tests specified in 10 CFR 71.73, the criticality analysis for arrays during accident conditions conservatively assumes in-flooding of the cask containment.

As discussed in Section 6.5, the array calculations normally begin with an infinite array model. If the infinite array is adequately subcritical, no additional array calculations are necessary. The infinite array model developed for NCT in Section 6.5 is used as the baseline model for the HAC array calculations. The only differences being the addition of interspersed moderation (see Figure 6.4) between the casks in the array per 10 CFR 71.59(a) (2) and the worst case single Cask model evaluated under HAC. The NCT array cases assumed nothing in between the casks per 10 CFR 71.59(a) (1).

With a hexagonal infinite array of casks, there are two basic orientations of the fissile sphere in a hexagonal cell, either at the flat (Figure 6-13) or at the apex (Figure 6-14). If the fissile sphere is at the flat, two spheres in adjacent cells are very close (four spheres if at the base or lid of the cask). If the fissile sphere is at the apex, three spheres in adjacent cell are farther apart (six spheres if at the base or lid of the case).

Figure 6-13. Plan View of an Infinite Array of HAC 10-160B Casks (MCNP case f022flat00).

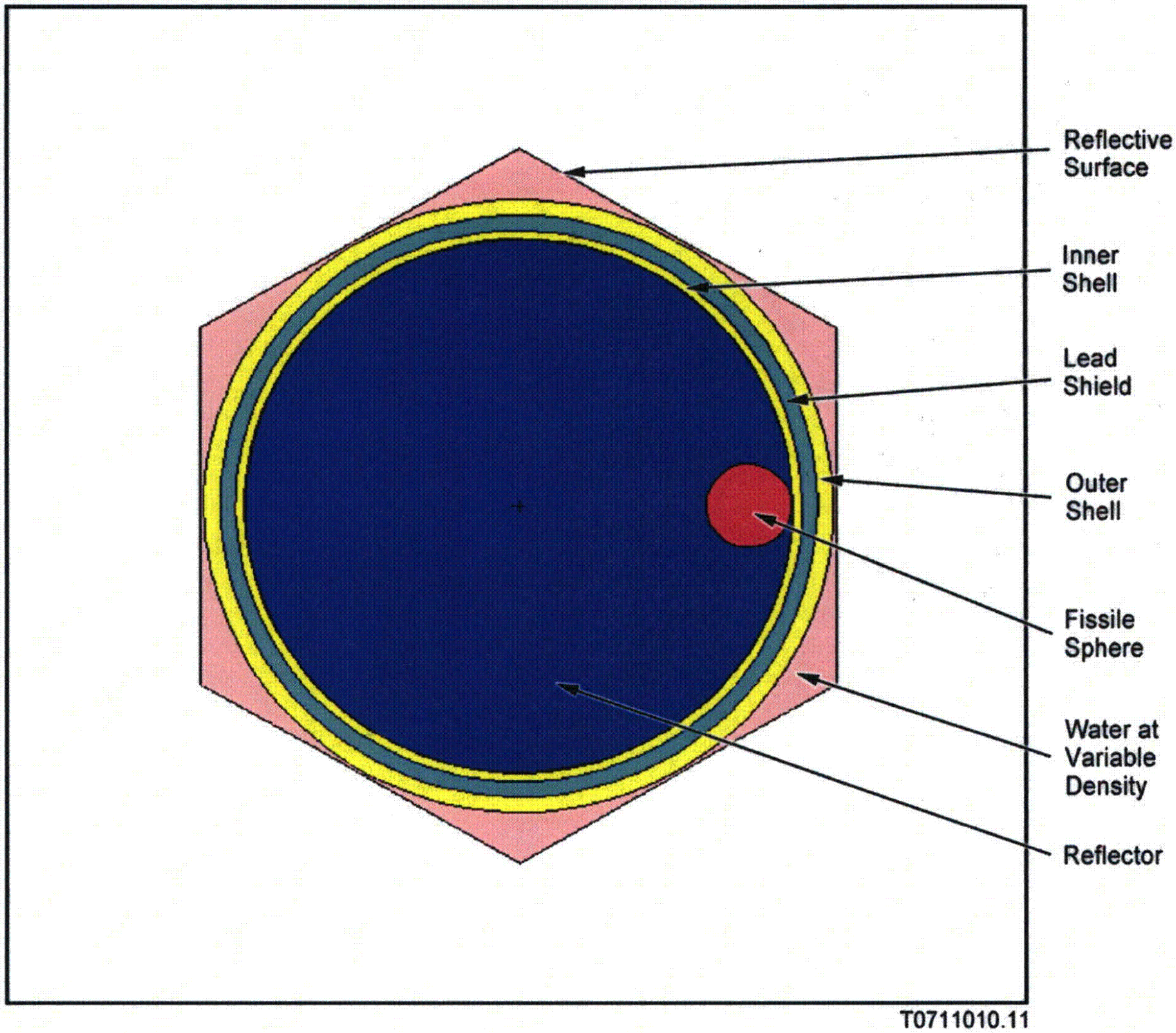
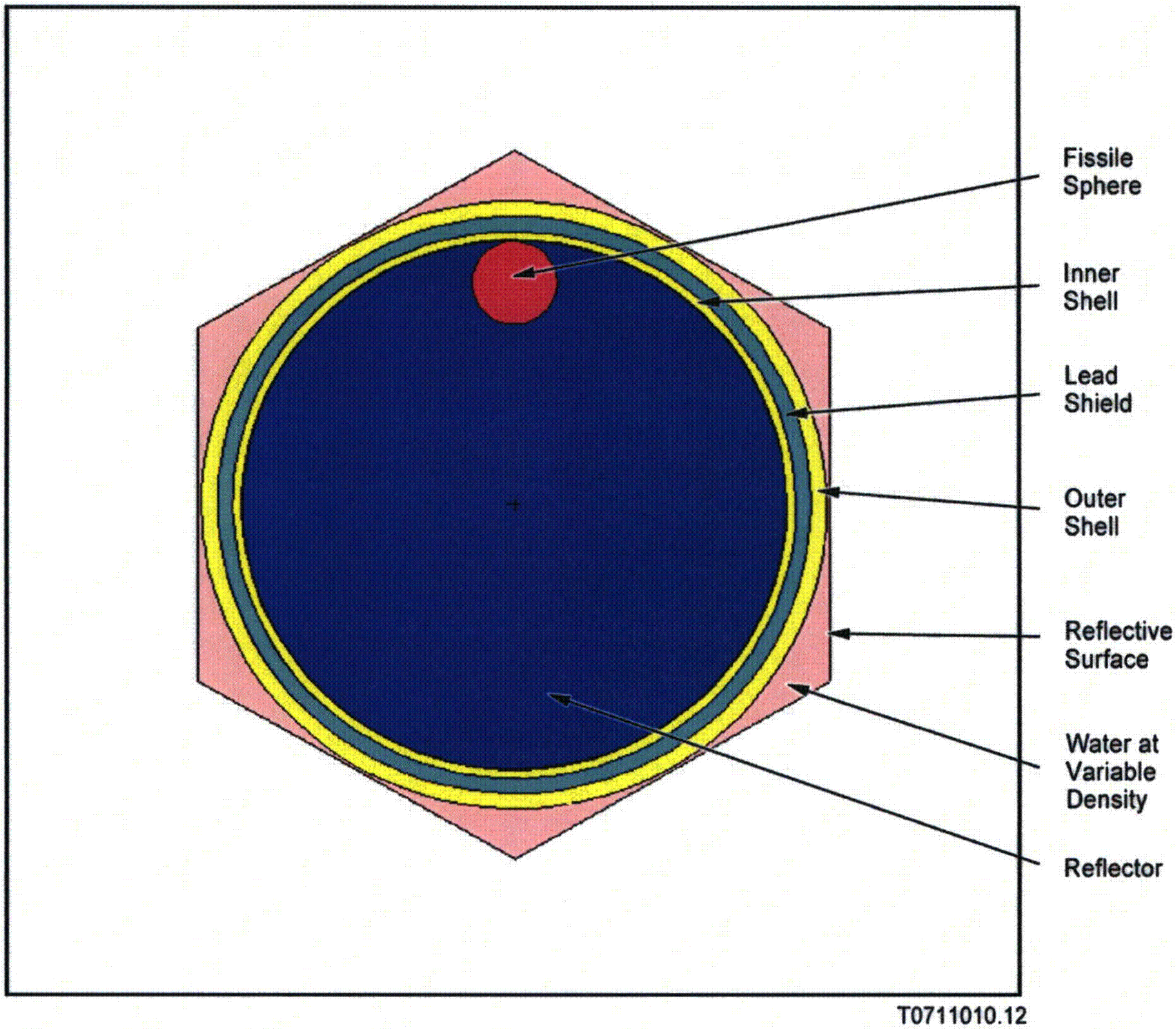


Figure 6-14. Plan View of an Infinite Array of HAC 10-160B Casks (MCNP case f022apex00).



6.6.2 RESULTS

The individual HAC cases, as summarized in Table 6.7, show that case f033 was the most reactive. Case f033 was a lid corner case. Since the effective axial distance between adjacent casks in an infinite array is greater with a lid corner case, the most reactive base corner case (f022) was selected for infinite array evaluation as well.

The HAC array cases have a baseline external configuration identical to the NCT array cases except that the interspersed region is filled with water at various densities and the fissile sphere is evaluated at the apex and flat (see Figures 6.13 and 6.14). Table 6.9 summarizes the values of K_{eff} for an infinite array of 10-160B casks under HAC for various interspersed water densities ranging from 0.00 to 1.00 g/cm^3. As noted before, single unit cases designated as f033 and f022 were selected for infinite array evaluation in the apex and flat orientations. Table 6.9 presents the evaluation of these four general cases for water densities ranging from 0.00 to 0.10 g/cm^3. The f022 flat cases were extended to a maximum water density of 1.00 g/cm^3 since that composition and orientation was the most reactive from 0.00 to 0.10 g/cm^3.

The differences between the k_{eff} values for very low interspersed water densities (i.e., 0 to 0.001 g/cm^3) are statistically insignificant. However, water densities greater than 0.01 g/cm^3 indicate that the k_{eff} values decrease with increasing density. This is most likely due to the increased absorption of neutrons in the water. Therefore, optimum interspersed moderation corresponds to dry, or very low, moderation between the casks in the array.

The results for the HAC array calculations indicate that an infinite array of 10-160B Casks loaded with any of the fissile configurations is safely subcritical with a maximum k_{eff} value of 0.93873 (case f022flat02). Because an infinite array of 10-160B Casks, with the contents described in Section 6.2, are safely subcritical during HAC no finite array cases are necessary. Appendix 6.9.2 contains representative MCNP input files used in this evaluation.

Table 6.9. Values of K_{eff} vs Interspersed Water Densities for an Infinite Array of 10-160B Casks Under HAC.

HAC 10-160 B Infinite Array					
Location	MCNP Case	Water Fraction	K_{eff}	σ_{MCNP}	AEF[a] (eV)
HAC Base Corner	f022apex00	0.00000	0.93764	0.00021	0.0548
	f022apex01	0.00010	0.93749	0.00020	0.0548
	f022apex02	0.00100	0.93770	0.00020	0.0548
	f022apex03	0.01000	0.93754	0.00020	0.0548
	f022apex04	0.10000	0.93594	0.00020	0.0549
	f022flat00	0.00000	0.93871	0.00020	0.0548
	f022flat01	0.00010	0.93870	0.00020	0.0548
	f022flat02	0.00100	0.93873	0.00020	0.0548
	f022flat03	0.01000	0.93829	0.00021	0.0548
	f022flat04	0.10000	0.93745	0.00021	0.0548
	f022flat05	0.20000	0.93708	0.00021	0.0549
	f022flat06	0.30000	0.93674	0.00020	0.0548
	f022flat07	0.40000	0.93611	0.00020	0.0548
	f022flat08	0.50000	0.93551	0.00021	0.0549
	f022flat09	0.60000	0.93535	0.00020	0.0549
	f022flat10	0.70000	0.93529	0.00021	0.0549
	f022flat11	0.80000	0.93518	0.00020	0.0548
	f022flat12	0.90000	0.93461	0.00020	0.0548
	f022flat13	1.00000	0.93468	0.00020	0.0549
HAC Lid Corner	f033apex00	0.00000	0.93610	0.00020	0.0537
	f033apex01	0.00010	0.93613	0.00020	0.0537
	f033apex02	0.00100	0.93609	0.00020	0.0537
	f033apex03	0.01000	0.93603	0.00020	0.0537
	f033apex04	0.10000	0.93391	0.00020	0.0537
	f033flat00	0.00000	0.93692	0.00020	0.0536
	f033flat01	0.00010	0.93700	0.00020	0.0537
	f033flat02	0.00100	0.93713	0.00020	0.0537
	f033flat03	0.01000	0.93666	0.00020	0.0537
	f033flat04	0.10000	0.93568	0.00021	0.0537

[a] Energy corresponding to the average neutron lethargy causing fission (AEF)

6.7 FISSILE MATERIAL PACKAGES FOR AIR TRANSPORT

This section is not applicable. The Applicant did not design the 10-160B Cask for air transport nor does the Applicant seek authorization for air transport.

6.8 BENCHMARK EVALUATIONS

This section summarizes calculations for experimental criticality benchmarks used to validate the computer code MCNP 5 (LANL 2003) with pointwise ENDF/B-VI cross sections processed as described in Appendix G of the MCNP manual. The bias factor obtained from these calculations of the critical experiments is applied to the MCNP-calculated k_{eff} values in Sections 6.4 and 6.5 to ensure that adequate subcriticality margin exists for shipment of the 10-160B Cask.

The MCNP 5 executable was verified initially by executing the 42 standard test problems provided by the code developer, Los Alamos National Laboratory, and confirming that the results agree with the standard output (OUTP and MCTAL) files provided by Los Alamos National Laboratory. This section focuses on validation of MCNP's pointwise ENDF/B-VI cross-sectional library using 40 experimental criticality benchmarks involving plutonium.

6.8.1 APPLICABILITY OF BENCHMARK EXPERIMENTS

The experimental benchmarks are taken from NEA/NSC/DOC (95)03, *International Handbook of Evaluated Criticality Safety Benchmark Experiments*, [4] which discusses each experiment in detail. It includes estimates of the uncertainty in the measurements, detailed information regarding dimensions and material compositions, comparisons between the multiplication factor calculated by various computer codes, and a list of input files that are used in their calculations.

The cases of interest to establish a bias for this criticality evaluation involve critical experiments for thermal plutonium solution forms. The plutonium measurements are designated in NEA/NSC/DOC (95)03 as PU-SOL-THERM-001, -002, -003, -004, -006, and -009. These are judged to be the most applicable to the 10-160B Cask criticality evaluation, which contains plutonium in solution form.

The MCNP input files for these critical experiments are taken directly from NEA/NSC/DOC (95)03 with one modification. The material definitions for several elements were modified because some elements in the MCNP ENDF/B-V cross-sectional library no longer have corresponding cross sections in the ENDF/B-VI library. This results in the need to convert material compositions for an element into the corresponding material compositions for the naturally occurring isotopes of that element. For example, if the original input file has a material composition consisting entirely of iron (cross-section ID = 26000.50c), the revised input file for the ENDF/B-VI cross sections contains a material composition as follows:

26054.66c	0.0584	(^{54}Fe)
26056.66c	0.9175	(^{56}Fe)
26057.66c	0.0212	(^{57}Fe)
26058.66c	0.0028	(^{58}Fe)

This procedure is done to reflect the naturally occurring isotopic abundances of iron of 0.058, 0.9172, 0.022, and 0.0028 for ^{54}Fe, ^{56}Fe, ^{57}Fe, and ^{58}Fe, respectively. Similar changes are made for the following elements: silicon (z=14), chromium (z=24), nickel (z=28), copper (z=29), and lead (z=82).

Additionally, three elements were simulated with the single isotope present in the EDF/B-V cross-sectional library. The material compositions were modified to allow for the additional naturally-occurring isotope available in the ENDF/B-VI library. Therefore, hydrogen was expanded from 1001.50c to 1001.66c and 1002.66c. Nitrogen was expanded from 7014.50c to 7014.66c and 7015.66c. Oxygen was expanded from 8016.50c to 8016.66c and 8017.66c. Cross-sections were not available for 8018.66c so that naturally occurring percentage was lumped into the 8016.66c. These are minor changes that reflect the cross-section philosophy used in the criticality evaluations.

6.8.2 BIAS DETERMINATION

The results of the plutonium benchmark calculations are shown in Table 6.10. The first three columns of this table show a unique case number and case identifier. The fourth column shows the ratio of elemental hydrogen to fissile (Pu^{239} plus Pu^{241}). The fifth column shows the Pu^{240} content as a percentage of the total Pu. The sixth column shows the MCNP calculated k_{eff} value, and the seventh column is the one-standard-deviation statistical uncertainty in the MCNP calculation. The eighth column is an estimate of the one-standard-deviation experimental uncertainty. The ninth column of Table 6.10 shows the average neutron energy causing fission (AEF) for these experiments that is calculated by MCNP. This parameter is useful for characterizing the neutron spectrum of the system.

These benchmark cases were chosen to bracket the criticality simulations of the 10-160B Cask. As presented at the bottom of Table 6.10, the H/X ratio of the benchmark cases ranged from a low of 91 to a high of 2807, with eighteen between 700 and 1100.

The Pu^{240} content of the 10-160B criticality simulations was assumed to be zero since Pu^{240} acts as a neutron poison. However, Pu^{239} without Pu^{240} would be unusual so benchmark cases with low Pu^{240} content were chosen when possible. All forty benchmark cases had Pu^{240} contents less than 4.65%. Thirty-three benchmark cases had Pu^{240} contents less than 3.1% and four cases less than 0.54% Pu^{240}.

The AEF values for the criticality cases for the 10-160B Cask (see Tables 6.6, 6.7, 6.8, and 6.9) range from 0.0495 to 0.0594, and are well bracketed by the AEF values for the benchmark cases.

Table 6.10. Results of Monte Carlo N-Particle Calculations of the Forty Plutonium Benchmark Experiments.

	Case Identifier[a]		H/X	Pu240/Pu	K_{eff}	σ_{MCNP}	$\sigma_{experiment}$	AEF (eV)[b]
1	pust.001	Case 1.T8A	370	0.04650	1.00441	0.00045	0.005	0.0877
2	pust.001	Case 2.T8A	271	0.04650	1.00505	0.00045	0.005	0.1106
3	pust.001	Case 3.T8A	215	0.04650	1.00735	0.00046	0.005	0.1344
4	pust.001	Case 4.T8A	190	0.04650	1.00338	0.00046	0.005	0.1507
5	pust.001	Case 5.T8A	180	0.04650	1.00682	0.00047	0.005	0.1591
6	pust.001	Case 6.T8A	91	0.04650	1.00752	0.00046	0.005	0.3477
7	pust.002	Case 1	524	0.03107	1.00393	0.00044	0.0047	0.0707
8	pust.002	Case 2	505	0.03107	1.00401	0.00044	0.0047	0.0724
9	pust.002	Case 3	451	0.03107	1.00264	0.00043	0.0047	0.0775
10	pust.002	Case 4	421	0.03107	1.00527	0.00045	0.0047	0.0808
11	pust.002	Case 5	393	0.03107	1.00835	0.00044	0.0047	0.0844
12	pust.002	Case 6	344	0.03107	1.00344	0.00044	0.0047	0.0924
13	pust.002	Case 7	309	0.03107	1.00599	0.00044	0.0047	0.0998
14	pust.003	Case 1	788	0.01753	1.00347	0.00041	0.0047	0.0579
15	pust.003	Case 2	756	0.01753	1.00198	0.00041	0.0047	0.0590
16	pust.003	Case 3	699	0.03107	1.00564	0.00042	0.0047	0.0615
17	pust.003	Case 4	682	0.03107	1.00431	0.00042	0.0047	0.0623
18	pust.003	Case 5	627	0.03107	1.00564	0.00042	0.0047	0.0651
19	pust.003	Case 6	563	0.03107	1.00524	0.00043	0.0047	0.0690
20	pust.003	Case 7	738	0.03107	1.00698	0.00042	0.0047	0.0588
21	pust.003	Case 8	714	0.03107	1.00567	0.00042	0.0047	0.0598
22	pust.004	Case 1	987	0.00538	1.00454	0.00039	0.0047	0.0530
23	pust.004	Case 2	977	0.00538	0.99927	0.00039	0.0047	0.0532
24	pust.004	Case 3	935	0.00538	1.00143	0.00039	0.0047	0.0543
25	pust.004	Case 4	889	0.00538	0.99917	0.00039	0.0047	0.0555
26	pust.004	Case 5	942	0.01753	1.00023	0.00040	0.0047	0.0542
27	pust.004	Case 6	927	0.03107	1.00216	0.00040	0.0047	0.0544
28	pust.004	Case 7	892	0.03107	1.00588	0.00040	0.0047	0.0555
29	pust.004	Case 8	869	0.03107	1.00186	0.00040	0.0047	0.0562
30	pust.004	Case 9	805	0.03107	1.00147	0.00041	0.0047	0.0583
31	pust.004	Case 10	689	0.03107	1.00171	0.00040	0.0047	0.0629
32	pust.004	Case 11	592	0.03107	1.00023	0.00041	0.0047	0.0679
33	pust.004	Case 12	893	0.03107	1.00326	0.00039	0.0047	0.0554
34	pust.004	Case 13	903	0.03416	1.00041	0.00040	0.0047	0.0553
35	pust.006	Case 1	1061	0.03107	1.00133	0.00037	0.0035	0.0521
36	pust.006	Case 2	1018	0.03107	1.00273	0.00038	0.0035	0.0531
37	pust.006	Case 3	940	0.03107	1.00220	0.00038	0.0035	0.0548
38	pust.009	Case 1A	2652	0.02511	1.01585	0.00043	0.0033	0.0413
39	pust.009	Case 2A	2783	0.02511	1.02009	0.00041	0.0033	0.0408
40	pust.009	Case 3A	2807	0.02511	1.01875	0.00040	0.0033	0.0408
Average of All Experiments					1.00474	0.00042	0.00455	
Range		Minimum	91	0.00538	0.99917	0.00037		0.0408
		Maximum	2807	0.04650	1.02009	0.00047		0.3477

[a] All cases from NEA/NSC/DOC(95)03

[b] Energy corresponding to the average neutron lethargy causing fission (AEF), in units of electronvolts

NEA/NSC/DOC(95)03, *International Handbook of Evaluated Criticality Safety Benchmark Experiments*[4]

NUREG/CR-5661, *Recommendations for Preparing the Criticality Safety Evaluation of Transportation Packaging for Radioactive Material,* [5] recommends the following general relationship for establishing acceptance criteria for criticality calculations:

$$k_c - \Delta k_u \geq k_{eff} + 2\sigma + \Delta k_m,$$

where:

k_c	=	k_{eff} resulting from the calculation of benchmark critical experiments using a specific calculational method and data
Δk_u	=	An allowance for the calculational uncertainty
Δk_m	=	A required margin of subcriticality (0.05)
k_{eff}	=	The calculated value obtained from the Monte Carlo analysis for the package or array of packages
σ	=	The standard deviation of the k_{eff} value obtained from the Monte Carlo analysis.

