SCIENTIFIC ECOLOGY GROUP, INC.

STD-R-02-020

Safety Analysis Report for the SEG 10-142A Cask

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Rev.	DCN No.	Originator	Reviewed By	Quality Assurance	Manager	Date
0	NA	[signature]	[signature]	[signature]	[signature]	1/25/94

☒ New Document ☐ Title Change ☐ Minor Revision ☐ General Revision ☐ Rewrite

This document supersedes LN-88-002.

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1. GENERAL INFORMATION

1.1 Introduction

This report concerns the Model 10-142A Type A Transportation Cask. The Model 10-142A cask is intended for the safe transportation of radioactive materials other than in the liquid form. The intended contents of the cask would be fissile radioactive materials quantities licensed for Type A packaging under 10 CFR 71, Subpart E.

The cask consists of a cylindrical container comprising an inner steel liner surrounded by a layer of lead shielding and an exterior steel shell. The top and bottom of the container are fabricated from heavy steel plate and are attached to the container walls by bolting and welding respectively. Exterior to the cask are impact limiters fitted to and surrounding the cask top and bottom. These impacts limiters offer protection to the cask from both normal conditions of transport and hypothetical accident conditions.

Authorization for the Model 10-142A Cask is sought for shipments by cargo vessel, rail and land vehicle.

1.2 Package Description

1.2.1 Packaging

1.2.1.1 Containment Cask Construction - Figure 1.2.1-1 shows the general arrangement of the 10-142A shipping cask. The cask consists of two concentric cylindrical shells of ASTM A516 Gr. 70 steel with an annular gap of 3.5 in. between them. The inner shell is 66.75 in. mean diameter, 72 in. high and 0.5 in. thick. The outer shell is 75 in. mean diameter, 84 in. high and 1 in. thick. The annular space between the shells is filled with lead for shielding. The cask bottom cover plate consists of two 3 in. thick ASTM A516 Gr. 70 steel plates joined together to form a 6 in. thick plate. The bottom plates are welded to the cylindrical shells of the cask body by a combination of fillet and full penetration groove welds.

The top of the cask is provided with a combination of two lids identified as the primary lid and the secondary lid. The primary lid is of a stepped construction which is made of two 3 inch thick ASTM A516 Gr. 70 steel plates of 76 in. diameter and 66 in. diameter, joined together to form an integral 6 inch thick lid. The primary lid is secured to the cask body by eight high strength ratchet binders (breaking strength = 160,000 lb.) and fits in the cask body. The closure ring is of ASTM A516 Gr. 70 steel and fits in the annular space between the cask shells above the lead. The closure ring is welded to the shells through a combination of fillet and full penetration groove welds.
The secondary lid which covers the 29 in. diameter hole at the center of primary lid is also of stepped construction consisting of two 3 in. thick plates. The secondary lid is secured to the primary lid through eight (8) 1 in.-8 UNC high strength bolts of ASTM A320 Gr. L7 material. High temperature silicone gaskets are provided at the cask-primary lid and the primary lid-secondary lid interfaces. The latter is also provided with an additional neoprene seal.

The inner surfaces of the cask and the lid are clad with 12 gauge ASTM A240 304 stainless steel. The portion of the cask body that is not covered by the impact limiters is covered with a 10 gauge ASTM A240 304 stainless steel thermal shield. There is a 1/4 in. gap between the shell and the thermal shield which is maintained using 1/4 in. spacers.

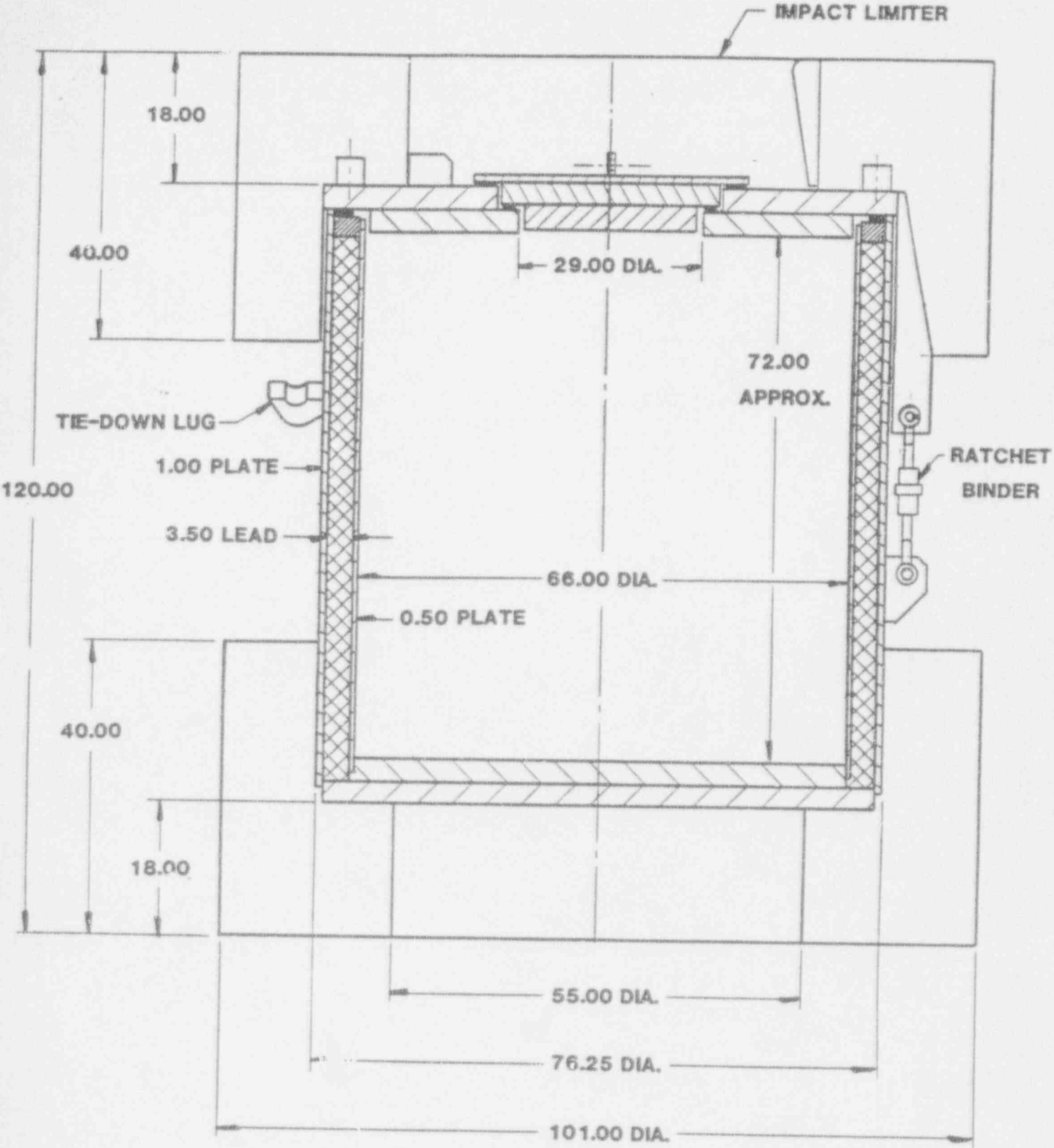


FIGURE 1.2.1-1 Schematic drawing of 10-142A cask

1.2.1.2 Lifting Devices - Three reinforced lugs of ASTM A240 type 304 stainless steel, UNS #32550 are provided for lifting the cask. These are shown in the general arrangement drawing in Figure 1.2.1-1.

1.2.1.3 Tiedown Lugs - The tiedown lugs of ASTM A240 type 304 stainless steel UNS #32550 are integral parts of the cask body and are welded to the outer steel shell of the cask body. Four tiedown lugs, two in the front and two in the rear, are provided as shown in Figure 1.2.1-1.

1.2.1.4 Impact Limiters - The cask package system consists of two impact limiters at the top and bottom of the cask as shown in Figure 1.2.1-1. Each impact limiter shell is constructed of 12 gauge ASTM A240 304 stainless steel. The ductility of the material permits the shell to undergo large deformation without fracturing. The cavity between the inner and outer shell of the impact limiter is filled with shock absorbing and thermal insulating rigid polyurethane foam material. This material has a density of 20 lb./cu. ft. and it bonds to the impact limiter steel shells forming an integral construction for packaging. The mechanical properties of this material are given in Section 2.3.

The lower impact limiter is attached integrally to the body of the cask. The upper impact limiter is secured to the cask through impact limiter tiedown tabs which are secured to the cask lugs with 1/2 in. diameter ball lock pins. Eight such lugs are provided to hold down the impact limiter.

1.2.1.5 Ratchet Binder Lugs - The bottom eyelet of each ratchet binder is secured to the cask body by a lug welded to the cask outer shell. Each lug is 1.5 inches thick and is made of ASTM A240 UNS #32550 stainless steel.

1.2.1.6 Primary Lid Lug - A total of eight lugs are spaced equally along the perimeter of the cask primary lid. Each lug is welded to the primary lid and extends vertically along the cask outer wall. Each lug is 1.5 inches thick and is made of ASTM A240 UNS 32550. The upper eyelet of each ratch binder is attached to the lower end of each primary lug.

1.2.1.7 Neutron Absorbers - The cask package system does not make use of materials for neutron absorption or moderation.

1.2.1.8 Weight - The empty cask weighs 54,000 lbs. and the payload weighs 10,000 lbs. A more detailed breakdown of the weight is given in Section 2.2.

1.2.1.9 Internal and External Structures - Other than the lifting lugs, tiedown lugs, impact limiters, primary lid lugs and ratchet binder lugs already described, there are no external structures attached to the cask. The cask contains no internal structure.

1.2.1.10 Pressure Relief - There is no pressure relief system. Rather the cask is designed to contain expected maximum pressure developing from the normal conditions of transport.

1.2.1.11 Heat Dissipation - The cask is designed such that special heat dissipation devices or coolants are not required. Analysis demonstrates that the container and contents would not be compromised by exposure to thermal loading under normal conditions of transport. A structural means for thermal shielding of the cask is provided by a covering of 10 gauge ASTM A240 304 stainless steel over areas of the cask body not covered by the impact limiters. This stainless steel cover serves as a thermal shield and is further separated from the cask body by a thermal radiation gap of 1/4 in.

1.2.1.12 Ratchet Binders - The cask primary lid is secured by eight high strength ratchet binders. The ratchet binder is secured to the primary lid hold-down lugs with a 1 5/8" diameter retaining pin, and to the ratchet binder lug by 1 5/8" diameter bolts. Each ratchet screw is 1 3/4" diameter with Acme threads.

1.2.2 Operational Features

Other than the use of tiedown lugs for securement to a semi-trailer for transport, there are no operational features relative to the cask which have any significance during shipping.

1.2.3 Contents of Packaging

The package will contain the following radioactive material as defined in 10 CFR 71 and 49 CFR 173:

(a) Type A materials and greater than Type A quantities of low specific activity radioactive materials in secondary containers with weight not exceeding 10,000 lbs.

(b) The package contents will be solid in physical form with no restriction as to chemical form. This includes dewatered ion exchange resins and miscellaneous radioactive solid waste materials in secondary containers. The contents of the packaging shall be limited such that radioactive decay does not result in exceeding the external temperature limits for exclusive use shipments as stated in 10 CFR 71.43 (G), nor the external radiation dose rate limits specified in 10 CFR 71.47.

1.3 Appendix

The general arrangement of the 10-142A shipping cask has already been shown schematically in Fig. 1.2.1-1. In addition, an engineering drawing of the general cask arrangement, Drawing No. STD-02-107 , Rev. 0, sheets 1 and 2 of 2 is provided as an attachment to this report. This engineering drawing provides a further detailed description of the cask, materials of construction, sizing of component parts and method of assembly.

2. STRUCTURAL EVALUATION

This section describes the stress analysis of principle components of the cask to verify the compliance with the performance requirements of 10 CFR 71.

2.1 Structural Design

2.1.1 Discussion

The principal structural members which have been subject to structural analysis are as follows:

(a) The cask body which consists of two concentric steel cylindrical shells, a 1/2 in. thick inner shell, a 1 in. thick outer shell, and a 3-1/2 in. thick annular space in between filled with lead.

(b) The bottom of the cask which consists of two 3 in. thick steel plates laminated to form a 6 in. thick plate, welded to the cylindrical cask body.

(c) The primary lid which also consists of two 3 in. thick steel plates laminated to form a 6 in. thick plate, bolted to the cylindrical cask body, and containing a 29 in. diameter central hole to accept a secondary lid.

(d) A secondary lid which also consists of two 3 in. thick steel plates laminated to form a 6 in. thick plate, bolted to the primary lid and covering the 29 in. diameter central hole in the primary lid.

(e) Lifting lugs consisting of 1-1/2 in. thick steel plate welded to the top surface of the primary lid.

(f) Tiedown lugs consisting of 2.5 in. thick steel plates welded directly to the 1 in. thick outer shell of the cask body.

(g) Impact limiters consisting of an outer shell of 12 gauge 304 stainless steel which forms a cavity filled with a shock absorbing polyurethane foam material.

(h) Primary lid lugs consisting of eight 1.5 inch thick plates used to fasten the upper eyelet of the ratchet binder. Analyses will be shown in section 2.6.7.

(i) Ratchet binder lugs, eight 1.5 inch thick plates fastened to the cask outer shell which are used to secure the lower eyelet of each ratchet binder. Analyses will be shown in section 2.6.7.

2.1.2 Design Criteria

Structural analysis of the cask involves (a) design against yielding which would otherwise cause permanent deformation of individual cask components and result in a compromise of a containment seal and (b), for the case of external pressure, design against buckling.

For the normal loading conditions the ASME Section III Service Level A, an allowable stress of 2/3 F_y is used. For the components, thes‿ allowable stresses are F_{ty} for the normal stress and F_{sy} for shear stress. For bolts, the smaller of 0.7 F_{tu} of F_{ty} for axial stresses and the smaller of 0.42 F_{tu} or 0.6 F_{ty} for shear stresses are used. (See ASME Section III Division 1 - Appendix F, Paragraphs F-1335.1 and F-1335.2).

For all other instances of design against yielding, the maximum allowable stress is limited to 20% of the yield strength. For instances of buckling, the maximum allowable load is limited to 20% of the load to buckle.

The cask by itself provides shielding from the irradiated materials it contains. The integrity of the cask must, therefore, be maintained, specifically at seal interfaces between the primary and secondary lids and between the primary lid and the cask body. The impact limiters, therefore, are designed to provide adequate localized protection to the components of the cask assembly, particularly to the primary and secondary lids and the cask interface.

Lifting attachments are designed to lift three times the package and content weight and not exceed material yield strength. The requirements on tiedown devices are that no stress in the package material exceeds yield stress when the following static factors are applied to the center of gravity of the cask:

a. Two times the cask and content weight in the vertical direction.

b. Ten times the cask and content weight in the horizontal direction in which the vehicle is traveling, and

c. Five times the cask and content weight in the direction transverse to that in which the vehicle is traveling.

2.2 Weights and Center of Gravity

The following table gives the weights of the individual components of the cask and the payload.

Weight of lead shielding	23,900 lbs.
Weight of steel shells and accessories	10,300 lbs.
Weight of steel bottom plate	6,600 lbs.
Total weight of cask body	40,800 lbs.
Weight of primary lid	5,445 lbs.
Weight of secondary lid	1,755 lbs.
Weight of two impact limiters (each weighs 3,000 lbs.)	6,000 lbs.
Total weight of cask without payload	54,000 lbs.
Weight of the payload	10,000 lbs.
Total weight of cask and payload	64,000 lbs.

The cask is symmetric about all the three axes. It will be assumed that the mass distribution is also symmetric and that the center of gravity of the cask is at its geometric centroid.

2.3 Mechanical Properties of the Materials

The cask body, primary and secondary lids, impact limiter tiedown tabs, and the cask lugs are made out of ASTM A516 Gr. 70 steel. The tiedown, primary lid, and cask lugs are made out of ASTM A240 304 stainless steel, UNS #32550. The bolts attaching the secondary lid to the cask body are of ASTM A320 Gr. L7 steel. The material properties relevant to the stress analysis of the cask components are given in the following table. The ultimate and yield stresses in shear are taken as 0.577 times the corresponding tensile stresses.

Material	Ultimate Stress Tension (F_{tu})	Yield Stress Tension (F_{ty})	Ultimate Stress Shear (F_{su})	Yield Stress Shear (F_{sy})	Bearing Stress (F_{brg})
ASTM A516 GR. 70	70,000 psi	38,000 psi	40,400 psi	22,000 psi	90,000 psi
ASTM A320 GR. L7	125,000 psi	105,000 psi	72,100 psi	60,600 psi	---
ASTM A240	70,000 psi	25,000 psi	40,400 psi	14,400 psi	---
ASTM A240 UNS #32550	110,000 psi	80,000 psi	63,500 psi	46,100 psi	---

The impact limiters contain rigid polyurethane foam of a self-extinguishing variety which fills the cavity between the impact limiter shells. Figure 2.3-1 shows the stress-strain curve for this foam which has a density of 20 lbs/cu. ft. The curves provide both minimum and maximum compressive stress-strain properties of the foam. Test properties cover the range of stress and strains reached during the 10 CFR 71 free drop test. These stress-stain curves are developed based on actual tests performed and are reliable up to 70 percent of strain. Data obtained over the years shows that the form of the curves will continue within the tolerance band shown on Figure 2.3-1 through the 80 percent range.

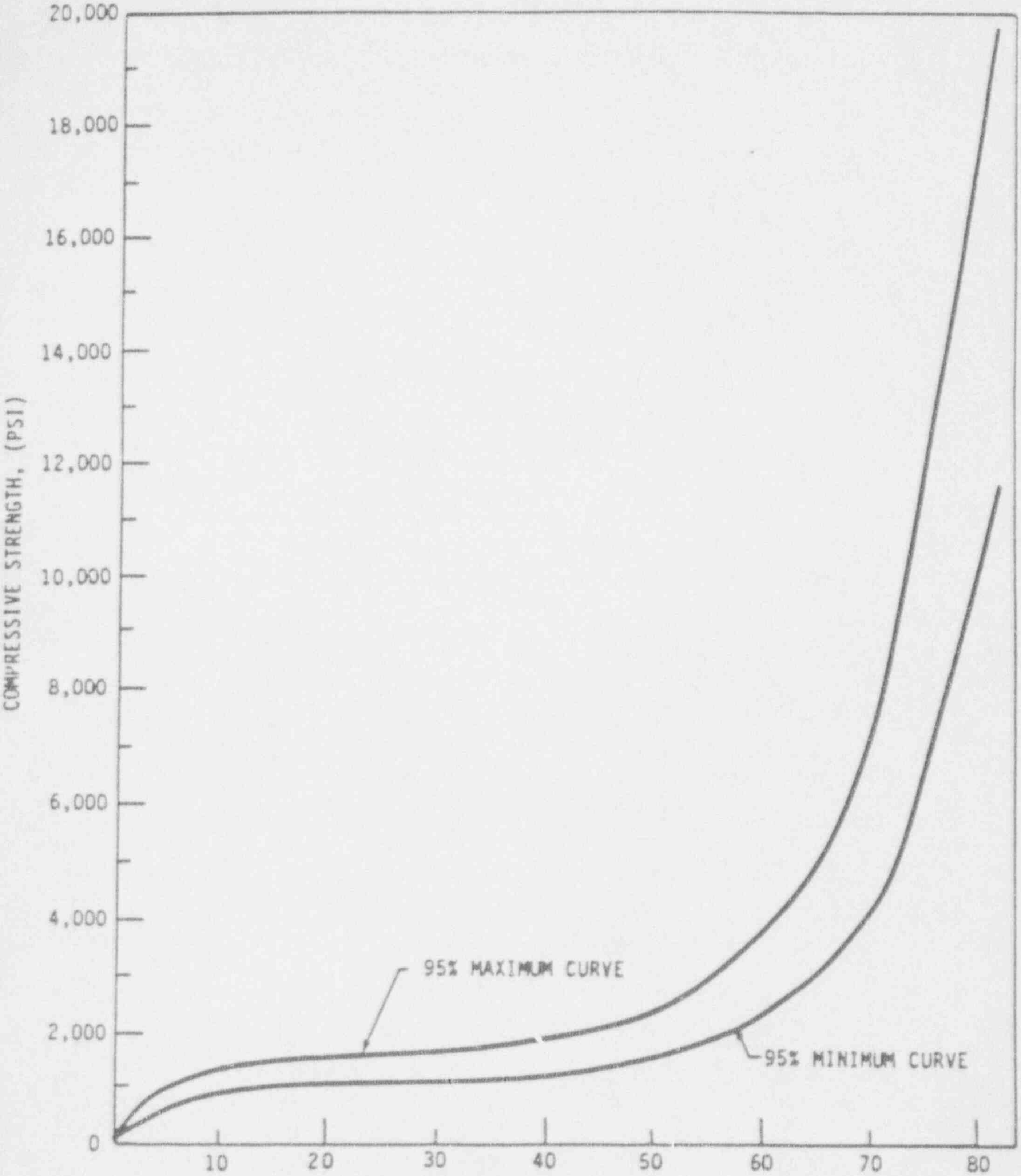


FIGURE 2.3-1 Stress-strain curve for 20 lb/ft^3 density foam

Testing samples from each batch during the pour of the impact limiters has been conducted at several strain levels with at least one sample from each impact limiter tested to 80 percent strain to demonstrate that the foam is within the design tolerance band. In accordance with SEG, NRC-approved 10 CFR 71, Subpart H, QA Program, the test data from each actual pour has been monitored, analyzed, approved and maintained.

2.4 General Standard for All Packages

This section demonstrates that the general standards for packages as specified in Section 71.43 of 10 CFR 71 are met.

2.4.1 Minimum Package Size

The overall size of the 10-142A cask is such that it considerably exceeds the minimum specified dimension of 10 cm (four inches).

2.4.2 Security Seals

The 10-142A Cask incorporates security seals on both the primary and secondary lid closures. If the lead seals, which are shown on Drawing No. STD-02-107, sheets 1 and 2 of 2, are broken tampering with the cask is indicated.

2.4.3 Positive Closure

The arrangement for container closure has already been described in Section 1.2.1.1 and is shown schematically in Figure 1.2.1-1. Closure involves primary and secondary lids. The primary lid is 6 in. thick steel comprised of two plates 3 in. thick. This lid is secured with eight high strength ratchet binders, and a silicon gasket seal.

The secondary lid covers a 29 in. diameter hole centrally located in the primary lid. It also is 6 in. thick, comprised of two 3 in. thick plates. The secondary lid is attached to the primary lid by eight (8) 1 in. diameter bolts. The entire assembly is of such an arrangement that it cannot be inadvertently opened.

2.4.4 Chemical and Galvanic Reactions

The materials of construction of the 10-142A cask and the arrangement in which these materials are used is such that significant corrosion will not occur. The nature of the assembly and of materials of assembly does not involve the use of materials which are significantly galvanically dissimilar nor does it involve the presence of an aggressive electrolyte. Direct corrosive attack by the package contents is not expected and the possibility is further minimized by the application of stainless steel cladding over the entire cask interior.

2.5 Lifting and Tiedown Devices

2.5.1 Lifting Devices

2.5.1.1 Cask Lifting Lugs - Three lifting lugs are provided for the 10-142A shipping cask (as shown in Figure 2.5.1-1). Total load carried by each lug is:

P_{lug} = (64,000) (3g's)/3 = 64,000 lbs.

Using a 40^{0} load direction for shear tear out, the capacity of each lug is:

= (F_{sy}) (2t) [e_d - (d/2) (cos 40)]
= (22,000) (2) (1.5) [2.5 - (2/2) (cos 40)]
= 114,441 lbs.

Margin of safety = (114,441/64,000) - 1 = 0.788

Capacity of the lug-to-primary lid weld:

Awt = Area of weld throat
= (2) (0.5) (6) (0.707) + (0.5) (1.5) (0.707)
= 4.77 $in.^2$

Capacity based on weld metal (E70 electrodes)

= (0.3) (70,000) (4.77) = 100,170 lbs.

Awb = Area of the weld leg = 4.77/0.707 = 6.75 $in.^2$

Capacity based on base metal (A516 Gr. 70)
= (0.4) (38,000) 6.75 = 102,600 lbs.