If the calculational bias β is defined as $\beta= 1 - k_c$, then the bias is positive if $k_c < 1$ and negative if $k_c > 1$. The acceptance relationship may be rewritten as:

$$1.00 - \beta - \Delta k_u \geq k_{eff} + 2\sigma + 0.05, \text{ or}$$

$$k_{eff} + \beta + 2\sigma + \Delta k_u \leq 0.95.$$

To account for the calculational and experimental uncertainty for the benchmark criticals, the mean value of σ_{MCNP} from MCNP for the critical experiments and the experimental uncertainty $\sigma_{experiment}$ ($=\Delta k_u$) are combined in quadrature with the standard deviation (σ) of the k_{eff} value obtained from the MCNP NCT or HAC analysis. This results in the following acceptance relationship:

$$k_{eff} + \beta + 2(\sigma^2 + \sigma^2_{MCNP} + \sigma^2_{experiment})^{0.5} \leq 0.95$$

The statistical summary at the bottom of Table 6-10 is used to obtain the calculational and experimental uncertainties for the benchmark criticals. There were no observable trends for the benchmark k_{eff} values (i.e., versus AEF, H/X, etc.) that would impact the bias determination. All but 2 of the benchmark experiments had k_{eff} values greater than 1.0. Because the average k_{eff} is greater than 1.0, and the 2 benchmark experiments with k_{eff} values below 1.0 are greater than 0.999, the bias, β, was set to zero in the determination of the effective criticality limit for this evaluation. Therefore, with the bias and uncertainties, the acceptance criteria is:

$$k_{eff} + 0.00 + 2(\sigma^2 + 0.00092^2 + 0.00479^2)^{0.5} \leq 0.95$$

In a typical MCNP calculation for the 10-160B Cask, the standard deviation (σ_{MCNP}) is less than 0.00025. Therefore, solving for keff yields:

$$k_{eff} \leq 0.95 - [0.00 + 2(\sigma^2 + 0.00092^2 + 0.00479^2)^{0.5}]$$

The k_{eff} from the above equation is 0.94002 for $\sigma = \sigma_{MCNP} = 0.00025$.

The effective criticality limit for this evaluation is set to 0.9400, which assumes that the MCNP calculation is run long enough to obtain a $\sigma_{MCNP} \leq 0.00025$. This means that the MNCP-calculated k_{eff} values must be less than 0.9400 to demonstrate adequate subcriticality margin after accounting for bias and uncertainties as long as $\sigma_{MCNP} \leq 0.00025$.

6.9 APPENDIX

The appendices to Chapter 6 include a list of references and representative MCNP input listings.

6.9.1 REFERENCES

1 *Packaging and Transportation of Radioactive Material*, Code of Federal Regulations, Title 10, Part 71, Washington, DC (January 2006)

2. FSWO-QAP-001, *Quality Assurance Procedures*, Procedure QP 3-10, *Software Management*, Energy*Solutions* Federal Services, Inc., Western Operations, Richland, Washington

3. *MCNP—A General Monte Carlo N-Particle Transport Code, Version 5*, LA-UR-03-1987, Release 1.4, Los Alamos National Laboratory, Los Alamos, New Mexico (2003)

4. *International Handbook of Evaluated Criticality Safety Benchmark Experiments*, NEA/NSC/DOC(95)03, September 2002 Edition, *Organization for Economic Co-operation and Development*, Nuclear Energy Agency, Paris, France (2002)

5. *Recommendations for Preparing the Criticality Safety Evaluation of Transportation Packaging for Radioactive Material,* NUREG/CR-5661, U.S. Nuclear Regulatory Commission, Washington, DC (1997)

6. U.S. Department of Energy (DOE), *Remote-Handled Transuranic Waste Authorized Methods for Payload Control* (RH-TRAMPAC), Revision 0, 2006, U.S. Department of Energy, Carlsbad Field Office, Carlsbad, New Mexico.

7. *RH-TRU 72-B Safety Analysis Report, Revision 4, 2006.*

8. WP-8-PT.09, *Test Plan to Determine the TRU Waste Polyethylene Packing Fraction*, Washington TRU Solutions, LLC., Revision 0, June 2003.

6.9.2 REPRESENTATIVE MCNP INPUT FILES

NCT Single Cask – f369

```
10-160B
c
3000   139 -0.238656         -2000
                                   imp:n=1
3001   169 -0.233058   +2000 +120  -2100 -30
                                   imp:n=1
4000   500 -0.00122    +120  -149   -30 +2100
c     4000   901 -0.983047   +120  -149   -30
c     4000   902 -0.985333   +120  -149   -30
c     4000   903 -0.987607   +120  -149   -30
                     #(+130  +10   )
                                   imp:n=1
c
c  Cask Regions
5      300 -8.03 ((30:-120)(-40 110 -130)):(130 -140 10 -40):
               (10 -20 140 -149):(149 -150 -20)      imp:n=1   $ Liner 11 ga - SS304
10     200 -7.85 (100 -109 -70)                      imp:n=1   $ Base-Carbon Steel
15     200 -7.85 (109 -110 -50)                      imp:n=1   $ Base-Carbon Steel
20     200 -7.85 (110 -140 40 -50)                   imp:n=1   $ Inner Shell-Carbon Steel
25     400 -11.34 (109 -140 50 -60)                  imp:n=1   $ Lead wall
30     200 -7.85  (109 -140 60 -70)                  imp:n=1   $ steel
40     200 -7.85 (140 -150 20 -70):(150 -160 -70):(160 -170 -25)
                                                     imp:n=1 $ Prim/2ndary lid-Carbon Steel
c
c     Water reflector
5000  600 -1.0      (-500 510 -520) (((70:-100) -160):(160 25):170)
                                                     imp:n=1 $ 1st 5 cm
5001  600 -1.0      (-501 511 -521) (500:-510:520)  imp:n=0.25 $ Out to 12 inches
5002  0                    (501:-511:521)            imp:n=0    $ Outside universe
c
9000  0                        -2001                 imp:n=1
c
c  Cask Radial Zones
10      cz       39.0525  $ Lid recess liner
20      cz       39.37    $ Lid recess
25      cz       58.42    $ 2ndary lid
30      cz       86.0425  $ Inner cavity
40      cz       86.36    $ OD Liner (11 ga)
50      cz       89.2175  $ OD Inner shell
60      cz       93.98    $ OD Lead
70      cz       99.06    $ OD Outer shell
80      cz       99.695   $ OD Thermal barrier-not included in model
c  Cask Axial Zones
100     pz       0.0001   $ Bottom cask
109     pz       11.43    $ Bottom lead in side wall
110     pz       13.97    $ Base plate
120     pz       14.2875  $ Bottom liner
125     pz       174.32655  $ Top of mixture for H/D=0.93
130     pz       209.2325 $ Cavity hgt
140     pz       209.55   $ Top liner
149     pz       216.8525 $ Lid recess liner
150     pz       217.17   $ Top of lid recess
160     pz       223.52   $ Primary lid
170     pz       231.14   $ Top of 2nd lid
c
c Planes for water reflector - 1st 5 cm and out to 12 inches
c
500     cz   104.06
501     cz   129.54
510     pz  -5
511     pz  -30.48
520     pz   236.14
521     pz   261.62
c
1000    so   1000          $ beyond problem
```

```
c
2000   s    61.948    0.000     38.382    23.994894
2001   s    61.948    0.000     38.382    19.0
2002   s    61.948    0.000     38.382    79.210227
c
2100  pz 103.79361
c
c
mode n
kcode    4000 0.9   50  4000
sdef   x=d1   y=d2   z=d3     ccc=9000 eff=0.00001
c     ksrc    0   0  120
c
si1    -19.0     86.1
sp1      0        1
c
si2    -19.0     19.0
sp2      0        1
c
si3     14.0    210.0
sp3      0        1
c
c Material Definitions
c
c
c    H/Pu    1400
c    H2O/CH2    0.0000000
c    Be w%    1.000000%    of CH2 + Pu
c    Radius    23.994894    cm
c    Pu-239 Mass    325.000000    g
c    Density    0.238656    g/cc
c     0.000    0.000    120.000    23.99489      Center
c     0.000    0.000     38.382    23.99489      Bottom
c    61.948    0.000     38.382    23.99489      Lower Corner
c    61.948    0.000    185.138    23.99489      Upper Corner
c
m139     1001.66c    -0.13886897    $    H-1
         1002.66c    -0.00004163    $    H-2
         4009.66c    -0.00990099    $    Be-nat
         6000.66c    -0.82765605    $    C-nat
c         8016.66c    0.00000000    $    O-16 & O-18
c         8017.66c    0.00000000    $    O-17
        94239.66c    -0.02353235    $    Pu-239
mt139   poly.60t     be.60t
c
c
c    H2O/CH2    0.000
c    Be w%    1.00%    of CH2
c    Density    0.104514    g/cc    Full Vessel
c    Density    0.233058        Sphere Reflector
c    Radius    79.210227        Sphere Reflector
c    Height    0.000000
c
m169     1001.66c    -0.14224992    $    H-1
         1002.66c    -0.00004265    $    H-2
         4009.66c    -0.00990099    $    Be-nat
         6000.66c    -0.84780644    $    C-nat
c         8016.66c    0.00000000    $    O-16 & O-18
c         8017.66c    0.00000000    $    O-17
mt169   poly.60t     be.60t
c
c
c
c      Carbon Steel
c    Density    7.85         g/cc
c
m200   6000.66c    -0.003000       $ C-nat
      14028.66c    -0.002572       $ Si-28
      14029.66c    -0.000135       $ Si-29
      14030.66c    -0.000092       $ Si-30
      15031.66c    -0.000400       $ P-31
```

```
      16000.66c    -0.000500        $ S-nat
      25055.66c    -0.010300        $ Mn-55
      26054.66c    -0.055383        $ Fe-54
      26056.66c    -0.901554        $ Fe-56
      26057.66c    -0.021193        $ Fe-57
      26058.66c    -0.002870        $ Fe-58
      29063.66c    -0.001370        $ Cu-63
      29065.66c    -0.000630        $ Cu-65
c
c     SS-304 - from STDNEUT.dos file
c    Density    8.03        g/cc
c
m300   6000.66c    -0.000300        $ C-nat
      24050.66c    -0.008345        $ Cr-50
      24052.66c    -0.167349        $ Cr-52
      24053.66c    -0.019341        $ Cr-53
      24054.66c    -0.004905        $ Cr-54
      25055.66c    -0.019994        $ Mn-55
      26054.66c    -0.038378        $ Fe-54
      26056.66c    -0.624743        $ Fe-56
      26057.66c    -0.014686        $ Fe-57
      26058.66c    -0.001989        $ Fe-58
      28058.66c    -0.067178        $ Ni-58
      28060.66c    -0.026768        $ Ni-60
      28061.66c    -0.001183        $ Ni-61
      28062.66c    -0.003834        $ Ni-62
      28064.66c    -0.001008        $ Ni-64
c
c     Lead
c    Density   11.34        g/cc
c
m400  82000.50c    -1.0             $ Lead
c
c     Air
m500   7014.66c    -0.761985        $ N-14
       7015.66c    -0.003015        $ N-15
       8016.66c    -0.234905        $ O-16 & O-18
       8017.66c    -0.000095        $ O-17
c
c    Water
c    Density    1.00        g/cc
c
m600    1001.66c    -0.11186481    $    H-1
        1002.66c    -0.00003354    $    H-2
        8016.66c    -0.88774309    $    O-16 & O-18
        8017.66c    -0.00035857    $    O-17
mt600   lwtr.60t
c
c
c       Be       1.85       g/cc
c
m800    4009.66c    -0.00497513    $    Be-nat
mt800   be.60t
c
print
```

HAC Single Cask – f033

```
10-160B
c
3000   103 -1.011186        -2000
                                  imp:n=1
4000   153 -0.991739   +120  -149   -30
                       +2000
                      #(+130  +10   )
                                  imp:n=1
c
c  Cask Regions
5     300 -8.03 ((30:-120)(-40 110 -130)):(130 -140 10 -40):
              (10 -20 140 -149):(149 -150 -20)      imp:n=1   $ Liner 11 ga - SS304
10    200 -7.85 (100 -109 -70)                      imp:n=1   $ Base-Carbon Steel
15    200 -7.85 (109 -110 -50)                      imp:n=1   $ Base-Carbon Steel
20    200 -7.85 (110 -140 40 -50)                   imp:n=1   $ Inner Shell-Carbon Steel
25    400 -11.34 (109 -140 50 -60)                  imp:n=1   $ Lead wall
30    200 -7.85  (109 -140 60 -70)                  imp:n=1   $ steel
40    200 -7.85 (140 -150 20 -70):(150 -160 -70):(160 -170 -25)
                                                    imp:n=1 $ Prim/2ndary lid-Carbon Steel
c
c     Water reflector
5000  600 -1.0 (-500 510 -520) (((70:-100) -160):(160 25):170)
                                                    imp:n=1 $ 1st 5 cm
5001  600 -1.0 (-501 511 -521) (500:-510:520)       imp:n=0.25 $ Out to 12 inches
5002  0                   (501:-511:521)            imp:n=0    $ Outside universe
c
9000  0                     -2001                   imp:n=1
c
c  Cask Radial Zones
10      cz      39.0525  $ Lid recess liner
20      cz      39.37    $ Lid recess
25      cz      58.42    $ 2ndary lid
30      cz      86.0425  $ Inner cavity
40      cz      86.36    $ OD Liner (11 ga)
50      cz      89.2175  $ OD Inner shell
60      cz      93.98    $ OD Lead
70      cz      99.06    $ OD Outer shell
80      cz      99.695   $ OD Thermal barrier-not included in model
c  Cask Axial Zones
100     pz      0.0001   $ Bottom cask
109     pz      11.43    $ Bottom lead in side wall
110     pz      13.97    $ Base plate
120     pz      14.2875  $ Bottom liner
125     pz      174.32655  $ Top of mixture for H/D=0.93
130     pz      209.2325 $ Cavity hgt
140     pz      209.55   $ Top liner
149     pz      216.8525 $ Lid recess liner
150     pz      217.17   $ Top of lid recess
160     pz      223.52   $ Primary lid
170     pz      231.14   $ Top of 2nd lid
c
c Planes for water reflector - 1st 5 cm and out to 12 inches
c
500     cz   104.06
501     cz   129.54
510     pz  -5
511     pz  -30.48
520     pz   236.14
521     pz   261.62
c
1000    so   1000           $ beyond problem
c
2000    s  72.331    0.000    195.521    13.611761
2001    s  72.331    0.000    195.521    12.5
c
c
mode n
kcode   4000 0.9   50  4000
```

```
sdef   x=d1   y=d2   z=d3    ccc=9000 eff=0.00001
c     ksrc    0   0  120
c
si1    -12.5     86.1
sp1      0        1
c
si2    -12.5     12.5
sp2      0        1
c
si3     14.0    210.0
sp3      0        1
c
c Material Definitions
c
c
c    H/Pu     900
c    H2O/CH2     3.245
c    Be w%    1.00000%    of CH2 + Pu
c    Radius    13.611761    cm
c    Pu-239 Mass     325.0000    g
c    Density     1.011186    g/cc
c     0.000     0.000    120.000    13.611761        Center
c     0.000     0.000     27.999    13.611761        Bottom
c    72.331     0.000     27.999    13.611761        Lower Corner
c    72.331     0.000    195.521    13.611761        Upper Corner
c
m103     1001.66c    -0.11541840    $     H-1
         1002.66c    -0.00003460    $     H-2
         4009.66c    -0.00258227    $     Be-nat
         6000.66c    -0.19506425    $     C-nat
         8016.66c    -0.65621111    $     O-16 & O-18
         8017.66c    -0.00026505    $     O-17
        94239.66c    -0.03042431    $     Pu-239
mt103    lwtr.60t    be.60t
c
c
c    H2O/CH2     8.453226
c    Be w%    1.00000%    of CH2
c    Density     0.991739    g/cc
c
m153     1001.66c    -0.11510778    $     H-1
         1002.66c    -0.00003451    $     H-2
         4009.66c    -0.00105672    $     Be-nat
         6000.66c    -0.09048548    $     C-nat
         8016.66c    -0.79299521    $     O-16 & O-18
         8017.66c    -0.00032030    $     O-17
mt153    lwtr.60t    be.60t
c
c
c
c      Carbon Steel
c    Density     7.85        g/cc
c
m200    6000.66c    -0.003000       $ C-nat
       14028.66c    -0.002572       $ Si-28
       14029.66c    -0.000135       $ Si-29
       14030.66c    -0.000092       $ Si-30
       15031.66c    -0.000400       $ P-31
       16000.66c    -0.000500       $ S-nat
       25055.66c    -0.010300       $ Mn-55
       26054.66c    -0.055383       $ Fe-54
       26056.66c    -0.901554       $ Fe-56
       26057.66c    -0.021193       $ Fe-57
       26058.66c    -0.002870       $ Fe-58
       29063.66c    -0.001370       $ Cu-63
       29065.66c    -0.000630       $ Cu-65
c
c      SS-304 - from STDNEUT.dos file
c    Density     8.03        g/cc
c
m300    6000.66c    -0.000300       $ C-nat
```

```
      24050.66c    -0.008345        $ Cr-50
      24052.66c    -0.167349        $ Cr-52
      24053.66c    -0.019341        $ Cr-53
      24054.66c    -0.004905        $ Cr-54
      25055.66c    -0.019994        $ Mn-55
      26054.66c    -0.038378        $ Fe-54
      26056.66c    -0.624743        $ Fe-56
      26057.66c    -0.014686        $ Fe-57
      26058.66c    -0.001989        $ Fe-58
      28058.66c    -0.067178        $ Ni-58
      28060.66c    -0.026768        $ Ni-60
      28061.66c    -0.001183        $ Ni-61
      28062.66c    -0.003834        $ Ni-62
      28064.66c    -0.001008        $ Ni-64
c
c     Lead
c    Density   11.34        g/cc
c
m400  82000.50c    -1.0             $ Lead
c
c     Air
m500   7014.66c    -0.761985        $ N-14
       7015.66c    -0.003015        $ N-15
       8016.66c    -0.234905        $ O-16 & O-18
       8017.66c    -0.000095        $ O-17
c
c    Water
c    Density    1.00        g/cc
c
m600     1001.66c    -0.11186481    $     H-1
         1002.66c    -0.00003354    $     H-2
         8016.66c    -0.88774309    $     O-16 & O-18
         8017.66c    -0.00035857    $     O-17
mt600    lwtr.60t
c
c
c        Be        1.85         g/cc
c
m800     4009.66c    -0.00497513    $     Be-nat
mt800    be.60t
c
print
```

NCT Infinite Array – f369a

```
10-160B
c
3000   139 -0.238656          -2000
                                    imp:n=1
3001   169 -0.233058   +2000 +120  -2100 -30
                                    imp:n=1
4000   500 -0.00122    +120  -149   -30 +2100
c      4000   901 -0.983047   +120  -149   -30
c      4000   902 -0.985333   +120  -149   -30
c      4000   903 -0.987607   +120  -149   -30
                     #(+130   +10    )
                                    imp:n=1
c
c  Cask Regions
5      300 -8.03 ((30:-120)(-40 110 -130)):(130 -140 10 -40):
               (10 -20 140 -149):(149 -150 -20)      imp:n=1   $ Liner 11 ga - SS304
10     200 -7.85 (100 -109 -70)                      imp:n=1   $ Base-Carbon Steel
15     200 -7.85 (109 -110 -50)                      imp:n=1   $ Base-Carbon Steel
20     200 -7.85 (110 -140 40 -50)                   imp:n=1   $ Inner Shell-Carbon Steel
25     400 -11.34 (109 -140 50 -60)                  imp:n=1   $ Lead wall
30     200 -7.85  (109 -140 60 -70)                  imp:n=1   $ steel
40     200 -7.85 (140 -150 20 -70):(150 -160 -70):(160 -170 -25)
                                                     imp:n=1 $ Prim/2ndary lid-Carbon Steel
c
c      Around cask, interspersed
201     0          (-503 504 -508 507 -505 506 501 -502)
                    (((70:-100) -160):(160 25):170) imp:n=1
c      Outside World
200     0        (503:-504:508:-507:505:-506:-501:502) imp:n=0
c
c
9000  0                        -2001                 imp:n=1
c
c  Cask Radial Zones
10       cz       39.0525  $ Lid recess liner
20       cz       39.37    $ Lid recess
25       cz       58.42    $ 2ndary lid
30       cz       86.0425  $ Inner cavity
40       cz       86.36    $ OD Liner (11 ga)
50       cz       89.2175  $ OD Inner shell
60       cz       93.98    $ OD Lead
70       cz       99.06    $ OD Outer shell
80       cz       99.695   $ OD Thermal barrier-not included in model
c  Cask Axial Zones
100      pz       0.0001   $ Bottom cask
109      pz       11.43    $ Bottom lead in side wall
110      pz       13.97    $ Base plate
120      pz       14.2875  $ Bottom liner
125      pz       174.32655  $ Top of mixture for H/D=0.93
130      pz       209.2325 $ Cavity hgt
140      pz       209.55   $ Top liner
149      pz       216.8525 $ Lid recess liner
150      pz       217.17   $ Top of lid recess
160      pz       223.52   $ Primary lid
170      pz       231.14   $ Top of 2nd lid
c
c      Hexagonal Cell Surrounding Cask for Infinite array
c
c        inner hex surfaces bounding lattice, (n-0.5)*p*cos30
c      surfaces for outer hexagonal duct
*501         pz       -1.000  $
*502         pz      232.140  $
*503         px      100.0000
*504         px     -100.0000
*505          p      -1.0000000      1.7320508      0.0000000     200.0000
*506          p      -1.0000000      1.7320508      0.0000000    -200.0000
*507          p       1.0000000      1.7320508      0.0000000    -200.0000
*508          p       1.0000000      1.7320508      0.0000000     200.0000
```

```
c
1000   so   1000           $ beyond problem
c
2000   s    61.948    0.000     38.382    23.994894
2001   s    61.948    0.000     38.382    19.0
2002   s    61.948    0.000     38.382    79.210227
c
2100  pz 103.79361
c
c
mode n
kcode   4000 0.9   50  4000
sdef   x=d1   y=d2   z=d3    ccc=9000 eff=0.00001
c     ksrc    0   0  120
c
si1    -19.0     86.1
sp1      0        1
c
si2    -19.0     19.0
sp2      0        1
c
si3     14.0    210.0
sp3      0        1
c
c Material Definitions
c
c
c    H/Pu     1400
c    H2O/CH2     0.0000000
c    Be w%     1.000000%    of CH2 + Pu
c    Radius    23.994894    cm
c    Pu-239 Mass    325.000000    g
c    Density    0.238656    g/cc
c     0.000    0.000    120.000    23.99489       Center
c     0.000    0.000     38.382    23.99489       Bottom
c    61.948    0.000     38.382    23.99489       Lower Corner
c    61.948    0.000    185.138    23.99489       Upper Corner
c
m139     1001.66c    -0.13886897    $    H-1
         1002.66c    -0.00004163    $    H-2
         4009.66c    -0.00990099    $    Be-nat
         6000.66c    -0.82765605    $    C-nat
c         8016.66c    0.00000000    $    O-16 & O-18
c         8017.66c    0.00000000    $    O-17
        94239.66c    -0.02353235    $    Pu-239
mt139   poly.60t    be.60t
c
c
c    H2O/CH2    0.000
c    Be w%    1.00%    of CH2
c    Density    0.104514    g/cc    Full Vessel
c    Density    0.233058        Sphere Reflector
c    Radius    79.210227        Sphere Reflector
c    Height    0.000000
c
m169     1001.66c    -0.14224992    $    H-1
         1002.66c    -0.00004265    $    H-2
         4009.66c    -0.00990099    $    Be-nat
         6000.66c    -0.84780644    $    C-nat
c         8016.66c    0.00000000    $    O-16 & O-18
c         8017.66c    0.00000000    $    O-17
mt169   poly.60t    be.60t
c
c
c
c     Carbon Steel
c    Density    7.85        g/cc
c
m200    6000.66c    -0.003000        $ C-nat
       14028.66c    -0.002572        $ Si-28
       14029.66c    -0.000135        $ Si-29
```

```
      14030.66c    -0.000092        $ Si-30
      15031.66c    -0.000400        $ P-31
      16000.66c    -0.000500        $ S-nat
      25055.66c    -0.010300        $ Mn-55
      26054.66c    -0.055383        $ Fe-54
      26056.66c    -0.901554        $ Fe-56
      26057.66c    -0.021193        $ Fe-57
      26058.66c    -0.002870        $ Fe-58
      29063.66c    -0.001370        $ Cu-63
      29065.66c    -0.000630        $ Cu-65
c
c     SS-304 - from STDNEUT.dos file
c    Density    8.03        g/cc
c
m300   6000.66c    -0.000300        $ C-nat
      24050.66c    -0.008345        $ Cr-50
      24052.66c    -0.167349        $ Cr-52
      24053.66c    -0.019341        $ Cr-53
      24054.66c    -0.004905        $ Cr-54
      25055.66c    -0.019994        $ Mn-55
      26054.66c    -0.038378        $ Fe-54
      26056.66c    -0.624743        $ Fe-56
      26057.66c    -0.014686        $ Fe-57
      26058.66c    -0.001989        $ Fe-58
      28058.66c    -0.067178        $ Ni-58
      28060.66c    -0.026768        $ Ni-60
      28061.66c    -0.001183        $ Ni-61
      28062.66c    -0.003834        $ Ni-62
      28064.66c    -0.001008        $ Ni-64
c
c     Lead
c    Density   11.34        g/cc
c
m400  82000.50c    -1.0             $ Lead
c
c     Air
m500   7014.66c    -0.761985        $ N-14
       7015.66c    -0.003015        $ N-15
       8016.66c    -0.234905        $ O-16 & O-18
       8017.66c    -0.000095        $ O-17
c
c    Water
c    Density    1.00        g/cc
c
m600    1001.66c    -0.11186481    $    H-1
        1002.66c    -0.00003354    $    H-2
        8016.66c    -0.88774309    $    O-16 & O-18
        8017.66c    -0.00035857    $    O-17
mt600   lwtr.60t
c
c
c       Be       1.85        g/cc
c
m800    4009.66c    -0.00497513    $    Be-nat
mt800   be.60t
c
print
```