Margin of safety = (100,170/64,000) - 1 = 0.565

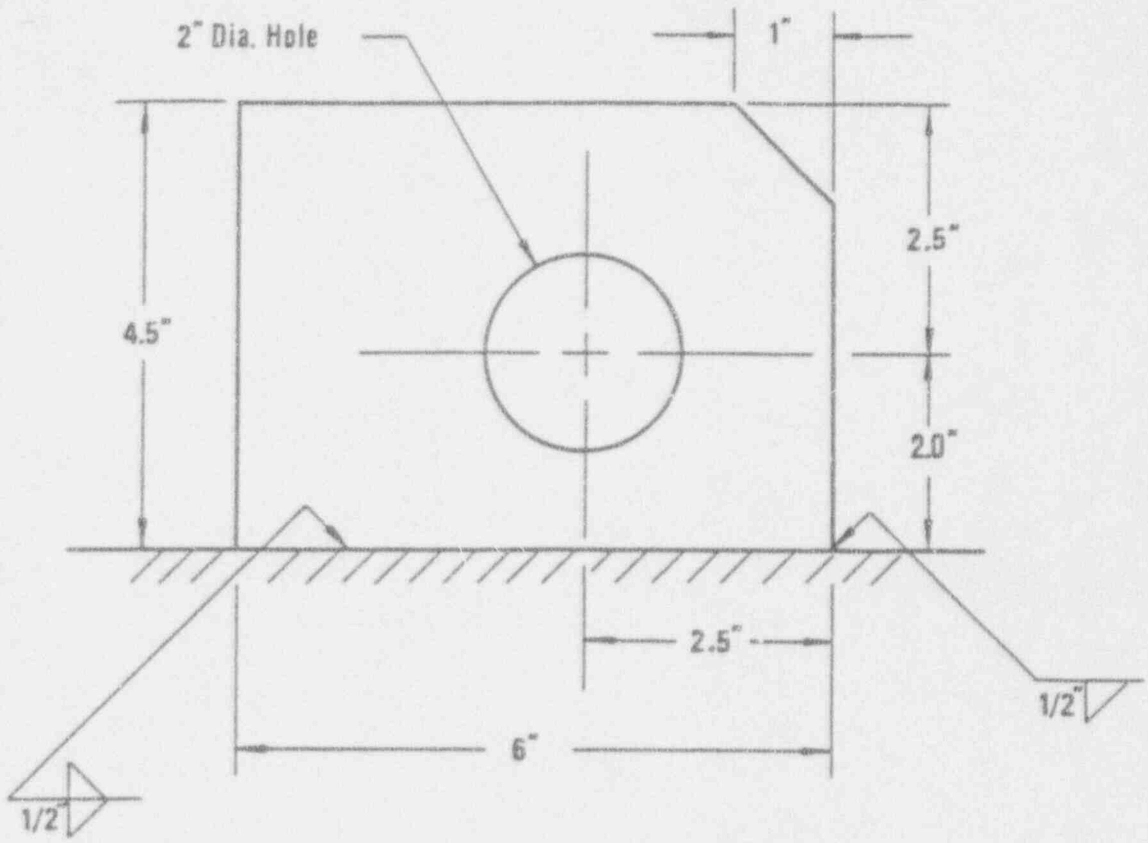


FIGURE 2.5.1-1 Sketch of cask lifting lug (1-1/2 in. thick; ASTM A240 UNS #32550; welded to top of primary lid)

The loads are transferred to the cask body by the ratchet binders attaching the primary lid to the cask body. There are eight (8) 1-3/4 in. ratchet binders. The applied force per binder is

= (3) (64,000)/8 = 24,000 lbs.

Allowable stress is the smaller of 0.7 F_{tu} = 112,000 psi or F_{ty} = 145,000 psi

Capacity of each ratchet binder = (112,000) (1.851) = 207,312 lbs.

Margin of safety = (207,312/24,000) - 1 = 7.64

Therefore, it is concluded that the lifting lugs are adequate to carry the lifting loads imposed on them.

<u>2.5.1.2 Upper Impact Limiter Lifting Lugs</u> - Since the upper impact limiter is removable, it is provided with its own lifting lugs (as shown in Figure 2.5.1-2). The weight of the upper impact limiter is 3,000 lbs. There are three lugs provided for lifting the upper impact limiter.

Capacity based on the shear tearout of the lug is given by:

F_{sy} (2t) [e_d - (d/2) (cos 40)]

F_{sy} (A516 Gr. 70) = 22,000 psi

t = 3/8 in.

e_d = 1.5 (hole edge distance)

d = 1 in. (hole dia.)

Therefore, the lug capacity is
= (22,000) (2) (3/8) [1.5 - (1/2) (cos 40)]
= 18,430 lbs.

Capacity of the weld:

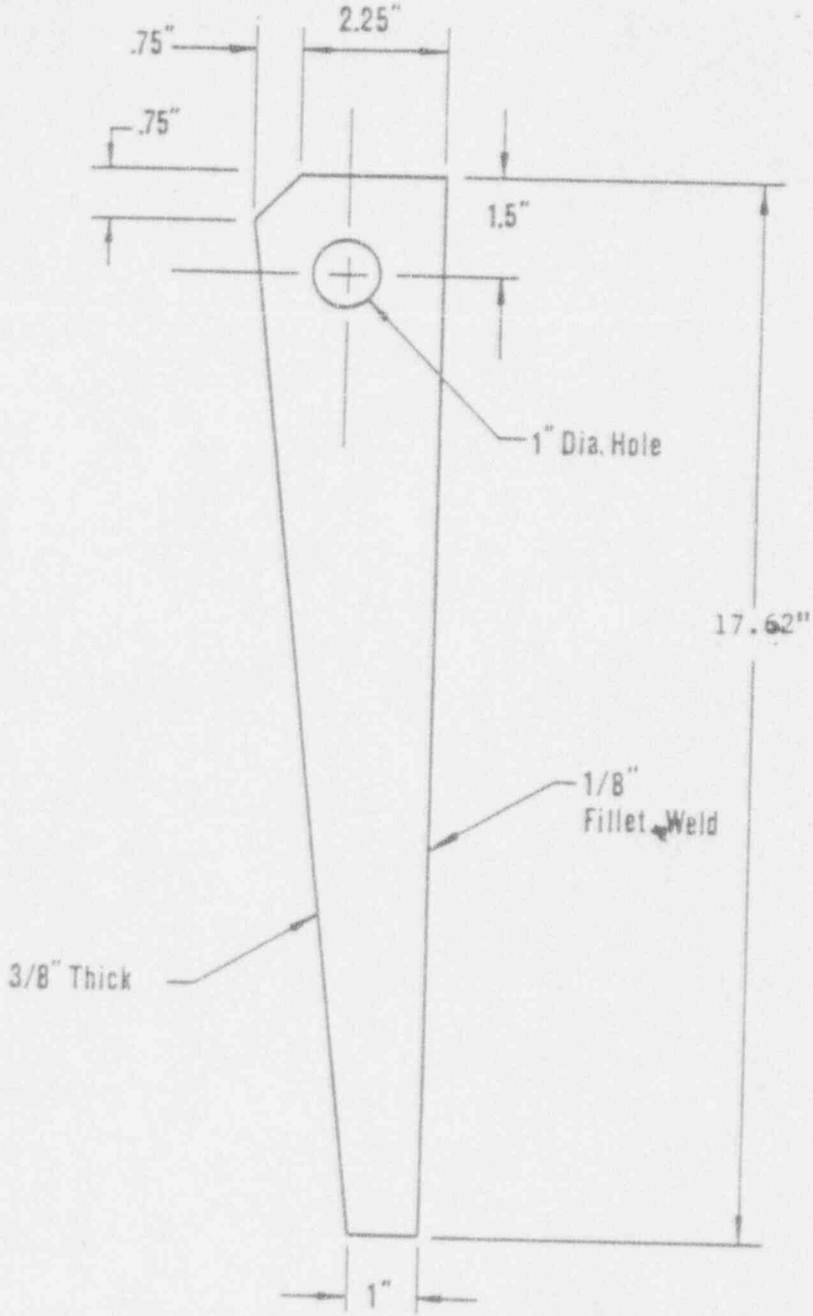


FIGURE 2.5.1-2 Sketch of upper impact limiter lifting lugs (3/8 in. thick; 304 stainless steel; welded to exterior of the upper impact limiter shell)

Based on weld metal: (17.62) (1/8) (0.707) (0.3) (70,000) = 32,701 lbs.

Based on base metal: (17.62) (1/8) (0.4) (38,000) = 33,478

Load carried by each lug = (3,000) (3g's)/3 = 3,000 lbs.

Margin of safety = (18,430/3,000) - 1 = 5.14

The impact limiter lifting lugs are adequate.

2.5.2 Tiedown Devices

Four tiedown lugs are provided as shown in Figure 2.5.2-1 and 2.5.2-2. These lugs are used to tie down the cask during transportation. In accordance with 10 CFR 71.45 (b)(1), the lugs must be designed for the following load factors:

10g acceleration in the longitudinal direction
5g acceleration in the transverse direction
2g acceleration in the vertical direction.

Longitudinal axis is the axis parallel to the direction of the truck travel.

Two lugs in the front are symmetrically placed with respect to the longitudinal axis and make 45^{o} angles with this axis. Similarly, two lugs in the rear are provided. The cask is tied down using flexible cables. The front lugs are inclined at 24^{o} to the horizontal. The topmost point of the lug is 79.5 in. above the base of impact limiter.

Since the cables are flexible:

- o Either the front or the rear cables resist the forces due to 10g longitudinal acceleration.

- o One front and one rear cable located on the same side of the cask resist the forces due to 5g transverse acceleration.

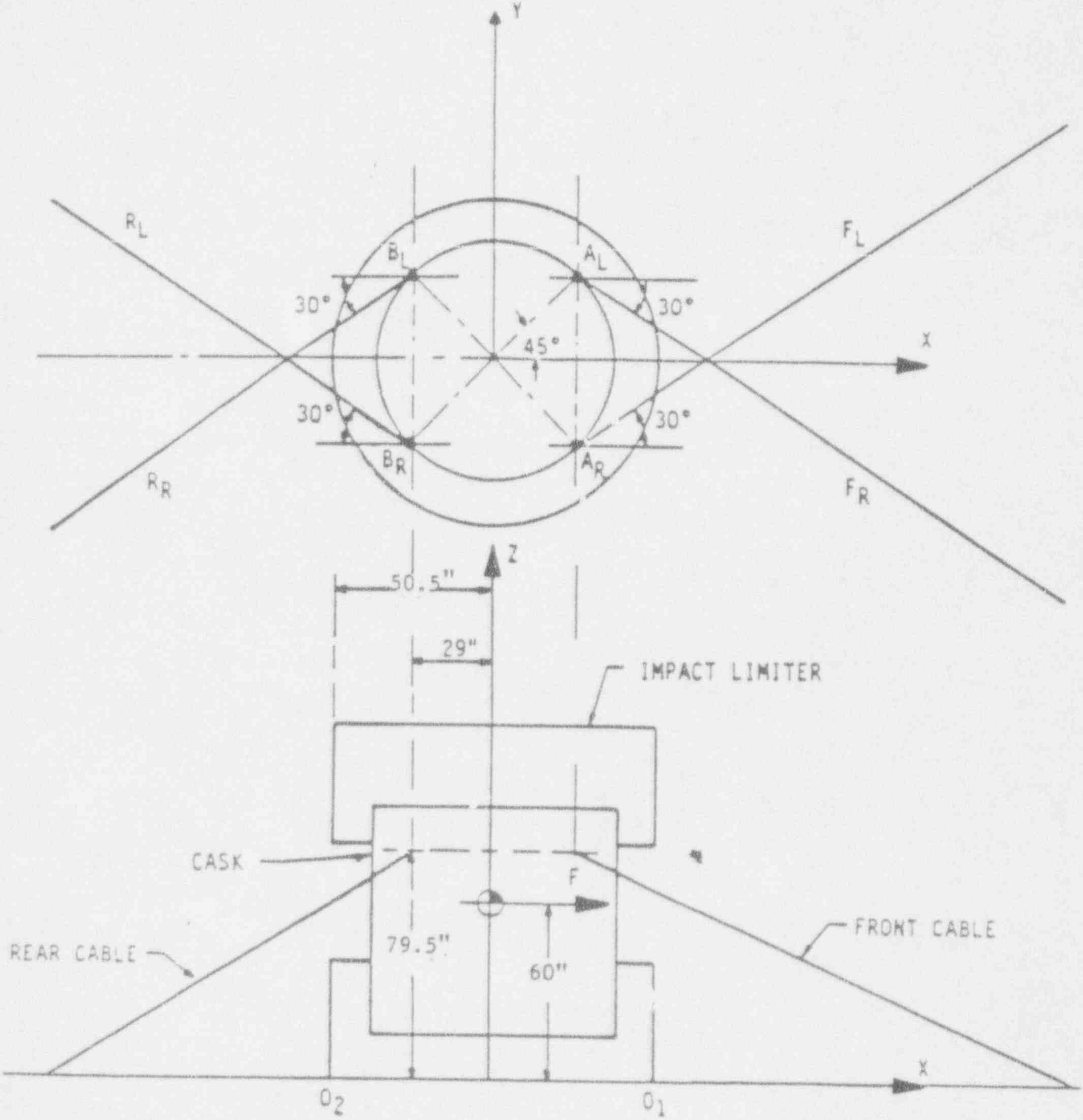


FIGURE 2.5.2-1 Tiedown Configuration

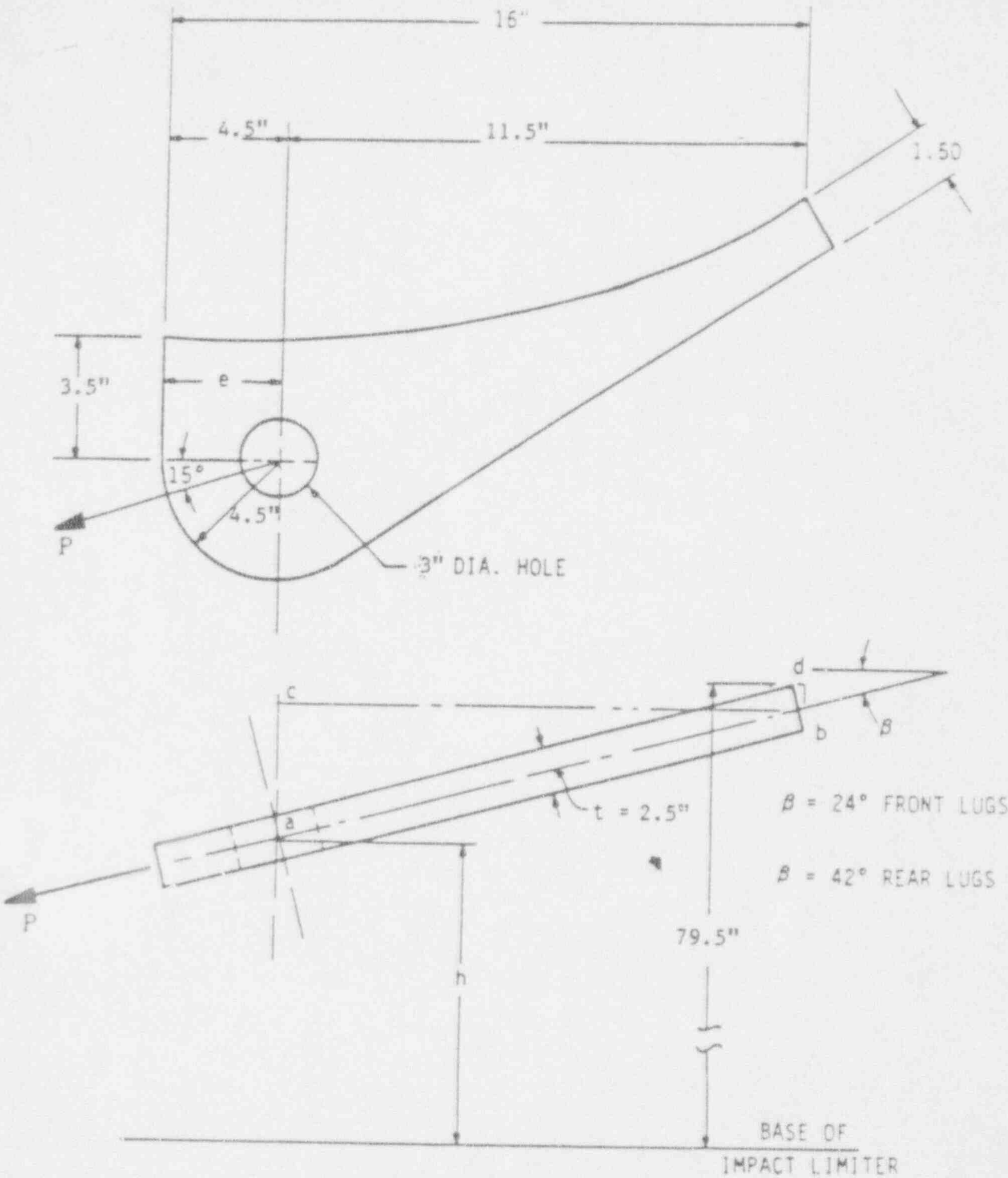


FIGURE 2.5.2-2 Sketch of tiedown lug showing direction of applied force ASTM A240 304 stainless steel, UNS #32550; welded to exterior of cask body outer shell

- All the four cables together resist the 2g vertical acceleration.

In order to determine the forces in the cables, the direction cosines for the cables must be known. For this purpose a coordinate system is defined as follows:

- The origin is placed at the base of the impact limiter where the vertical axis of the cask intersects this plane.

- The x-axis is assumed parallel to the longitudinal axis and is positive from the rear to front of the cask.

- The z-axis is vertical and is positive upwards.

- The y-axis is in the transverse direction and is positive as determined from the right-handed coordinate system.

The cables, for the sake of convenience, are identified as:

F_L - front left cable
F_R - front right cable
R_L - rear left cable
R_R - rear right cable

The locations of the cable at the cask are identified as points, A_L, A_R, B_L and B_R as shown in Figure 2.5.2-1.

The height of the point at wh. t e tiedown cables are attached to the lugs, h, is calculated as follows (see Figure 2.5.2-1 and 2.5.2-2 for dimensions):

Angle subtended by the arc ab is given by $\sin^{-1}$ (11.5/38.125) radians

Arc. length ab = (38.125) $\sin^{-1}$ (11.5/38.125)
= 11.68 in.

Distance ac = ab tan β = 11.68 sin β
= 4.75 in. for front lugs
= 7.82 in. for rear lugs

h (front lugs) = 79.5 - 4.75 - (t/2) (cos β) = 75.89

h (rear lugs) 79.5 - 7.82 - (t/2) (cos β) = 72.61 in.

The cable makes an angle of 24^o (or 42^o) with the horizontal plane, therefore, it makes an angle of 114^o (or 132^o) with the positive x-axis.

Projected length of cable on the horizontal plane
= L_{xy} = h/tan β

Projected length along x-axis = L_{xy} cos 30 = (h cos 30)/tan β

along y-axis = L_{xy} sin 30 = (h sin 30)/tan β

Length of the cable, L = $[(h^2/\tan^2 \beta) (\cos^2 30 + \sin^2 30) + h^2]^{1/2}$
= (h sec β)/tan β = h/sin β

Direction cosines are given by:

l = X/L = [(h cos 30)/tan β]/(h/sin β) = (cos β) (cos 30)

m = Y/L = (cos β) (sin 30) ; n = h/L = -sin β

The direction cosines are given in the following table:

	Front-Left	Front-Right	Rear-Left	Rear-Right
l	0.7912	0.7912	-0.6436	-0.6436
m	0.4568	-0.4568	0.3716	-0.3716
n	-0.4067	-0.4067	-0.6691	-0.6691

Coordinates of the lug points with respect to the chosen origin are given in the following table:

Radial distance of the center of the hole

= 38.125 + 3.5 = 41.625 in.

x = y = 41.625 cos 45 = 29.43 in.

	Front-Left	Front-Right	Rear-Left	Rear-Right
x	29.43	29.43	29.43	29.43
y	29.43	-29.43	29.43	-29.43
z	75.89	75.89	72.61	72.61

2.5.2.1 Lug and Cable Forces for 10g Longitudinal Acceleration - This force is reacted by either the two front or the two rear cables. On account of symmetry, the forces in the two (front or rear) cables are the same. Let P_{1r} and P_{1f} be the forces in the rear and front cables respectively, and P_x and P_y are the longitudinal and vertical components. Taking moments about 0_1 (for rear cable forces):

$$2[(P_x)(72.61) + (P_z)(50.5 + 29)] - (F)(60) = 0$$

$$2P_{1r}[(.6436)(72.61) + (.6691)(79.9)] = (64,000)(60)(10)$$

or

$$P_{1r} = 191,630 \text{ lbs.}$$

Taking moments about O_2 (for front cable forces):

$$2P_{1f} [(0.7912) (75.89) + (0.4067) (79.9)] = (64,000) (10) (60)$$

or

$$P_{1f} = 207,479 \text{ lbs.}$$

2.5.2.2 Lug and Cable Forces for 5g Transverse Acceleration - This force is reacted by one front and one rear cable located on the same side of the cask. Let P_{2r} and P_{2f} be the forces in the rear and front cables respectively. Taking moments about O_3 gives:

$$(P_{2r}) (.3716) (72.61) + (P_{2r}) (.6691) (50.5 - 29)$$
$$+ (P_{2f}) (.4568) (75.89) + (P_{2f}) (.4067) (50.5 - 29) = 64,000 (5) (60)$$

or

$$P_{2r} (41.37) + P_{2f} (43.41) = 19,200,000$$

Assuming no twisting of the cask, and setting the moments of all the forces about z-axis to zero gives:

$$(P_{2r}) (.6436) (29) + (P_{2r}) (.3716) (29)$$
$$- (P_{2f}) (0.7912) (29) - (P_{2f}) (.4568) (29) = 0$$

or

$$P_{2r} = (1.2293) P_{2f}$$

Finally: $P_{2f} = 203,679$
$P_{2r} = 250,383$

2.5.2.3 Lug and Cable Forces for 2g Vertical Acceleration - This force is reacted by all four cables. The forces in the two front cables are the same, P_{3f}, and the forces in the two rear cables, P_{3r}, will be the same. Force equilibrium in the vertical direction gives:

$$(2)\ (P_{3r})\ (0.6691) + (2)\ (P_{3f})\ (0.4067) = (64{,}000)\ (2)$$

or

$$(1.3382)\ P_{3r} + (0.8134)\ P_{3f} = 128{,}000$$

Assuming no rotation of the cask about the transverse axis through O_1 (or O_2) and setting the corresponding moment to zero gives:

$$\begin{aligned}&(2)\ (P_{3r})\ (0.6436)\ (72.61) + (2)\ (P_{3r})\ (0.6691)\ (50.5 + 29)\\ &- (2)\ (P_{3f})\ (0.7912)\ (75.89) + (2)\ (P_{3f})\ (0.4067)\ (50.5 - 29)\\ &= (64{,}000)\ (2)\ (50.5)\end{aligned}$$

or

$$P_{3r} = (0.5134)\ P_{3r} + 32{,}344$$

Therefore, P_{3r} = 61,332 lbs.
P_{3f} = 56,462

2.5.2.4 Evaluation of the Lugs and Welds - Total force in the cables, and hence on the tiedown lugs, is conservatively calculated as:

$$P = 207{,}479 + 250{,}383 + 61{,}332 = 519{,}194$$

The adequacy of the tiedown lugs is checked for this load.

The lug material is ASTM A240 stainless steel UNS #32550 with:

F_{tu} = 110,000 psi $\quad$ F_{ty} = 80,000 psi

The lug will be analyzed according to the procedure given in "Structures Methods Manual - SSD60048R", Hughes Aircraft Company, February, 1966.