HAC Infinite Array – f022flat02

```
10-160B
c
3000   102 -1.012911         -2000
                                   imp:n=1
4000   152 -0.991738   +120  -149   -30
                       +2000
                      #(+130  +10   )
                                   imp:n=1
c
c  Cask Regions
5      300 -8.03  ((30:-120)(-40 110 -130)):(130 -140 10 -40):
               (10 -20 140 -149):(149 -150 -20)      imp:n=1   $ Liner 11 ga - SS304
10     200 -7.85 (100 -109 -70)                      imp:n=1   $ Base-Carbon Steel
15     200 -7.85 (109 -110 -50)                      imp:n=1   $ Base-Carbon Steel
20     200 -7.85 (110 -140 40 -50)                   imp:n=1   $ Inner Shell-Carbon Steel
25     400 -11.34 (109 -140 50 -60)                  imp:n=1   $ Lead wall
30     200 -7.85  (109 -140 60 -70)                  imp:n=1   $ steel
40     200 -7.85 (140 -150 20 -70):(150 -160 -70):(160 -170 -25)
                                                     imp:n=1 $ Prim/2ndary lid-Carbon Steel
c
c
c      Around cask, interspersed
201    600 -0.0010    (-503 504 -508 507 -505 506 501 -502)
                      (((70:-100) -160):(160 25):170)  imp:n=1
c      Outside World
200     0      (503:-504:508:-507:505:-506:-501:502)  imp:n=0
c
9000   0                      -2001                  imp:n=1
c
c  Cask Radial Zones
10       cz      39.0525  $ Lid recess liner
20       cz      39.37    $ Lid recess
25       cz      58.42    $ 2ndary lid
30       cz      86.0425  $ Inner cavity
40       cz      86.36    $ OD Liner (11 ga)
50       cz      89.2175  $ OD Inner shell
60       cz      93.98    $ OD Lead
70       cz      99.06    $ OD Outer shell
80       cz      99.695   $ OD Thermal barrier-not included in model
c  Cask Axial Zones
100      pz      0.0001   $ Bottom cask
109      pz      11.43    $ Bottom lead in side wall
110      pz      13.97    $ Base plate
120      pz      14.2875  $ Bottom liner
125      pz      174.32655  $ Top of mixture for H/D=0.93
130      pz      209.2325 $ Cavity hgt
140      pz      209.55   $ Top liner
149      pz      216.8525 $ Lid recess liner
150      pz      217.17   $ Top of lid recess
160      pz      223.52   $ Primary lid
170      pz      231.14   $ Top of 2nd lid
c
c      Hexagonal Cell Surrounding Cask for Infinite array
c
c        inner hex surfaces bounding lattice, (n-0.5)*p*cos30
c      surfaces for outer hexagonal duct
*501        pz      -1.000  $
*502        pz      232.140  $
*503        px      100.0000
*504        px     -100.0000
*505         p      -1.0000000      1.7320508      0.0000000     200.0000
*506         p      -1.0000000      1.7320508      0.0000000    -200.0000
*507         p       1.0000000      1.7320508      0.0000000    -200.0000
*508         p       1.0000000      1.7320508      0.0000000     200.0000
c
1000    so    1000            $ beyond problem
c
2000    s  72.587    0.000     27.743     13.355327
```

```
2001   s  72.587     0.000      27.743     12.5
c
c
mode n
kcode    4000 0.9    50  4000
sdef   x=d1    y=d2    z=d3      ccc=9000 eff=0.00001
c     ksrc     0   0  120
c
si1    -12.5      86.1
sp1      0         1
c
si2    -12.5      12.5
sp2      0         1
c
si3     14.0     210.0
sp3      0         1
c
c Material Definitions
c
c
c    H/Pu     850
c    H2O/CH2     3.245
c    Be w%     1.00000%     of CH2 + Pu
c    Radius     13.355327     cm
c    Pu-239 Mass     325.0000     g
c    Density     1.012911     g/cc
c     0.000     0.000     120.000     13.355327
c     0.000     0.000      27.743     13.355327
c    72.587     0.000      27.743     13.355327
c    72.587     0.000     195.778     13.355327
c
m102     1001.66c     -0.11521015     $     H-1
         1002.66c     -0.00003454     $     H-2
         4009.66c     -0.00259548     $     Be-nat
         6000.66c     -0.19471229     $     C-nat
         8016.66c     -0.65502711     $     O-16 & O-18
         8017.66c     -0.00026457     $     O-17
        94239.66c     -0.03215585     $     Pu-239
mt102    lwtr.60t     be.60t
c
c
c    H2O/CH2     8.451753
c    Be w%     1.00000%     of CH2
c    Density     0.991738     g/cc
c
m152     1001.66c     -0.11510828     $     H-1
         1002.66c     -0.00003451     $     H-2
         4009.66c     -0.00105689     $     Be-nat
         6000.66c     -0.09049956     $     C-nat
         8016.66c     -0.79298046     $     O-16 & O-18
         8017.66c     -0.00032029     $     O-17
mt152    lwtr.60t     be.60t
c
c
c
c      Carbon Steel
c    Density     7.85          g/cc
c
m200    6000.66c    -0.003000        $ C-nat
       14028.66c    -0.002572        $ Si-28
       14029.66c    -0.000135        $ Si-29
       14030.66c    -0.000092        $ Si-30
       15031.66c    -0.000400        $ P-31
       16000.66c    -0.000500        $ S-nat
       25055.66c    -0.010300        $ Mn-55
       26054.66c    -0.055383        $ Fe-54
       26056.66c    -0.901554        $ Fe-56
       26057.66c    -0.021193        $ Fe-57
       26058.66c    -0.002870        $ Fe-58
       29063.66c    -0.001370        $ Cu-63
       29065.66c    -0.000630        $ Cu-65
```

```
c
c     SS-304 - from STDNEUT.dos file
c    Density    8.03         g/cc
c
m300   6000.66c    -0.000300        $ C-nat
      24050.66c    -0.008345        $ Cr-50
      24052.66c    -0.167349        $ Cr-52
      24053.66c    -0.019341        $ Cr-53
      24054.66c    -0.004905        $ Cr-54
      25055.66c    -0.019994        $ Mn-55
      26054.66c    -0.038378        $ Fe-54
      26056.66c    -0.624743        $ Fe-56
      26057.66c    -0.014686        $ Fe-57
      26058.66c    -0.001989        $ Fe-58
      28058.66c    -0.067178        $ Ni-58
      28060.66c    -0.026768        $ Ni-60
      28061.66c    -0.001183        $ Ni-61
      28062.66c    -0.003834        $ Ni-62
      28064.66c    -0.001008        $ Ni-64
c
c     Lead
c    Density   11.34         g/cc
c
m400  82000.50c    -1.0             $ Lead
c
c     Air
m500   7014.66c    -0.761985        $ N-14
       7015.66c    -0.003015        $ N-15
       8016.66c    -0.234905        $ O-16 & O-18
       8017.66c    -0.000095        $ O-17
c
c    Water
c    Density    1.00         g/cc
c
m600     1001.66c    -0.11186481    $     H-1
         1002.66c    -0.00003354    $     H-2
         8016.66c    -0.88774309    $     O-16 & O-18
         8017.66c    -0.00035857    $     O-17
mt600    lwtr.60t
c
c
c        Be        1.85        g/cc
c
m800     4009.66c    -0.00497513    $     Be-nat
mt800    be.60t
c
print
```

7. OPERATING PROCEDURES

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 14,250 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 Appendices 4.11.2 through 4.11.7, as applicable.

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.

7.1.9 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

NOTE **PRESSURE DROP LEAK TESTS OF THE PRIMARY LID AND SECONDARY LID O-RINGS AND THE VENT AND DRAIN PORTS ARE REQUIRED FOR EACH SHIPMENT, EXCEPT FOR LSA MATERIAL OR SCO OBJECT**

SHIPMENTS THAT MEET THE EXEMPTION STANDARDS IN 10 CFR 71.14(b)(3)(i) AND DO NOT REQUIRE PRE-SHIPMENT LEAK TEST.

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 Install anti-tamper seals, secondary lid thermal shield, and upper impact limiter, as follows:

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.

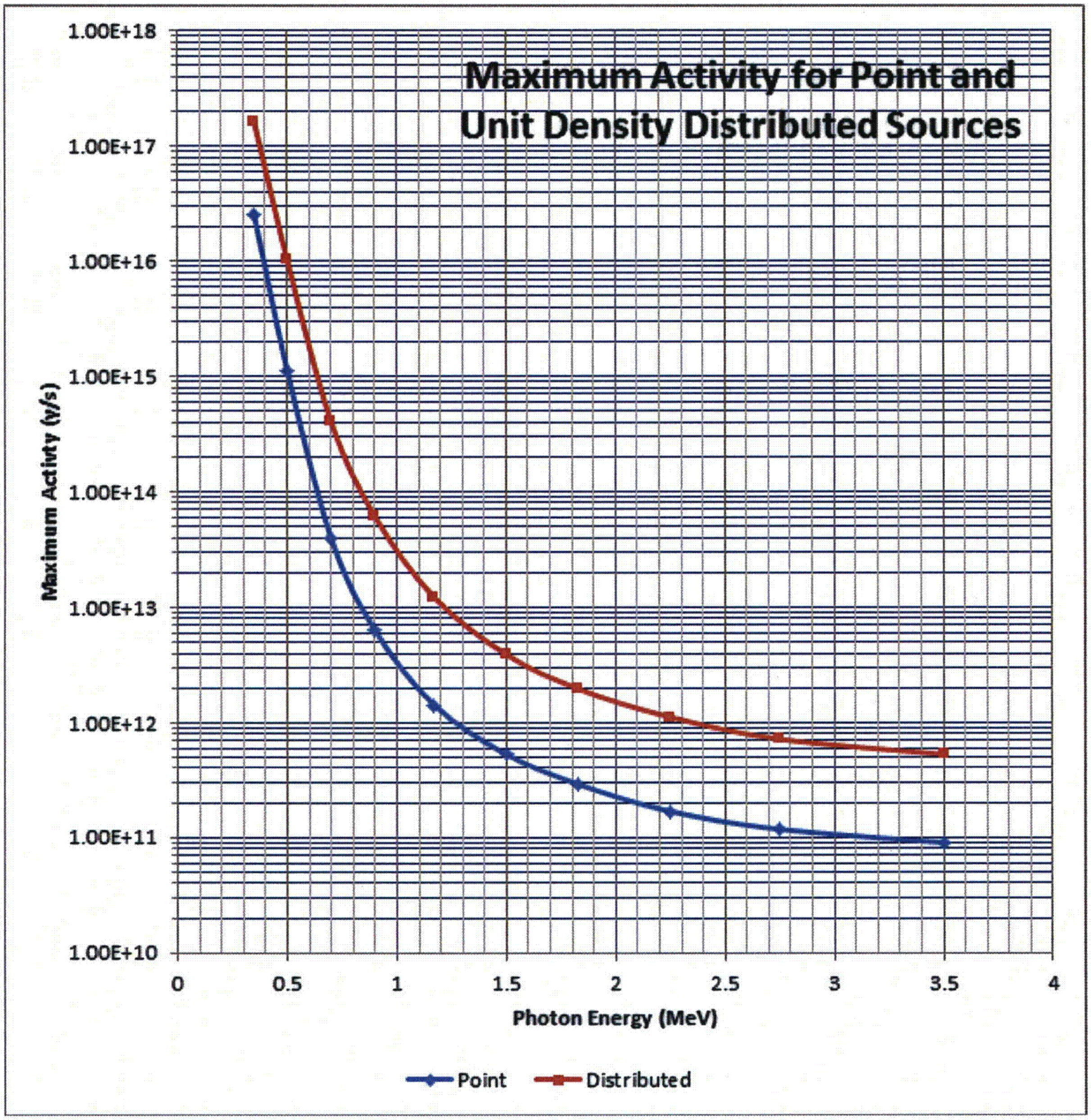
Attachment 1
Determination of Acceptable Activity
(see Chapter 5 for the derivation of the gamma activity limits)

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.

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8. ACCEPTANCE TESTS AND MAINTENANCE

8.1 ACCEPTANCE TEST

Prior to the first use of the 10-160B package, the following tests and evaluations will be performed:

8.1.1 VISUAL EXAMINATION

The package will be examined visually for any adverse conditions in materials or fabrication.

8.1.2 STRUCTURAL TESTS

Containment welds identified on Dwg. C-110-D-29003-010 are inspected per ASME Code, Section III, Div. I, Subsection ND, Article ND-5000.

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.

All non-ferromagnetic material welds are liquid penetrant (PT) inspected per ASME Code, Section V, Article 6 with acceptance criteria per ASME Code, Section III, Div. I, Subsection NF, NF-5350.

Welds on lifting and tiedown lugs are inspected before and after 150% load test in accordance with the ASME Code requirements for MT examination as specified above.

8.1.3 LEAK TESTS

This test shall be performed, prior to acceptance and operation of a newly fabricated package, in accordance with ASTM E-427 using a halogen leak detector or ASTM E-499 using a helium leak detector depending on the test gas used. The detector shall be capable of meeting the applicable sensitivity requirements specified in Figures 4.4, 4.8, or 4.12 in Chapter 4. Calibration of the leak detector shall be performed using a leak rate standard traceable to NIST. The leak standard's setting shall correspond to the approved leak test rate (see Chapter 4). The annulus between the o-ring seals of the 10-160B primary and secondary lids will be evacuated to a minimum vacuum of 20"Hg, and then be pressurized to a minimum pressure of 25 psig with pure dichlorodifluoromethane (R-12) or 1,1,1,2 – tetrafluoroethane (R-134a). Helium testing does not require evacuation of the annulus prior to pressurization. The detector probe shall be moved along the interior surface of the inner seal according to the specifications of ASTM E-427 or E-499.

If installed, the vent and drain lines will be tested as above by evacuating and pressurizing the inlet (cavity) side of the lines and checking for leaks at the outlet side of the cap screw.

The maximum allowable leak rate (which is temperature dependent) is specified in Section 4.5, 4.6, or 4.7 (depending on the test gas used). Any condition, which results in leakage in excess of this value, shall be corrected.

8.1.4 COMPONENT TESTS

Gasket and seals will be procured and examined in accordance with the Energy*Solutions* Quality Assurance Program.

8.1.5 TEST FOR SHIELDING INTEGRITY

Shielding integrity of the package will be verified by gamma scan or gamma probe methods to assure package is free of significant voids in the poured shield annulus. All gamma scanning will be performed on a 4-inch square or less grid system. The acceptance criteria will be that voids resulting in shield loss in excess of 10% of the normal lead thickness in the direction measured shall not be acceptable.

8.1.6 THERMAL ACCEPTANCE TESTS

No thermal acceptance testing will be performed on the 10-160B package. Refer to the Thermal Evaluation, Section 3.0 of this report.

8.1.7 IMPACT LIMITER FOAM

Acceptance testing of the impact limiter foam will be performed as required by ES-M-172, which is included in Appendix 8.3.1.

8.1.8 PRESSURE TEST

A pressure test of the containment system will be performed as required by 10CFR71.85. As determined in Section 3.4.4, the maximum normal operating pressure for the cask cavity is 8.4 psig, therefore the minimum test pressure will be 1.5 x 8.4 = 12.6 psig.

8.2 MAINTENANCE PROGRAM

Energy*Solutions* is committed to an ongoing preventative maintenance program for all shipping packages. The 10-160B package will be subjected to routine and periodic inspection and tests as outlined in this section and Energy*Solutions* approved procedure.

8.2.1 ROUTINE MAINTENANCE

Unless noted otherwise, for loaded packages containing large quantity LSA materials or greater than Type A quantities of non-LSA materials, each of the following safety related items and functional features shall be visually examined for defects or replacement. Corrective action for defects shall be as noted.

8.2.1.1 Fasteners

The primary and secondary lid bolts shall be visually inspected for defects whenever it is necessary to remove the corresponding lid. Obtain replacement parts as specified on Drawing C-110-D-29003-010 (current revision) for any components that show cracking or other visual signs of distress.

The cap screws for the vent port, test ports and drain shall be visually inspected for defects whenever it is necessary to remove them. Obtain replacement cap screws as specified on Drawing C-110-D-29003-010 (current revision) for any cap screws that show cracking or other visual signs of distress.

8.2.1.2 Gaskets and Seals

a. Primary Lid Seals

The primary lid O-ring seals shall be visually inspected for serviceability, ensuring that they are in the proper position and free of cracks, tears, cuts or discontinuities that may prevent them from sealing properly. The seal seating surfaces shall be visually inspected to ensure that they are free of damage, dirt, gravel or any foreign matter, which might damage the seals. If any defects are detected, the seals shall be replaced and/or the seal seating surfaces shall be reworked as necessary to ensure that the lid will seal properly.

New O-rings shall be lightly coated with a lightweight lubricant such as Parker Super O-Lube or equivalent prior to installation. The lubricant will minimize deterioration or cracking of the elastomer during usage and tearing if removal from the dovetail groove is necessary for inspection. If new O-rings have not been installed, coat the exposed surfaces of the O-rings with the lightweight lubricant immediately prior to closing the lid. Excess lubricant shall be wiped off before closing the lid.

b. Secondary Lid Seals

The secondary lid O-ring seals and seating surfaces shall be inspected as specified in Section 8.2.1.2 (a) at any time it is necessary to remove the secondary lid. Seal replacement and/or seating surface repair shall be as specified in Section 8.2.1.2 (a).

c. Test/Vent Ports and Drain Seals

The above seals and seating surfaces shall be inspected as specified in Section 8.2.1.2 (a) at any time it is necessary to remove them. Seal replacement and/or seating surface repair shall be as specified in Section 8.2.1.2 (a).

8.2.1.3 Painted Surfaces Identification Markings and Match Marks Used for Closure Orientation

The above items shall be visually inspected to ensure that painted surfaces are in good condition, identification markings are legible and that match marks used for closure orientation remain legible and are easy to identify.

8.2.2 PERIODIC MAINTENANCE

The following inspections and/or tests shall be performed as specified.

8.2.2.1 Periodic Leak Tests

The package shall be leak tested as described in Section 8.1.3 after its third use. In addition, the containment system, before actual use for shipment, shall have been leak tested according to Section 8.1.3, or to the Leaktight Test specified below, within the preceding 12-month period.

The Leaktight Test shall be performed in accordance with ANSI N14.5 using a mass spectrometer leak detector capable of meeting the sensitivity requirements specified in Chapter 4, Section 4.9. Calibration of the leak detector shall be performed using a leak rate standard traceable to NIST. The leak standard's setting shall correspond to the leaktight leak test rate (see Chapter 4, Section 4.9). The test is conducted by evacuating the cask cavity to a 90% vacuum then pressurizing the cask cavity with helium (+1 psig, -0 psig). The annulus between the O-rings is evacuated until the vacuum is sufficient to operate the helium mass spectrometer leak detector and the helium concentration in the annulus is monitored. The monitored leak rate must satisfy the leak criterion specified in Section 4.9. If installed, the vent and drain lines will be tested as above by evacuating and pressurizing the inlet (cavity) side of the lines and monitoring the helium concentration at the outlet side of the cap screw. Any condition, which results in leakage in excess of the leak criterion, shall be corrected before use of the cask.

Also, before actual use for shipment, all seals shall have been replaced within the preceding 12-month period.

8.2.2.2 Assembly Verification Leak Test

This test is required before each shipment of Type B material quantities. The test will verify that the containment system has been assembled properly.

The test will be performed by pressurizing the annulus between the O-ring seals of either the primary or the secondary lid or the inlet to the vent and drain lines with dry air or nitrogen.

NOTE: IF AIR IS USED FOR THE TEST, THE AIR SUPPLY SHOULD BE CLEAN AND DRY. IF IT IS NOT, OR IF THE QUALITY OF THE AIR SUPPLY IS UNCERTAIN, THE TEST SHOULD BE PERFORMED WITH NITROGEN TO ENSURE RELIABLE RESULTS.

The test shall be performed using a pressure gauge, accurate within 1%, or less, of full scale.

The test pressure shall be applied for at least 15 minutes (10 minutes for vent or drain ports). A drop in pressure of greater than the minimum detectable amount shall be cause for test failure. The maximum sensitivity of the gauge shall be 0.1 psig.

Sensitivity at the test conditions is equivalent to the prescribed procedure sensitivity of 10^{-3} ref-cm^3/sec based on dry air at standard conditions as defined in ANSI N14.5-1997 (See Section 4.4 for the determination of the test conditions).

8.2.2.3 Ratchet Binders

Ratchet binders are designed for long use with minimal maintenance. Inspection for operation is conducted prior to each use of the cask. The ratchet binder mechanism as well as the threads on the joining bolt are checked for dryness and ease of operation. If required, these parts are lubricated with standard chassis lubricant.

Ratchet binders which show excessive wear or have received impact or suspected overloading in an accident must be completely disassembled and inspected or replaced. Cause for rejection during an inspection shall include:

a. Cracks in the jaws or joining bolt.
b. Deformation of the jaws or joining bolt.
c. Excessive rust or corrosion pitting in the threads of the jaw or joining bolts.

8.2.3 SUBSYSTEM MAINTENANCE

The 10-160B package contains no subsystem assemblies.

8.2.4 VALVES RUPTURE DISCS AND GASKETS ON CONTAINMENT VESSEL

As a minimum, all gasket seals will be replaced prior to the annual leak test specified in 8.2.2.1.

8.2.5 SHIELDING

No shielding tests will be performed after acceptance testing unless there has been a repair to a damaged area, which will affect shield integrity. Any shield testing which might be required would be in accordance with the original criteria specified in Section 8.1.5.

8.2.6 REPAIR OF BOLT HOLES

Helical threaded inserts may be used for repair of bolt holes. The minimum tensile strength of the insert material must be greater than or equal to 150 ksi and the minimum length of the insert must be equal to one (1) bolt diameter. The following steps shall be performed for each repair using a helical threaded insert.

a. Install helical threaded insert(s), sized per manufacturer's recommendation, per the manufacturer's instructions for bottoming style taps. Helical threaded inserts may be tack welded to the base metal to keep them from backing out during cask operations.
b. At a minimum, each repaired bolt hole(s) will be tested for proper installation by assembling the joint components where the helical threaded insert is used and tightening the bolts to their required torque value.

   Note: If the repair is to bolt holes for lifting components, then a load test will also be performed to the affected components equal to 150% of maximum service load.

c. Each helical threaded insert shall be visually inspected after testing to insure that there is no visible damage or deformation to the insert.

8.3 APPENDIX

8.3.1 POLYURETHANE FOAM SPECIFICATION ES-M-172

Available on request.

SHIELD INSERT A ADDENDUM

FOR

MODEL 10-160B

TYPE B RADWASTE SHIPPING CASK

CONSOLIDATED SAR REVISION 7

November 2013

ENERGYSOLUTIONS

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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 Shield Insert, used to contain the radioactive sources, is added as an additional component of the packaging. This insert is identified as the 10-160B Shield Insert A.

Shield Insert A provides photon (gamma) shielding in the forms of lead and steel. The photon shield has side walls consisting of lead with a total thickness of 6.72 inches, located between an inner 8-inch SCH 40 steel pipe and an outer 24-inch 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 5/8 inches), steel bolting plate, and flat elastomeric 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 Shield Insert A as specified in the drawings in Section 1.3 of this Addendum.

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

3) The contents of Shield Insert A have a maximum mass of 500 pounds.

4) The total weight of contents, shoring, and Shield Insert A shall not exceed 14,250pounds.

5) The contents of Shield Insert A shall not include water or organic materials, explosives, corrosives, pyrophorics, or compressed gases.

1.3 APPENDIX

10-160B Shield Insert A Drawings

- Drawing No. C-038-145083-004, *"10-160B Shield Insert A Assembly and Details"*
- Drawing No. C-038-145083-005, *"Source Insert Steel Cribbing"*

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

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 14,250 lbs. The weight of Shield Insert A is itemized as follows:

Shield Insert A Body	6,500 lb
Shield Insert A Lid	500 lb
Source Payload	500 lb
Shield Insert A	7,500 lb
Design Shield Insert A 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 13,000lbs – much smaller than the licensed weight of 14,250 lbs.

The Shield 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 (ASTM A516 Gr. 70) and the lead (ASTM B29) material used for the construction of the Shield 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
Ultimate 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 remains the same. No changes in the SAR for lifting analyses of the package are made. The handling of Shield Insert A 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 Shield Insert A 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 Shield Insert A has been performed in Section 3 of this 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 Shield Insert A 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 Shield Insert A will be negligible.

2.6.2 COLD

No changes.

2.6.3 PRESSURE

The cavity temperature of the 10-160B Cask, with Shield Insert A 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 Shield Insert A 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 Shield Insert A 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 Shield Insert A 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 HYPOTHETICAL ACCIDENT CONDITIONS

No changes.

2.7.1 FREE DROP

The SAR has evaluated the 10-160B Cask for the hypothetical accident drop test conditions with a generic payload. The specific payload comprised of Shield Insert A and the cribbing, meets the payload limits of the SAR. Therefore, there is no change in SAR analyses. The evaluation of Shield Insert A 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 Shield Insert A 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 Shield Insert A 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.

Lead slump in the Shield Insert is controlled using a zone-solidification fabrication process by which the unit is slowly cooled from bottom to top. As a result, molten lead backfills any radial lead shrinkage as the lead solidifies from bottom to top of the pour. The finished product is gamma scanned to assure adequate lead thickness and uniformity. As a result, the residual radial void into which lead could slump under the HAC end drop is negligible. The effect of lead slump in the Shield Insert has been evaluated in Section 6.4.1 of Reference 26. The lead-shielding used in the insert undergoes a maximum deformation of 0.049 inches. Since the stresses in the lead column are much smaller than the plastic flow stress, most of this deformation is recovered resulting in a very small axial lead slump, if any.

2.7.1.2 Reference Free Drop Impact-Side Drop

The effect of 30-ft free drop of the cask package in the side drop orientation on Shield Insert A has been analyzed in Section 6.2.3 of Reference 26. It is shown that the stresses in every component of Shield Insert A 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 Shield Insert A has been addressed in Section 6.2 of Reference 26. It has been shown that the deceleration loading on Shield Insert A during this drop is enveloped by the end drop and side deceleration loadings. No separate evaluation of Shield Insert A 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 Shield Insert A 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 Shield Insert A 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. 1, 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 watts. 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 Shield Insert A 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 watts. Conservatively, 200 watts of internal heat load is used in the thermal analyses reported in this addendum.

The results for Shield Insert A are summarized for NCT 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 Shield Insert.

3.2 SUMMARY OF THERMAL PROPERTIES OF MATERIALS

No new thermal properties have been used in the analyses of the Shield Insert.

3.3 TECHNICAL SPECIFICATIONS OF COMPONENTS

The steel and the lead material used for the construction of Shield Insert A 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 Shield Insert A comprises of 2-dimensional axisymmetric solid and contact elements. The details of the finite element model used in the analyses are provided in Reference 13. The Shield Insert model uses some conservative simplifications that are documented in Reference 13.

The boundary conditions used in the analysis of the Shield Insert are the same as those used in the SAR.

3.4.2 MAXIMUM TEMPERATURES

The maximum temperatures in various parts of the Shield Insert 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 (530°R).
2) The pressure in the cask at 240°F (700°R) (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

   $P_2 = 19.4$ psi

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

$$MNOP = 19.4 - 14.7 = 4.7 \text{ psig}$$

The value used for MNOP is conservatively set at 35.0 psig. Since the MNOP for the Shield 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 Shield Insert A comprises of 2-dimensional axisymmetric solid and contact elements. The details of the finite element model used in the analyses are provided in Reference 13. The Shield Insert model uses some conservative simplifications that are documented in Reference 13.

The boundary conditions used in the analysis of the Shield Insert are the as those used in the SAR with some conservative modifications that are detailed in Reference 13.

3.5.2 PACKAGE CONDITIONS AND ENVIRONMENT

No changes.

3.5.3 PACKAGE TEMPERATURES

The maximum temperatures in various parts of the Shield Insert 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 (530°R), the pressure in the cask at 300°F (760°R), P_2, may be calculated by the ideal gas relationship:

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

$$P_2 = 21.1 \text{ psia}$$

Therefore, the maximum pressure during the HAC fire,

$$P_{max} = 21.1 - 14.7 = 6.4 \text{ psig}$$

The value used for P_{max} is conservatively set at 100 psig. Since the P_{max} for the Shield 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

13. Energy*Solutions* Document TH-031, Rev. 1, 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 (Table 3.1-1)
Difference across the cask body	0.11[(1)]	0.2
Difference across the outer shell	0.04[(2)]	0.0
Difference across the inner shell	0.01[(3)]	0.0
Average Wall	166.1[(4)]	173
Lead	166.2[(5)]	173
Body	168.4[(6)]	175
Seal	168.1[(7)]	174
Bulk Air	231.2[(8)]	188
Payload (Source)	233.1[(9)]	-

NOTES:

(1) Difference of Node 377 and Node 314 Temperature. See Figure 7 of Reference 13.
(2) Difference of Node 377 and Node 409 Temperature. See Figure 7 of Reference 13.
(3) Difference of Node 283 and Node 314 Temperature. See Figure 7 of Reference 13.
(4) Average of Node 377 and Node 314 Temperature. See Figure 7 of Reference 13.
(5) Average of Node 409 and Node 283 Temperature. See Figure 7 of Reference 13.
(6) Maximum temperature from Figure 8 of Reference 13.
(7) Maximum of Node 153 and Node 80 temperatures. See Figure 7 of Reference 13.
(8) Maximum temperature from Figure 9 of Reference 13.
(9) Maximum temperature from Figure 10 of Reference 13.

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 (Table 3.1-2)	Value Analyzed in the SAR (Table 3.1-2)
Difference across the cask body	31.7[1]	39.8	45
Difference across the outer shell	15.2[2]	20.2	24
Difference across the inner shell	1.65[3]	2.3	2
Average Wall	294[4]	279	334
Lead	294[5]	274	335
Body	302[6]	289	352
Seal	206[7]	375	375
Bulk Air	296[8]	281	290
Payload (Source)	253[9]	-	-

NOTES:

(1) Difference of Node 377 and Node 314 Temperature. See Appendix 3 of Reference 13.
(2) Difference of Node 377 and Node 409 Temperature. See Appendix 3 of Reference 13.
(3) Difference of Node 283 and Node 314 Temperature. See Appendix 3 of Reference 13.
(4) Average of Node 377 and Node 314 Temperature. See Appendix 3 of Reference 13.
(5) Average of Node 409 and Node 283 Temperature. See Appendix 3 of Reference 13.
(6) Maximum temperature at Node 377. See Figure 7 and Appendix 3 of Reference 13.
(7) Maximum of Node 153 and Node 80 temperatures. See Appendix 3 of Reference 13.
(8) Maximum temperature from Figure 13. See also Appendix 3 of Reference 13.
(9) Maximum temperature from Figure 19. See also Appendix 3 of Reference 13.

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.

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5.0 SHIELDING EVALUATION

This shielding evaluation supports exclusive use shipment of Shield Insert A containing a maximum 10,000 Curies of Co-60 in the Model 10-160B Transport Cask. The evaluation results documented in this chapter show that the combined shielding of Shield Insert A 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 10-160B 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 exclusive use shipments. The 10-160B Cask is designed to carry a payload of Type B quantity radioactive byproduct, source, or special nuclear material weighing no more than 14,250 pounds (6,463 kilograms). 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.

Shield Insert A is designed, constructed, and prepared for shipment as a shielded insert to the 10-160B Cask. Shield Insert A is comprised of gamma (i.e. photon) shielding that is to be supported and centered in the 10-160B Cask cavity by a cribbing structure. Shield Insert A is loaded into the 10-160B Cask, which is then transported on an 8-foot wide trailer.

Tests and analyses have demonstrated the ability of the packaging to maintain its shielding integrity under NCT. The cribbing structure is also shown by analysis to maintain its geometry under HAC, thus Shield Insert A is approximately centered within the 10-160B Cask cavity for both NCT and HAC conditions. The cribbing structure (and materials) is not modeled, however, in either the NCT or HAC analyses, so its shielding properties are conservatively neglected.

5.1.1.2 Shielding Design

Representative views of the 10-160B Cask and Shield Insert A are presented in Figures 5-1 through 5-3. A representative view of the shielding model of the 10-160B Cask, Shield Insert A and the Co-60 source 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 secondary lid thermal shield has been conservatively neglected in this evaluation.

As presented in Table 5-1, the 10-160B 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 77 inches. The 10-160B Cask bottom, outer and inner lids are all comprised of two layers of steel with a total thickness of 5-½ inches. The 10-160B 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/10-160B 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 10-160B Cask as located on the trailer. The impact limiter materials are conservatively ignored for the purpose of the shielding evaluation.

The Co-60 source is loaded into the Shield Insert A cavity. Shield Insert A is then centered inside the 10-160B Cask both radially and axially, as shown in Figure 5-4. As presented in Figure 5-2, the Shield Insert A inner shell side walls are comprised of cast lead (density of 11.34 g/cm^3 and a total thickness of 6.72 inches) located between an inner 8-inch SCH 40 steel pipe and an outer 24-inch 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.

The Shield Insert A drain line consists of ½-inch SCH 40 steel pipe, which has an O.D. and I.D. of 0.84 inches and 0.62 inches, respectively. Vertical and horizontal pipe sections are joined by a 90-degree elbow section (as illustrated in Figure 5-5). The horizontal pipe section's centerline lies 2.25 inches above the bottom of the Insert's lead shielding. The vertical pipe section's centerline lies 0.75 inches from the edge of the Insert's inner cavity.

With the exception of a few minor (small) components, all steel components of the 10-160B Cask and Shield Insert A consist of carbon steel. The optional stainless steel 10-160B Cask cavity liner is conservatively neglected in the shielding analysis.

Figure 5-1 - 10-160B Cask General Arrangement

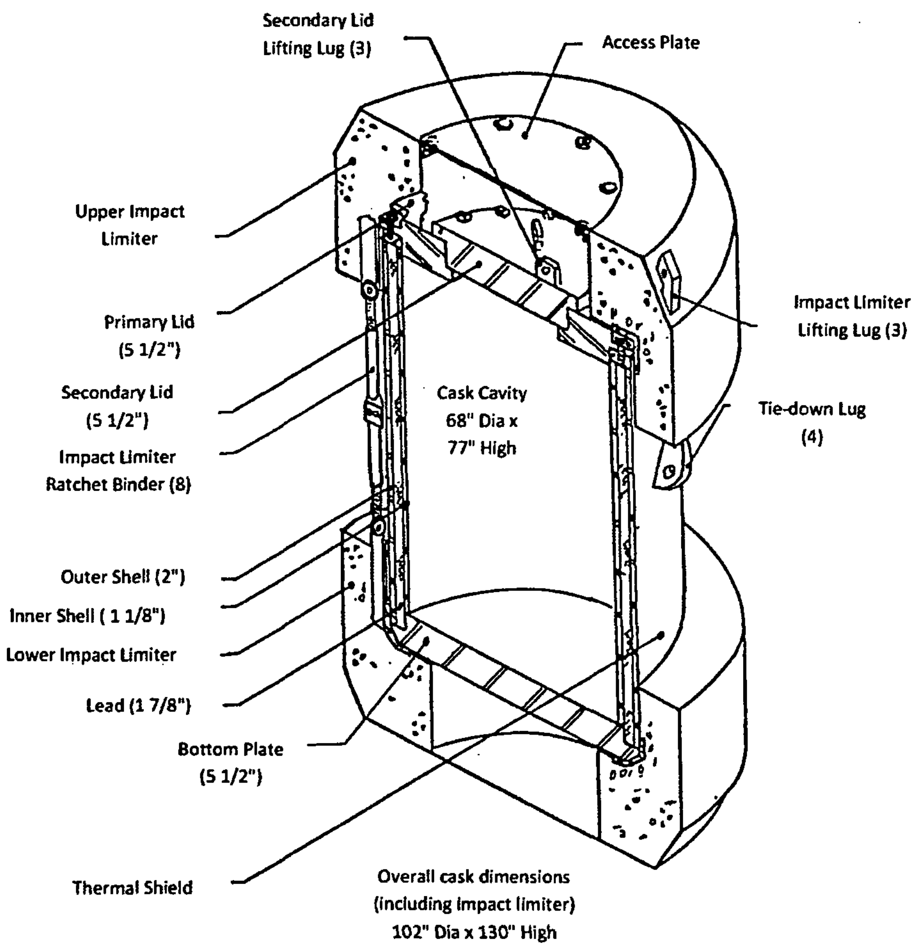


Figure 5-2 - Cutaway View of Shield Insert A

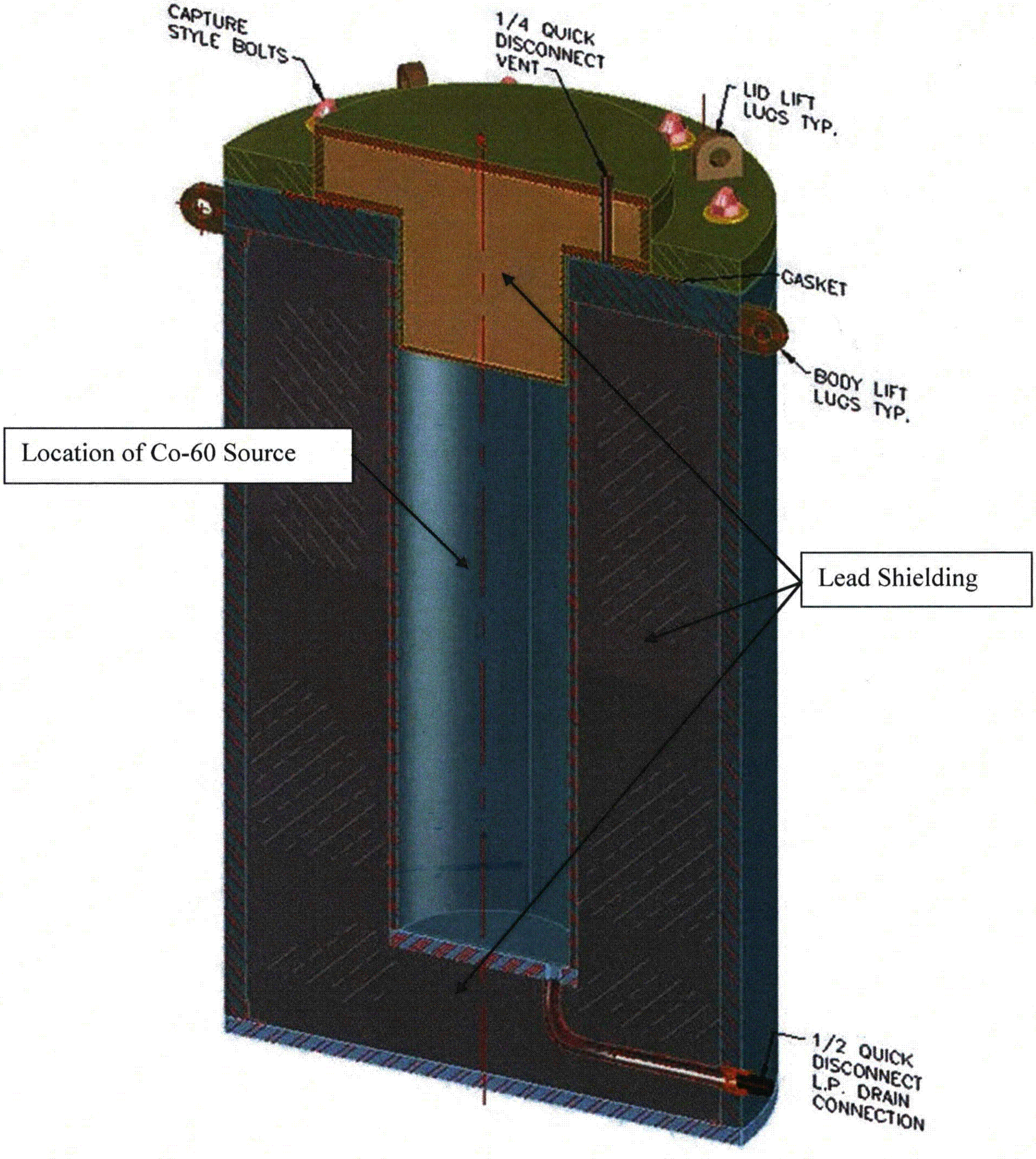


Figure 5-3 - Elevation Plan View of Shield Insert A

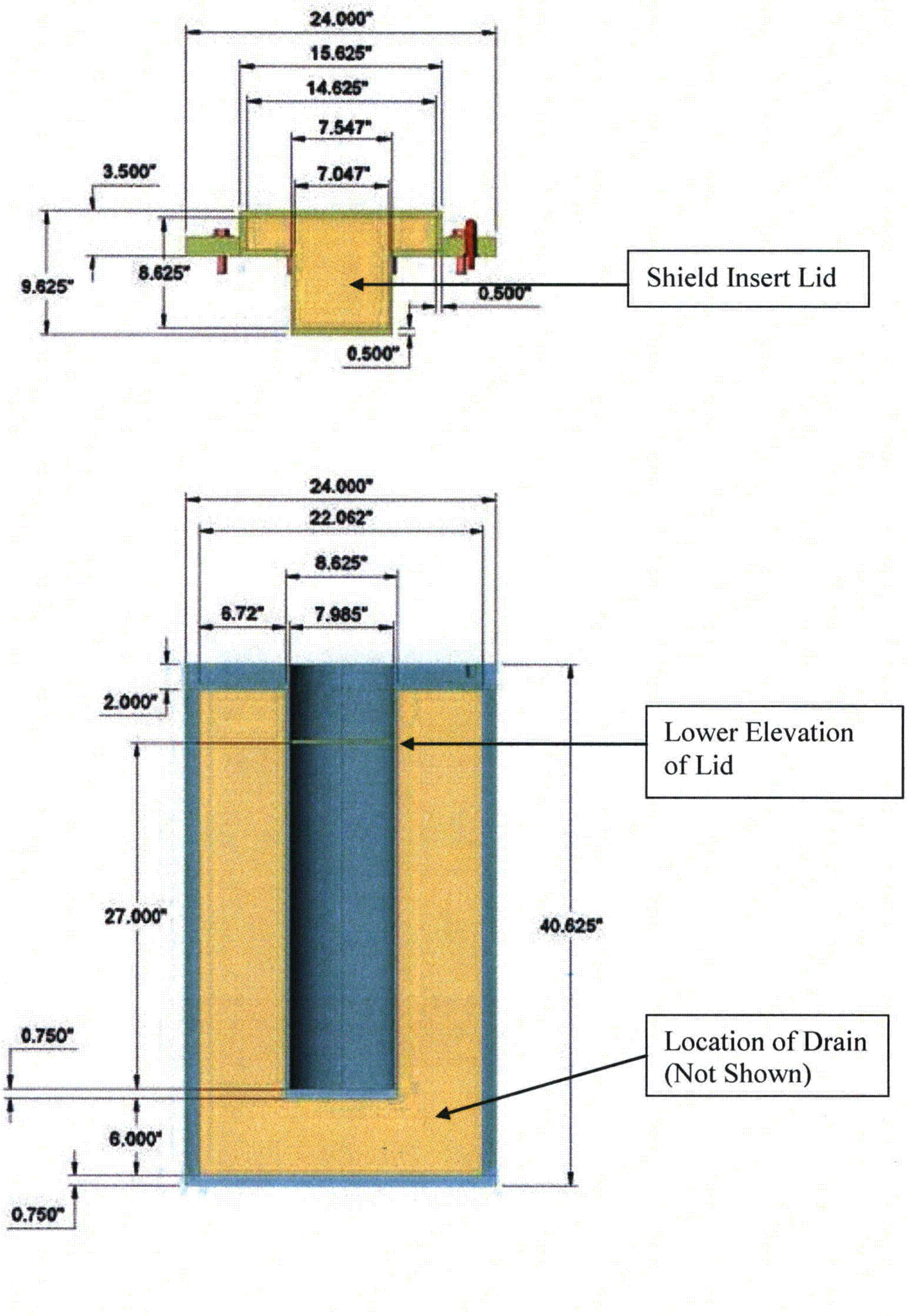


Figure 5-4 - Elevation View of Shielding Model (NCT and HAC)