FIGURE 2.4.4-3

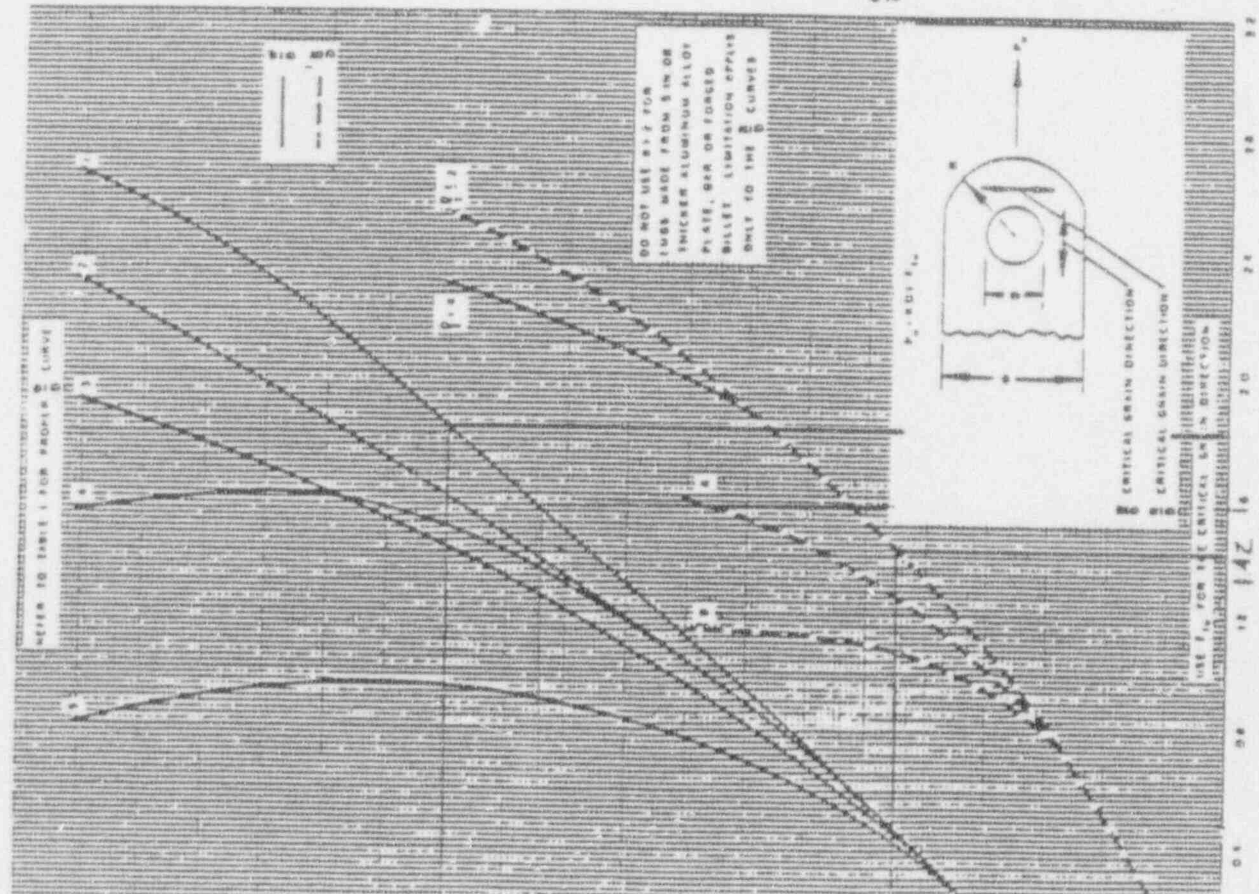


Figure 4.4.1-1. Axially Loaded Lug Design Chart

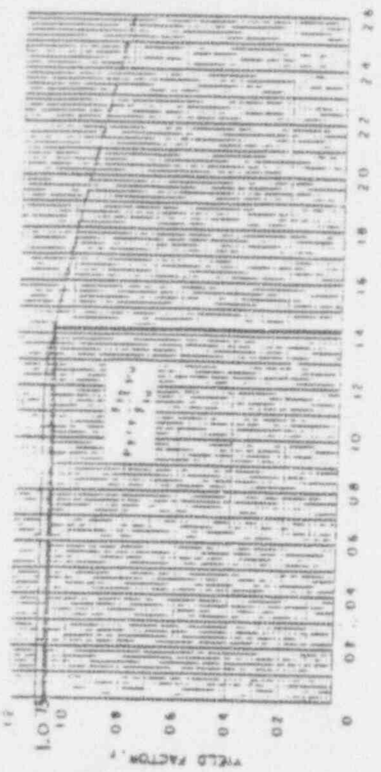


Figure 4.4.1-2 Yield Correction Factor for Axially Loaded Lugs

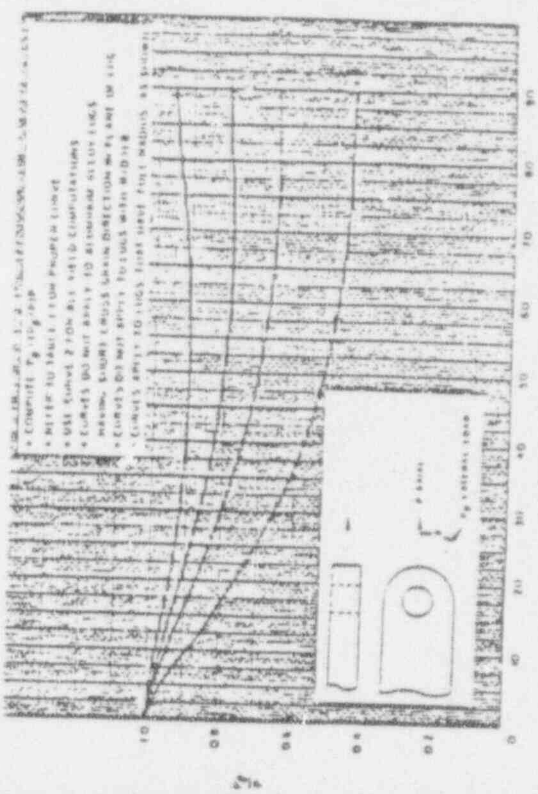


Figure 4.4.1-3. Allowable Lateral Lug Loads

For the lug: $W/D = 8/3 = 2.667$

$R/D = 4.5/3 = 1.5$

From curves on Figure 4.4.1-1 of the manual, the efficiency factor K is 1.42 for R/D=1.5 or 1.6 for W/D=2.667. The smaller value of 1.42 will be used. From Figure 4.4.1-2 of the manual, for K=1.42, the yield factor Y=1.075.

The allowable yield load:

$$P_y = K\ Y\ D\ t\ F_{ty}$$
$$= (1.42)\ (1.075)\ (3)\ (2.5)\ (80{,}000) = 915{,}900 \text{ lbs.}$$

Margin of safety = (915,900/519,194) - 1 = .764

The lug is welded to the cask body by a combination of a 1/2 in. bevel groove weld plus a 1/2 in. fillet weld. Total length of the weld is (2) (16 + 2.5) = 37 in. The adequacy of the weld is verified for:

1. The weld metal for stress on the throat.
2. The cask material, ASTM A516 Gr. 70.
3. The lug material, ASTM A240 UNS #32550.

Capacity based on limiting weld metal stress:

the ultimate strength of the filler metal used for welding with the ASTM A240 UNS #32550 material is F_u = 70,000 psi. According to AISC code, the allowable stress for normal loading condition is $0.3F_u$. For the accident condition considered, a factor of 1.6 will be used such that the allowable stress in the weld metal is:

$$F_{su} = (1.6)\ (0.3)\ (70{,}000) = 33{,}600 \text{ psi}$$

Load capacity = (2) (16 + 2.5) (1.0) (0.707) (33,600) = 878,942

Capacity based on limiting base metal stress:

The lug is ASTM A240 UNS #32550 with a limiting shear stress of (0.577) (110,000) = 63,470 psi. The cask material is ASTM A-516 Gr. 70 with a limiting shear stress of (0.577) (70,000) = 40,390 psi, and this governs the load capacity.

Load capacity = (2) (16 + 2.5) (1) (40,390) = 1.494 x 10^6 lbs.

The margin of safety of the lug based on least weld capacity is = 878,942/519,194 - 1 = 0.693

The tiedown lugs are adequate to take the 10 g longitudinal, 5 g transverse and 2g vertical acceleration of the cask.

2.5.2.5 Primary Lid Hold-Down Lugs and Retainer Pins

See analyses beginning on page 2-71.

2.5.2.6 Lower Ratchet Binder Tie Down Lug and Retainer Bolts

See analyses beginning on page 2-71.

2.6 Normal Conditions of Transport

This section demonstrates that the normal conditions of transportation have been met.

2.6.1 Heat

The thermal evaluation of the cask under conditions of elevated temperature due to normal transport conditions is contained in Section 3.4. Consideration of normal conditions of transport based on the results of the analysis in Section 3.4 is contained in this section.

2.6.1.1 Summary of Pressures and Temperatures - For a summary of temperatures experienced during normal conditions of transport, reference is to Figure 3.4.2-1. The temperatures given are steady state. A maximum of 200°F temperature in the container occurs at the center of the lid. The temperature of the structural shell ranges from 158°F to 167°F. In all locations the temperature gradients through the container wall are small. The maximum determined temperature gradient does not exceed 10°F. Referencing Section 3.4.4, the maximum pressure differential developed in the container is 24.6 psi.

2.6.1.2 Differential Thermal Expansion - Thermal stresses can arise due to temperature gradients in solid materials. In addition, stresses can be induced when a structural member is heated uniformly but fabricated as a composite with materials having different coefficients of thermal expansion. As seen in Figure 3.4.1-1, the wall temperatures are practically uniform. Thus, the thermal stresses are primarily due to the difference in the thermal expansion coefficients of lead and steel (16.3×10^{-6}/F and 6.5×10^{-6}/F respectively). The maximum thermal stress occurs in the inner and outer steel cylindrical shells. An approximate calculation of the thermal stress is made by assuming that the steel and lead shells have the same growth. The axial and hoop stresses of the steel are given by:

$$S_s = (\alpha_l - \alpha_s)\ \Delta T/(1/E_s + A_s/A_l E_l)$$

where α_l and α_s are the thermal expansion coefficients of lead and steel respectively, T is the temperature change, E_l and E_s are the moduli of elasticity of lead and steel respectively, and A_l and A_s are the cross-section areas. The cross-sectional area of the steel is determined by combining inner and outer shells. A temperature change 70°F to 167°F is assumed.

$E_s = 30x10^6$ psi

$E_l = 2x10^6$ psi

$A_s = \Pi\ (66.75)\ (0.5) + \Pi(72)\ (1.00) = 331\ in^2$

$A_l = \Pi\ (68.25)\ (3.5) = 750\ in^2$

$S_s = (16.3 \times 10^{-6} - 6.5 \times 10^{-6})\ (167 - 70)/[1/30x10^6$
$+ (331)/(750)(2x10^6)] = 3743$ psi

Allowable stress for the shell wall = 38,000 psi

Margin of safety = (38,000/3,743) - 1 = 9.2

2.6.1.3 Stress Calculations - The maximum pressure differential developed in the container (normal condition of transport) is 24.6 psi. Assuming the inner 1/2 inch thick shell resists this pressure, the stress in the shell is:

$f = pr/t = (24.6)\ (33)/(0.5) = 1,625$ psi

Allowable stress = F_{ty} = 38,000 psi

Margin of safety = (38,000/1,625) - 1 = 22.4

The lid will also be subjected to this pressure. The maximum bending stress assuming only a 3 in. thick lid is:

$f = 3qa^2\ (3 + \nu)/8t^2$

$= (3)\ (24.6)\ (38.125)^2\ (3 + 0.3)/(8)\ (3)^2$

$= 4,917$ psi

[Roark, R.J. and Young, W.C., Formulas for Stress and Strain, 5th Edition, McGraw-Hill, 1975, Table 24, Case No. 10, pages 363 and 333].

Margin of safety = (22,800/4,917) - 1 = 3.64

The primary and secondary bolts have been found adequate for much larger loads resulting from the hypothetical accident condition load plus the pressure of 11.2 psi in Section 2.6.7.

Therefore, the cask is adequate to withstand a differential of 24.6 psi.

Regarding lead pour, the maximum expected casting temperature of lead is 830°F. This temperature is not high enough to produce any significant metallurgical change in the container structural wall. A temporary rise in temperature of the structural wall will occur during lead pour. However, as the thermal analysis in Chapter 3 demonstrates, the temperature gradient through the wall would be small and significant thermal stresses are not expected. Regarding lead cool down, the lead has a much lower yield strength than the steel container shell. The lead therefore will yield to conform to the container shell dimension long before significant stress is developed in the container wall.

The only expected superposition of stresses expected due to the effects of heat in normal transport are the thermal stresses and stresses due to pressurization in the container shell. In both cases treated separately, the margin of safety is greater than 9.0. The combination of these stresses would still result in a large margin of safety.

2.6.2 Cold

The minimum expected temperature is -40°F as specified in 10 CFR 71 Section 71(c)(2). The primary structural material used in fabricating the cask is ASTM A516 Gr. 70 steel. This material is classified as a pressure vessel plate material for low and moderate temperature service. This steel is manufactured such that it has excellent resistance to low stress fracture at reduced service temperatures. The specification for this material is such that is must meet requirements for notch toughness and must meet stringent manufacturing requirements limiting allowable surface and edge imperfections. It is the structural steel typically specified for low temperature service.

Mechanical tests of foam material such as that used in the impact limiters have been conducted at temperatures as low as -20°F. The strength of the foam at this reduced temperature increases relative to the strength at ambient conditions. There is no significant change in behavior which would otherwise compromise the crush deformation characteristics of the material. The nature of this type of material is such that, at temperatures as low as -40°F, the strength would be further increased and any change in deformation characteristics would still be insignificant.

Regarding other materials of construction, materials used in this cask package are in no way inferior and in many cases superior to materials used in many other Type A and B packages of similar design which have been in service for many years without incident.

2.6.3 Reduced External Pressure

According to Paragraph 71.71 (c)(3) of 10 CFR 71, the cask must withstand a reduced external pressure of 3.5 psi. This is equivalent to the cask being subjected to a differential pressure of 14.7 - 3.5 = 11.2 psi. An analysis of the cask for a much larger differential pressure of 24.6 psi has been conducted in Section 2.6.1.3. The container was demonstrated to be adequate.

2.6.4 Increased External Pressure

The requirement that the cask should not suffer loss of contents when subjected to an external pressure of 20 psi will be examined.

2.6.4.1 Design of Cask Ends Against Yielding - It will be conservatively assumed that the pressure across the ends of the cask is carried by a 3 in. thick steel plate fabricated from ASTM A516 Gr. 70 steel. The model assumes a circular plate of constant thickness supporting a uniformly distributed load and having its edge simply supported.

$$M_c = (qa^2/16)\ (3 + \nu)$$
$$= [(20)\ (38.125)^2/16]\ (3 + 0.3) = 5{,}996 \text{ in.-lbs.}$$

$$f = 6M_c/t^2 = 6\ (5{,}996)/(3)^2 = 3{,}997 \text{ psi}$$

[Roark, R.J. and Young, W.C., Formulas for Stress and Strain, 5th Edition, McGraw-Hill, 1975, Table 24, Case No. 10a, page 363.]

Allowable stress for the cask lid = F_{ty} = 38,000 psi

Margin of safety = (38,000/3,997) - 1 = 8.5

The cask ends will not be compromised due to external pressure of 20 psi.

2.6.4.2 Design of Cask Body Against Yielding - It will be conservatively assumed that the pressure exerted on the cylindrical shell of the cask is carried by the outer shell fabricated from ASTM A516 Gr. 70 steel, 0.5 in. thick plate.

$$f = pr/t = (20)\ (38.125)/(0.5) = 1{,}525 \text{ psi}$$

Allowable stress for the shell wall = 38,000 psi

Margin of safety = (38,000/1,525) - 1 = 23.9

2.6.4.3 Design of Cask body Against Buckling - It will be conservatively assumed that the pressure exerted on the cylindrical shell of the cask is carried by the outer shell. The axial stress on the shell will be ignored recognizing that (a) the assumption is conservative in only considering the outer shell and (b) the primary buckling load on the shell would be lateral pressure for a relatively short, larger diameter shell.

The thickness ratio, λ, is calculated as follows:

$$\lambda = 1.2\ (r/t)^{0.25}\ [(t/L)\ (E/F_{ty})]^{-0.5}$$
$$= 1.2\ (38.125)^{0.25}\ [(1/80)\ (30{,}000{,}000/38{,}000)]^{-0.5}$$
$$= 0.95$$

where t = wall thickness = 1 in.
r = radius of cylinder = 38.125 in.
L = height of cylinder = 80 in.
E = elastic modulus
F_{ty} = yield strength

Since 0.35 > λ > 2.5, a mixed mode of response to external pressure is expected. An upper bound estimate for buckling pressure applicable to short cylinders is as follows:

$$P_c = (0.87)\ (E)\ (t/L)/(r/t)^{1.5}$$
$$= (0.87)\ (30{,}000{,}000)\ (1/80)/(38.125/1)^{1.5}$$
$$= 1{,}386 \text{ psi}$$

Margin of safety = (1,386/20) - 1 = 68

[Blake, A., Practical Stress Analysis in Engineering Design, Marcel Dekker, 1982, Chapter 36, "External Pressure", Pages 515 to 553.]

2.6.5 Vibration

Vibration loads from ordinary transport are expected to have insignificant effects on the container. Various components of the structural shell are either welded or held together with multiple threaded fasteners, including the attachments of the primary and secondary lids. Fastening arrangements similar to that applied to this container have been used on Type A and B containers for many years without incident.

2.6.6 Water Spray

Since the package exterior is constructed of steel, this test is not required.

2.6.7 Free Drop

Dropping a 64,000 pound package a distance of one foot is not a normal condition of transport. The package is permanently affixed or tied to a special tri-axle trailer. As such, it will not be handled like general freight at a truck terminal.

For conservatism we have combined the one foot handling drop with the 30 foot hypothetical accident drop condition and analyzed the package for a single 31 foot drop. The subsequent analysis demonstrates the package's ability to withstand the combined 31 foot drop height.

To demonstrate the structural integrity of the package and its ability to withstand the 31 foot free drop test, a detailed computerized analysis was conducted. It is important to note that the techniques, analysis methods, assumptions, and routines employed follow closely those u. for other petitions such as:

1. DOT 6400 Super Tiger
2. DOT 6553 Paducah Tiger
3. DOT 6272 Poly Panther
4. DOT 6679 Half Super Tiger
5. DOT 6744 Poly Tiger
6. AECB - Resin Flask
7. Model MO-1 packaging - Docket No. 71-9069

These are proven techniques that agree closely with full scale tests as well as other publicized standards such as ORNL-NSIC-68. In all cases the analysis has been proven to be conservative when compared with full scale testing.

It was suggested that, for conservatism the 1 foot drop condition associated with normal handling be combined with the 30 foot accident condition to provide total drop height of 31 feet. Therefore, the following analysis have been conducted on the package using the full gross weight and a 31 foot drop.

The high density foam contained within the impact limiters is designed to crush on impact thus absorbing and distributing the load.

The mechanical properties for the foam used in this package can be found on page 2-6. These properties are applicable for loading conditions in the direction parallel and perpendicular to the rise direction. High density foams, greater than 18 pcf, exhibit these isotropic properties for two reasons. First, because of their high density, the amount of rise during the formation of the foam is small thus producing a cell structure that is very uniform and not elongated. Second, the size of the overpack allows the foam to expand laterally as well as vertically. Again, resulting in uniform grain structure and its associated isotropic properties. The two curves shown on page 2-6 represent the maximum and minimum statistical compressive properties based on a 95% probability for loading in either direction. The values obtained from tests of the actual foam in the 10-142A impact limiters fall within these two curves, thereby providing validity to the results of the computer analyses.

Three drop conditions for the package have been evaluated, i.e. end, corner and side. For each we have reviewed the failure mechanism that would produce maximum load as well as maximum deformation. In these evaluations maximum and minimum mechanical properties were used to produce the most conservative results.

2.6.7.1 Free Drop Impact Analysis - End Impact - Energy to be absorbed by the impact limiter can be calculated as follows:

K.E. = Wh

Where

$W = 64,000$ lbs.

$h = 31$ ft.

K.E. = (64,000 lbs.) (31 ft.)

$= 1.98 \times 10^6$ ft.-lbs.

Assume: 1. Full area of overpack reacts load

2. Drop Height = 31 ft.

Energy absorption is calculated by:

Energy = (Foam Volume Crushed) (Crush Strength)

K.E. $= VF_c$

Where:

V = (AREA) (Depth)

$$= \frac{\pi}{4} [(D_o^2 - D_1^2)] h$$

$$= \frac{\pi}{4} [(101)^2 - (55)^2] h$$

$$= 5,636 \text{ h in}^3$$

F_c = 1,000 psi (Nominal) @ 10% Strain

$(1.98 \times 10^6)(12) = (5,636)h(1,000)$

$h = 4.22$ in. (or 23% strain)

Assuming the 4.22 in deflection produces a 23% strain it is conservative to use the stress at 23% to calculate the acceleration. Therefore, at 23% strain the maximum compression stress is 1,300 psi. Therefore:

$$\text{Acceleration} = \frac{(1{,}300 \text{ psi})\ (5{,}636 \text{ in.}^2)}{64{,}000 \text{ lb.}}$$

$$= 114 \text{ g's}$$

Repeating the same analysis, but with the following assumption:

Assume: 1. Only projected area of cask reacts load

2. Drop height = 31 ft.

$KE = A\ F_c\ h$

$$(64{,}000)\ (31)\ (12) = \frac{\Pi}{4}\ (76.25^2 - 55^2)\ (1{,}000)\ h$$

$h = 10.86$ in.

Strain = 10.86 in./18 in. = .60 or 60% strain

Stress @ 60% strain = 2,500 psi (Max.)

Acceleration = (2,500 psi) (2,190 in.^{2})/(64,000 lbs.)

= 85.5 g's

Therefore, the maximum acceleration experienced will be 114 g's.

Since the primary lid will be reacting these loads in direct compression, the binder will not be loaded. The secondary lid attachments must react these loads. Therefore, bolt stress can be found from the following:

The secondary lid weight is:

$W_L = 1{,}755$ lbs.

Assume the lid must also react the projected area portion of the payload.

$$W_Y = (10,000 \text{ lbs.})\ (29)^2 / (66)^2$$

$$W_Y = 1,931 \text{ lbs.}$$

Total equivalent wt.

$$W_T = 1,755 \text{ lbs.} + 1,931 \text{ lbs.}$$

$$W_T = 3,686 \text{ lbs.}$$

Bolt Loads:

$$P = (3,686 \text{ lbs})\ (114 \text{ g})/8 \text{ bolts}$$

$$P = 52,526 \text{ lbs./bolt}$$

Using the 125 ksi 1 inch diameter bolts (ASTM A320 Grade L7) their strength is 75,750 lbs. (Area = .606 in.^{2})

Margin of Safety = 75,750 / 52,526 - 1

M.S. = <u>+.44</u>

Conclusion:

It is therefore safe to conclude that the package can safely react the maximum loads for a 31 foot end drop without detrimental effects.

2.6.7.2 Free Drop Impact Analysis - Corner Drop - For the case of corner drop or edge impact the deformations experienced by the overpack are more difficult to approximate with a simple analysis. In order to account for the strain hardening which takes place in the foam, a detailed computer program (CYDROP) was generated.

CYDROP treats the corner impact of a cylindrical package upon an unyielding surface. The package itself consists of a cylindrical payload portion surrounded by a larger cylindrical volume composed of a crushable media. So long as the deformations of the crushable media are modest - the problem may be approximately solved by assuming a uniform crush stress exists over the elliptical surface of the crush plane (contact surface). CYDROP was developed specifically to address problems of large deformations of this crushable media and to treat geometries where the cylindrical overpack envelope possesses axisymmetric cylindrical voids (e.g. does not completely cover the cylindrical ends of the payload package).

The large deformation behavior of the crushable media is accommodated by determining the actual strain of the crushable media at a point. This strain is used to determine the corresponding stress from an implicit tabular definition of media stress-strain characteristics. The total crush force is found by a double integration over the contact area of the crush plane.

Strain energy absorbed by the crushable media is determined by integrating the crush force and its associated deformation. The package is assumed to be at "rest" when the computed strain energy value equals the applied kinetic (drop) energy.

The geometric calculations for the contact surface and the associated strains are carried out using a moving (x, y, z) coordinate system in which the x-y plane corresponds to the crush plane, see Figure A. The crush plane itself represents a segment of an ellipse. The contact area is this ellipse segment, provided no cylindrical and void exists. When a cylindrical end void exists, the contact area of the crush plane is reduced by the removal of a second elliptical region associated with the projection of this void into the contact plane.

Calculation of strain is somewhat more complex. In principal, the distance from point (x, y) in the crush plane to the payload is found and denoted. δ_{top}. Similarly the distance to the undeformed external overpack envelope is found and denoted, δ_{bot}. The strain represents deformation divided by original thickness, or:

$$\Sigma = \frac{\delta_{bot}}{\delta_{bot} + \delta_{top}}$$

At any point (x, y), the calculation of δ_{top} may follow three branches, according to location. The three possible branches relate to the payload surface intercepted. They are:

<u>The Circular Bottom of the Payload</u>
The bottom of the payload cylinder describes an ellipse in the crush plane. If (x, y) is inside this ellipse, the point is considered "backed" by the bottom of the payload. An exception to this general statement is noted in the discussion of the "Unbacked Region", see below.

<u>The Cylindrical Surface of the Payload</u>
The cylindrical surface of the payload describes a rectangular region tangent to the payload bottom ellipse at its major axes. If (x, y) is outside the bottom ellipse yet possesses an x coordinate less than the radius of the payload bottom, the point is considered "backed" by the payload cylinder.

<u>Unbacked Regions</u>
Unbacked regions are of two forms; those associated with the cylindrical end void and those near the external surface of the overpack. The unbacked region associated with the end void is a point in the crush plane which lies within the ellipse defined by the void circle lying in the plane of the payload bottom. The unbacked region associated with points near the overpack extremities is defined by those points (x, y) where the x coordinate exceeds the radius of the payload volume. Points which are "unbacked" employ a nominal crush stress for force integration purposes. (For current analysis, this stress was set to zero.)

The calculation of δ_{bot}, the distance to the undeformed overpack envelope, may follow two branches. These branches correspond to intercepts with either the cylindrical surface of the overpack or the circular end of the overpack.