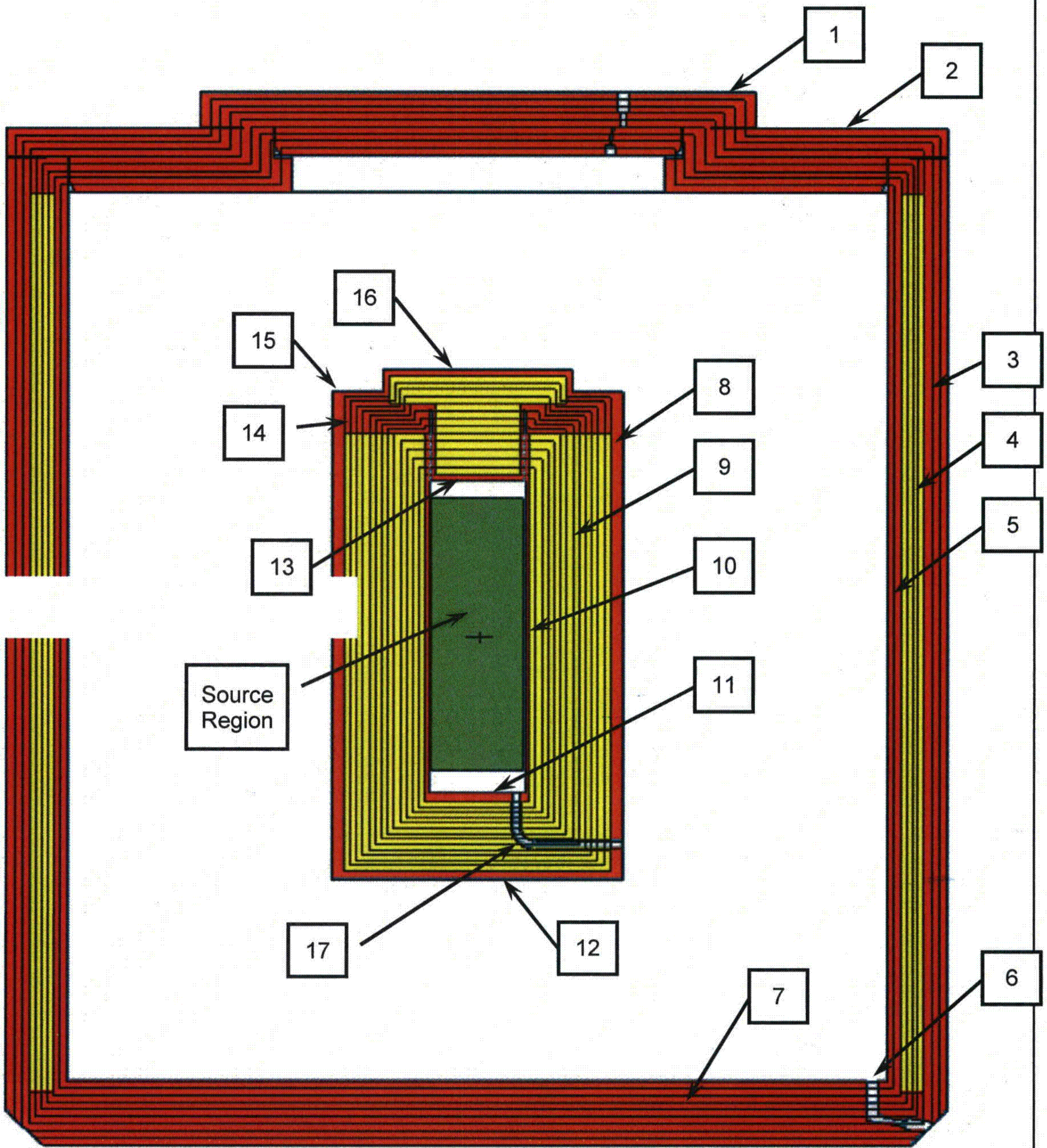


Table 5-1 - Component Description and Material Specifications

Item Number (Figure 5-4)	Component Description and Material Specification
1	10-160B Secondary Lid: 5.5-inches thick, carbon steel
2	10-160B Primary Lid: 5.5-inches thick, carbon steel
3	10-160B Outer Shell: 2.0-inches thick, carbon steel
4	Lead Shield: 1.875-inches thick
5	10-160B Inner Shell: 1.125-inches thick, carbon steel
6	10-160B Cask Drain
7	10-160B Base: 5.5-inches thick, carbon steel
8	Seamless Pipe, 24-in SCH. 60, carbon steel
9	Cast Lead Shield: 6.72-inches thick
10	Seamless Pipe, 8-in SCH 40, carbon steel
11	Plate: 0.75-inches thick, carbon steel
12	Plate: 0.75-inches thick, carbon steel
13	Plate: 0.50-inches thick, carbon steel
14	Plate: 2.0-inches thick, carbon steel
15	Plate: 1.5-inches thick, carbon steel
16	Plate: 0.5-inches thick, carbon steel
17	Insert Drain
18	10-160B Cask Vents

Table 5-2 - 10-160B Cask Dimensions

Component	Diameter (in)	Height (in)	Thickness (in)
Cavity	68	77	-
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

5.1.2 SUMMARY OF MAXIMUM DOSE RATES

Table 5-3 summarizes the dose rates for NCT, for a 10-160B Cask loaded with a distributed 10,000 Ci Co-60 payload inside Shield Insert A. 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

Location	Package Surface			2 Meters from 8' Trailer Side
	Top	Side	Bottom	
Gamma Dose Rate mSv/h (mrem/h)	0.0520 (5.20)	0.0087 (0.87)	0.0398 (3.98)	0.0007 (0.07)
10 CFR 71.47(b) Limit	2 (200)	2 (200)	2 (200)	0.1 (10)

Table 5-4 summarizes the dose rates for HAC, for a 10-160B Cask loaded with a distributed 10,000 Ci Co-60 payload inside Shield Insert A. 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

Location	One Meter from Cask Surface		
	Top	Side	Bottom
Gamma Dose Rate mSv/h (mrem/h)	0.0263 (2.63)	0.0018 (0.18)	0.0181 (1.81)
10 CFR 71.51(b) Limit	10 (1000)	10 (1000)	10 (1000)

5.2 SOURCE SPECIFICATION

5.2.1 GAMMA SOURCE

As shown in Table 5-5, each decay of Co-60 emits two photons (gammas), with one photon emitted at each of two specific energies. The photon source activity of 10,000 Curies of Co-60 is determined as follows:

Co-60 Activity = (10,000 Ci) x (3.7E+10 disintegration/s/Ci) x (2 γ/disintegration) = 7.4E+14 γ/s

The Co-60 gamma source is modeled as being distributed over the Shield Insert A cavity volume, with a nominal void volume above and below the source to allow for dunnage and/or incomplete filling of the cavity (see Figure 5-5). If no dunnage is used, then the model is conservative because it slightly concentrates the maximum source term.

The composition of the source region is conservatively modeled as air. This conservatively eliminates any self-shielding due to the source material.

Table 5-5 – Co-60 Gamma Energy and Abundance

Gamma Energy MeV	Abundance (# of gamma/decay)
1.176	1
1.333	1

Thus, in summary, a gamma source of 7.4E+14 γ/s is modeled, with half the gammas at 1.176 MeV, and half the gammas at 1.333 MeV.

5.2.2 NEUTRON SOURCE

The Co-60 source term contains no neutron emitting radioisotopes.

5.3 SHIELDING MODELS

5.3.1 NCT MODEL

Figure 5-5 shows a detail of the Shield Insert A shielding model. The insert is centered, axially and radially, within the 10-160B Cask cavity. It should be noted that there are no penetrations or discontinuities in either the 10-160B Cask or Insert A designs that require special studies for positional tolerances, therefore all models have the insert centered within the cask cavity. The 10-160B Cask and Shield Insert A configuration is illustrated in Figure 5-4. The physical dimensions of the 10-160B Cask and Shield Insert A are given in Figure 5-1 and Figure 5-3, respectively, as well as in Tables 5-1 and 5-2 (which also give the component materials).

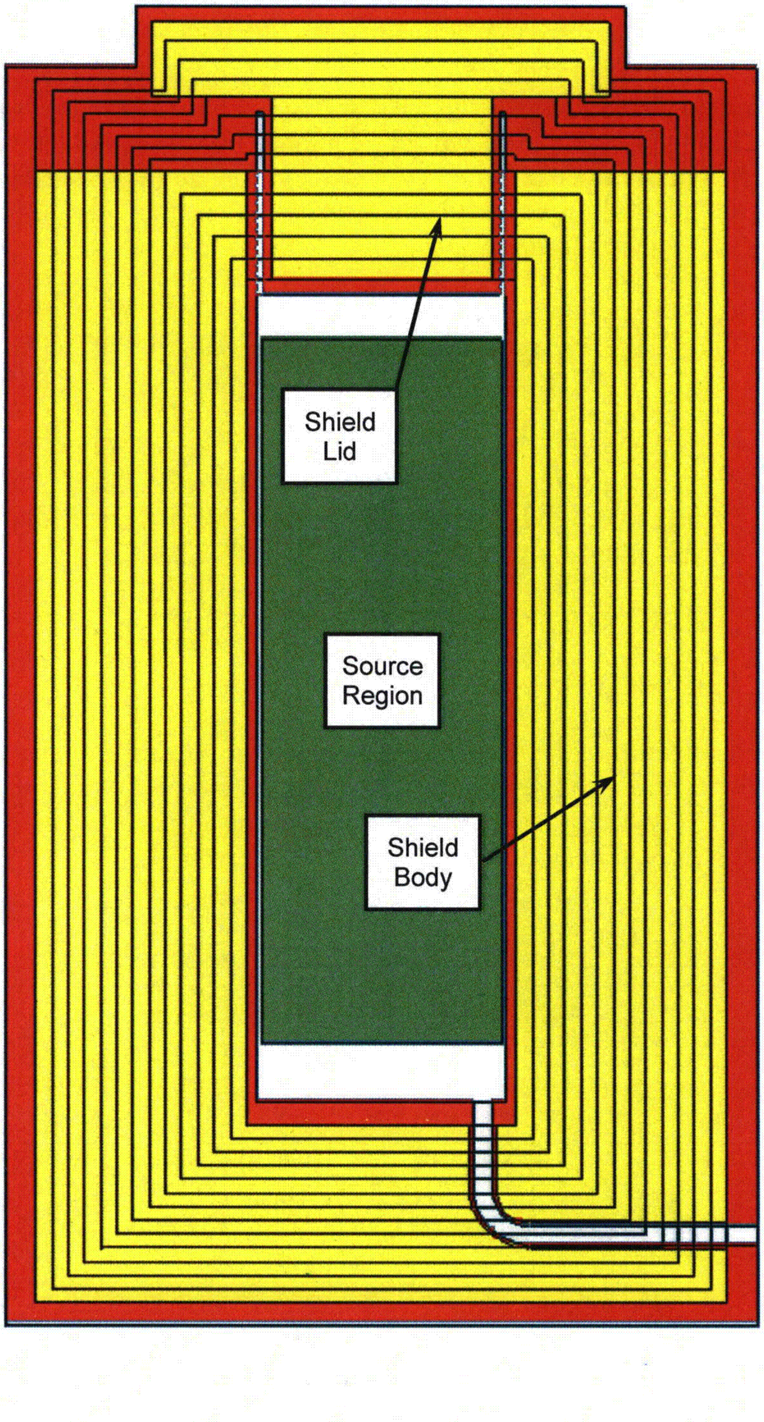
Although the impact limiter materials are conservatively neglected, the NCT dose rates are tallied on the impact limiter side and end surfaces, as they are the "package surface" on which the 200 mrem/hr regulatory limit applies. The dose rates are also tallied on the cask body radial surface, over the axial span between the top and bottom impact limiters since that is also part of the "package surface". These impact limiter and cask body surfaces make up the "package surface" on which the 200 mrem/hr dose rate limit applies. Dose rates are also tallied on a vertical plane 322 cm from the cask centerline, which corresponds to a plane 2 meters from the side of an 8-foot trailer.

The only significant features of the 10-160B cask and Shield Insert A that are not azimuthally symmetric are the Insert and Cask drain penetrations (shown in Figure 5-4). These penetrations will have no impact on cask top end dose rates or most cask side dose rates. They may have some impact on dose rates on the cask bottom surfaces or near the bottom of the cask side surfaces. Thus, a primary analysis is performed which uses dose rate tally bands that extend over the entire (360-degree) azimuthal span, which results in low levels of statistical error. Then, a second run is performed which evaluates any effects of the drain penetrations, focusing on dose locations that may increase due to their presence. There is no difference in the physical configuration modeled in the primary analysis and the drain penetration evaluation. The only difference is in the areas over which the cask exterior dose rates are tallied. The drain evaluation only tallies the dose rates over a narrow azimuthal span, right at the azimuth of the Insert and Cask drain line penetrations (where those penetrations will have the maximum potential impact). The drain evaluation only tallies dose rates at elevations below the bottom of the Insert cavity.

As discussed below in Section 5.3.2, the only physical change in the cask system configuration under HAC is a 0.02-inch high lead slump gap at the top of the 10-160B cask radial lead shield. This slump gap is conservatively modeled in the NCT analysis as well, which allows a single model to be used for both NCT and HAC. Thus, a total of two analyses are performed, i.e., a primary analysis and drain line analysis (as discussed above), each of which cover both NCT and HAC.

Additional details of the NCT shielding models are given in Reference 1.

Figure 5-5 - Elevation View of Standalone Shielding Model for Shield Insert A



5.3.2 HAC MODEL

Reference 26 (Chapter 2 of this Addendum) shows that the cribbing remains stable under HAC. Shield Insert A is therefore centered in the HAC models. Furthermore, HAC tests do not result in any significant permanent deformation of the 10-160B Cask or Shield Insert A components. The only physical change with shielding significance is the axial lead slump at the top of the 10-160B Cask radial lead cavity, discussed in Section 2.7.1.1 of the SAR. This slump is included in the shielding models. As described in Section 2.7.1.1.3 of this SAR Addendum, no significant slumping of the insert lead is predicted. Figure 5-5 shows that the top of the insert's radial lead shield is well above the top of the source cavity, so gamma streaming through a lead slump gap (at the top of the lead shield) would be at an oblique angle. Thus, the Shield Insert A shielding models do not require a lead slump gap.

Since the only significant difference between the NCT and HAC packaging conditions is the 10-160B Cask's lead slump, the same shielding model was used for NCT and HAC, resulting in slightly conservative results for NCT.

For HAC, the dose rates are tallied on surfaces one meter from the 10-160B Cask body side, top, and bottom ends. These tally surfaces are added to the NCT tallies in the MCNP analyses (which cover both NCT and HAC). These one-meter surface tallies are added to both the primary and drain line evaluation analyses discussed in Section 5.3.1.

Additional details of the HAC shielding models are given in Reference 1.

5.3.3 MATERIAL PROPERTIES

The compositions and densities of the materials modeled in the shielding analyses are described in Table 5-6 below. The table also lists the MCNP material/cross-section identifier (ZAID) for each modeled material. Any (small) stainless steel components are conservatively modeled as carbon steel (which has a lower density than stainless steel).

Table 5-6 - Material Compositions and Densities

Material	Total Density (g/cc)	Composition	MCNP ZAID
Carbon Steel	7.82	99% Fe 1% C	26000.84p 8000.84p
Lead	11.34	100% Pb	82000.84p
Air	0.001205	76.508% N 23.479% O 0.013% C	7000.84p 8000.84p 6000.84p

5.4 SHIELDING EVALUATION

5.4.1 ANALYSIS METHODOLOGY

The peak 10-160B Cask exterior dose rates are determined, for the evaluated 10,000 Ci Co-60 payload, using the following steps:

1) Extract unit-source gamma dose rates (that are given in units of mrem/hr per gamma/sec) from the (MCNP) shielding code output files.

2) Determine the peak unit-source gamma dose rates that occur for each of the regulated 10-160B Cask exterior surfaces (i.e., the package side, package top, package bottom and 2-meter surfaces for NCT, and the one meter side, top and bottom surfaces for HAC).

3) For the bottom and side surfaces, use the peak unit-source dose rates from the Insert and Cask drain evaluation MCNP run if they exceed the peak unit source dose rates output by the primary MCNP run.

4) Conservatively increase the peak unit-source dose rates output by MCNP by their corresponding relative statistical error level (also output by MCNP).

5) Multiply the peak unit-source gamma dose rate for each regulated surface (determined in the steps above) by the overall Co-60 source strength (7.4E+14 γ/s) to yield the absolute peak gamma dose rate (in mrem/hr) for each regulated surface.

6) The resulting absolute gamma dose rates are presented, and compared to their corresponding 10CFR71 limits, in Table 5-3 and Table 5-4.

Additional details of the shielding analysis methodology are given in Reference 1.

5.4.2 COMPUTER CODE

The Monte-Carlo N-Particle Version 5 (MCNP5) Release 1.51 computer program was used to perform the analyses documented in this report. MCNP5 is a general-purpose, continuous energy, generalized-geometry, time-dependent, coupled neutron/photon/electron Monte Carlo transport code.

The MCNP5 input and output files are provided in Reference 1.

5.4.3 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 2) 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

Gamma Energy (MeV)	DCV (rem/hr) per (γ/cm²-sec)
0.015	1.95E-06
0.025	8.01E-07
0.045	3.17E-07
0.08	2.61E-07
0.15	3.79E-07
0.30	7.59E-07
0.50	1.15E-06
0.65	1.44E-06
0.75	1.60E-06
0.90	1.83E-06
1.25	2.32E-06
1.75	2.93E-06
2.5	3.72E-06
3.5	4.63E-06
4.5	5.42E-06
5.5	6.19E-06
6.5	6.93E-06
7.5	7.66E-06
9.0	8.77E-06
12.0	1.10E-05

5.4.4 EXTERNAL RADIATION LEVELS

5.4.4.1 NCT Results

Table 5-3 presents the peak dose rates for NCT, given a 10-160B Cask with a centered Shield Insert A containing a distributed 10,000 Ci Co-60 source. Note that the maximum dose rate at 2 m from the 10-160B 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).

The Insert and Cask drain evaluation discussed in Section 5.3.1 shows that the presence of the drain lines increases the NCT package bottom dose rate by 33%. The dose rate presented in Table 5-3 reflects that increase. The peak package side and 2-meter side dose rates are not affected by the drain lines, because the peak side surface dose rates occur near the cask axial midplane elevation, well above the (lower) elevations potentially affected by gamma streaming through the drain lines. Package top surface dose rates are not affected by the drain lines.

5.4.4.2 HAC Results

Table 5-4 presents the peak dose rates that occur for HAC, on the surfaces one meter from the 10-160B Cask body side, top and bottom.

The Insert and Cask drain evaluation discussed in Section 5.3.1 shows that the presence of the drain lines increases the HAC one-meter bottom dose rate by 26%. The dose rate presented in Table 5-4 reflects that increase. The peak one-meter side dose rate is not affected by the drain lines, because it occurs near the cask axial midplane elevation, well above the (lower) elevations potentially affected by gamma streaming through the drain lines. One-meter top surface dose rates are not affected by the drain lines.

5.5 REFERENCES

1. Energy*Solutions* Calculation Package No. (CALC-CSK-145103-EG-002), "Shielding Evaluation of 10-160B Shield Insert A," Revision 0.

2. ANSI/ANS-6.1.1-1977, American Nuclear Society, 1977, "Neutron and Gamma-Ray Flux-to-Dose-Rate Factors."

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6.0 CRITICALITY EVALUATION

There is no fissile material in the contents addressed by this addendum. Thus, a criticality evaluation is not applicable.

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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.

7.1 PROCEDURE FOR LOADING SHIELD INSERT A

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 Shield Insert A lid to the insert body.

7.1.2 Remove the Shield Insert A 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 Shield Insert A lid.

7.1.6 Assure bolt threads are adequately lubricated and secure the Shield Insert A 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 + 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 the drawing in Section 1.3 of this Addendum 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 Confirm and independently verify that the Insert closure nuts are torqued to the specified value of 75 ± 10 ft-lbs using a star pattern. 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 Shield Insert A are given below.

8.1 ACCEPTANCE TEST

Prior to the first use of the Shield 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, Division 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, Division 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 Shield Insert A.

8.1.4 COMPONENT TESTS

Shield Insert A will be subjected to Load Testing and Shielding Integrity Testing.

8.1.5 TEST FOR SHIELDING INTEGRITY

Shielding integrity of Shield Insert A 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 Shield Insert.

8.1.7 IMPACT LIMITER FOAM

There is no foam in Shield Insert A.

8.1.8 PRESSURE TEST

No pressure testing will be performed on Shield Insert A.

8.2 MAINTENANCE PROGRAM

The 10-160B package will be subjected to routine and periodic inspection and tests as outlined in Section 8.2 of the base 10-160B SAR.

The Shield Insert A maintenance requirements are described below.

8.2.1 ROUTINE MAINTENANCE

8.2.1.1 Fasteners

The Insert lid bolts shall be visually inspected for defects prior to each shipment. Obtain replacement parts as specified on the SAR drawings in Chapter 1 of this Addendum for any components that show cracking or other visual signs of distress.

8.2.1.2 Gaskets and Seals

Shield Insert A has an elastomeric lid gasket that must be inspected for damage or compression set and replaced as necessary with every shipment.

Seals in the vent or drain port may be repaired or refurbished as necessary to meet the requirements of the drawing in Section 1.3 of this Addendum

8.2.1.3 Painted Surfaces Identification Markings and Match Marks Used for Closure Orientation

Shield Insert A has painted match marks that shall be visually inspected to ensure that surfaces are in good condition, identification markings are legible and that match marks used for closure orientation remain legible and are easy to identify.

8.2.2 PERIODIC MAINTENANCE

8.2.2.1 Periodic Leak Tests

Shield Insert A does not provide containment; therefore there are no periodic leak tests.

8.2.2.2 Assembly Verification Leak Test

Shield Insert A does not provide containment; therefore there are no assembly verification leak tests.

8.2.2.3 Ratchet Binders

Shield Insert A does not have ratchet binders.

8.2.2.4 Repair of Bolt Holes

Helical threaded inserts may be used for repair of bolt holes. The minimum tensile strength of the insert material must be greater than or equal to 150 ksi and the minimum length of the insert must be equal to one (1) bolt diameter. The following steps shall be performed for each repair using a helical threaded insert.

a. Install helical threaded insert(s), sized per manufacturer's recommendation, per the manufacturer's instructions for bottoming style taps. Helical threaded inserts may be tack welded to the base metal to keep them from backing out during cask operations.
b. At a minimum, each repaired bolt hole(s) will be tested for proper installation by assembling the joint components where the helical threaded insert is used and tightening the bolts to their required torque value.

   Note: Shield Insert A has no bolt holes used for lifting components; therefore a load test is not required.
c. Each helical threaded insert shall be visually inspected after testing to insure that there is no visible damage or deformation to the insert.

8.2.3 SUBSYSTEM MAINTENANCE

Shield Insert A contains no subsystem assemblies.

8.2.4 VALVES RUPTURE DISCS AND GASKETS ON CONTAINMENT VESSEL

Shield Insert A does not provide containment, therefore there are no valves or rupture disk/gaskets.

8.2.5 SHIELDING

No shielding tests will be performed after acceptance testing unless there has been a repair to a damaged area, which will affect shield integrity. Any shield testing which might be required would be in accordance with the original criteria specified in Section 8.1.5 of this Addendum.

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SHIELD INSERT B ADDENDUM

FOR

MODEL 10-160B

TYPE B RADWASTE SHIPPING CASK

CONSOLIDATED SAR REVISION 7

NOVEMBER 2013

ENERGYSOLUTIONS

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1.0 GENERAL INFORMATION

1.1 INTRODUCTION

This Addendum demonstrates that the Model 10-160B Cask, ID number USA/9204/B(U)F-96, can be used as a shipping package to transport a Shield Insert containing radionuclide source material in compliance with regulatory requirements under both normal conditions of transport and hypothetical accident conditions as required by 10 CFR 71.

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 Shield Insert, used to contain the radioactive sources, is added as an additional component of the packaging. This insert is identified as the 10-160B Shield Insert B.

Shield Insert B provides photon (gamma) shielding in the forms of lead and steel. The photon shield has side walls consisting of lead with a total thickness of 6.72 inches, located between an inner 8-inch SCH 40 steel pipe and an outer 24-inch 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 of 8 5/8 inches), steel bolting plate, and flat elastomeric 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 cask contents consists of radioactive items loaded into Shield Insert B. Other items, such as dunnage, baskets, handling devices, etc. may be included along with the radioactive items if they meet the 10-160B contents specifications for the cask (Section 1.2.3 of the base SAR) and this Section.

For this Addendum,

The type and form of material will include:

1) Normal or special form radioactive material as described in Section 1.2.3.1 of the SAR, except that sources must meet the limits established in Chapter 5 of this Addendum.

2) Small sources that fit within the envelope of a 1 cm high by 1 cm diameter cylinder must be encapsulated in a sealed metallic enclosure with no external dimension less than 1 cm in length.

Maximum quantity of material per package:

1) Radioactive source material meeting the source term requirements in Chapter 5 of this Addendum, contained in Shield Insert B as specified in Section 1.3 of this Addendum.

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

3) The contents of Shield Insert B have a maximum weight of 500 pounds.

4) The total weight of contents, cribbing, and Shield Insert B shall not exceed 14,250 pounds.

5) The contents of Shield Insert B shall not include water or organic materials, explosives, corrosives, pyrophorics, or compressed gases.

1.3 APPENDIX

<u>10-160B Shield Insert B Drawings</u>

- Drawing No. DWG-LIN-201588-ME-0001, *"10-160B Shield Insert B Assembly and Details"*
- Drawing No. C-038-145083-005, *"Source Insert Steel Cribbing"*

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

2.0 STRUCTURAL EVALUATION

No changes.

2.1 STRUCTURAL DESIGN

No changes.

2.2 WEIGHTS AND CENTER OF GRAVITY

The maximum payload weight for the 10-160B Cask is limited to 14,250 pounds. The weight of Shield Insert B is itemized as follows:

Shield Insert B Body	6,500 lb
Shield Insert B Lid	500 lb
Shield Insert B Payload	500 lb
Shield Insert B Total	7,500 lb
Design Shield Insert B Weight	8,000 lb

The steel cribbing that will be used to support Shield Insert B inside the 10-160B Cask cavity will weigh less than 5,000 pounds. Therefore, the combined weight of Shield Insert B and the steel cribbing is less than 13,000 pounds, which is less than the payload weight limit of 14,250 pounds.

Shield Insert B is placed in the 10-160B Cask in such a way that its C.G. is located near that 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 (ASTM A516 Gr. 70) and the lead (ASTM B29) materials used for the construction of Shield Insert B 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 J429 Grade5. The mechanical properties of these bolts are as follows.

Yield Stress, S_y	=	92,000 psi
Ultimate 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 remains the same. No changes in the SAR for lifting analyses of the package are made. The handling of Shield Insert B 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 Shield Insert B 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 Shield Insert has been performed in Section 3 of this 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 Shield 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 Shield Insert will be negligible.

2.6.2 COLD

No changes.

2.6.3 PRESSURE

The cavity temperature of the 10-160B Cask, with the Shield 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 Shield 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 Shield 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 Shield 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 HYPOTHETICAL ACCIDENT CONDITIONS

No changes.

2.7.1 FREE DROP

The SAR has evaluated the 10-160B Cask for the hypothetical accident drop test conditions with a generic payload. The specific payload, comprised of Shield Insert B and the cribbing, meets the payload limits of the SAR. Therefore, there is no change in SAR analyses. The evaluation of Shield Insert B 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 Shield 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 Shield 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.

Lead slump in the Shield Insert is controlled using a zone-solidification fabrication process by which the unit is slowly cooled from bottom to top. As a result, molten lead backfills any radial lead shrinkage as the lead solidifies from bottom to top of the pour. The finished product is gamma scanned to assure adequate lead thickness and uniformity. As a result, the residual radial void into which lead could slump under the HAC end drop is negligible. The effect of lead slump in the Shield Insert has been evaluated in Section 6.4.1 of Reference 26. The lead-shielding used in the insert undergoes a maximum deformation of 0.049 inches. Since the stresses in the lead column are much smaller than the plastic flow stress, most of this deformation is recovered resulting in a very small axial 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 Shield Insert has been analyzed in Section 6.2.3 of Reference 26. It is shown that the stresses in every component of the Shield 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 Shield Insert has been addressed in Section 6.2 of Reference 26. It has been shown that the deceleration loading on the Shield Insert during this drop is enveloped by the end drop and side deceleration loadings. No separate evaluation of the Shield 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 Shield 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 Shield Insert 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.1, 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 watts. 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 Shield Insert for the NCT and HAC fire test have been performed using 2-d axisymmetric models with the appropriate dimensions and geometry.

Conservatively 200 watts of internal heat load is used in the thermal analyses reported in this addendum.

The results for the Shield Insert are summarized for NCT 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 Shield Insert.

3.2 SUMMARY OF THERMAL PROPERTIES OF MATERIALS

No new thermal properties have been used in the analyses of the Shield Insert.

3.3 TECHNICAL SPECIFICATIONS OF COMPONENTS

The steel and the lead material used for the construction of the Shield 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 Shield 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 13. The Shield Insert model uses some conservative simplifications that are documented in Reference 13.

The boundary conditions used in the analysis of the Shield Insert are the same as those used in the SAR.

3.4.2 MAXIMUM TEMPERATURES

The maximum temperatures in various parts of the Shield Insert 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 (530°R).
2) The pressure in the cask at 240°F (700°R) (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

   $P_2 = 19.4$ psi

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

$$\text{MNOP} = 19.4 - 14.7 = 4.7 \text{ psig}$$

The value used for MNOP is conservatively set at 35.0 psig. Since the MNOP for the shield 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 Shield 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 13. The Shield Insert model uses some conservative simplifications that are documented in Reference 13.

The boundary conditions used in the analysis of the Shield Insert are the as those used in the SAR with some conservative modifications that are detailed in Reference 13.

3.5.2 PACKAGE CONDITIONS AND ENVIRONMENT

No changes.

3.5.3 PACKAGE TEMPERATURES

The maximum temperatures in various parts of the Shield Insert 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 (530°R), the pressure in the cask at 300°F (760°R), P_2, may be calculated by the ideal gas relationship:

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

$$P_2 = 21.1 \text{ psia}$$

Therefore, the maximum pressure during the HAC fire,

$$P_{max} = 21.1 - 14.7 = 6.4 \text{ psig}$$

The value used for P_{max} is conservatively set at 100 psig. Since the P_{max} for the Shield 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

13. Energy*Solutions* Document TH-031, Rev.1, 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 (Table 3.1-1)
Difference across the cask body	0.11[1]	0.2
Difference across the outer shell	0.04[2]	0.0
Difference across the inner shell	0.01[3]	0.0
Average Wall	166.1[4]	173
Lead	166.2[5]	173
Body	168.4[6]	175
Seal	168.1[7]	174
Bulk Air	231.2[8]	188
Payload (Source)	233.1[9]	-

NOTES:

(1) Difference of Node 377 and Node 314 Temperature. See Figure 7 of Reference 13.
(2) Difference of Node 377 and Node 409 Temperature. See Figure 7 of Reference 13.
(3) Difference of Node 283 and Node 314 Temperature. See Figure 7 of Reference 13.
(4) Average of Node 377 and Node 314 Temperature. See Figure 7 of Reference 13.
(5) Average of Node 409 and Node 283 Temperature. See Figure 7 of Reference 13.
(6) Maximum temperature from Figure 8 of Reference 13.
(7) Maximum of Node 153 and Node 80 temperatures. See Figure 7 of Reference 13.
(8) Maximum temperature from Figure 9 of Reference 13.
(9) Maximum temperature from Figure 10 of Reference 13.

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 (Table 3.1-2)	Value Analyzed in the SAR (Table 3.1-2)
Difference across the cask body	31.7(1)	39.8	45
Difference across the outer shell	15.2(2)	20.2	24
Difference across the inner shell	1.65(3)	2.3	2
Average Wall	294(4)	279	334
Lead	294(5)	274	335
Body	302(6)	289	352
Seal	206(7)	375	375
Bulk Air	296(8)	281	290
Payload (Source)	253(9)	-	-

NOTES:

(1) Difference of Node 377 and Node 314 Temperature. See Appendix 3 of Reference 13.
(2) Difference of Node 377 and Node 409 Temperature. See Appendix 3 of Reference 13.
(3) Difference of Node 283 and Node 314 Temperature. See Appendix 3 of Reference 13.
(4) Average of Node 377 and Node 314 Temperature. See Appendix 3 of Reference 13.
(5) Average of Node 409 and Node 283 Temperature. See Appendix 3 of Reference 13.
(6) Maximum temperature at Node 377. See Figure 7 and Appendix 3 of Reference 13.
(7) Maximum of Node 153 and Node 80 temperatures. See Appendix 3 of Reference 13.
(8) Maximum temperature from Figure 13. See also Appendix 3 of Reference 13.
(9) Maximum temperature from Figure 19. See also Appendix 3 of Reference 13.

4.0 CONTAINMENT

There are no changes to the containment evaluation found in Chapter 4 of the base SAR.

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5.0 SHIELDING EVALUATION

This shielding evaluation supports exclusive use shipment of Shield Insert B, containing various gamma, beta or neutron sources in the Model 10-160B Transport Cask. The evaluation documented in this chapter determines maximum allowable source strengths (in particles/sec), that may be shipped in Shield Insert B within the 10-160B Cask, while meeting all the radiological requirements of 10 CFR 71 for exclusive use shipments.

Maximum allowable gamma source strengths are determined as a function of gamma energy, for a wide range of gamma energies (i.e., 0.5 MeV to 4.0 MeV). Beta sources are converted into equivalent gamma sources using the methodology discussed in Section 5.6.1. The neutron source strength limit of 1.1×10^8 neutrons/sec established for the 10-160B in Chapter 5 of the SAR remains applicable for Shield Insert B (i.e., the neutron shielding properties of the insert are conservatively neglected). Sources that emit multiple types of radiation (gamma, beta and neutron) or multiple gamma energies are treated using the sum of fractions methodology discussed in Section 5.6.2.

In addition to the general analyses described above, specific evaluations are performed, in Section 5.6.3, for five isotopes commonly used in the concentrated radiation sources that will typically be shipped in Shield Insert B. The isotopes are Co-60, Cs-137, Ir-192, Se-75 and Sr-90. These specific evaluations determine the maximum allowable activity level for each isotope, in curies, at which all 10 CFR 71 radiological requirements are met, as well as the 200 watt heat generation limit and 3000 A_2 activity limits.

5.1 DESCRIPTION OF SHIELDING DESIGN

5.1.1 DESIGN FEATURES

5.1.1.1 Operating Design

The 10-160B 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 exclusive use shipments. The 10-160B Cask is designed to carry a payload of Type B quantity radioactive byproduct, source, or special nuclear material weighing no more than 14,250 pounds (6,463 kilograms). 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.

Shield Insert B is designed, constructed, and prepared for shipment as a shielded insert to the 10-160B Cask. Shield Insert B is comprised of gamma (i.e. photon) shielding that is to be supported and centered in the 10-160B Cask cavity by a cribbing structure. Shield Insert B is loaded into the 10-160B Cask, which is then transported on an 8-foot wide trailer.

Tests and analyses have demonstrated the ability of the packaging to maintain its shielding integrity under NCT. The cribbing structure is also shown by analysis to maintain its geometry under HAC. Thus, the Shield Insert is approximately centered within the 10-160B Cask cavity for both NCT and HAC conditions. The cribbing structure (and materials) is not modeled, however, in either the NCT or HAC analyses, so its shielding properties are conservatively neglected.

This shielding evaluation supports the shipment of gamma, beta or neutron sources that may have any size, material or geometric configuration. The payloads are conservatively modeled as small point sources (i.e., a 1 cm diameter by 1 cm high cylinder) that are located in the worst possible location within the cavity of Shield Insert B. Section 1.2.3.1 of this Addendum discusses encapsulation requirements for smaller sources.

5.1.1.2 Shielding Design

Representative views of the 10-160B Cask and Shield Insert B are presented in Figures 5-1 through 5-3. A representative view of the shielding model of the 10-160B Cask, Shield Insert B, and the modeled source 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 secondary lid thermal shield has been conservatively neglected in this evaluation.

As presented in Table 5-1, the 10-160B 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 77 inches. The 10-160B Cask bottom, outer and inner lids are all comprised of two layers of steel with a total thickness of 5-½ inches. The 10-160B 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/10-160B 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 10-160B Cask as located on the trailer. The impact limiter materials are conservatively ignored for the purpose of the shielding evaluation.

The source is loaded into the Shield Insert B cavity. Shield Insert B is then centered inside the 10-160B Cask both radially and axially, as shown in Figure 5-4. As presented in Figure 5-2, the Shield Insert B inner shell side walls are comprised of lead (density of 11.34 g/cm^3 and a total thickness of 6.72 inches) located between an inner 8-inch SCH 40 steel pipe and an outer 24-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.

With the exception of a few minor (small) components, all steel components of the 10-160B Cask and Shield Insert B consist of carbon steel. The optional stainless steel 10-160B Cask cavity liner is conservatively neglected in the shielding analysis.

Figure 5-1 - 10-160B Cask General Arrangement

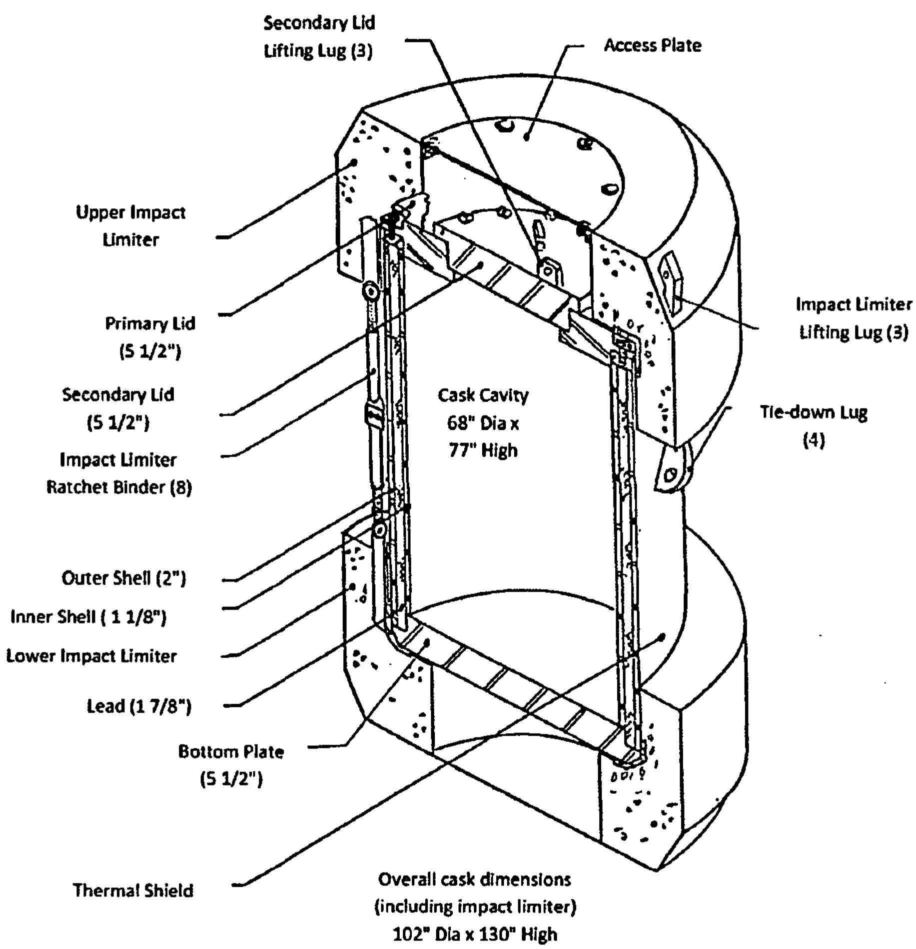


Figure 5-2 - Cutaway View of Shield Insert B

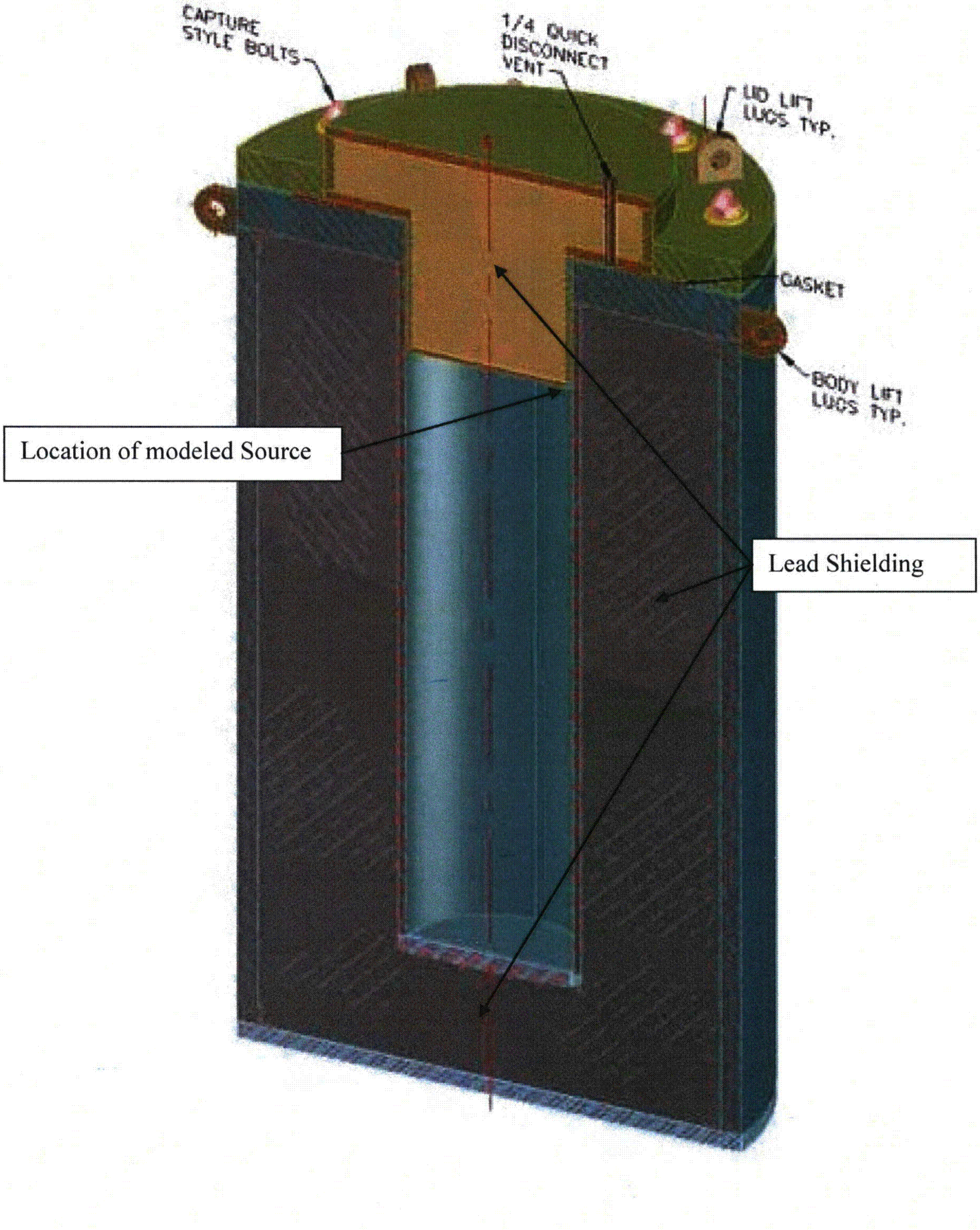


Figure 5-3 - Elevation Plan View of Shield Insert B

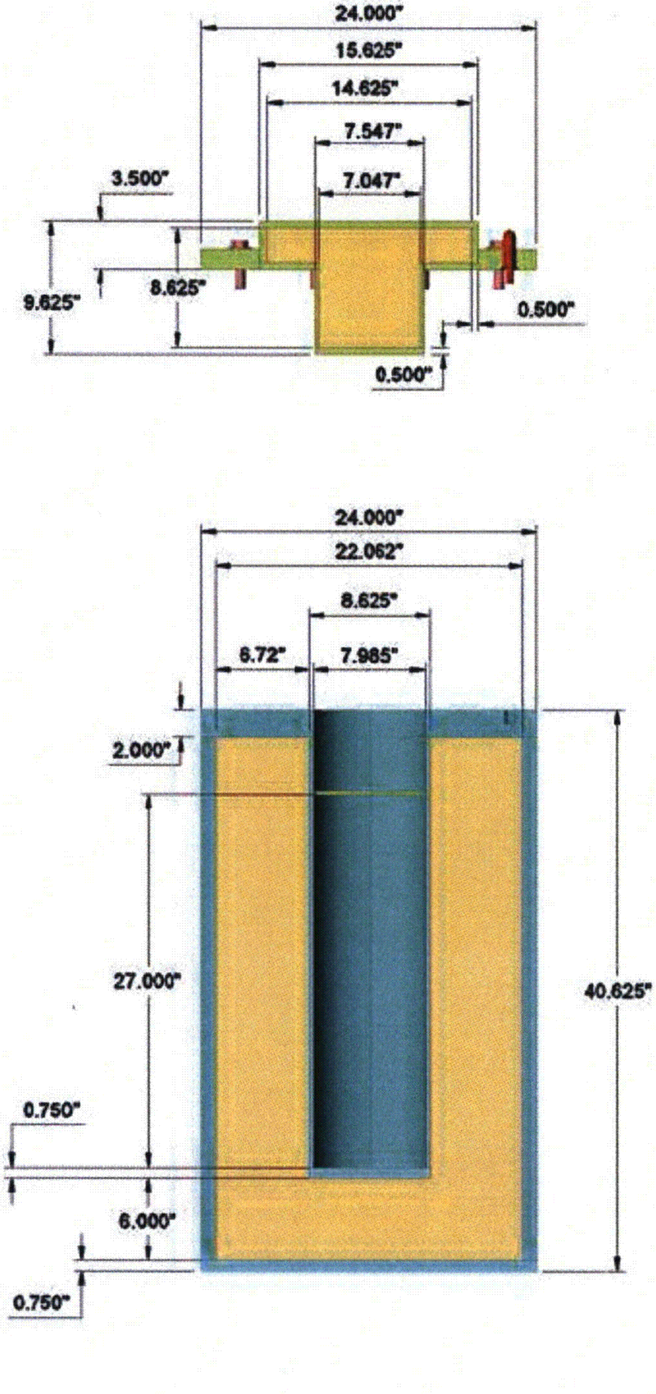


Figure 5-4 - Elevation View of Shielding Model (NCT & HAC)