The analytics describing the geometry discussed above, consists of the sequential application of a series of geometric transformations of surfaces described in the coordinates of the cylindrical package (X, Y, Z) to the coordinates of the contact plane (x, y, z). The surfaces in package coordinates are:

<u>Overpack Cylinder</u>

$$X^2 + Y^2 = R_c^2$$

<u>Overpack Bottom Circle</u>

$$X^2 + Y^2 = R_c^2$$
$$Z = -l_c/2$$

<u>Payload Cylinder</u>

$$X^2 + Y^2 = R_p^2$$

<u>Payload Bottom Circle</u>

$$X^2 + Y^2 = R_p^2$$
$$Z = -l_p/2$$

<u>Void Circle at Payload</u>

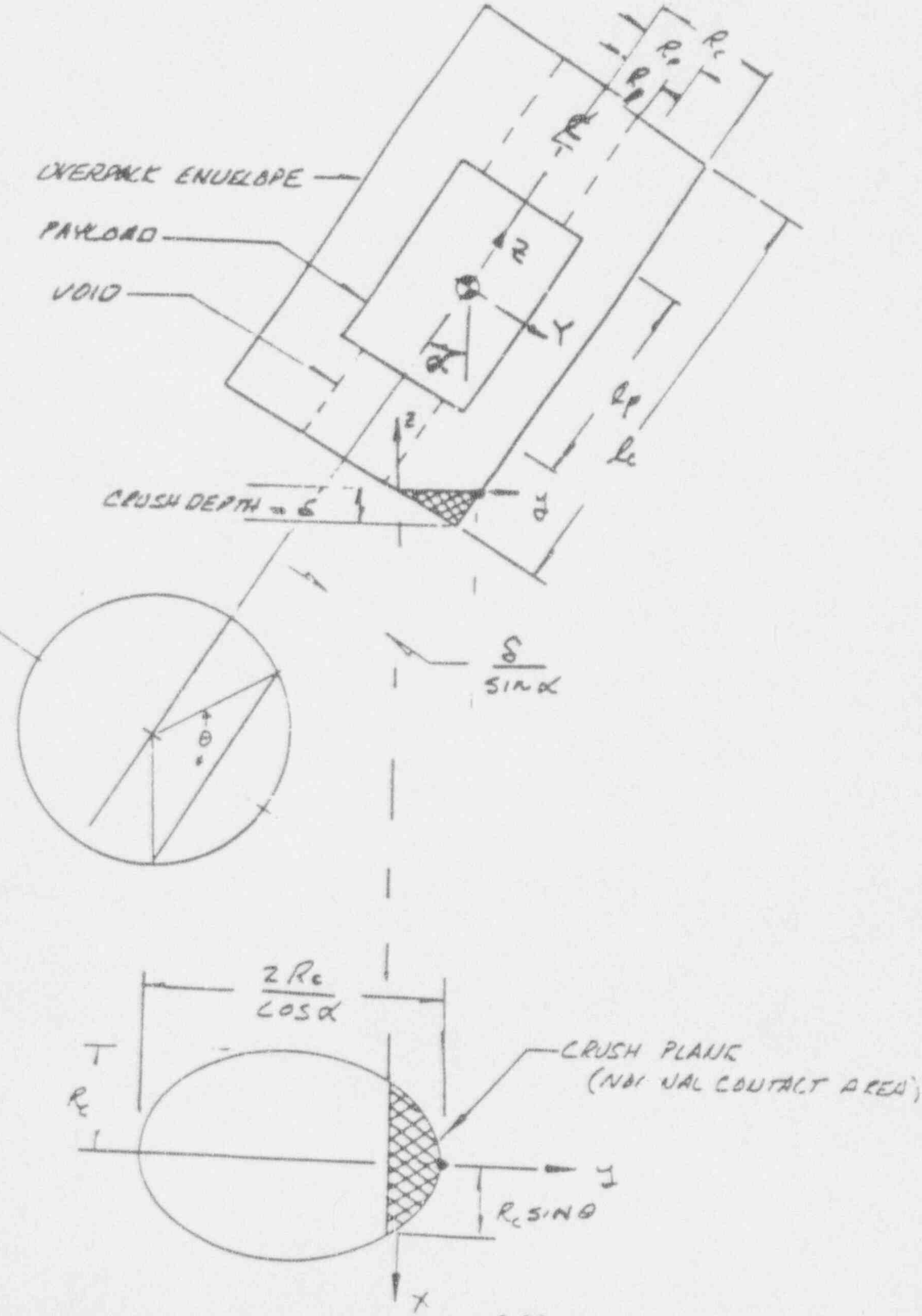
$$X^2 + Y^2 = R_f^2$$
$$Z = -l_p/2$$

<u>Void Circle at Overpack Exterior</u>

$$X^2 + Y^2 = R_f^2$$
$$Z = -l_c/2$$

FIGURE A

CORNER CYLINDER IMPACT GEOMETRY



In order to determine the maximum acceleration experienced, a total of 4 cases were run. Full range stress strain curves were used representing both minimum and maximum compressive stresses. These curves can be found on Page 2-6 and represent 95% probability numbers based to twenty samples. These samples included both perpendicular as well as parallel properties. This data is consistent with the actual tested values of the foam used in the 10-142A.

In addition to the variation in mechanical properties, the effects of the central hole in the overpack were evaluated. Since the program was written to ignore any energy contribution to unbacked foam a portion of the central overpack area was analytically eliminated because of the 55 in. diameter hole. By decreasing the central hole (Package External Hole Diam.) the program would assume that that area was backed and able to absorb energy. Therefore, the backed and unbacked cases were also evaluated at the minimum and maximum material properties.

Case No. 1

Minimum mechanical properties
Full 55 inch central hole

Case No. 2

Minimum mechanical properties
Central hole filled

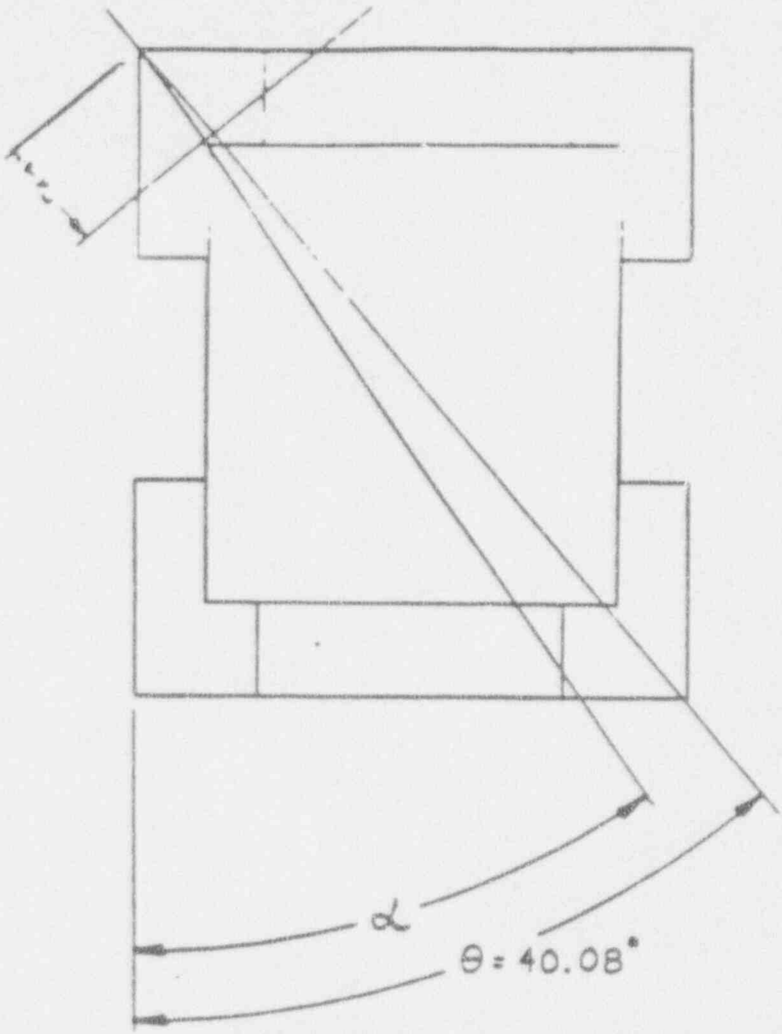
Case No. 3

Maximum mechanical properties
Full 55 inch central hole

Case No. 4

Maximum mechanical properties
Central hole filled

From the printouts it can be seen that columns 6 and 7 provide the total kinetic energy and absorbed strain energy for incremental crush depths. When these values become identical, the package is in equilibrium. Column 8 provides this ratio for rapid evaluation. It is important to note that a large amount of additional energy absorbing capability remains in the package. From Case No. 1 it can be seen that the package comes to rest after reaching a crush depth of 20.50 inches.

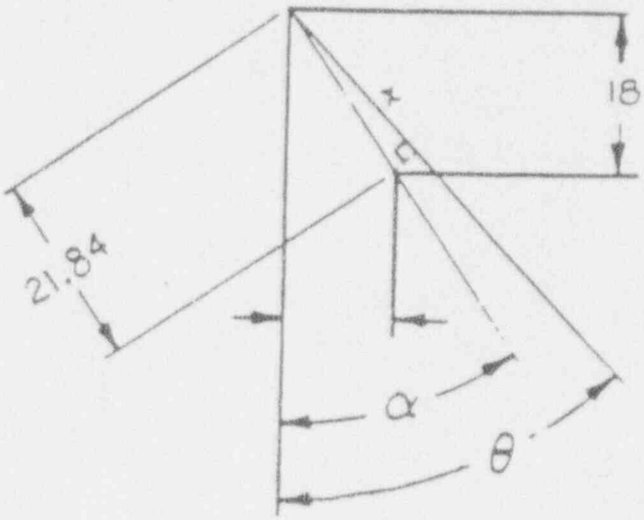


The available foam thickness can be calculated as follows:

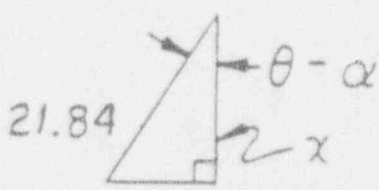
$$\theta = \tan^{-1} (101/120) = 40.08^{0}$$

The actual available thickness varies slightly from the diagonal thickness by the following amount:

$\alpha = \tan^{-1} (101 - 76.25)/(2)/18 = 34.51^{0}$



$[18^2 + 12.375^2]^{1/2} = 21.84$ (Diagonal Thickness)



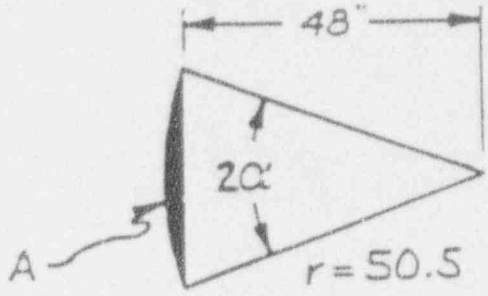
$x = 21.84 \cos (40.08 - 34.51)$

$x = 21.74$ in. (Actual Available Thickness)

From Case No. 1 the maximum strain energy is 32,160,741 in.-lbs. at 21.74 in deflection.

Margin of Safety = 32,360,741/25,200,000 - 1 = + .28

If the corner drop was to occur in the flattened area of the overpack, some additional deformation would take place. The deformation would be directly related to the loss of available foam volume. This volume can be calculated as follows:



$A = 1/2\ r^2\ (\alpha - \sin\alpha)$

Where:

$r = 50.5$ in.

$1/2\ \alpha = \cos^{-1}\alpha/2 = 48/50.5 = 18.1^0$, thus $\alpha = 36.2^0$ or .632 radians

$A = 1/2\ 50.5^2\ (.632 - \sin 36.3^0)$

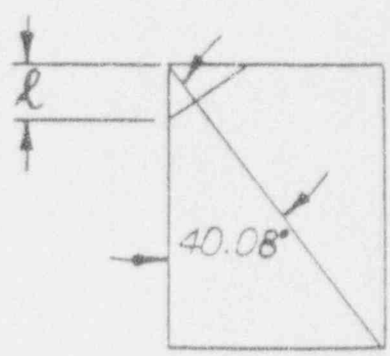
$A = 52.8$ in.^{2}

or

Vol = 52.8 in.^{2}/in of affected length

The effected zone will extend down the package by the following:

$\delta = 20.5$ in (Per Pg. 2.40)



$l = \delta/\cos 40.08^0$

$l = 20.5/\cos 40.08^0$

$l = 26.7$ in.

Lost Volume is:

$$V = (26.7 \text{ in.}) (52.8 \text{ in.}^3/\text{in.})$$
$$B = 1,410 \text{ in.}^3$$

The total volume of foam used during the compression is given on Page 2-50, Column 3.

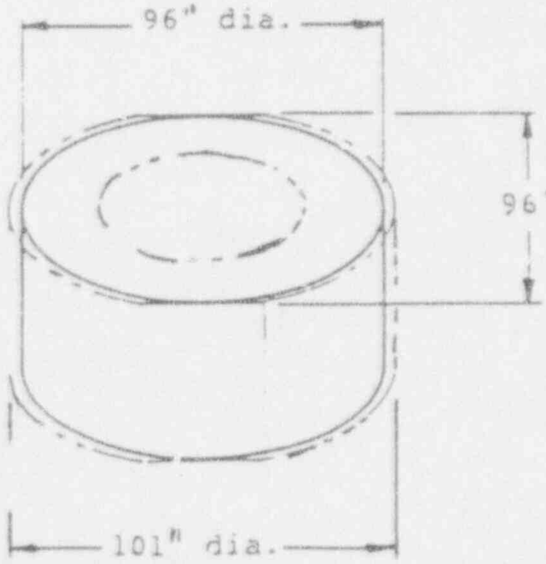
$$V_T = 22,684 \text{ in.}^3$$

or

$$\text{Loss} = 1,410/22,684 = .06$$
Loss = 6% due to flattened sides

Therefore, the absence of foam in the local flat area of the overpack results in only a 6% reduction in the available foam as calculated. This small reduction is more than offset by the availability of the additional crush depth and associated additional foam as calculated above. A positive Margin of Safety exists.

An alternate method of evaluating the effect of the overpack flats is to conservatively assume that the complete overpack is reduced to a diameter equal to the width across the flats. This approach analytically reduces the amount of foam available for energy absorption and is therefore conservative.



In order to establish the maximum deformation for this case, the following CYDROP corner case was run. From the attached output the maximum deformation was found to be 20.16 in. for a 31 foot drop. The available foam is:

$$t_a = [((96-76.25)/2)^2 + 18^2]^{1/2} \cos[\tan^{-1} 96/120 - \tan^{-1} (96-76.25)/2/18]$$

t_a = 20.22 in. (Available)

t_r = 20.16 in. (Required) [from column 1, page 2-48]

After impact a small amount of foam remains.

This analysis conservatively neglects the presence of energy absorbing foam in the region from 96 inch diameter out to 101 inch diameter. Therefore, it can be again concluded that a positive Margin of Safety will exist for impact on to the flat portion of the overpack.

Loads or accelerations experienced by the package are also plotted as a function of crush depth. Accelerations were found to vary from a low of 72.2 g's to a high of 76.4 for the full range of conditions. The small spread in these accelerations is explained by the following. As the compressive strength is reduced, the crush depth and contact area increase. Therefore, the small stress multiplied by a large area produces numbers equivalent to the product of high stresses multiplied by a smaller impact area. Thus, normal variations in crush strength do not significantly affect package loading.

SEG 10-142A -- SOFT FOAM --CASE NR.2

Package Wei,ht	=	64000. (LBS)
Package External Length	=	120.00 (IN)
Package External Diameter	=	96.00 (IN)
Package External Hole Diameter	=	55.00 (IN)
Payload Envelope Length	=	84.00 (IN)
Payload Envelope Diameter	=	76.00 (IN)
Drop Height	=	31.00 (FT)
Orientation Angle	=	.6747 (RADIANS)
Nominal Crush Stress	=	0.00 (PSI)

STRAIN VS STRESS TABLE

PT	STRAIN	STRESS
1	0.00	0.00
2	.05	650.00
3	.07	850.00
4	.10	950.00
5	.20	1000.00
6	.25	1050.00
7	.30	1150.00
8	.40	1260.00
9	.45	1400.00
10	.50	1600.00
11	.60	2250.00
12	.70	3850.00
13	.75	5300.00
14	.80	7400.00
15	.90	13800.00
16	.95	18500.00
17	.99	24000.00

10-142A -- SOFT FOAM -- CASE NR. 2

CRUSH DEPTH	* * CRUSH PLANE * * AREA (IN2)	VOLUME (IN3)	* * * IMPACT * * * FORCE (LBS)	ACCEL. (G)	* * * * ENERGY * * * * KINETIC (IN-LB)	STRAIN (IN-LB)	RATIO (SE/KE)	DISTRIBUTION OF STRAIN RATIOS BY PERCENT OF CONTACT AREA LE.70	GT.70 LE.80	GT.80 LE.90	GT.90 LE.95	GT.95
0.50	11.9	3.	1316.	.0	23840000.	329.	.000	100.00	0.00	0.00	0.00	0.00
1.00	33.6	14.	7658.	.1	23872000.	2573.	.000	100.00	0.00	0.00	0.00	0.00
1.50	61.5	38.	21158.	.3	23904000.	9777.	.000	100.00	0.00	0.00	0.00	0.00
2.00	94.2	77.	42382.	.7	23936000.	25662.	.001	100.00	0.00	0.00	0.00	0.00
2.50	131.1	133.	70224.	1.1	23968000.	53813.	.002	100.00	0.00	0.00	0.00	0.00
3.00	171.6	209.	103557.	1.6	24000000.	97258.	.004	100.00	0.00	0.00	0.00	0.00
3.50	215.3	306.	141672.	2.2	24032000.	158566.	.007	100.00	0.00	0.00	0.00	0.00
4.00	261.9	425.	183806.	2.9	24064000.	239935.	.010	100.00	0.00	0.00	0.00	0.00
4.50	311.1	568.	228129.	3.6	24096000.	342919.	.014	100.00	0.00	0.00	0.00	0.00
5.00	362.7	732.	272777.	4.3	24128000.	468145.	.019	100.00	0.00	0.00	0.00	0.00
5.50	416.5	932.	317627.	5.0	24160000.	615746.	.025	100.00	0.00	0.00	0.00	0.00
6.00	472.4	1154.	363875.	5.7	24192000.	786122.	.032	100.00	0.00	0.00	0.00	0.00
6.50	530.2	1404.	407788.	6.4	24224000.	979038.	.040	100.00	0.00	0.00	0.00	0.00
7.00	589.8	1684.	454530.	7.1	24256000.	1194617.	.049	100.00	0.00	0.00	0.00	0.00
7.50	651.0	1995.	502768.	7.9	24288000.	1433941.	.059	100.00	0.00	0.00	0.00	0.00
8.00	713.7	2336.	554496.	8.7	24320000.	1698257.	.070	100.00	0.00	0.00	0.00	0.00
8.50	777.9	2709.	603525.	9.4	24352000.	1987763.	.082	100.00	0.00	0.00	0.00	0.00
9.00	843.4	3114.	659547.	10.3	24384000.	2303531.	.094	100.00	0.00	0.00	0.00	0.00
9.50	910.2	3552.	717595.	11.2	24416000.	2647816.	.108	100.00	0.00	0.00	0.00	0.00
10.00	978.1	4025.	776332.	12.1	24448000.	3021298.	.124	100.00	0.00	0.00	0.00	0.00
10.50	1047.1	4531.	832616.	13.0	24480000.	3423535.	.140	100.00	0.00	0.00	0.00	0.00
11.00	1117.1	5072.	900835.	14.1	24512000.	3856898.	.157	100.00	0.00	0.00	0.00	0.00
11.50	1188.0	5648.	973294.	15.2	24544000.	4325430.	.176	100.00	0.00	0.00	0.00	0.00
12.00	1259.2	6260.	1054924.	16.5	24576000.	4832485.	.197	100.00	0.00	0.00	0.00	0.00
12.50	1332.3	6908.	1139482.	17.8	24608000.	5381086.	.219	100.00	0.00	0.00	0.00	0.00
13.00	1405.6	7593.	1222977.	19.1	24640000.	5971701.	.242	100.00	0.00	0.00	0.00	0.00
13.50	1479.5	8314.	1315391.	20.6	24672000.	6606293.	.268	100.00	0.00	0.00	0.00	0.00
14.00	1554.0	9072.	1427121.	22.3	24704000.	7291921.	.295	100.00	0.00	0.00	0.00	0.00
14.50	1629.1	9868.	1552290.	24.3	24736000.	8036774.	.325	100.00	0.00	0.00	0.00	0.00
15.00	1704.6	10701.	1699129.	26.5	24768000.	8848629.	.357	100.00	0.00	0.00	0.00	0.00
15.50	1780.6	11523.	1855846.	29.0	24800000.	9738373.	.393	100.00	0.00	0.00	0.00	0.00

10-142A - SOFT FOAM -- CASE NR. 2

CRUSH DEPTH	* * CRUSH PLANE * * AREA (IN2)	VOLUME (IN3)	* * * IMPACT * * * FORCE (LBS)	ACCEL. (G)	* * * * ENERGY * * * * KINETIC (IN-LB)	STRAIN (IN-LB)	RATIO (SE/KE)	DISTRIBUTION OF STRAIN RATIOS BY PERCENT OF CONTACT AREA LE.70	GT.70 LE.80	GT.80 LE.90	GT.90 LE.95	GT.95
16.00	1856.9	12482.	2050383.	32.0	24832000.	10714930.	.431	97.76	2.24	0.00	0.00	0.00
16.50	1933.5	13430.	2270540.	35.5	24864000.	11795161.	.474	93.66	6.34	0.00	0.00	0.00
17.00	2010.4	14416.	2540788.	39.7	24896000.	12997993.	.522	91.68	8.32	0.00	0.00	0.00
17.50	2087.5	15440.	2836023.	44.3	24928000.	14342195.	.575	87.99	12.01	0.00	0.00	0.00
18.00	2164.7	16503.	3173465.	49.6	24960000.	15844567.	.635	85.94	11.94	2.11	0.00	0.00
18.50	2242.1	17605.	3606530.	56.4	24992000.	17539566.	.702	84.16	10.14	6.10	0.00	0.00
19.00	2319.5	18745.	4105660.	64.2	25024000.	19467614.	.778	81.27	10.73	8.00	0.00	0.00
19.50	2396.9	19924.	4683926.	73.2	25056000.	21665010.	.865	78.08	12.12	8.28	1.52	0.00
20.00	2474.2	21142.	5385546.	[illegible]	25088000.	24182379.	.964	75.21	11.61	10.59	2.59	0.00
20.50	2551.5	22399.	6232986.	[illegible]	25120000.	27087012.	1.078	73.49	11.52	10.26	2.78	1.95
21.00	2628.6	23694.	7134589.	111.[illegible]	25152000.	30428905.	1.210	71.45	11.86	8.84	5.00	2.84
21.50	2705.5	25027.	8073221.	126.1	25184000.	34230858.	1.359	69.81	11.37	9.25	5.20	4.37
22.00	2782.2	26399.	9126656.	142.6	25216000.	38530828.	1.528	68.33	10.40	10.47	3.38	7.41
22.50	2858.5	27809.	10241591.	160.0	25248000.	43372889.	1.718	66.40	9.39	10.38	4.49	9.34
23.00	2934.6	29257.	10691524.	167.1	25280000.	48606168.	1.923	66.43	8.60	10.66	5.15	9.16
23.50	3010.2	30744.	11121935.	173.8	25312000.	54059533.	2.136	65.95	7.98	11.61	3.63	10.84

SEG 10-142A -- SOFT FOAM --CASE NR.1

Package Weight	=	64000. (LBS)
Package External Length	=	120.00 (IN)
Package External Diameter	=	101.00 (IN)
Package External Hole Diameter	=	55.00 (IN)
Payload Envelope Length	=	84.00 (IN)
Payload Envelope Diameter	=	76.00 (IN)

Drop Height	=	31.00 (FT)
Orientation Angle	=	.6997 (RADIANS)
Nominal Crush Stress	=	0.00 (PSI)

STRAIN VS STRESS TABLE

PT	STRAIN	STRESS
1	0.00	0.00
2	.05	650.00
3	.07	850.00
4	.10	950.00
5	.20	1000.00
6	.25	1050.00
7	.30	1150.00
8	.40	1260.00
9	.45	1400.00
10	.50	1600.00
11	.60	2250.00
12	.70	3850.00
13	.75	5300.00
14	.80	7400.00
15	.90	13800.00
16	.95	18500.00
17	.99	24000.00

10-142A -- SOFT FOAM -- CASE NR. 1

	* * CRUSH PLANE * *		* * * IMPACT * * *		* * * * ENERGY * * * *			DISTRIBUTION OF STRAIN RATIOS BY PERCENT OF CONTACT AREA				
CRUSH DEPTH	AREA (IN2)	VOLUME (IN3)	FORCE (LBS)	ACCEL. (G)	KINETIC (IN-LB)	STRAIN (IN-LB)	RATIO (SE/KE)	LE.70	GT.70 LE.80	GT.80 LE.90	GT.90 LE.95	GT.95
1.00	33.6	8.	7511.	.1	23872000.	1878.	.000	100.00	0.00	0.00	0.00	0.00
1.50	61.5	32.	20788.	.3	23904000.	8953.	.000	100.00	0.00	0.00	0.00	0.00
2.00	94.4	71.	41761.	.7	23936000.	24590.	.001	100.00	0.00	0.00	0.00	0.00
2.50	131.4	128.	69438.	1.1	23968000.	52389.	.002	100.00	0.00	0.00	0.00	0.00
3.00	172.0	203.	102638.	1.6	24000000.	95408.	.004	100.00	0.00	0.00	0.00	0.00
3.50	215.0	300.	140552.	2.2	24032000.	166206.	.006	100.00	0.00	0.00	0.00	0.00
4.00	262.7	420.	182312.	2.8	24064000.	216922.	.010	100.00	0.00	0.00	0.00	0.00
4.50	312.1	564.	227408.	3.6	24096000.	339352.	.014	100.00	0.00	0.00	0.00	0.00
5.00	364.1	733.	275454.	4.3	24128000.	465068.	.019	100.00	0.00	0.00	0.00	0.00
5.50	418.3	928.	325933.	5.1	24160000.	615414.	.025	100.00	0.00	0.00	0.00	0.00
6.00	474.6	1152.	377426.	5.9	24192000.	791254.	.033	100.00	0.00	0.00	0.00	0.00
6.50	532.9	1402.	429861.	6.7	24224000.	993076.	.041	100.00	0.00	0.00	0.00	0.00
7.00	593.0	1685.	484055.	7.6	24256000.	1221555.	.050	100.00	0.00	0.00	0.00	0.00
7.50	654.8	1997.	535687.	8.4	24288000.	1476490.	.061	100.00	0.00	0.00	0.00	0.00
8.00	718.2	2340.	593708.	9.3	24320000.	1758839.	.072	100.00	0.00	0.00	0.00	0.00
8.50	783.1	2715.	640936.	10.1	24352000.	2069000.	.085	100.00	0.00	0.00	0.00	0.00
9.00	849.4	3124.	705899.	11.0	24384000.	2407209.	.099	100.00	0.00	0.00	0.00	0.00
9.50	917.1	3565.	767761.	12.0	24416000.	2775624.	.114	100.00	0.00	0.00	0.00	0.00
10.00	985.9	4041.	824105.	12.9	24448000.	3173590.	.130	100.00	0.00	0.00	0.00	0.00
10.50	1056.0	4551.	890594.	13.9	24480000.	3602265.	.147	100.00	0.00	0.00	0.00	0.00
11.00	1127.1	5097.	961483.	15.0	24512000.	4065284.	.156	100.00	0.00	0.00	0.00	0.00
11.50	1199.2	5679.	1030083.	16.1	24544000.	4563175.	.186	100.00	0.00	0.00	0.00	0.00
12.00	1272.3	6297.	1104672.	17.3	24576000.	5096864.	.207	100.00	0.00	0.00	0.00	0.00
12.50	1346.2	6951.	1182835.	18.5	24608000.	5668741.	.230	100.00	0.00	0.00	0.00	0.00
13.00	1421.0	7643.	1271717.	19.9	24640000.	6282379.	.255	100.00	0.00	0.00	0.00	0.00
13.50	1496.5	8372.	1364653.	21.3	24672000.	6941471.	.281	100.00	0.00	0.00	0.00	0.00
14.00	1572.8	9140.	1468632.	22.9	24704000.	7649792.	.310	100.00	0.00	0.00	0.00	0.00
14.50	1649.6	9945.	1568501.	24.5	24736000.	8409076.	.346	100.00	0.00	0.00	0.00	0.00
15.00	1727.1	10790.	1681236.	26.3	24768000.	9221508.	.372	100.00	0.00	0.00	0.00	0.00
15.50	1805.0	11673.	1810680.	28.3	24800000.	10094486.	.407	100.00	0.00	0.00	0.00	0.00

10-142A -- SOFT FOAM -- CASE NR. 1

	* * CRUSH PLANE * *		* * * IMPACT * * *		* * * * ENERGY * * * *			DISTRIBUTION OF STRAIN RATIOS BY PERCENT OF CONTACT AREA				
CRUSH DEPTH	AREA (IN2)	VOLUME (IN3)	FORCE (LBS)	ACCEL. (G)	KINETIC (IN-LB)	STRAIN (IN-LB)	RATIO (SE/KE)	LE.70	GT.70 LE.80	GT.80 LE.90	GT.90 LE.95	GT.95
16.00	1883.5	12595.	1967184.	30.7	24832000.	11038952.	.445	100.00	0.00	0.00	0.00	0.00
16.50	1962.4	13556.	2134168.	33.3	24864000.	12064290.	.485	98.45	1.55	0.00	0.00	0.00
17.00	2041.7	14557.	2341443.	36.6	24896000.	13183192.	.530	96.13	3.87	0.00	0.00	0.00
17.50	2121.3	15598.	2563596.	40.1	24928000.	14409452.	.578	93.75	6.25	0.00	0.00	0.00
18.00	2201.2	16679.	2844667.	44.9	24960000.	15761523.	.631	91.85	8.15	0.00	0.00	0.00
18.50	2281.3	17799.	3154357.	49.3	24992000.	17261284.	.691	89.70	8.72	1.59	0.00	0.00
19.00	2361.6	18960.	3472857.	54.3	25024000.	18918088.	.756	87.10	10.48	2.42	0.00	0.00
19.50	2442.1	20161.	3883307.	60.7	25056000.	20757129.	.828	85.69	9.65	4.06	0.00	0.00
20.00	2522.7	21402.	4363359.	66.2	25088000.	22818795.	.910	84.34	8.97	6.68	0.00	0.00
20.50	2603.3	22684.	4891323.	76.4	25120000.	25132466.	1.000	81.42	10.13	6.77	1.68	0.00
21.00	2683.9	24005.	5525357.	86.3	25152000.	27736635.	1.103	76.13	11.57	7.80	2.50	0.00
21.50	2764.5	25367.	6274154.	96.0	25184000.	30686513.	1.218	75.83	11.43	9.84	1.23	1.68
22.00	2845.0	26770.	7119670.	111.2	25216000.	34034969.	1.350	74.41	11.24	9.14	2.69	2.91
22.50	2925.4	28212.	7960613.	124.4	25248000.	37805040.	1.497	73.08	11.38	8.47	4.16	2.92
23.00	3005.6	29695.	8831494.	138.0	25280000.	42003167.	1.652	71.37	11.72	8.53	4.21	4.47
23.50	3085.7	31218.	9829162.	153.0	25312000.	46668431.	1.844	70.19	9.53	10.25	4.18	5.75

SEG 10-142A -- SOFT FOAM --CASE NR.1

Package Weight	=	64000. (LBS)
Package External Length	=	120.00 (IN)
Package External Diameter	=	101.00 (IN)
Package External Hole Diameter	=	1.00 (IN)
Payload Envelope Length	=	84.00 (IN)
Payload Envelope Diameter	=	76.00 (IN)

Drop Height	=	31.00 (FT)
Orientation Angle	=	.6997 (RADIANS)
Nominal Crush Stress	=	0.00 (PSI)

STRAIN VS STRESS TABLE

PT	STRAIN	STRESS
1	0.00	0.00
2	.05	650.00
3	.07	850.00
4	.10	950.00
5	.20	1000.00
6	.25	1050.00
7	.30	1150.00
8	.40	1260.00
9	.45	1400.00
10	.50	1600.00
11	.60	2250.00
12	.70	3850.00
13	.75	5300.00
14	.80	7400.00
15	.90	13800.00
16	.95	18500.00
17	.99	24000.00

10-142A -- SOFT FOAM -- CASE NR. 2

CRUSH DEPTH	* * CRUSH PLANE * * AREA (IN2)	VOLUME (IN3)	* * * IMPACT * * * FORCE (LBS)	ACCEL. (G)	* * * * ENERGY * * * * KINETIC (IN-LB)	STRAIN (IN-LB)	RATIO (SE/KE)	DISTRIBUTION OF STRAIN RATIOS BY PERCENT OF CONTACT AREA LE.70	GT.70 LE.80	GT.80 LE.90	GT.90 LE.95	GT.95
1.00	33.6	8.	7511.	.1	23872000.	1878.	.000	100.00	0.00	0.00	C.00	0.00
1.50	61.5	32.	20788.	.3	23904000.	8953.	.000	100.00	0.00	0.00	0.00	0.00
2.00	94.4	71.	41761.	.7	23936000.	24590.	.001	100.00	0.00	0.00	0.00	0.00
2.50	131.4	128.	69438.	1.1	23968000.	52389.	.002	100.00	0.00	0.00	0.00	0.00
3.00	172.0	203.	102638.	1.6	24000000.	95408.	.004	100.00	0.00	0.00	0.00	0.00
3.50	215.0	300.	140552.	2.2	24032000.	136206.	.006	100.00	0.00	0.00	0.00	0.00
4.00	262.7	420.	182312.	2.8	24004000.	236922.	.010	100.00	0.00	0.00	0.00	0.00
4.50	312.1	564.	227408.	3.6	24096000.	339352.	.014	100.00	0.00	0.00	0.00	0.00
5.00	364.1	733.	275454.	4.3	24128000.	465068.	.019	100.00	0.00	0.00	0.00	0.00
5.50	418.3	928.	326552.	5.1	24160000.	615414.	.025	100.00	0.00	0.00	0.00	0.00
6.00	474.6	1152.	380759.	5.9	24192000.	792397.	.033	100.00	0.00	0.00	0.00	0.00
6.50	532.9	1403.	438457.	6.8	24224000.	997176.	.041	100.00	0.00	0.00	0.00	0.00
7.00	593.0	1685.	499808.	7.8	24256000.	1231717.	.051	100.00	0.00	0.00	0.00	0.00
7.50	654.8	1997.	565055.	8.8	24288000.	1497944.	.062	100.00	0.00	0.00	0.00	0.00
8.00	718.2	2340.	633725.	9.9	24320000.	1797628.	.074	100.00	0.00	0.00	0.00	0.00
8.50	783.1	2715.	705404.	11.0	24352000.	2132410.	.088	100.00	0.00	0.00	0.00	0.00
9.00	849.4	3124.	780135.	12.2	24384000.	2503795.	.103	100.00	0.00	0.00	0.00	0.00
9.50	917.1	3565.	857894.	13.4	24416000.	2913302.	.119	100.00	0.00	0.00	0.00	0.00
10.00	985.9	4041.	939325.	14.7	24448000.	3362607.	.138	100.00	0.00	0.00	0.00	0.00
10.50	1056.0	4551.	1024968.	16.0	24480000.	3853680.	.157	100.00	0.00	0.00	0.00	0.00
11.00	1127.1	5097.	1115365.	17.4	24512000.	4380763.	.179	100.00	0.00	0.00	0.00	0.00
11.50	1199.2	5679.	1210601.	18.9	24544000.	4970255.	.203	100.00	0.00	0.00	0.00	0.00
12.00	1272.3	6297.	1311190.	20.5	24576000.	5600703.	.228	100.00	0.00	0.00	0.00	0.00
12.50	1346.2	6951.	1418181.	22.8	24608000.	6283048.	.255	100.00	0.00	0.00	0.00	0.00
13.00	1421.0	7643.	1530829.	23.9	24640000.	7020298.	.285	100.00	0.00	0.00	0.00	0.00
13.50	1496.6	8372.	1649884.	25.3	24672000.	7815476.	.317	100.00	0.00	0.00	0.00	0.00
14.00	1572.8	9140.	1780597.	[illegible]	24704000.	8673097.	.351	100.00	0.00	0.00	0.00	0.00
14.50	1649.6	9945.	1917674.	[illegible]	24736000.	9597664.	.388	100.00	0.00	0.00	0.00	0.00
15.00	1727.1	10790.	2072378.	[illegible]	24768000.	10595177.	.428	100.00	0.00	0.00	0.00	0.00
15.50	1805.0	11673.	2235243.	[illegible]	24800000.	11672083.	.471	100.00	0.00	0.00	0.00	0.00

10-142A -- SOFT FOAM -- CASE NR. 2

	* * CRUSH PLANE * *		* * * IMPACT * * *		* * * * ENERGY * * * *			DISTRIBUTION OF STRAIN RATIOS BY PERCENT OF CONTACT AREA				
CRUSH DEPTH	AREA (IN2)	VOLUME (IN3)	FORCE (LBS)	ACCEL. (G)	KINETIC (IN-LB)	STRAIN (IN-LB)	RATIO (SE/KE)	LE.70	GT.70 LE.80	GT.80 LE.90	GT.90 LE.95	GT.95
16.00	1883.5	12595.	2424983.	37.9	24832000.	12837139.	.517	100.00	0.00	0.00	0.00	0.00
16.50	1962.4	13556.	2626268.	41.0	24864000.	14099952.	.567	98.84	1.16	0.00	0.00	0.00
17.00	2041.7	14557.	2866743.	44.8	24896000.	15473204	.622	97.12	2.88	0.00	0.00	0.00
17.50	2121.3	15598.	3124205.	48.8	24928000.	16970941.	.681	95.38	4.62	0.00	0.00	0.00
18.00	2201.2	16679.	3437190.	53.7	24960000.	18611290.	.746	93.98	6.02	0.00	0.00	0.00
18.50	2281.3	17799.	3795930.	59.3	24992000.	20419570.	.817	92.44	6.40	1.16	0.00	0.00
19.00	2361.6	18960.	4184583.	65.4	25024000.	22414698.	.8 6	90.68	7.57	1.75	0.00	0.00
19.50	2442.1	20161.	4655505.	72.7	25056000.	24624720.	.983	89.74	6.92	3.34	0.00	0.00
20.00	2522.7	21402.	5195005.	81.2	25088000.	27087348.	1.080	88.83	6.40	4.77	0.00	0.00
20.50	2603.3	22684.	5781457.	90.3	25120000.	29031463.	1.188	86.85	7.17	4.79	1.19	0.00
21.00	2683.9	24005.	6486851.	101.4	25152000.	32898540.	1.308	84.61	8.14	5.49	1.76	0.00
21.50	2764.5	25367.	7302667.	114.1	25184000.	36345920.	1.443	83.02	8.03	6.91	0.86	1.18
22.00	2845.0	26770.	8228953.	128.6	25216000.	40228825.	1.595	82.08	7.87	6.40	1.89	1.76
22.50	2925.4	28212.	9156420.	143.1	25248000.	44576168.	1.765	81.22	7.94	5.91	2.90	2.04
23.00	3005.6	29695.	10108771.	157.9	25280000.	49391466.	1.854	79.10	8.96	5.91	2.98	3.10
23.50	3085.7	31218.	11214907.	175.2	25312000.	54722385.	2.162	77.63	8.43	7.08	2.89	3.97

SEG 10-142A -- SOFT FOAM --CASE NR.3

Package Weight	=	64000. (LBS)
Package External Length	=	120.00 (IN)
Package External Diameter	=	101.00 (IN)
Package External Hole Diameter	=	55.00 (IN)
Payload Envelope Length	=	84.00 (IN)
Payload Envelope Diameter	=	76.00 (IN)

Drop Height	=	31.00 (FT)
Orientation Angle	=	.6997 (RADIANS)
Nominal Crush Stress	=	0.00 (PSI)

STRAIN VS STRESS TABLE

PT	STRAIN	STRESS
1	0.00	0.00
2	.05	850.00
3	.07	1000.00
4	.10	1050.00
5	.20	1200.00
6	.25	1300.00
7	.30	1350.00
8	.40	1500.00
9	.45	1620.00
10	.50	1850.00
11	.60	2550.00
12	.70	4400.00
13	.75	6100.00
14	.80	8350.00
15	.90	15300.00
16	.95	20500.00
17	.99	25600.00

10-142A -- SOFT FOAM -- CASE NR. 3

	* * CRUSH PLANE * *		* * * IMPACT * * *		* * * * ENERGY * * * *			DISTRIBUTION OF STRAIN RATIOS BY PERCENT OF CONTACT AREA				
CRUSH DEPTH	AREA (IN2)	VOLUME (IN3)	FORCE (LBS)	ACCEL. (G)	KINETIC (IN-LB)	STRAIN (IN-LB)	RATIO (SE/KE)	LE.70	GT.70 LE.80	GT.80 LE.90	GT.90 LE.95	GT.95
1.00	33.6	8.	12013.	.2	23872000.	3003.	.000	100.00	0.00	0.00	0.00	0.00
1.50	61.5	32.	30340.	.5	23904000.	13592.	.001	100.00	0.00	0.00	0.00	0.00
2.00	94.4	71.	56752.	.9	23936000.	35855.	.001	100.00	0.00	0.00	0.00	0.00
2.50	131.4	128.	89753.	1.4	23968000.	71991.	.003	100.00	0.00	0.00	0.00	0.00
3.00	172.0	203.	128181.	2.0	24000000.	126474.	.005	100.00	0.00	0.00	0.00	0.00
3.50	215.0	300.	171537.	2.7	24032000.	201404.	.008	100.00	0.00	0.00	0.00	0.00
4.00	242.7	420.	219409.	3.4	24064000.	299140.	.012	100.00	0.00	0.00	0.00	0.00
4.50	312.1	564.	271686.	4.2	24096000.	421914.	.018	100.00	0.00	0.00	0.00	0.00
5.00	364.1	733.	328314.	5.1	24128000.	571914.	.024	100.00	0.00	0.00	0.00	0.00
5.50	418.3	928.	388344.	6.1	24160000.	751078.	.031	100.00	0.00	0.00	0.00	0.00
6.00	474.6	1152.	449733.	7.0	24192000.	960598.	.040	100.00	0.00	0.00	0.00	0.00
6.50	532.9	1403.	512461.	8.0	24224000.	1201146.	.050	100.00	0.00	0.00	0.00	0.00
7.00	593.0	1685.	576906.	9.0	24256000.	1473488.	.061	100.00	0.00	0.00	0.00	0.00
7.50	654.8	1997.	638194.	10.0	24288000.	1777260.	.073	100.00	0.00	0.00	0.00	0.00
8.00	718.2	2340.	706812.	11.0	24320000.	2113509.	.087	100.00	0.00	0.00	0.00	0.00
8.50	783.1	2715.	770541.	12.0	24352000.	2482848.	.102	100.00	0.00	0.00	0.00	0.00
9.00	849.4	3124.	841234.	13.1	24384000.	2805791.	.118	100.00	0.00	0.00	0.00	0.00
9.50	917.1	3565.	915577.	14.3	24416000.	3324994.	.136	100.00	0.00	0.00	0.00	0.00
10.00	985.9	4041.	983033.	15.4	24448000.	3799647.	.155	100.00	0.00	0.00	0.00	0.00
10.50	1056.0	4551.	1061537.	16.6	24480000.	4310789.	.176	100.00	0.00	0.00	0.00	0.00
11.00	1127.1	5097.	1144121.	17.9	24512000.	4862204.	.198	100.00	0.00	0.00	0.00	0.00
11.50	1199.2	5679.	1222842.	19.1	24544000.	5453944.	.222	100.00	0.00	0.00	0.00	0.00
12.00	1272.3	6297.	1307835.	20.4	24576000.	6085614.	.240	100.00	0.00	0.00	0.00	0.00
12.50	1346.2	6951.	1396678.	21.8	24608000.	6762742.	.275	100.00	0.00	0.00	0.00	0.00
13.00	1421.0	7643.	1497254.	23.4	24640000.	7486225.	.304	100.00	0.00	0.00	0.00	0.00
13.50	1496.6	8372.	1602148.	25.0	24672000.	8261076.	.335	100.00	0.00	0.00	0.00	0.00
14.00	1572.8	9140.	1720645.	26.9	24704000.	9091774.	.368	100.00	0.00	0.00	0.00	0.00
14.50	1649.6	9945.	1832950.	28.6	24736000.	9980173.	.403	100.00	0.00	0.00	0.00	0.00
15.00	1727.1	10790.	1960605.	30.6	24768000.	10928562.	.441	100.00	0.00	0.00	0.00	0.00
15.50	1805.0	11673.	2107074.	32.9	24800000.	11945481.	.482	100.00	0.00	0.00	0.00	0.00

10-142A -- SOFT FOAM -- CASE NR. 3

CRUSH DEPTH	* * CRUSH PLANE * * AREA (IN2)	VOLUME (IN3)	* * * IMPACT * * * FORCE (LBS)	ACCEL. (G)	* * * * ENERGY * * * * KINETIC (IN-LB)	STRAIN (IN-LB)	RATIO (SE/KE)	DISTRIBUTION OF STRAIN RATIOS BY PERCENT OF CONTACT AREA LE.70	GT.70 LE.80	GT.80 LE.90	GT.90 LE.95	GT.95
16.00	1883.5	12595.	2285795.	35.7	24832000.	13043699.	.525	100.00	0.00	0.00	0.00	0.00
16.50	1962.4	13556.	2476197.	38.7	24864000.	14234197.	.572	98.45	1.65	0.00	0.00	0.00
17.00	2041.7	14557.	2714529.	42.4	24896000.	15531878.	.624	96.13	3.87	0.00	0.00	0.00
17.50	2121.3	15598.	2969074.	46.4	24928000.	16952778.	.680	93.75	6.25	0.00	0.00	0.00
18.00	2201.2	16679.	3289842.	51.4	24960000.	18517508.	.742	91.85	8.15	0.00	0.00	0.00
18.50	2281.3	17799.	3640436.	56.9	24992000.	20250078.	.810	89.70	8.72	1.59	0.00	0.00
19.00	2361.6	18960.	3998210.	62.5	25024000.	22159739.	.886	87.10	10.48	2.42	0.00	0.00
19.50	2442.1	20161.	4457618.	69.7	25056000.	24273606.	.969	85.69	9.65	4.66	0.00	0.00
20.00	2522.7	21402.	4993450.	78.0	25088000.	26636465.	1.062	84.34	8.97	6.68	0.00	0.00
20.50	2603.3	22684.	5582081.	87.2	25120000.	29280351.	1.166	81.42	10.13	6.77	1.68	0.00
21.00	2683.9	24005.	6289609.	98.3	25152000.	32248274.	1.282	78.13	11.57	7.80	2.50	0.00
21.50	2764.5	25367.	7113058.	111.1	25184000.	35598940.	1.414	75.83	11.43	9.84	1.23	1.68
22.00	2845.0	26770.	8027222.	125.4	25216000.	39384010.	1.562	74.41	11.24	9.14	2.69	2.51
22.50	2925.4	28212.	8947618.	139.8	25248000.	43627720.	1.728	73.08	11.38	8.47	4.16	2.92
23.00	3005.6	29695.	9900345.	154.7	25280000.	48839718.	1.912	71.37	11.42	8.53	4.21	4.47
23.50	3085.7	31218.	10978198.	171.5	25312000.	64559851.	2.116	70.19	9.63	10.25	4.18	5.75

SEG 10-142A -- SOFT FOAM --CASE NR.4

Package Weight	=	64000. (LBS)
Package External Length	=	120.00 (IN)
Package External Diameter	=	101.00 (IN)
Package External Hole Diameter	=	1.00 (IN)
Payload Envelope Length	=	84.00 (IN)
Payload Envelope Diameter	=	76.00 (IN)
Drop Height	=	31.00 (FT)
Orientation Angle	=	.6997 (RADIANS)
Nominal Crush Stress	=	0.00 (PSI)

STRAIN VS STRESS TABLE

PT	STRAIN	STRESS
1	0.00	0.00
2	.05	850.00
3	.07	1000.00
4	.10	1050.00
5	.20	1200.00
6	.25	1300.00
7	.30	1350.00
8	.40	1500.00
9	.45	1620.00
10	.50	1800.00
11	.60	2550.00
12	.70	4400.00
13	.75	6100.00
14	.80	8350.00
15	.90	15300.00
16	.95	20500.00
17	.99	25600.00