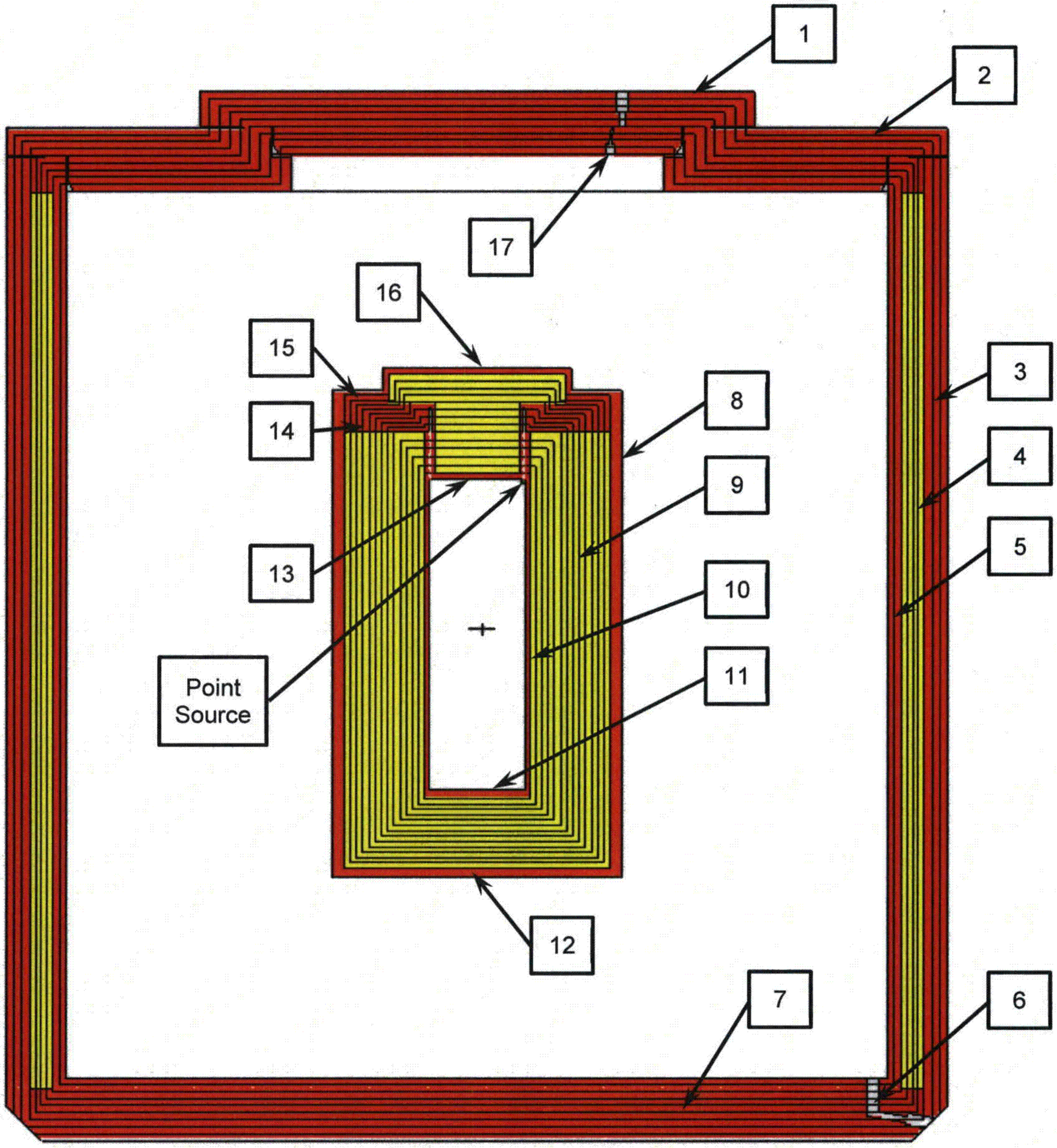


Table 5-1 - Component Description and Material Specifications

Item Number (Figure 5-4)	Component Description and Material Specification
1	10-160B Secondary Lid: 5.5-inches thick, carbon steel
2	10-160B Primary Lid: 5.5-inches thick, carbon steel
3	10-160B Outer Shell: 2.0-inches thick, carbon steel
4	Lead Shield: 1.875-inches thick
5	10-160B Inner Shell: 1.125-inches thick, carbon steel
6	10-160B Cask Drain
7	10-160B Base: 5.5-inches thick, carbon steel
8	Seamless Pipe, 24-in SCH. 60, carbon steel
9	Cast Lead Shield: 6.72-inches thick
10	Seamless Pipe, 8-in SCH. 40, carbon steel
11	Plate: 0.75-inches thick, carbon steel
12	Plate: 0.75-inches thick, carbon steel
13	Plate: 0.50-inches thick, carbon steel
14	Plate: 2.0-inches thick, carbon steel
15	Plate: 1.5-inches thick, carbon steel
16	Plate: 0.5-inches thick, carbon steel
17	10-160B Cask Vents

Table 5-2 - 10-160B Cask Dimensions

Component	Diameter (in)	Height (in)	Thickness (in)
Cavity	68	77	-
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

5.1.2 SUMMARY OF MAXIMUM DOSE RATES

Tables 5-3 and 5-4 summarize the maximum dose rates for NCT and HAC, respectively. Results are presented for two common source isotopes: Co-60 and Cs-137[1]. The values correspond to the dose rates produced by the maximum allowable radiological source strengths for each isotope, without regard for thermal or A_2 constraints on the payload. Because of the shielding methodology, one location will always be equal to the regulatory limit. For Shield Insert B, the limit is always at the package top because of the very conservative source modeling approach. As shown in Section 5.6.3, thermal and A_2 constraints significantly reduce the allowable activity for many isotopes, which results in lower cask exterior dose rates. For example, the thermal constraint reduces the Co-60 source dose rates to 96% of the values below, and the Cs-137 dose rates to 0.2% of the values below.

Table 5-3 - Peak NCT Dose Rates

Isotope	Package Surface mSv/h (mrem/h)			2 Meters from 8' Trailer Side mSv/h (mrem/h)
	Top	Side	Bottom	
Co-60	2.00 (200)	0.028 (2.8)	0.047 (4.7)	0.0013 (0.13)
Cs-137	2.00 (200)	0.025 (2.5)	0.0003 (0.03)	0.0011 (0.11)
10 CFR 71.47(b) Limit	2 (200)	2 (200)	2 (200)	0.1 (10)

Table 5-4 - Peak HAC Dose Rates

Isotope	1 Meter from Cask Surface mSv/h (mrem/h)		
	Top	Side	Bottom
Co-60	0.93 (93.0)	0.004 (0.4)	0.022 (2.2)
Cs-137	0.869 (86.9)	0.005 (0.5)	0.0002 (0.02)
10 CFR 71.51(b) Limit	10 (1000)	10 (1000)	10 (1000)

[1] Includes the Ba-137m daughter at equilibrium

5.2 SOURCE SPECIFICATION

5.2.1 GAMMA SOURCE

Analyses are performed for Co-60, Cs-137, and for several discrete gamma energies ranging from 0.5 MeV to 4.0 MeV. The gamma quantities (per decay) and modeled energy spectra for Co-60 and Cs-137 are presented in Table 5-5 below. The Cs-137 source includes an equilibrium amount of Ba-137m.

Unit (1.0 gamma/sec) sources are modeled in the shielding analyses. The resulting peak unit source gamma dose rates are then compared to the regulatory dose limits to determine the maximum gamma source strength (in gammas/sec) at which all 10 CFR 71 dose rate limits are met. These maximum allowable gamma source strengths are determined for Co-60, Cs-137, and all evaluated gamma energy levels, as discussed in Section 5.4.

The gamma source is modeled as a point source (1 cm diameter x 1.0 cm high) in the worst Shield Insert B cavity location. This conservative approach neglects all shielding properties of the source material and any other materials inside the insert cavity. It also concentrates the source to the maximum extent (which maximizes peak dose rates) and places the source as close as possible to the regulated cask exterior surfaces.

Table 5-5 - Gamma Energy and Abundance

Radionuclide	Gamma Energy MeV	Abundance # of Gamma/decay
^{60}Co	1.176	1
	1.333	1
^{137}Cs	0.662	0.85

5.2.2 NEUTRON SOURCE

A Pu-Be neutron source of 1.1×10^8 neutrons/sec is qualified for the 10-160B Cask in Chapter 5 of the main 10-160B Cask SAR. No further credit is taken for the neutron shielding properties of the insert. Payloads that contain both neutron and gamma sources are addressed using the sum of fractions methodology discussed in Section 5.6.2.

5.3 SHIELDING MODELS

5.3.1 NCT MODEL

Figure 5-5 shows a detail of the Shield Insert B shielding model. The insert is centered, axially and radially, within the 10-160B Cask cavity. It should be noted that there are no penetrations or discontinuities in either the 10-160B Cask or Shield Insert B designs that require special studies for positional tolerances, therefore all models have the insert centered within the cask cavity. The 10-160B Cask and Shield Insert B configuration is illustrated in Figure 5-4. The physical dimensions of the 10-160B Cask and Shield Insert B are given in Figure 5-1 and Figure 5-3, respectively, as well as in Tables 5-1 and 5-2 (which also give the component materials).

Two analyses are performed for each gamma energy: one with the point source in the insert cavity top corner, and one with the point source in the insert cavity bottom corner. For example, the modeled location of the top corner point source within the insert cavity is illustrated in Figure 5-5. The bottom and top corner point source models are used to calculate 10-160B Cask bottom and top end exterior dose rates, respectively.

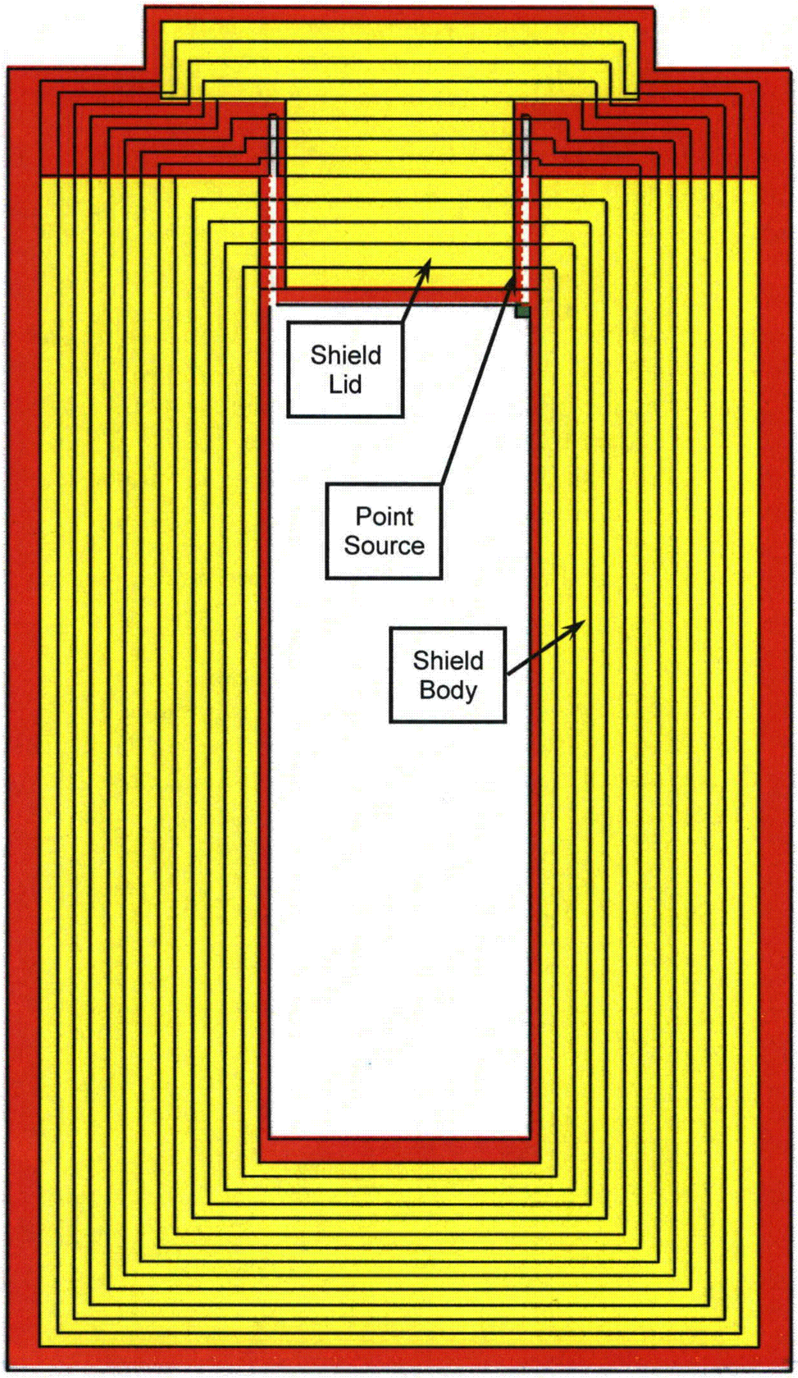
As shown in Figure 5-4 and Figure 5-5, the amount of radial shielding does not vary with axial location of the source within the insert cavity. Thus, both the bottom and top corner analyses yield peak side dose rates. The amount of shielding (between source and detector surface) for the 10-160B Cask and Shield Insert B bottom ends does not vary with radial the location of the source within the insert cavity. Thus, a point source placed in the bottom corner of the insert cavity will (simultaneously) produce maximum peak bottom surface and peak side surface dose rates. As shown in Figure 5-5, peak cask top end doses are maximized by placing the point source in the top corner of the insert cavity, due to the gap between the insert top plug and the radial insert body.

Although the impact limiter materials are conservatively neglected, the NCT dose rates are tallied on the impact limiter side and end surfaces, as they are the "package surface" on which the 200 mrem/hr regulatory limit applies. The dose rates are also tallied on the cask body radial surface, over the axial span between the top and bottom impact limiters since that is also part of the "package surface". These impact limiter and cask body surfaces make up the "package surface" on which the 200 mrem/hr dose rate limit applies. Dose rates are also tallied on a vertical plane 322 cm from the cask centerline, which corresponds to a plane 2 meters from the side of an 8-foot trailer. All tallies are taken over a narrow azimuthal span, at the same azimuth where the point sources lie. This minimizes the distance between source and dose location, and thus maximizes calculated dose rates.

As a modeling convenience, the same models are used for NCT and HAC. This is conservative for the NCT cases. The HAC features are discussed below.

Additional details of the NCT shielding models are given in Reference 1.

Figure 5-5 - Elevation View of the Shielding Model for Shield Insert B



5.3.2 HAC MODEL

Reference 26 (Chapter 2 of this Addendum) shows that the cribbing remains stable under HAC. Shield Insert B is therefore centered in the HAC models. Furthermore, HAC tests do not result in any significant permanent deformation of the 10-160B Cask or Shield Insert B components. The only physical change with shielding significance is the axial lead slump at the top of the10-160B Cask radial lead cavity, discussed in Section 2.7.1.1 of the SAR. This slump is included in the shielding models. As described in Section 2.7.1.1.3 of this SAR Addendum, no significant slumping of the insert lead is predicted. Figure 5-5 shows that the top of the insert's radial lead shield is well above the top of the source cavity, so gamma streaming through a lead slump gap (at the top of the lead shield) would be at an oblique angle. Thus, the Shield Insert B shielding models do not require a lead slump gap.

Since the only significant difference between the NCT and HAC packaging conditions is the 10-160B Cask's lead slump, the same shielding model was used for NCT and HAC, resulting in slightly conservative results for NCT.

For HAC, the dose rates are tallied on surfaces one meter from the 10-160B Cask body side, top, and bottom ends. Dose rates are tallied (on the side, top and bottom one meter surfaces) over a narrow azimuthal span that lies directly above the modeled point sources. These tally surfaces are added to the NCT tallies in the MCNP analyses (which cover both NCT and HAC). Two analyses are performed (for each gamma energy) which model point sources at the top and bottom corners of the insert cavity, respectively.

Additional details of the HAC shielding models are given in Reference 1.

5.3.3 MATERIAL PROPERTIES

The compositions and densities of the materials modeled in the shielding analyses are described in Table 5-6 below. The table also lists the MCNP material/cross-section identifier (ZAID) for each modeled material. Any (small) stainless steel components are conservatively modeled as carbon steel (which has a lower density than stainless steel).

Table 5-6 - Material Compositions and Densities

Material	Total Density (g/cc)	Composition	MCNP ZAID
Carbon Steel	7.82	99% Fe 1% C	26000.84p 8000.84p
Lead	11.34	100% Pb	82000.84p
Air	0.001205	76.508% N 23.479% O 0.013% C	7000.84p 8000.84p 6000.84p

5.4 SHIELDING EVALUATION

5.4.1 ANALYSIS METHODOLOGY

The maximum allowable gamma source strengths and corresponding peak 10-160B Cask dose rates are determined for each evaluated isotope or gamma energy using the following steps:

1) Extract unit-source gamma dose rates (that are given in units of mrem/hr per gamma/sec) from the (MCNP) shielding code output files.

2) Determine the peak unit-source gamma dose rates that occur for each of the regulated 10-160B Cask exterior surfaces (i.e., the package side, package top, package bottom and 2-meter surfaces for NCT, and the one meter side, top and bottom surfaces for HAC).

3) For each regulated surface, divide the regulatory dose rate limit by the peak unit-source gamma dose rate to yield the gamma source strength (in gammas/sec) at which the peak dose rate would equal the regulatory limit.

4) Select the lowest of the allowable gamma source strengths determined above. This is the maximum allowable source strength for the isotope or gamma energy in question.

5) Multiply the peak unit-source gamma dose rate for each regulated surface (determined in Step 2, above) by the maximum allowable gamma source strength to yield the absolute peak gamma dose rate that applies for that surface. Because of this methodology, one of the surfaces will always have a dose rate equal to the regulatory limit.

Additional details of the shielding analysis methodology are given in Reference 1.

5.4.2 COMPUTER CODE

The Monte-Carlo N-Particle Version 5 (MCNP5) Release 1.51 computer program was used to perform the analyses documented in this report. MCNP5 is a general-purpose, continuous energy, generalized-geometry, time-dependent, coupled neutron/photon/electron Monte Carlo transport code.

The MCNP5 input and output files are provided in Reference 1.

5.4.3 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 2) 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

Gamma Energy (MeV)	DCV (rem/hr) per (γ/cm^2-sec)
0.015	1.95E-06
0.025	8.01E-07
0.045	3.17E-07
0.08	2.61E-07
0.15	3.79E-07
0.30	7.59E-07
0.50	1.15E-06
0.65	1.44E-06
0.75	1.60E-06
0.90	1.83E-06
1.25	2.32E-06
1.75	2.93E-06
2.5	3.72E-06
3.5	4.63E-06
4.5	5.42E-06
5.5	6.19E-06
6.5	6.93E-06
7.5	7.66E-06
9.0	8.77E-06
12.0	1.10E-05

5.4.4 EXTERNAL RADIATION LEVELS

5.4.4.1 NCT Results

Table 5-8 presents the peak dose rates for NCT. Note that the maximum dose rate at 2 m from the 10-160B 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).

In all cases, the limiting dose rate (that determines the maximum allowable gamma source) occurs on the top impact limiter top surface, at the location directly above the point source in the top corner of the insert cavity. For this reason, the package top surface dose rates in Table 5-8 are all equal to the 200 mrem/hr regulatory limit. Sections 5.1.2 and 5.6.3 of this Addendum discuss the effects of thermal and A_2 source constraints, which generally reduce the expected maximum dose rates below these values.

5.4.4.2 HAC Results

Table 5-9 presents the peak dose rates that occur on the surfaces one meter from the 10-160B Cask body side, top and bottom. Peak dose rates are presented for Co-60, Cs-137, and the ten evaluated gamma energies. None of the peak one meter surface dose rates are close to the regulatory limit. That is because the maximum allowable gamma source strengths are governed by the NCT top impact limiter surface location (as shown in Table 5-8).