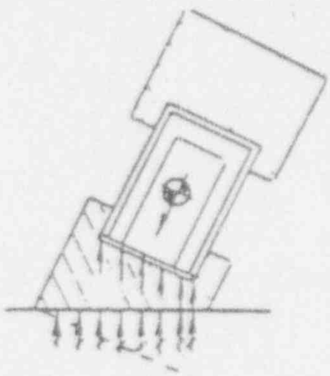
10-142A -- SOFT FOAM -- CASE NR. 4

	* * CRUSH PLANE * *		* * * IMPACT * * *		* * * * ENERGY * * * *			DISTRIBUTION OF STRAIN RATIOS BY PERCENT OF CONTACT AREA				
CRUSH DEPTH	AREA (IN2)	VOLUME (IN3)	FORCE (LBS)	ACCEL. (G)	KINETIC (IN-LB)	STRAIN (IN-LB)	RATIO (SE/KE)	LE.70	GT.70 LE.80	GT.80 LE.90	GT.90 LE.95	GT.95
1.00	33.6	8.	12013.	.2	23872000.	3003.	.000	100.00	0.00	0.00	0.00	0.00
1.50	61.5	32.	30340.	.5	23904000.	13592.	.001	100.00	0.00	0.00	0.00	0.00
2.00	94.4	71.	56752.	.9	23936000.	35365.	.001	100.00	0.00	0.00	0.00	0.00
2.50	131.4	128.	89753.	1.4	23968000.	71991.	.003	100.00	0.00	0.00	0.00	0.00
3.00	172.0	203.	128181.	2.0	24000000.	126474.	.005	100.00	0.00	0.00	0.00	0.00
3.50	215.9	300.	171537.	2.7	24032000.	201404.	.008	100.00	0.00	0.00	0.00	0.00
4.00	262.7	420.	219409.	3.4	24064000.	299140.	.012	100.00	0.00	0.00	0.00	0.00
4.50	312.1	564.	271686.	4.2	24096000.	421914.	.018	100.00	0.00	0.00	0.00	0.00
5.00	364.1	733.	328314.	5.1	24128000.	571914.	.024	100.00	0.00	0.00	0.00	0.00
5.50	418.3	928.	389474.	6.1	24160000.	751361.	.031	100.00	0.00	0.00	0.00	0.00
6.00	474.6	1152.	455076.	7.1	24192000.	962498.	.040	100.00	0.00	0.00	0.00	0.00
6.50	532.9	1403.	524925.	8.2	24224000.	1207499.	.050	100.00	0.00	0.00	0.00	0.00
7.00	593.0	1685.	598831.	9.4	24256000.	1488438.	.061	100.00	0.00	0.00	0.00	0.00
7.50	654.8	1997.	676367.	10.8	24288000.	1807237.	.074	100.00	0.00	0.00	0.00	0.00
8.00	718.2	2340.	757543.	11.8	24320000.	2165715.	.089	100.00	0.00	0.00	0.00	0.00
8.50	783.1	2715.	842528.	13.2	24352000.	2565732.	.105	100.00	0.00	0.00	0.00	0.00
9.00	849.4	3124.	931385.	14.6	24384000.	3009211.	.123	100.00	0.00	0.00	0.00	0.00
9.50	917.1	3565.	1024203.	16.0	24416000.	3498108.	.143	100.00	0.00	0.00	0.00	0.00
10.00	985.9	4041.	1121095.	17.5	24448000.	4034432.	.165	100.00	0.00	0.00	0.00	0.00
10.50	1056.0	4551.	1222327.	19.1	24480000.	4620288.	.189	100.00	0.00	0.00	0.00	0.00
11.00	1127.1	5047.	1328166.	20.8	24512000.	5257911.	.215	100.00	0.00	0.00	0.00	0.00
11.50	1199.2	5679.	1439102.	22.5	24544000.	5949728.	.242	100.00	0.00	0.00	0.00	0.00
12.00	1272.3	6297.	1555276.	24.3	24576000.	6698323.	.273	100.00	0.00	0.00	0.00	0.00
12.50	1346.2	6951.	1678469.	26.2	24608000.	7506757.	.305	100.00	0.00	0.00	0.00	0.00
13.00	1421.0	7643.	1807372.	28.2	24640000.	8378215.	.340	100.00	0.00	0.00	0.00	0.00
13.50	1496.6	8372.	1943268.	30.4	24672000.	9315875.	.378	100.00	0.00	0.00	0.00	0.00
14.00	1572.8	9140.	2093518.	32.7	24704000.	10325071.	.418	100.00	0.00	0.00	0.00	0.00
14.50	1649.6	9945.	225006[illegible].	35.2	24736000.	11410965.	.461	100.00	0.00	0.00	0.00	0.00
15.00	1727.1	10790.	24277[illegible]7.	37.9	24768000.	12580425.	.508	100.00	0.00	0.00	0.00	0.00
15.50	1805.0	11673.	2613737.	40.8	24800000.	13840903.	.558	100.00	0.00	0.00	0.00	0.00

10-142A -- SOFT FOAM -- CASE NR. 4

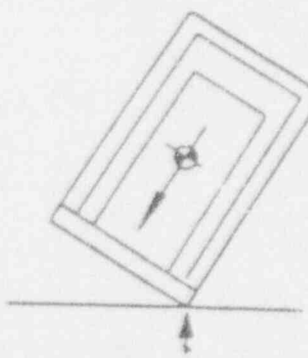
	* * CRUSH PLANE * *		* * * IMPACT * * *		* * * * ENERGY * * * *			DISTRIBUTION OF STRAIN RATIOS BY PERCENT OF CONTACT AREA				
CRUSH DEPTH	AREA (IN2)	VOLUME (IN3)	FORCE (LBS)	ACCEL. (G)	KINETIC (IN-LB)	STRAIN (IN-LB)	RATIO (SE/KE)	LE.70	GT.70 LE.80	GT.80 LE.90	GT.90 LE.95	GT.95
16.00	1883.5	12595.	2831821.	44.2	24832000.	15202192.	.612	100.00	0.00	0.00	0.00	0.00
16.50	1962.4	13556.	3062549.	47.9	24864000.	16675785.	.671	98.84	1.16	0.00	0.00	0.00
17.00	2041.7	14557.	3339847.	52.2	24896000.	18276384.	.734	97.12	2.88	0.00	0.00	0.00
17.50	2121.3	15598.	3835439.	58.8	24928000.	20020206.	.853	95.38	4.62	0.00	0.00	0.00
18.00	2201.2	16679.	3993153.	62.4	24960000.	21927354.	.878	93.98	6.02	0.00	0.00	0.00
18.50	2281.3	17799.	4400049.	68.8	24992000.	24025654.	.961	92.44	6.40	1.16	0.00	0.00
19.00	2361.6	18960.	4837746.	75.6	25024000.	26335103.	1.052	90.68	7.57	1.75	0.00	0.00
19.50	2442.1	20161.	5366887.	83.9	25056000.	28886261.	1.153	89.74	6.92	3.34	0.00	0.00
20.00	2522.7	21402.	5971071.	93.3	25088000.	31720751.	1.264	88.83	6.40	4.77	0.00	0.00
20.50	2603.3	22684.	6626995.	103.5	25120000.	34870267.	1.388	86.85	7.17	4.79	1.19	0.00
21.00	2683.9	24005.	7416167.	115.9	25152000.	38381058.	1.526	84.61	8.14	5.49	1.76	0.00
21.50	2764.5	25367.	8316292.	129.9	25184000.	42314172.	1.680	83.02	8.03	6.91	0.86	1.18
22.00	2845.0	26770.	9322867.	145.7	25216000.	46723962.	1.853	82.08	7.87	6.40	1.89	1.76
22.50	2925.4	28212.	10342615.	161.6	25248000.	51640332.	2.045	81.22	7.94	5.91	2.90	2.64
23.00	3005.6	29695.	11388160.	177.9	25280000.	57073011.	2.258	79.10	8.96	5.91	2.92	3.10
23.50	3085.7	31218.	12591105.	196.7	25312000.	63067813.	2.492	77.63	8.43	7.08	2.89	3.97

Impact accelerations produce internal loads on the lid of the package that must be reacted by the overpack and binders. The percent of respective load carried by the overpack or binder is dependent on the package configuration. For example, a package with an extremely thick overpack, the binders will experience no loads. Axial impact loads from the payload and lid are reacted in direct compression by the overpack to the impact surface. From the sketch below it can be seen that, for this case, the lid will be held in place relative to the cask body by the overpack. i.e. <u>no binder loads.</u>



(A)

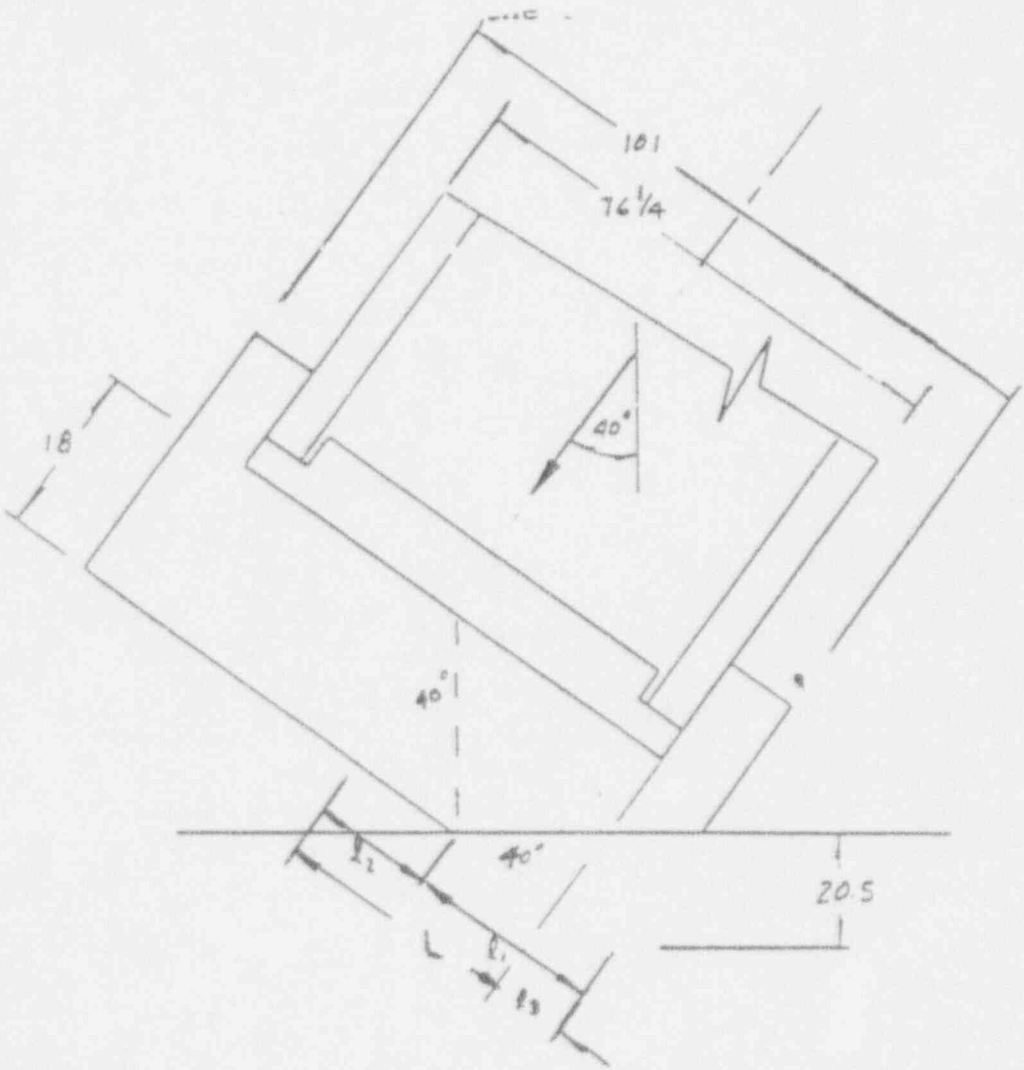
The opposite extreme would be that case in which the overpack was so thin as to provide no support to the lid.



(B)

Obviously in this case the lid would tend to pivot at the impact point under the effects of axial loading. The binders would be required to react this full load. i.e. no support from the overpack.

The 10-142A represents a configuration in between the two examples give above. In order to calculate the contribution that the overpack provides to the lid retention, the projected area must be calculated. If we conservatively neglect the load distribution ability of the overpack and assume the loads are only transferred through the projected area of the cask, the effective area can be calculated as follows:

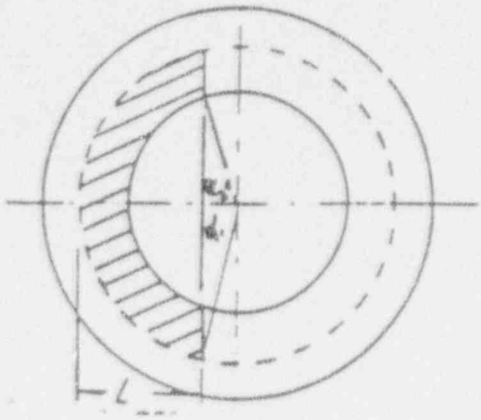


$$L = l_1 + l_2 - l_3$$

$$= 20.5/\sin 40^0 + 18 \tan 40^0 - (101 - 76.25)/2$$

$$= 34.61 \text{ in.}$$

The projected area is calculated as follows:



$\alpha_1 = 84.5^0$ @ R = 38"

$\alpha_2 = 82.4^0$ @ R = 27.5"

The lid will experience a compressive force across this projected area. Conservatively assume that the nominal 1,000 psi foam crush strength will be felt over this area. The area is given by:

$$A = r_1^2 \left(\alpha_1 - \frac{\sin 2\alpha_1}{2}\right) - r_2^2 - \left(\alpha_2 - \frac{\sin 2\alpha_2}{2}\right)$$

Where:

$r_1 = 38.125$ in.

$r_2 = 27.5$ in.

$\alpha_1 = 84.5^0$

$\alpha_2 = 82.4^0$

$A = 1,016.5 \text{ in.}^2$

The overpack reaction will be:

$R = A\ F_{cr}$

$= (1{,}016.5\ \text{in.}^2)\ (1{,}000\ \text{psi})$

$= 1{,}016{,}500\ \text{lbs.}$

This load will be applied of the centroid of the area. Distance to the centroid is given as:

$$x = 2 \sin \alpha\ (R_o{}^3 - R_1{}^3)/3\ \ (R_o{}^2 - R_1{}^2)$$

(Per Handbook of "Formulas for Stress & Strain" by Ungar)

Where:

$\alpha = 84.5^o$

$R_o = 38.125$ in.

$R_1 = 27.5$ in.

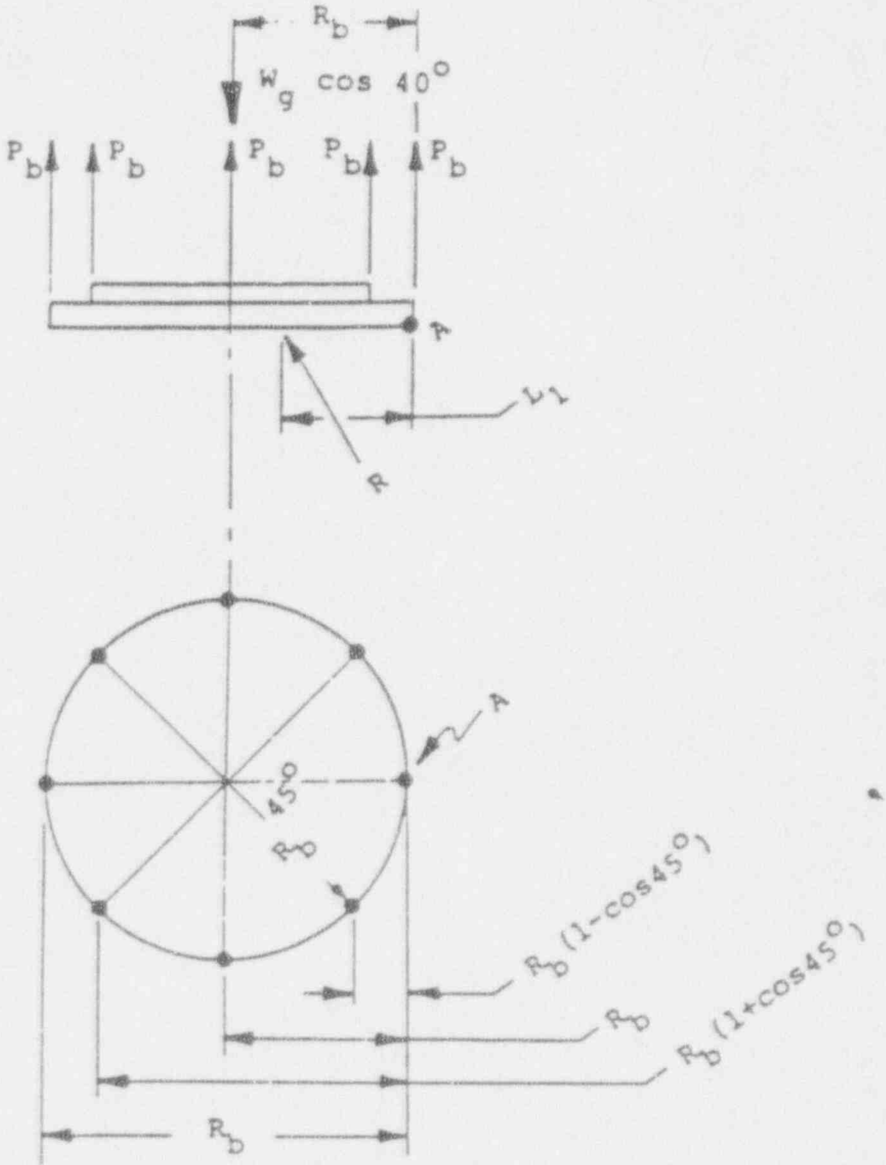
$$x = 2(\sin 84.5^{\circ})\ (38.125^3 - 27.5^3)/3(1.475)\ (38.125^2 - 27.5^2)$$

$x = 22.3$ in.

$L_1 = d/2 - x$

$= 76.25/2 - 22.3$

$= 15.83$ in.



Summing moments about point A:

$$W_gR_b \cos 40^o = RL_1\cos 40^o+P_b[2R_b(1-\cos 45^o)+2R_b+2R_b(1+\cos 45^o) + R_b]$$

where:

W = (Payload + Lid + Overpack)

= (10,000 lbs. + 7,200 lbs. + 3,000 lbs.)

= 20,200 lbs.

g = 76.4 g's (Max.)

R_b = 38.125 in.

R = 1,016,500 lbs.

L_1 = 15.83 in.

$$(20,200)\ (76.4)\ (38.125)\cos 40^{\circ} = (1,016,500)\ (15.83)\cos 40^{\circ} + (2)\ (38.125)P_b(1-\cos 45^{\circ}+1+1+\cos 45^{\circ}+.5)$$

$$45,072,178 = 12,326,571 + 266.875\ P_b$$

$$P_b = 122,700 \text{ lbs. per binder}$$

Therefore, the maximum binder load will be 122,700 lbs. Capacity of the high strength 1-3/4 in. binder is 160,000 lbs. The Margin of Safety is:

Margin of Safety = 160,000/122,700 - 1 = + .30

As noted on Page 2.59, the analysis was conservatively based, on the assumption that a uniform nominal 1,000 psi crush force was reacted across the projected area. This is a simplifying but conservative assumption that does not take into consideration the strain hardening effect of the foam. In reality, the compression force will vary from zero of the central edge of the contact surface to over 14,000 psi at the cask corner.

The 1,000 psi compression stress acting over the axial projected area was found to produce a maximum force of 1,016,500 lbs. Any increase in this force will reduce the actual binder load.

The actual maximum impact force is calculated by the CYDROP program and is presented on Page 2.50, Column 4 (i.e., 4,891,323 lbs.) or an axial component of F_a = 4,891,323 lbs. cos 40^o = 3,746,971 lbs. Therefore, the actual value will be 3,746,971 lbs. vs. the 1,016,500 lb. force conservatively assumed.

If this load was applied directly to the lid as shown in the analysis, it would show that the lid was in full compression and, therefore, the binder would experience no load.

It should be noted that F_a will not be applied at the centroid but will be applied at the true center of pressure. Since the determination of the center of pressure involves integrating discrete pressures over a unit area, the CYDROP program was modified to calculate the true center of pressure. The following output represents the rerun of the most critical corner drop case. The center of pressure location was found to be:

C of P = 23.155 in.

SEG 10-142A -- SOFT FOAM --CASE NR.1

Package Weight	=	64000. (LBS)
Package External Length	=	120.00 (IN)
Package External Diameter	=	101.00 (IN)
Package External Hole Diameter	=	55.00 (IN)
Payload Envelope Length	=	84.00 (IN)
Payload Envelope Diameter	=	76.00 (IN)

Drop Height	=	31.00 (FT)
Orientation Angle	=	.6997 (RADIANS)
Nominal Crush Stress	=	0.00 (PSI)

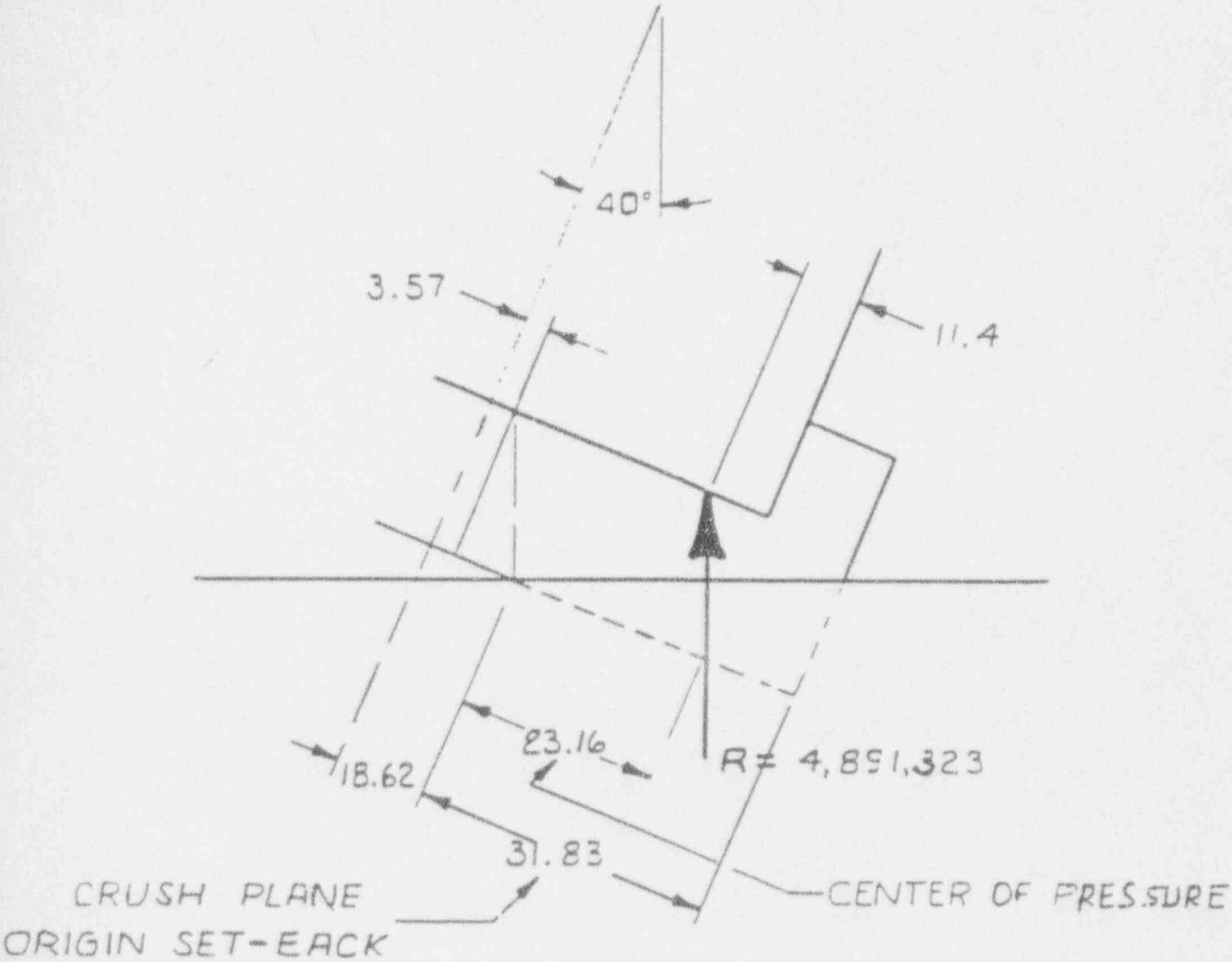
STRAIN VS STRESS TABLE

PT	STRAIN	STRESS
1	0.00	0.00
2	.05	650.00
3	.07	850.00
4	.10	950.00
5	.20	1000.00
6	.25	1050.00
7	.30	1150.00
8	.40	1260.00
9	.45	1400.00
10	.50	1600.00
11	.60	2250.00
12	.70	3850.00
13	.75	5300.00
14	.80	7400.00
15	.90	13800.00
16	.95	18500.00
17	.99	24000.00

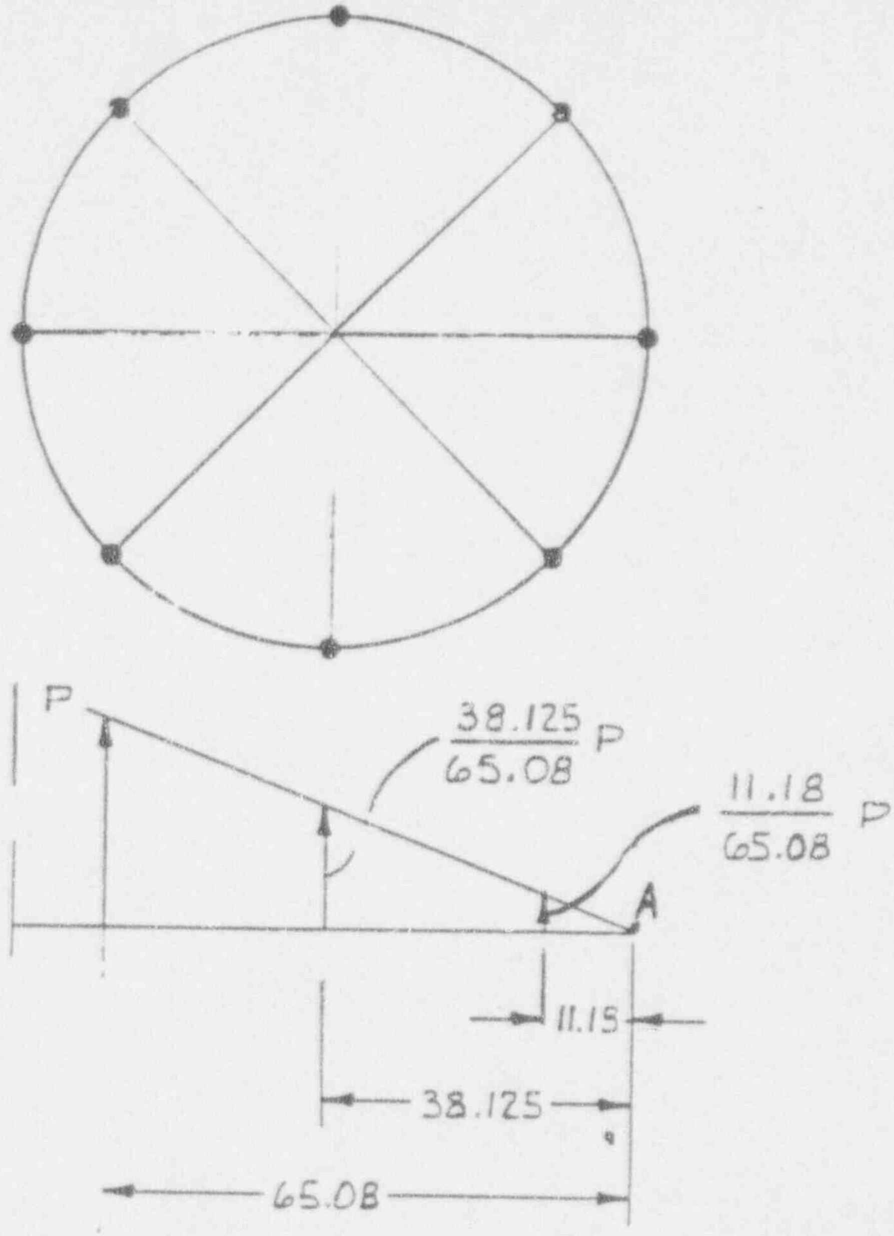
MODEL 10-142A OVERPACK - S. OAM (CASE 1)

CRUSH DEPTH (IN)	++ CRUSH PLANE ++ AREA (IN2)	VOLUME (IN3)	**** IMPACT **** FORCE (LBS)	ACCEL. (G)	****** ENERGY ****** KINETIC (IN-LB)	STRAIN (IN-LB)	RATIO (SE/KE)	DISTRIBUTION OF STRA[IN] PERCENT OF CONT[ACT] LE.70	GT.70 LE.80	GT.80 LE.90	RATIOS BY AREA GT.90 LE.95	GT.95	BY .95
1.00	33.6	8.	7506.	.1	23872000.	1876.	.000	100.00	0.00	0.00	0.00	0.00	.00
	CRUSH PLANE ORIGIN SETBACK (IN) =			1.553,	CENTER OF PRESSURE (IN) =		.927						
1.50	61.5	32.	20773.	.3	23904000.	8946.	.000	100.00	0.00	0.00	0.00	0.00	.00
	CRUSH PLANE ORIGIN SETBACK (IN) =			2.329,	CENTER OF PRESSURE (IN) =		1.392						
2.00	94.4	71.	41730.	.7	23936000.	24572.	.001	100.00	0.00	0.00	0.00	0.00	00
	CRUSH PLANE ORIGIN SETBACK (IN) =			3.106,	CENTER OF PRESSURE (IN) =		1.851						
2.50	131.4	128.	69382.	1.1	23968000.	52350.	.002	100.00	0.00	0.00	0.00	0.00	.00
	CRUSH PLANE ORIGIN SETBACK (IN) =			3.882,	CENTER OF PRESSURE (IN) =		2.301						
3.00	172.0	203.	102550.	1.6	24000000.	95333.	.004	100.00	0.00	0.00	0.00	0.00	.00
	CRUSH PLANE ORIGIN SETBACK (IN) =			4.658,	CENTER OF PRESSURE (IN) =		2.742						
3.50	215.9	300.	140413.	2.2	24032000.	156073.	.006	100.00	0.00	0.00	0.00	0.00	00
	CRUSH PLANE ORIGIN SETBACK (IN) =			5.435,	CENTER OF PRESSURE (IN) =		3.177						
4.00	262.7	420.	182146.	2.8	24064000.	236713.	.010	100.00	0.00	0.00	0.00	0.00	.00
	CRUSH PLANE ORIGIN SETBACK (IN) =			6.211,	CENTER OF PRESSURE (IN) =		3.604						
4.50	312.1	564.	227167.	3.5	24096000.	339041.	.014	100.00	0.00	0.00	0.00	0.00	00
	CRUSH PLANE ORIGIN SETBACK (IN) =			6.988,	CENTER OF PRESSURE (IN) =		4.026						
5.00	364.1	733.	275161.	4.3	24128000.	464623.	.019	100.00	0.00	0.00	0.00	0.00	00
	CRUSH PLANE ORIGIN SETBACK (IN) =			7.764,	CENTER OF PRESSURE (IN) =		4.445						
5.50	418.3	928.	325761.	5.1	24160000.	614853.	.025	100.00	0.00	0.00	0.00	0.0	0
	CRUSH PLANE ORIGIN SETBACK (IN) =			8.541,	CENTER OF PRESSURE (IN) =		4.870						
6.00	474.6	1152.	377288.	5.9	24192000.	790615.	.033	100.00	0.00	0.00	0.00	0.0	0
	CRUSH PLANE ORIGIN SETBACK (IN) =			9.317,	CENTER OF PRESSURE (IN) =		5.322						
6.50	532.9	1403.	429702.	6.7	24224000.	992363.	.041	100.00	0.00	0.00	0.00	0.0	00
	CRUSH PLANE ORIGIN SETBACK (IN) =			10.093,	CENTER OF PRESSURE (IN) =		5.799						
7.00	593.0	1685.	482641.	7.5	24256000.	1220448.	.050	100.00	0.00	0.00	0.00	0.0	00
	CRUSH PLANE ORIGIN SETBACK (IN) =			10.870,	CENTER OF PRESSURE (IN) =		6.304						
7.50	654.8	1997.	536434.	8.4	24288000.	1475217.	.061	100.00	0.00	0.00	0.00	0.0	00
	CRUSH PLANE ORIGIN SETBACK (IN) =			11.646,	CENTER OF PRESSURE (IN) =		6.830						
8.00	718.2	2340.	590769.	9.2	24320000.	1757018.	.072	100.00	0.00	0.00	0.00	0.0	00
	CRUSH PLANE ORIGIN SETBACK (IN) =			12.423,	CENTER OF PRESSURE (IN) =		7.372						
8.50	783.1	2715.	647160.	10.1	24352000.	2066506.	.085	100.00	0.00	0.00	0.00	0.0	00
	CRUSH PLANE ORIGIN SETBACK (IN) =			13.199,	CENTER OF PRESSURE (IN) =		7.911						
9.00	849.4	3124.	704837.	11.0	24384000.	2404510.	.099	100.00	0.00	0.00	0.00	0.0	00
	CRUSH PLANE ORIGIN SETBACK (IN) =			13.975,	CENTER OF PRESSURE (IN) =		8.454						
9.50	917.1	3565.	763659.	11.9	24416000.	2771634.	.114	100.00	0.00	0.00	0.00	0.0	00
	CRUSH PLANE ORIGIN SETBACK (IN) =			14.752,	CENTER OF PRESSURE (IN) =		9.004						
10.00	985.9	4041.	826029.	12.9	24448000.	3169056.	.130	100.00	0.00	0.00	0.00	0.0	.00

	SH PLANE ORIGIN SETBACK (IN) =			15.528,	CENT PRESSURE (IN) =		9.554					
10.50	1056.0	4551.	889017.	13.9	24448000.	3597817.	.147	100.00	0.00	0.00	0.00	0.00
	CRUSH PLANE ORIGIN SETBACK (IN) =			16.305,	CENTER OF PRESSURE (IN) =		10.120					
11.00	1127.1	5097.	956388.	14.9	24512000.	4059169.	.166	100.00	0.00	0.00	0.00	0.00
	CRUSH PLANE ORIGIN SETBACK (IN) =			17.081,	CENTER OF PRESSURE (IN) =		10.685					
11.50	1199.2	5679.	1030321.	16.1	24544000.	4555846.	.186	100.00	0.00	0.00	0.00	0.00
	CRUSH PLANE ORIGIN SETBACK (IN) =			17.857,	CENTER OF PRESSURE (IN) =		11.247					
12.00	1272.3	6297.	1104354.	17.3	24576000.	5089515.	.207	100.00	0.00	0.00	0.00	0.00
	CRUSH PLANE ORIGIN SETBACK (IN) =			18.634,	CENTER OF PRESSURE (IN) =		11.829					
12.50	1346.2	6951.	1185292.	18.5	24608000.	5661926.	.230	100.00	0.00	0.00	0.00	0.00
	CRUSH PLANE ORIGIN SETBACK (IN) =			19.410,	CENTER OF PRESSURE (IN) =		12.415					
13.00	1421.0	7643.	1267076.	19.8	24640000.	6275018.	.255	100.00	0.00	0.00	0.00	0.00
	CRUSH PLANE ORIGIN SETBACK (IN) =			20.187,	CENTER OF PRESSURE (IN) =		13.022					
13.50	1496.5	8372.	1359802.	21.2	24672000.	6931738.	.281	100.00	0.00	0.00	0.00	0.00
	CRUSH PLANE ORIGIN SETBACK (IN) =			20.963,	CENTER OF PRESSURE (IN) =		13.63					
14.00	1572.8	9140.	1459172.	22.8	24704000.	7636481.	.309	100.00	0.00	0.00	0.00	0.00
	CRUSH PLANE ORIGIN SETBACK (IN) =			21.739,	CENTER OF PRESSURE (IN) =		14.234					
14.50	1649.6	9945.	1564080.	24.4	24736000.	8392294.	.339	100.00	0.00	0.00	0.00	0.00
	CRUSH PLANE ORIGIN SETBACK (IN) =			22.515,	CENTER OF PRESSURE (IN) =		14.886					
15.00	1727.1	10790.	1690368.	26.4	24768000.	9205906.	.372	100.00	0.00	0.00	0.00	0.00
	CRUSH PLANE ORIGIN SETBACK (IN) =			23.292,	CENTER OF PRESSURE (IN) =		15.493					
15.50	1805.0	11673.	1814605.	28.4	24800000.	10082149.	.407	100.00	0.00	0.00	0.00	0.00
	CRUSH PLANE ORIGIN SETBACK (IN) =			24.069,	CENTER OF PRESSURE (IN) =		16.186					
16.00	1883.5	12595.	1968499.	30.8	24832000.	11027925.	.444	100.00	0.00	0.00	0.00	0.00
	CRUSH PLANE ORIGIN SETBACK (IN) =			24.845,	CENTER OF PRESSURE (IN) =		16.827					
16.50	1962.4	13556.	2134841.	33.4	24864000.	12053760.	.485	97.90	2.10	0.00	0.00	0.00
	CRUSH PLANE ORIGIN SETBACK (IN) =			25.622,	CENTER OF PRESSURE (IN) =		17.538					
17.00	2041.7	14557.	2332840.	36.5	24896000.	13170681.	.529	96.12	3.88	0.00	0.00	0.00
	CRUSH PLANE ORIGIN SETBACK (IN) =			26.398,	CENTER OF PRESSURE (IN) =		18.199					
17.50	2121.3	15598.	2547379.	39.8	24928000.	14390735.	.577	94.04	5.96	0.00	0.00	0.00
	CRUSH PLANE ORIGIN SETBACK (IN) =			27.174,	CENTER OF PRESSURE (IN) =		18.943					
18.00	2201.2	16679.	2818199.	44.0	24960000.	15732130.	.630	92.03	7.97	0.00	0.00	0.00
	CRUSH PLANE ORIGIN SETBACK (IN) =			27.951,	CENTER OF PRESSURE (IN) =		19.607					
18.50	2281.3	17799.	3128907.	48.9	24992000.	17218907.	.689	89.84	8.88	1.28	0.00	0.00
	CRUSH PLANE ORIGIN SETBACK (IN) =			28.727,	CENTER OF PRESSURE (IN) =		20.280					
19.00	2361.6	18960.	3470520.	54.2	25024000.	18868763.	.754	87.80	9.12	3.07	0.00	0.00
	CRUSH PLANE ORIGIN SETBACK (IN) =			29.504,	CENTER OF PRESSURE (IN) =		21.035					
19.50	2442.1	20161.	3873586.	60.5	25056000.	20704790.	.826	85.57	9.74	4.69	0.00	0.00
	CRUSH PLANE ORIGIN SETBACK (IN) =			30.280,	CENTER OF PRESSURE (IN) =		21.727					
20.00	2522.7	21402.	4348516.	67.9	25088000.	22760315.	.907	83.12	10.50	6.39	0.00	0.00
	CRUSH PLANE ORIGIN SETBACK (IN) =			31.056,	CENTER OF PRESSURE (IN) =		22.403					
20.50	2603.3	22684.	4863968.	76.0	25120000.	25063436.	.998	81.21	10.56	7.48	.75	0.00
	CRUSH PLANE ORIGIN SETBACK (IN) =			31.833,	CENTER OF PRESSURE (IN) =		23.155					
21.00	2683.9	24005.	5502860.	86.0	25152000.	27655143.	1.100	78.84	10.60	8.39	1.92	.25
	CRUSH PLANE ORIGIN SETBACK (IN) =			32.609,	CENTER OF PRESSURE (IN) =		23.801					
21.50	2764.5	25367.	6225497.	97.3	25184000.	30587233.	1.215	76.65	11.24	8.45	2.91	.75
	CRUSH PLANE ORIGIN SETBACK (IN) =			33.386,	CENTER OF PRESSURE (IN) =		24.465					



If we were to assume that one of the eight binders was destroyed prior to the 31 foot (9.45 m) drop and that the lid was infinitely rigid so that a triangular load distribution took place, the following maximum binder load can be calculated.



Summing moments about Point A:

$2\ (65.08)\ P + 2\ (38.125)^2 P/(65.08) + 2\ (11.18)^2 P/65.08$

$+3,746,971\ (11.4) = (20,200\ \text{lbs.})\ (76.4)\ (38.125)\ \cos 40^0$

$178.67\ P + 42,715,469 = 45,072,178$

P = 13,190 lbs./binder

Therefore, if one of the eight binders are lost prior to the 31 foot drop, impact loads will be a maximum of 13,190 lbs. per binder.

The Margin of Safety, based on the new binder load, will be:

Margin of Safety = 160,000 lbs./13,190 lbs. - 1
Margin of Safety = +11.13

The analysis presented on Page 2.59 is conservative. Actual maximum binder or associated bolt loads will be 13,190 lbs.

The 1-5/8 inch diameter binder retain pins are loaded in double shear and have the following capacity:

$$P = 2F_s A$$

Where:

$$F_s = .6F_{tu}$$
$$= (.6)(105,000 \text{ psi})$$
$$= 63,000 \text{ psi}$$
$$A = \Pi(1.625)^2/4$$
$$= 2.07 \text{ in.}^2$$

$$P = (2)(63,000 \text{ psi})(2.07 \text{ in.}^2)$$
$$P = 260,820 \text{ lbs.}$$

Margin of Safety = 260,820/122,700 - 1
M.S. = +1.13

Therefore, it can be concluded that the retaining pin has adequate capability of reacting the imposed loads.

Preloads are not an additive factor. Preloaded joints are relieved by the applied load and only cause an increase in fastener load when the applied load exceeds the preload.

Overpack Retainer Pins

The overpack is secured to the cask by means of eight (8) 1/2" diameter ball lock pins acting in double shear. These pins pass through the ratchet binder lugs on the lid and the guid channels on the overpack. The reaction force required to retain the overpack is directly proportional to P_b.

Therefore,

$$P_o = P_b \text{ (wt of overpack/w)}$$
$$= (122{,}700 \text{ lbs.})(3{,}000 \text{ lbs.})/(20{,}200 \text{ lbs.})$$
$$= 18{,}223 \text{ lbs. per pin}$$

The pins act in double shear through two thicknesses of 3/16 inch plate. Shear out capacity can be calculated as follows:

$$P_{su} = F_{su}2t \text{ (E.M. - } d/2 \cos 40^o)$$
$$= (35{,}000(2)(.375)(1.5 - .25 \cos 40^o)$$
$$= 34{,}350 \text{ lbs. Shear Out}$$

The Carr Lane Model Number CL-8-BLP ball-lock pin has a rated double shear capacity of 32,800 lbs.

Margin of Safety = 32,800 lbs./18,223 lbs. - 1

M.S. = <u>+.799</u>

Therefore, it can be concluded that the overpack retainer pins are more than adequate for securing the overpack to the cask.

The previous analysis is conservative since the average compressive stress acting across the lid face will be substantially greater than the nominal 1,000 psi assumed here. The higher foam compressive stress reduces the load that must be reacted by the binders. Secondly, the effective area will be considerably larger than that assumed. Foam does have the ability to distribute loads out over a larger footprint. This will also increase the load carried by the overpack. Third, a major portion of the overpack weight will be reacted directly onto the impact surface thus reducing the load experienced by the binders.

From the above, it can be seen that the binders can react the impact loads experienced in a 31 foot free drop.

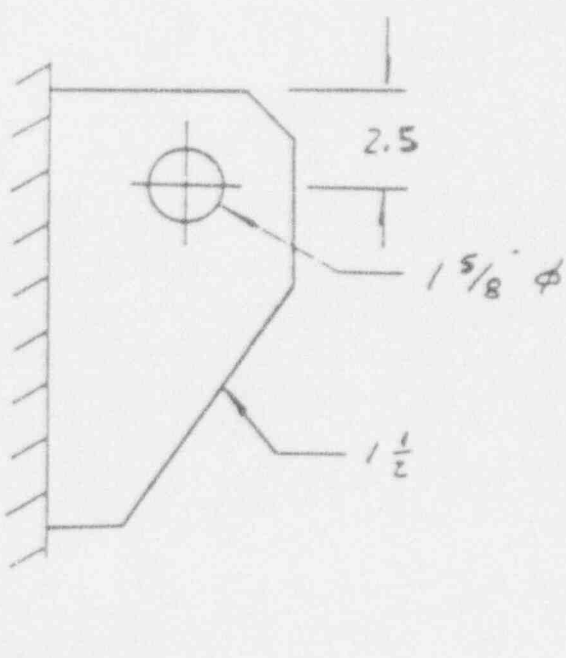
The capacities stated for the binders are established static allowables. They are manufactured from standard carbon steels and fail in the same manner as a bolt. Numerous studies have been conducted on the behavior of bolts under dynamic or impact loading. ORNL-TM-1312 Vol. 12 "Structural Analysis of Shipping Casks" states that carbon steel bolts "possess better physical properties under a condition of shock than indicated by static tests. Increases in the value of stress by a factor of 1.3 and a greater amount of strain before necking occurs were ported". This is substantiated by references 5, 8, 9, 10 and 11 of the same cument.

Therefore, it can be concluded that the binders static allowable capabilities will not be lower under shock or dynamic loading.

Therefore, it can be concluded that the binders will react the impact load and retain the lid.

The lugs at each end of the binder will possess the following capacity.

Body Lugs



Shear out:

Lug material: ASTM A240 Type 304 UNS #32550 $F_y = 80,000$ psi

Using the standard 40^0 shear out:

$$P_s = F_{sy}2t\ (E.M. - d/2 \cos 40^0)$$

Where:

$F_{sy} = 46,160$ psi
$t = 1.50$ in.
$EM = 2.50$
$d = 1.625$ in.

$$P_s = (46,160)(2)(1.50)(2.5 - .81 \cos 40^0)$$
$= 260,274$ lbs. shear out

Weld ar--:

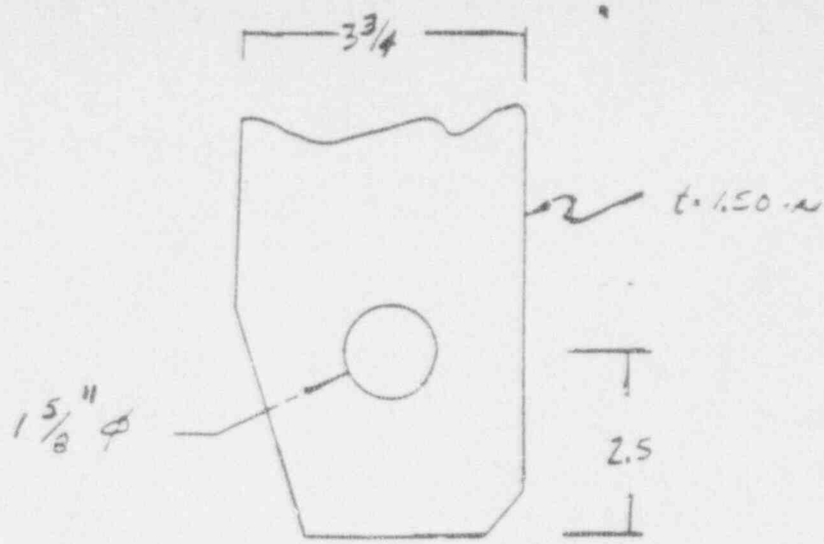
$$P_w = F_s A_w$$

Where:

$F_s = 46,160$ psi
$A_w = (18 \text{ in.})(.50)(\sin 45^0)$
$= 6.36 \text{ in.}^2$

$P_w = (46,160)(6.36 \text{ in.}^2)$
$P_w = 293,578$ lbs. weld shear

Primary Lid Lugs



Bearing stresses in the lugs can be calculated as follows:

$f_{brg} = P/A$

Where:

P = 122,700 lbs. per lug
A = (1.50 in. thick) (1.625 in. dia.)

$f_{brg} = 122{,}700/(1.50)(1.625)$
$f_{brg} = 50{,}338$ psi

Allowable bearing stress per Page 2.5

$f_{brg} = 90{,}000$ psi

Margin of Safety = 90,000/50,338 - 1
M.S. = <u>+.79</u>

The lug capability in net area is:

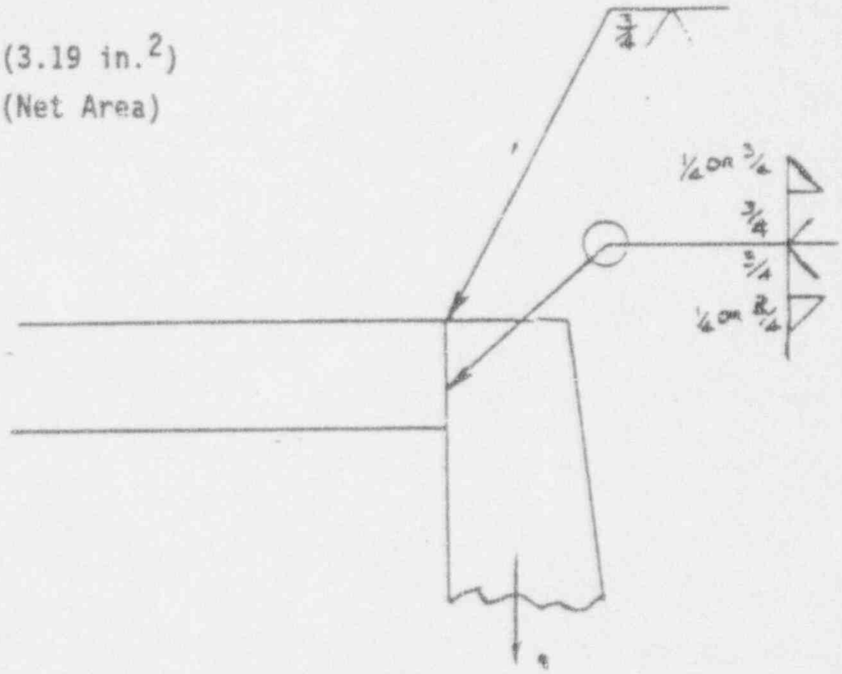
$P_t = F_{tu}A$

Where:

F_{tu} = 110,000 psi (ASTM A240 UNS #32550)
A = (3.75 - 1.625)(1.5)
= 3.19

P_t = (110,000 psi)(3.19 in.^{2})
P_t = 350,900 lbs. (Net Area)

Lug to lid attachment



Weld Shearing (counting bevel weld only)

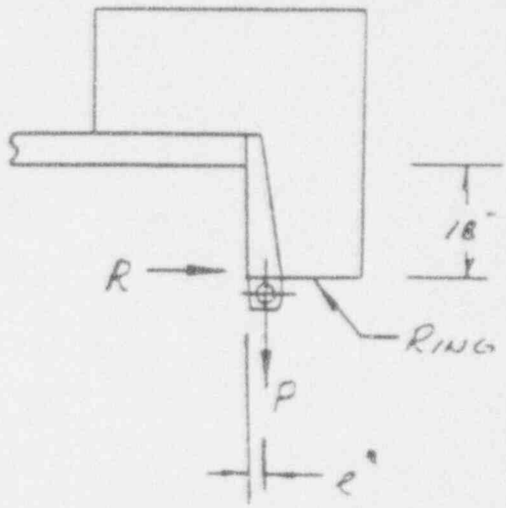
$P_s = F_s A$ weld

Where:

F_s = (1.6).3(70,000 psi) = 33,600 psi
A_w = (1.50 in.)(3.0 in.) = 4.5 in^2
P_s = (33,600 psi)(4.5 in.^{2})
P_s = 151,200 lbs.