5.5 REFERENCES

1. Energy*Solutions* Calculation Package No. CALC-CSK-145103-EG-001, "Shielding Evaluation of 10-160B Shield Insert B," Revision 0.

2. ANSI/ANS-6.1.1-1977, American Nuclear Society, 1977, "Neutron and Gamma-Ray Flux-to-Dose-Rate Factors."

3. Cember, H., "Introduction to Health Physics," Pergamon Press, 2nd Ed.

4. "Radiation Source Use and Replacement", National Research Council, The National Academies Press, Washington D.C., 2008.

5. MicroShield, Version 7.02, Grove Software, Inc.

Table 5-8 - Allowable Gamma Source Strengths and Peak NCT Dose Rates

Isotope/ Gamma Energy (MeV)	Maximum Allowable Gamma Source (gammas/sec)[1]	Peak Surface Gamma Dose Rate (mrem/hr)[2]			
		Package Side Surface[3]	Package Top Surface[4]	Package Bottom Surface	Plane 2 meters from 8' Trailer Side
Co-60	9.99E+14	2.8	200.0	4.7	0.13
Cs-137	6.49E+17	2.5	200.0	0.03	0.11
0.5	9.69E+19	2.9	200.0	0.0	0.14
0.7	3.01E+17	2.4	200.0	0.1	0.11
0.9	1.74E+16	2.2	200.0	0.7	0.09
1.17	1.77E+15	2.0	200.0	3.2	0.10
1.5	3.45E+14	5.4	200.0	7.5	0.27
1.83	1.26E+14	9.0	200.0	11.1	0.47
2.25	5.47E+13	11.7	200.0	13.8	0.66
2.75	2.89E+13	13.2	200.0	15.8	0.75
3.5	1.59E+13	11.8	200.0	15.5	0.72
4.0	1.27E+13	11.4	200.0	14.9	0.70
10CFR71 Dose Limit		200	200	200	10

NOTES:

(1) The dose rates presented in the following columns are calculated based on these gamma source strengths.

(2) On each surface (top, bottom and side), the peak dose rate occurs at the point directly above, below, or across from the point source in the insert cavity (i.e., at the surface location that is closest to the source point), with one exception (see Note 3).

(3) For most gamma energies, the peak side dose rates occur at the same elevation as the source point within the insert cavity. For low energy gammas, the peak occurs further up, on the top impact limiter side surface and high on the 2-meter plane. This is because the lead is an efficient attenuator at low energies, so streaming up the gap followed by scattering in the insert plug shifts the peak.

(4) In all cases, the limiting dose rate (that determines the maximum allowable gamma source) occurs on the top impact limiter top surface, at the location directly above the point source in the top corner of the insert cavity. For this reason, the package top surface dose rates are equal to the 200 mrem/hr regulatory limit.

Table 5-9 - Allowable Gamma Source Strengths and Peak HAC Dose Rates

Isotope/ Gamma Energy (MeV)	Maximum Allowable Gamma Source (gammas/sec)[2]	Peak Surface Gamma Dose Rate (mrem/hr)[1]		
		Side One Meter Surface[2]	Top One Meter Surface	Bottom One Meter Surface
Co-60	9.99E+14	0.4	93.0	2.2
Cs-137	6.49E+17	0.5	86.9	0.02
0.5	9.69E+19	0.6	84.0	0.0
0.7	3.01E+17	0.5	88.1	0.0
0.9	1.74E+16	0.4	89.0	0.3
1.17	1.77E+15	0.4	91.7	1.4
1.5	3.45E+14	0.8	93.6	3.5
1.83	1.26E+14	1.4	94.8	5.4
2.25	5.47E+13	1.9	96.3	6.7
2.75	2.89E+13	2.2	95.9	7.7
3.5	1.59E+13	2.1	96.5	7.8
4.0	1.27E+13	2.0	95.4	7.5
10CFR71 Dose Limit		1000	1000	1000

NOTES:

(1) On each surface (top, bottom and side), the peak dose rate occurs at the point directly above, below, or across from the point source in the insert cavity (i.e., at the surface location that is closest to the source point. One exception is that on lower gamma energies, the peak dose rate on the one meter side plane occurs at a higher elevation. This is because the lead is an efficient attenuator at low energies, so streaming up the gap followed by scattering in the insert plug shifts the peak.

(2) These source strengths are from Table 5-8. The NCT package top surface dose rate is the limiting factor that governs the maximum allowable gamma source strengths.

5.6 APPENDICES

5.6.1 TREATMENT OF BETA-EMITTING ISOTOPES

Beta particles lose their energy continuously as they pass through matter, emitting Bremsstrahlung gammas over their range. These Bremsstrahlung gammas, however, have the potential to be significant contributors to package dose rates because the allowable (3000 A_2) source activity for betas can be much higher than for gamma emitters. The method for qualifying significant beta emitters is to represent the beta emitter as an equivalent gamma emitter and treat it like any other gamma energy line per the methods described in Section 5.4.

This method is only applied to significant beta sources (pure beta emitters) with activities greater than 2E+12 betas per second and peak beta energy levels between 0.3 MeV and 4.0 MeV. Isotopes with peak beta energies less than 0.3 MeV can be neglected. Isotopes with peak beta energies over 4.0 MeV may not be shipped in the 10-160B Cask. Beta source strengths less than 2E+12 betas per second do not contribute significantly to 10-160B Cask exterior dose rates and are, thus, not significant. See Reference 1 for additional details and validating calculations.

The beta source can be converted to an equivalent gamma source by:

$$S_\gamma = S_\beta \cdot \frac{S_\gamma}{S_\beta}$$

where:

S_γ = equivalent monoenergetic gamma source strength, γ/sec, at the maximum beta energy E_{max}.

S_β = beta source strength, β/sec, at the beta energy spectrum for the nuclide of interest and

$$\frac{S_\gamma}{S_\beta} = (\textit{fraction of energy converted from betas to photons})\left(\frac{beta\ E_{avg}}{photon\ energy}\right)$$

Conservatively assume all gammas are at the beta maximum energy E_{max}, the energy ratio becomes:

$$\frac{S_\gamma}{S_\beta} = f\left(\frac{E_{avg}}{E_{\max}}\right)$$

where:

E_{avg}=average energy of the beta source distribution, MeV

E_{max}=maximum energy of the source distribution, MeV.

The fraction of the incident beta energy that is converted to gamma energy, f, is given by (Reference 3)

$$f \cong 3.5 \times 10^{-4} ZE_{\max}$$

where:

f=the fraction of the incident beta energy that is converted to gamma energy,

Z=atomic number of the absorber

So:

$$\frac{S_{\gamma}}{S_{\beta}} = 3.5 \times 10^{-4} ZE_{\max}\left(\frac{E_{avg}}{E_{\max}}\right)$$

The resulting equation to convert a beta source to an equivalent gamma source at the beta's maximum energy is therefore:

$$S_{\gamma} = S_{\beta}\left(3.5 \times 10^{-4} ZE_{avg}\right)$$

For a single material absorber, use the Z of the material. For compounds or mixtures, use a weighted average Z_W:

$$Z_W = \sum_{i=1}^{n}\left(\frac{m_i}{m_{total}} \cdot Z_i\right)$$

Z_W should be determined, as described above, for both the waste payload and the wall of the secondary container (liner) that the waste resides in. Then, the higher of the two Z_W values should be conservatively used as the basis of the equivalent gamma source calculation. This conservatism is necessary since it is not known what fraction of the beta-to-gamma conversion occurs within the waste material and within the secondary container wall material.

The proposed method for qualifying significant beta emitters is to represent the beta emitter as an equivalent gamma emitter and treat it like any other gamma energy line per the methods described in the remainder of this calculation. In this way, significant beta emitters can be accounted for along with other gamma emitters. The entire (equivalent) gamma source (S_{γ}) is modeled at the same energy as the peak beta energy for the beta-emitting isotope. This gamma energy level is rounded up to the nearest (higher) gamma energy level for which source limits are presented in Table 5-8.

For common container and waste materials (for which Z is 26 or less), the formula above yields an equivalent gamma source that is less than 1% of the isotope's beta source. Furthermore, comparisons to rigorous MCNP beta shielding analyses show that the method (and formula) described above yields 10-160B Cask exterior gamma dose rates (due to payload beta emissions) that are conservative (high) by more than a factor of 100. Thus, a beta source will yield 10-160B

Cask exterior dose rates that are only ~0.01% as high as the 10-160B Cask exterior dose rates produced by a gamma source of the same strength and energy level.

For the above reasons, the beta source for isotopes that emit both betas and gammas can be neglected, since any 10-160B Cask exterior dose rate contributions from the beta source will be negligible compared to those produced by the isotope's gamma source. Thus, the procedure described above is only to be used for pure beta-emitting isotopes with a significant beta source.

5.6.2 TREATMENT OF MULTIPLE RADIATION SOURCES

The maximum allowable gamma source strengths are given, for Co-60, Cs-137, and for multiple gamma energies, in Table 5-8. However, 10-160B Cask and Shield Insert B payloads may contain multiple isotopes and/or may emit multiple radiation types (beta, gamma and neutron), or emit multiple gamma energies. Thus, a method for treating such sources must be developed.

5.6.2.1 Multi-Energy Gamma Sources

Sources that produce multiple gamma energies are evaluated using a "sum of fractions" approach. The essential argument is that if the gamma source at a given energy is (say) half the Table 5-8 limit (for that energy), that gamma energy will produce dose rates that are half the regulatory limit, at the governing dose location. If the payload has another gamma source strength, at another energy, that is also half its Table 5-8 limit, that gamma energy will also yield a dose rate, at the governing location, that is half the regulatory limit. Thus, such a two-energy gamma source would yield a dose rate right at the limit, at the limiting dose location.

In other words, a gamma source at a given energy may be divided by the corresponding limit (shown in Table 5-8) to yield a fraction. Similar fractions can then be determined for all gamma energies, and the resulting fractions can be summed. As long as the sum of the fractions does not exceed 1.0, all 10 CFR 71 10-160B Cask exterior dose rate limits will be met.

Note that if the limiting (lowest margin) dose rates occurred at different 10-160B Cask exterior locations, for different gamma energies, the sum of fractions method would be conservative, since it assumes the highest dose rate vs. allowable fractions for each energy, regardless of where they occur. In the case of the 10-160B Cask and Shield Insert B, this conservatism does not exist since the limiting dose rates occur at the same location for all gamma energies, i.e., on the top impact limiter top surface, directly above the source point location.

Thus, multi-energy gamma sources are treated using the following steps:

1) For each individual gamma energy produced by the payload, round the energy up to the nearest gamma energy presented in Table 5-8.

2) Select the corresponding gamma source strength limit from Table 5-8.

3) Divide the payload's gamma source strength (at that energy) by the corresponding Table 5-8 limit to yield a fraction value for that energy.

4) Repeat the above process to produce fractions for all gamma energies emitted by the payload.

5) Sum the fractions.

6) If the sum of fractions is less than 1.0, the payload will not cause any 10 CFR 71 10-160B Cask exterior dose rate limits to be exceeded.

5.6.2.2 Beta Sources

Beta sources are converted into equivalent gamma sources using the methodology presented in Section 5.6.1. Then the normal procedure for qualifying gamma sources is used. The gamma energy is rounded up to the nearest value shown in Table 5-8. Then the (equivalent) gamma source is compared to the corresponding Table 5-8 source limit to see if the beta source will meet the radiological requirements.

With respect to the sum of fractions method, the beta source's equivalent gamma source is treated the same as any other gamma source, at the gamma energy in question. The source is divided by the corresponding Table 5-8 limit to yield a fraction. This fraction is added to the fractions that result from any other gamma energies (or beta sources) emitted by the payload. If the sum of fractions is less than 1.0, the overall payload will not result in 10-160B Cask exterior dose rates in excess of the 10CFR71 limits.

5.6.2.3 Neutron Sources

The 10-160B is currently radiologically qualified for a Pu-Be neutron source strength of 1.1×10^8 neutrons/sec. Neutron sources that are bounded by this are acceptable for shipment within Shield Insert B, but no credit is taken for the additional neutron shielding offered by the Insert. When a shipment includes a significant neutron emitter, it may be also accounted for using the sum of fractions method. The neutron source, divided by 1.1×10^8 neutrons/sec, must be added to any other source fractions to determine acceptability. This approach is conservative because the limiting gamma dose rates are highly peaked at the top surfaces (i.e., driven by streaming through the insert's annular lid gap), whereas the neutron peak dose rates may occur at a different location.

5.6.3 ISOTOPE-SPECIFIC EVALUATIONS

As shown in Reference 4, the majority of candidate sources likely to be shipped in Shield Insert B consist of five specific isotopes: Co-60, Cs-137, Ir-192, Se-75 and Sr-90. This section determines the activity (curie) limit for each of these isotopes, while also considering the 200 watt payload heat generation limit and the 3000 A_2 limit. This may reduce the amount of payload characterization and evaluation that must be performed by the cask user for most shipments.

None of the isotopes in question are neutron emitters. Also, the only pure beta emitter is Sr-90. Thus, the beta source treatment presented in Section 5.6.1 need only be performed for that isotope. As discussed in Section 5.6.1, that process need not be performed for isotopes that have any significant gamma source, in addition to their beta source.

The gamma source strengths, per Ci, produced by each of the five evaluated isotopes are presented in Table 5-10. Some of these isotopes produce gammas at large numbers of energies. These gamma sources are sub-divided into groups, based on which Table 5-8 source strength limit applies to them. The Table 5-8 source strength limit shown for each gamma energy applies to all gammas between that gamma energy and the next lower energy in the table. Gammas with energies below 0.3 MeV are neglected. Specific shielding analyses have been performed for Co-60 and Cs-137, and gamma source strength limits for those isotopes are presented in Table 5-8. Table 5-10 shows the source strength (in gammas/sec) in each energy group, for each isotope. The per-Ci gamma sources for the five isotopes are taken from Reference 5.

Sr-90 produces one beta (per decay) with a peak energy of 0.546 MeV and an average energy of 0.196 MeV. Its Y-90 daughter produces one beta (per decay) with a peak energy of 2.284 MeV and an average energy of 0.935 MeV. These are converted into equivalent (resulting) gamma sources using the process described in Section 5.6.1. Based on the atomic number of strontium (Z=38) the process yields a 0.546 MeV gamma source strength for Sr-90 which is 0.0026 times the beta source strength. For Y-90, the process yields a 2.284 MeV gamma source strength that is 0.0124 times the beta source strength. These fractions are multiplied by the one curie beta source strengths (i.e., 3.7×10^{10} betas/sec) to yield the gamma source strengths shown in Table 5-10. The 0.546 MeV Sr-90 gamma source falls into the "Cs-137" energy group, while the 2.284 MeV Y-90 gamma source falls into the 2.75 MeV energy group.

Table 5-10 - Gamma Source Strengths for Five Isotopes

Gamma Energy Group (MeV)	Per-Curie Gamma Source Strength (gammas/sec-Ci)				
	Co-60	Cs-137[1]	Ir-192	Se-75	Sr-90[1]
0.5			6.128E+10	4.751E+09	
0.7			6.701E+09		9.646E+07
0.9			1.480E+08		
2.75					4.599E+08
"Co-60"[2]	7.400E+10				
"Cs-137"[2]		3.150E+10			

NOTES:

(1) The Cs-137 and Sr-90 gamma sources include those from their B-137m and Y-90 daughters.

(2) Specific analysis are performed for the Co-60 and Cs-137 isotopes (and their associated gamma spectra), which directly yield gamma source strength limits for those isotopes. Thus, the gamma source strengths for Co-60 and Cs-137 are directly compared to the source strength limits presented in Table 5-8 for those isotopes.

The values shown in Table 5-10 are divided by the corresponding Table 5-8 source strength limits to calculate the source strength fractions, for each gamma energy group, that result from one curie of each isotope. For each isotope, the fractions are then summed over all applicable energies to yield an overall per-curie dose rate fraction for each isotope. This is the ratio of the peak dose rate vs. the regulatory limit, at the governing (i.e., NCT impact limiter top) location that results from one curie of the isotope in question.

These per-Ci dose rate fractions are presented in Table 5-11. Table 5-11 also presents the per-curie heat generation level for each isotope, as well as its (10 CFR 71) A_2 value. The per-decay energies (in MeV) for each isotope are taken from Reference 5.

Table 5-11 - Dose Rate Fraction, Heat Generation and A_2Values for Five Isotopes

Isotope	Peak Fraction of Allowable Dose Rate per Curie	Heat Generation		A_2Value (Ci)
		(MeV/decay)	(watts/Ci)	
Co-60	7.41E-05	2.598	1.54E-02	11
Cs-137	4.85E-08	0.832	4.93E-03	16
Ir-192	3.14E-08	1.034	6.13E-03	16
Se-75	4.90E-11	0.407	2.41E-03	81
Sr-90	1.59E-05	1.130	6.70E-03	8.1

Note: The dose rate fraction is the fraction of the dose rate limit produced by one curie of the isotope, which occurs at the governing 10-160B Cask exterior location.

A maximum allowable activity level (in Ci) can be determined for each of the fives isotopes, using the information shown in Table 5-11. The dose rate fractions and heat generation levels (in watts/Ci) are multiplied by a selected activity (in Ci) and compared to their limits (of 1.0 and 200 watts, respectively). The selected activity is also divided by the A_2 value, and the result is compared to the limit of 3000 A_2.. These calculations are presented in Table 5-12. The table presents the maximum allowable activity levels, for the five evaluated isotopes, and the dose rate fractions, payload heat generation levels, and overall A_2 values that result from those allowable isotope activity levels. For each isotope, one of the three values (shown in bold) will govern the allowable activity.

Table 5-12 - Final Isotope Activity Limit Calculation for Five Isotopes

Isotope	Maximum Allowable Activity (Ci)[1]	Peak Dose Rate Fraction[2]	Heat Generation (watts)[3]	Total A_2[4]
Co-60	12,970	0.961	**200**	1179
Cs-137	40,568	0.002	**200**	2536
Ir-192	32,626	0.001	**200**	2039
Se-75	82,988	0.000	**200**	1025
Sr-90	24,300	0.386	163	**3000**
Maximum Allowable Value =		1.000	200	3000

NOTES:

(1) Final result of evaluation. Activity at which the dose, heat or A_2 limit is reached.

(2) Calculated by multiplying the max allowable activity value by the value shown in the 2nd column of Table 5-11. Governing dose rate occurs on NCT top package surface, where the limit is 200 mrem/hr.

(3) Calculated by multiplying the maximum allowable activity value by the value shown in the 4th column of Table 5-11.

(4) Calculated by dividing the maximum allowable activity value by the A_2 value shown in the right column of Table 5-11.

6.0 CRITICALITY EVALUATION

There is no fissile material in the contents addressed by this addendum. Thus, a criticality evaluation is not applicable.

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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 10-160B Cask with the specified cribbing. The loaded Insert will be unloaded from the cask per Chapter 7 of the base SAR. Shield Insert B will not be unloaded.

7.1 PROCEDURE FOR LOADING SHIELDINSERT B

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 Shield Insert B lid to the insert body.

7.1.2 Remove the Shield Insert B lid using the four lifting lugs on the lid. Inspect the gasket for damage and confirm gasket position is in accordance with the Shield Insert B drawing in Section 1.3 of this Addendum. 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 Shield Insert B lid.

7.1.6 Assure bolt threads are adequately lubricated and secure the Shield Insert B lid by installing the eight (8) ¾ inch lid bolts. Torque the bolts to 75 ± 10 ft-lbs using a star pattern.

7.2 PROCEDURE FOR LOADING SHIELD INSERT B INTO THE 10-160B CASK

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 + 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 the drawing in Section 1.3 of this Addendum 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 Confirm and independently verify that the Shield Insert B closure nuts are torqued to the specified value of 75 ± 10 ft-lbs using a star pattern. 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 Shield Insert B are given below.

8.1 ACCEPTANCE TESTS

Prior to the first use of Shield Insert B, 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, Division 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, Division 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 Shield Insert B.

8.1.4 COMPONENT TESTS

Shield Insert B will be subjected to Load Testing and Shielding Integrity Testing.

8.1.5 TEST FOR SHIELDING INTEGRITY

Shielding integrity of Shield Insert B 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 Shield Insert B.

8.1.7 IMPACT LIMITER FOAM

There is no foam in ShieldInsert B.

8.1.8 PRESSURE TEST

No pressure testing will be performed on Shield Insert B.

8.2 MAINTENANCE PROGRAM

The 10-160B package will be subjected to routine and periodic inspection and tests as outlined in Section 8.2 of the base 10-160B SAR.

The Shield Insert B maintenance requirements are described below.

8.2.1 ROUTINE MAINTENANCE

8.2.1.1 Fasteners

The Insert lid bolts shall be visually inspected for defects prior to each shipment. Obtain replacement parts as specified on the SAR drawings in Chapter 1 of this Addendum for any components that show cracking or other visual signs of distress.

8.2.1.2 Gaskets and Seals

Shield Insert B has an elastomeric lid gasket that must be inspected for damage or compression set and replaced as necessary with every shipment.

8.2.1.3 Painted Surfaces Identification Markings and Match Marks Used for Closure Orientation

Shield Insert B has painted match marks that shall be visually inspected to ensure that surfaces are in good condition, identification markings are legible and that match marks used for closure orientation remain legible and are easy to identify.

8.2.2 PERIODIC MAINTENANCE

8.2.2.1 Periodic Leak Tests

Shield Insert B does not provide containment; therefore there are no periodic leak tests.

8.2.2.2 Assembly Verification Leak Test

Shield Insert B does not provide containment; therefore there are no assembly verification leak tests.

8.2.2.3 Ratchet Binders

Shield Insert B does not have ratchet binders.

8.2.2.4 Repair of Bolt Holes

Helical threaded inserts may be used for repair of bolt holes. The minimum tensile strength of the insert material must be greater than or equal to 150 ksi and the minimum length of the insert must be equal to one (1) bolt diameter. The following steps shall be performed for each repair using a helical threaded insert.

a. Install helical threaded insert(s), sized per manufacturer's recommendation, per the manufacturer's instructions for bottoming style taps. Helical threaded inserts may be tack welded to the base metal to keep them from backing out during cask operations.

b. At a minimum, each repaired bolt hole(s) will be tested for proper installation by assembling the joint components where the insert is used and tightening the bolts to their required torque value.

   Note: Shield Insert B has no bolt holes used for lifting components; therefore a load test is not required.

c. Each helical threaded insert shall be visually inspected after testing to insure that there is no visible damage or deformation to the insert.

8.2.3 SUBSYSTEM MAINTENANCE

Shield Insert B contains no subsystem assemblies.

8.2.4 VALVES RUPTURE DISCS AND GASKETS ON CONTAINMENT VESSEL

Shield Insert B does not provide containment, therefore there are no valves or rupture disk/gaskets.

8.2.5 SHIELDING

No shielding tests will be performed after acceptance testing unless there has been a repair to a damaged area, which will affect shield integrity. Any shield testing which might be required would be in accordance with the original criteria specified in Section 8.1.5 of this Addendum.

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