Margin of Safety = 151,200/122,700 - 1
M.S. = +.23

Since the binder load is reacted eccentrically, an inward radial load will be produced. This load is reacted by the lower circumferential skirt of the overpack. The load produces a compressive load on this skirt or ring. No additional load will be imposed on the upper lug weld due to this eccentricity condition.



Pe = RL

R = Pe/L

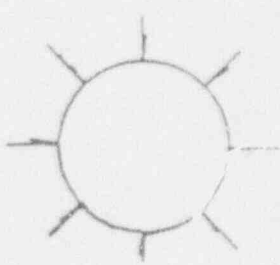
= (160,000 lbs.)(2.5 in.)/(18 in.)

= 22,222 lbs.

Where:

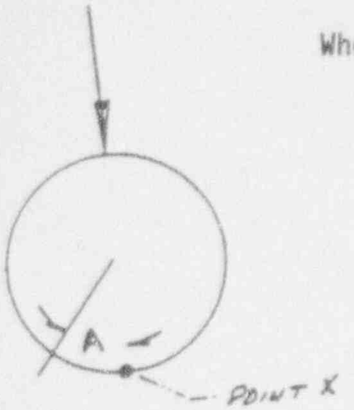
P = Maximum binder capacity

If these were totaled at each binder the ring would be loaded as follows:



Bending moment produced in a ring with two opposing loads is given by the following equation.

$M = K_m P$



Where:

$$K_m = \frac{\sin A}{2} - 1$$

(Ref. Blake, A., "Practical Stress Analysis in Engineering Design", 1982, Marcel Dekker)

$P = 22{,}222$ lbs.

$r = ((101 - 76.25)/2 + 76.25)/2$

$r = 44.31$ in.

By superposition

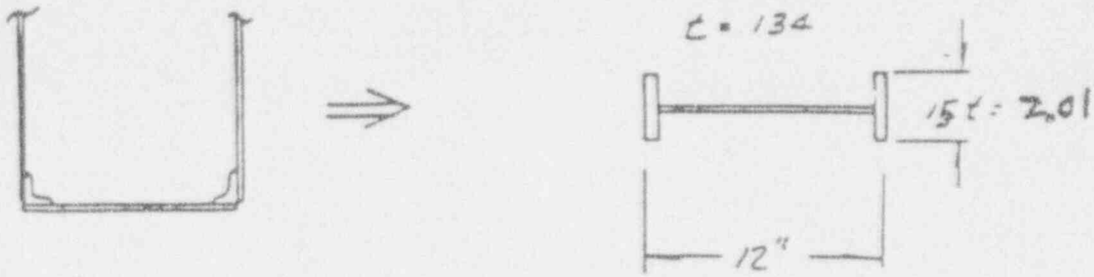
A	K_m		ΣK_m
0	-.31831	x 1 =	-.31831
45	+.03524	x 2 =	.07048
90°	+.18170	x 1 =	.18170
			-.06613

Therefore, the combined effect of the radial loads will produce a maximum $K_m = .06613$

$M = (.05613)\ (22{,}222 \text{ lbs.})\ (44.31 \text{ in.})$

$M = 65{,}116$ in.-lbs. (Max)

The ring has the following cross-section and associated modulus.



$$I_x = I_o + Ad^2$$

$$I_x = (.134)\ (1.2)^3/12 + (2)\ (.134)\ (2)\ (6)^2$$

$$I_x = 19.31 \text{ in.}^4$$

Stress in the ring is given as:

$$f_r = MC/I_x$$

Where:

M = 65,116 in.-lbs.

C = 6 in.

I_x = 19.31

$$f_r = (65{,}116)\ (6)/19.31$$

$$f_r = 20{,}232 \text{ psi}$$

Margin of Safety = 25,000/20,232 - 1

M.S. = +.24

Therefore, it can be concluded that the lower skirt of the overpack can safely react the eccentrically produced radial load. From the above, it can be seen that the critical load path for the binder attachment will be shear out at the lugs. The following positive margin of safety exists at those locations.

From page 2-76:

M.S = 260,274/122,962 - 1

M.S. = 1.12

It can be concluded that the binders and their fitting can safely react the maximum loads produced during impact.

2.6.7.3 Free Drop Impact Analysis, Side Drop - Detrimental effects resulting from a side drop are limited to the closure areas. Both primary and secondary lids are deeply stepped and manufactured from solid steel plates. The side impact loads produce lateral shear forces that are reacted in direct compression of the lapped joint. Bolts securing the secondary lid are not required to react this shear force since the radial clearance with their hole is greater than that of their stepped lid. i.e. lid bottom out before bolts contact.

In order to determine the amount of deformation that would be experienced by a side impact, it was assumed that only the projected length of the cask on the overpack would be effective. Therefore, the overpacks effective length would be 44 inches.

Through hand integration it was found that an average compressive stress of 1,700 psi was felt across the area producing contact angles of 67^0.

Therefore, deflection at 67^0 is:

$$\delta = (1 - \cos \theta/2)\ D/2$$

$$\delta = (1 - \cos 33.5^0)(101/2)$$

$$\delta = 8.39 \text{ in. Max}$$

Using the original thickness of 12.375 in. the maximum strain is:

Strain = 8.39 in./12.375 = 67%

This conservatively assures 4.00 in. of foam across the maximum damage area. Again it must be noted that this is extremely conservative since the overhanging portion of the overpack will absorb a large amount of energy thereby greatly reducing the total deformation.

Using the strain calculated above a <u>very conservative</u> acceleration can be calculated by assuming that the foam across the surface has all been stressed to a 67% strain. From the sketch below it can be seen that only that material directly beneath the cask experiences these strains and as you progress outward they rapidly decrease. Using this conservative assumption a strain of 67% will produce a maximum stress of 3,600 psi (Ref. page 2-6). The effective area is calculated as:

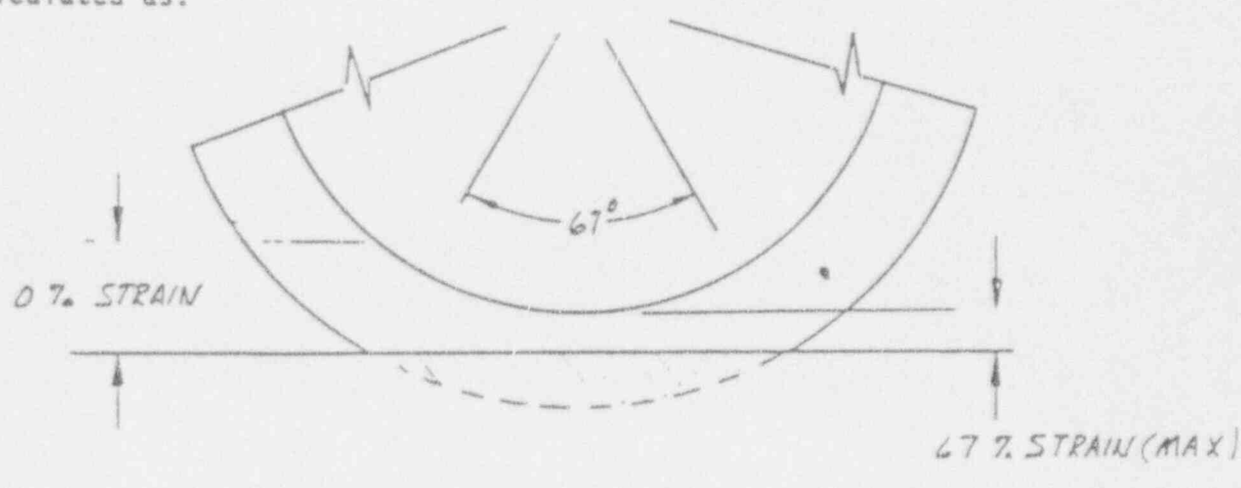


FIGURE 2.6.7.1

$$A = 2RL \sin(\theta/2)$$

$$A = (2)(50.5)(44)(\sin 33.5^{o})$$

$$A = 2{,}452 \text{ in.}^2$$

If we apply the maximum stress of 3,600 psi across the whole area the acceleration would be:

$$a = (2{,}452 \text{ in.}^2)(3{,}600)/64{,}000$$

$$a = 137.9 \text{ g's}$$

If the same integration analysis was repeated, using the full length of the overpack, an average compressive stress of 1,300 psi would produce an impact angle of 58^{o}.

$$= (1 - \cos 29^{o})\ 101/2$$
$$= 6.33 \text{ in.}$$

This would produce a maximum strain of:

$$\text{Strain} = 6.33 \text{ in.}/12.375 \text{ in.}$$
$$= 51\%$$

From page 2-6 the stress at a 51% strain is 1,900 psi.

The effective area is:

$$A = 2\ RL \sin \theta/2$$

$$A = (2)(50.5)(80) \sin 29^{o}$$

$$A = 3{,}917 \text{ in.}^2$$

The acceleration would be:

$$a = (3{,}917 \text{ in.}^2)\ (1{,}900 \text{ psi})/64{,}000 \text{ lbs.}$$

$$a = 116 \text{ g's}$$

Therefore, maximum acceleration and deformations are experienced when only the projected area of the cask is reacted by the overpack.

As noted earlier the secondary lid bolts do not react these shear loads due to the stepped lid design. The following analysis is provided to demonstrate what margin it safely <u>would</u> exhibit if they were required to react these loads.

Load per bolt is:

$$P = (1{,}755 \text{ lb. lid})\ (138 \text{ g's})/8 \text{ Bolts}$$
$$= 30{,}274 \text{ lbs./bolt (shear)}$$

Bolt shear capacity is:

$$R = (75{,}750 \text{ lbs.})\ (60\%)$$
$$= 45{,}450 \text{ lbs.}$$

Margin of safety = (45,450/30,274) - 1

M.S. = <u>+.50</u>

Conclusion:

From the above it can be concluded that under the most conservative conditions the package will maintain more than 4 in. of foam in the compressed area. Impact loads will not produce detrimental effects on the closure system since all loads are carried in direct compression across the deeply stepped joints. Therefore, the side drop of 31 feet will not produce detrimental effects to the package.

The foam material has been tested to -40^{0} and found to exhibit a small increase in compressive strength (< 16%). Samples failed in the same manner at -40^{0}C as they did at room temperature, indicating that brittle fracture is not apparent at this temperature range.

From the SAR it can be seen that impact accelerations decrease as compressive strength increases. Therefore, cold conditions will not produce detrimental loading and testing indicates that brittle fracture characteristics are not present.

2.6.8 <u>Corner Drop</u>

The issue of corner drop is addressed in Section 2.6.6.

2.6.9 <u>Compression</u>

Since the container package weighs in excess of 5,000 kg., this test condition is not applicable.

2.6.10 <u>Penetration</u>

The wall and lid thickness of the container are considerable in relation to impact loads developed by a 13 lb. rod dropped on the container from a height of 40 inches. Such a test would have a negligible effect on the container integrity.

<u>Conclusion</u>

Analyses in previous sections of this report demonstrate that the container meets all Type A package requirements of 10 CFR 71.

2.7 Hypothetical Accident Conditions

This section is not applicable.

2.8 Special Form

Since no special form is claimed, this section is not applicable.

2.9 Fuel Rods

Not applicable.

2.10 Appendix

2.10.1 References

1. "Structural Methods Manual -- SSD60048R," Hughes Aircraft Company, February, 1966.

2. Formulas for Stress and Strain, 5th edition, R.J. Roark and W.C. Young, McGraw-Hill, 1975.

3. Practical Stress Analysis in Engineering Design, A. Blake, Marcel Dekker, 1982.

4. A.E. Spaller, Structural Analysis of Shipping Casks, Vol. 2, Resistance to Puncture, ORNL-TM-1312, September, 1966.

5. H. Nelms, Structural Analysis of Shipping Casks, Vol. 3, Effects of Jacket Physical Properties and Curvature on Puncture Resistance, ORNL-TM-1312, June, 1968.

6. L.B. Shappert, et al., A Guide for the Design, Fabrication and Operation of Shipping Casks for Nuclear Application, ORNL-NSIC-68, February, 1970.

3. THERMAL EVALUATION

This section describes the thermal analysis of the cask to verify the compliance with the performance requirements of 10 CFR 71.

3.1 Discussion

The thermal protection features of the cask consist of the impact limiters placed at the top and bottom of the cask and the thermal shield surrounding the cylindrical section. The impact limiter consists of polyurethane foam enclosed in a 10 gauge stainless steel shell. Because of the low thermal conductivity of the polyurethane foam, the impact limiter reduces the heat transfer into the ends of the cask during hypothetical accident conditions.

The thermal shield consists of a 10 gauge stainless steel shell surrounding the cylindrical structural shell of the cask. A nominal gap of 0.25 inches exists between the thermal shield and the cylindrical structural shell. Because of the low conductivity of air contained in the gap, the heat resistance of the gap greatly reduces the heat transfer rate to the structural shell during a hypothetical accident condition.

During normal conditions of transport, the impact limiter and thermal shield cause the temperature to be somewhat higher than would occur without the shield. The contents of the container generate heat. The impact limiter and thermal shield now act as insulators offering resistance to heat flow from the container, resulting in higher internal temperatures. However, as this analysis has shown, the heat generation rate of 400 watts does not result in excessive temperatures or pressure.

3.2 Summary of Thermal Properties of Materials

The thermal properties of the materials are listed in Table 3.2-1. the metal properties were obtained from Reference [1] and polyurethane properties were obtained from Reference [2]. Material properties were assumed constant over the temperature range of the conditions investigated. The thermal properties of the silicone rubber and neoprene gasket are not included. These parts are thin gasket materials and, therefore, do not significantly effect the overall heat transfer rates. Only the solid properties for lead are listed in Table 3.2-1 because the melting point of 620^{o}F would not be reached even during a hypothetical accident condition.

Decomposition of polyurethane begins to occur at 400^{o}F. Therefore, the polyurethane properties are replaced with air properties [3] at this temperature. However, air and polyurethane thermal properties are not significantly different. Actually, the polyurethane properties are not critical because the polyurethane is essentially an adiabatic surface during the hypothetical accident.

Radiation heat transfer occurs at the outer surfaces of the cask and also in the gap between the thermal shield and the structural shell. The absorptivity of the surfaces are listed in Table 3.2-1 [4]. All external surfaces are stainless steel except the lid which is carbon steel with a white coating. Both surfaces within the gap are stainless steel. The absorptivity of weathered stainless steel was assumed for the outer surfaces and the gap surfaces were assumed to be machined.

TABLE 3.2-1 MATERIAL THERMOPHYSICAL AND SURFACE PROPERTIES

Material Thermophysical Properties

Material	Density lb/ft	Specific Heat BTU/16-F	Thermal Cond. BTU/hr-ft-F.
Carbon Steel	490	0.12	26
Stainless Steel	488	0.11	11
Lead	710	0.031	20
Polyurethane Foam	20	0.30	0.40

Surface Radiation Properties

Surface	Absorptivity*
Carbon Steel painted white	0.8
Weathered Stainless Steel	0.6
Enclosed Stainless Steel	0.2

*All external absorptivities were set equal to 1.0 during the hypothetical accident.

3.3 Technical Specifications of Components

Engineering drawing STD-02-107, Rev. 0, sheets 1 and 2 of 2, showing the general arrangement of the cask is provided as an attachment to this report. This drawing shows the cask dimensions and material specifications. All structural members are fabricated from commercial grade materials. Descriptions of structural materials are contained in Section 2.3.

The primary and secondary seal materials are silicone rubber and neoprene. These materials are capable of withstanding a transient temperature of 500^{o}F. Thus, the temperature of these materials must be maintained below 500^{o}F to ensure that loss of contents does not occur.

3.4 Thermal Evaluation for Normal Conditions of Transport

The thermal analysis for normal transport conditions was performed in accordance with 10 CFR 71. This condition assumes steady state conditions; (a) solar flux of 800 g cal/cm /12 hr and (b) ambient temperature of 100. In addition, the analysis considers a representative internal heat generation of 400 watts. An analytical model was developed to determine the temperature distribution of the cask.

3.4.1 Thermal Model

The heat transfer analysis was performed using a thermal analyzer which accepts resistor-capacitor (R-C) network representations of thermal systems. Convection and radiation boundary conditions can be handled in the model and time/temperature property variations can be included. The accuracy of the program has been verified by comparing with known theoretical solutions and previously published computer solutions.

The temperature distribution of the cask was assumed symmetric about the vertical axis and its horizontal midplane. Thus, the heat transfer model assumes two-dimensional heat transfer (i.e. radial and axial). This latter assumption is not exactly fulfilled when solar insolation occurs at the upper surface. In this case, the model yields temperatures that are slightly higher than expected. Since the higher temperatures are conservative, this procedure is satisfactory.

The thermal analyzer program is not limited to two-dimensional problems. If the thermal conditions were symmetric, a three-dimensional model could have been analyzed. However, a two-dimensional model is adequate in the situation under consideration.

The thermal model contains 55 nodes, which is sufficient to accurately predict the steady-state and transient thermal behavior of the cask. Additional assumptions that were made will now be discussed.

Radiation heat exchange between external surfaces of the cask were assumed to be negligible. Two locations exist where radiation exchange occurs. Radiation is exchanged between the outer surface of the lid and the impact limiter. In addition, the impact limiter exchanges radiation with the thermal shield. In both cases, the view factors are small and then the heat exchange is negligible.

Heat transfer within the contents of the cask was not analyzed. It was assumed that the heat generated was uniformly transferred to the surrounding cask surfaces. A total heat generation of 400 watts was assumed and, therefore, recognizing the symmetry of the model, 200 watts are transferred to surfaces contained in the model.

3.4.2 Maximum Temperatures

Figure 3.4.2-1 shows representative temperatures calculated using the thermal analyzer computer program. Temperatures are calculated at 55 locations by the model. The lid temperatures are greatest because of solar insolation. A maximum temperature of $200^{o}F$ occurs at the center of the lid. The temperature at the secondary lid seal is $194^{o}F$ and $172^{o}F$ at the primary seal. The radial temperature gradient in the lid is due to heat conduction from the lid into the cylindrical section. The axial temperature gradient in the cylinder is also due to heat conduction from the lid to the structural shell.

Because the thermal conductivity of the cask is relatively high, the temperature gradients are small. The gap between the thermal shield and the biological shield accounts for most of the thermal resistance of the cylindrical section.

3.4.3 Minimum Temperature

The minimum steady-state temperature for normal conditions of transport is the ambient temperature. The extreme minimum temperature during normal transport that is specified in 10 CFR 71 is $-40^{o}F$. Thus, the minimum temperature which has been assumed in the analysis of the cask structure is this temperature.

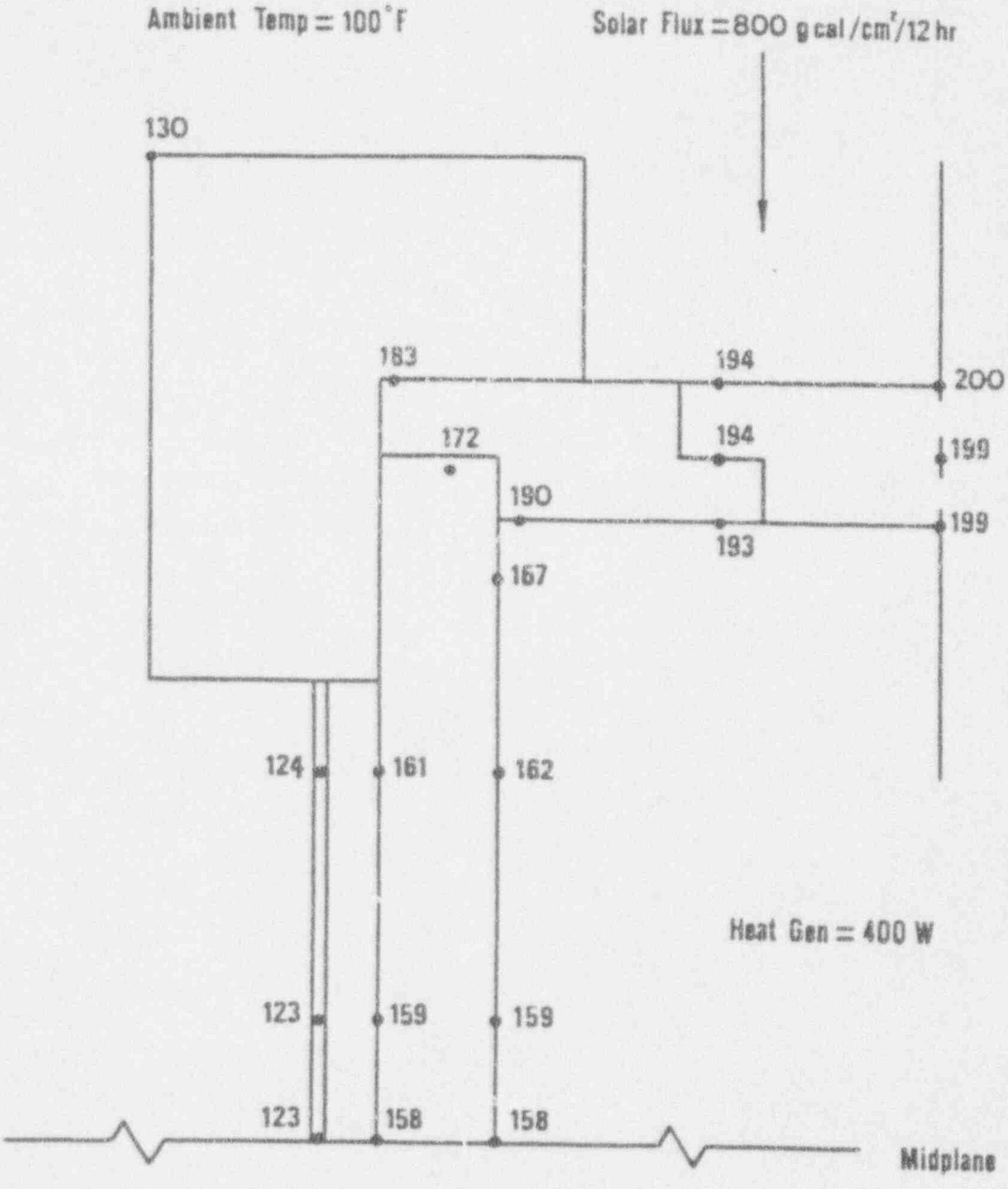


FIGURE 3.4.2-1 Representative temperat. es -- normal condition of transport

3.4.4 Maximum Internal Pressure

Figure 3.4.2-1 shows that the inside wall temperature varies from 193°F to 158°F. As a consequence, the internal pressure is elevated above atmospheric pressure. The internal pressure at steady-state can be estimated by assuming the atmosphere contains dry air at 14.7 psi and 70°F when the cask is closed. Because the contents will normally container water, it is assumed that at steady-state transport conditions the air is at a temperature of 193°F and saturated with water vapor. The internal pressure at 193°F is equal to the sum of the dry air and the vapor pressure of water which is:

$$P = (14.7 \text{ psi})(657 \text{ R}/530 \text{ R}) + 10 \text{ psi} = 28.1 \text{ psi}$$

Assuming the minimum pressure of 3.5 psi specified in 10 CFR 71 Section 71, the pressure differential is
28.1 - 3.5 = 24.6 psi.

Consideration of the stresses due to pressurization of the cask to 24.6 psi is contained in Section 2.6.1.3 of this report.

3.4.5 Maximum Thermal Stresses

Consideration of thermal stresses due to conditions of normal transport and due to lead pour during fabrication is contained in Section 2.6.1.2 of this report.

3.4.6 Evaluation of Package Performance for Normal Conditions of Transport

A summary of maximum temperatures due to normal transport conditions is given in Table 3.4.6-1. The maximum temperature of 200°F is significantly below any of the material limits. The silicone rubber and neoprene seals are capable of withstanding a temperature of 250°F continuously. In addition, the maximum temperature limit for continuous operation is 250°F for polyurethane foam. These materials are capable of withstanding a minimum temperature of -40°F without degradation.

The results of analysis concerning structural integrity of the cask as it is affected by temperature extremes during normal transport conditions is contained in Section 2.6.1 and 2.6.2 of this report.

TABLE 3.4.6-1 SUMMARY OF NORMAL TRANSPORT MAXIMUM EXPECTED TEMPERATURES

Transport Conditions	Comment
Lead: 200°F max	<620°F (Melting)
Carbon steel: 200°F	No significant effect
Stainless steel: 200°F	No significant effect
Silicon rubber seal: 193°F	<250°F
Neoprene seal: 193°F	<250°F
Polyurethane: 190°F	<250°F

3.5 Appendix

3.5.1 Description of the Thermal Analyzer Computer Program

A proprietary thermal analyzer program was written to calculate steady state and transient heat transfer in solids with radiation and convection boundary conditions. The accuracy of the program has been verified by comparison with theoretical solutions and published results obtained from other thermal analyzers. An example of a comparison with a theoretical solution is in the following section.

Heat conduction is represented in the program by a resistor-capacitor (R-C) network. The user inputs the resistance and capacitance values. Thermal conductivity variations with temperature are input in tables. Convective heat transfer coefficients at the boundary can either be input as a constant or have the form $h =$ [illegible]$(\Delta T)^n$. Thus, natural convection boundary conditions can be applied.

Radiation heat transfer at boundaries is also represented as a resistance. This resistance has the form:

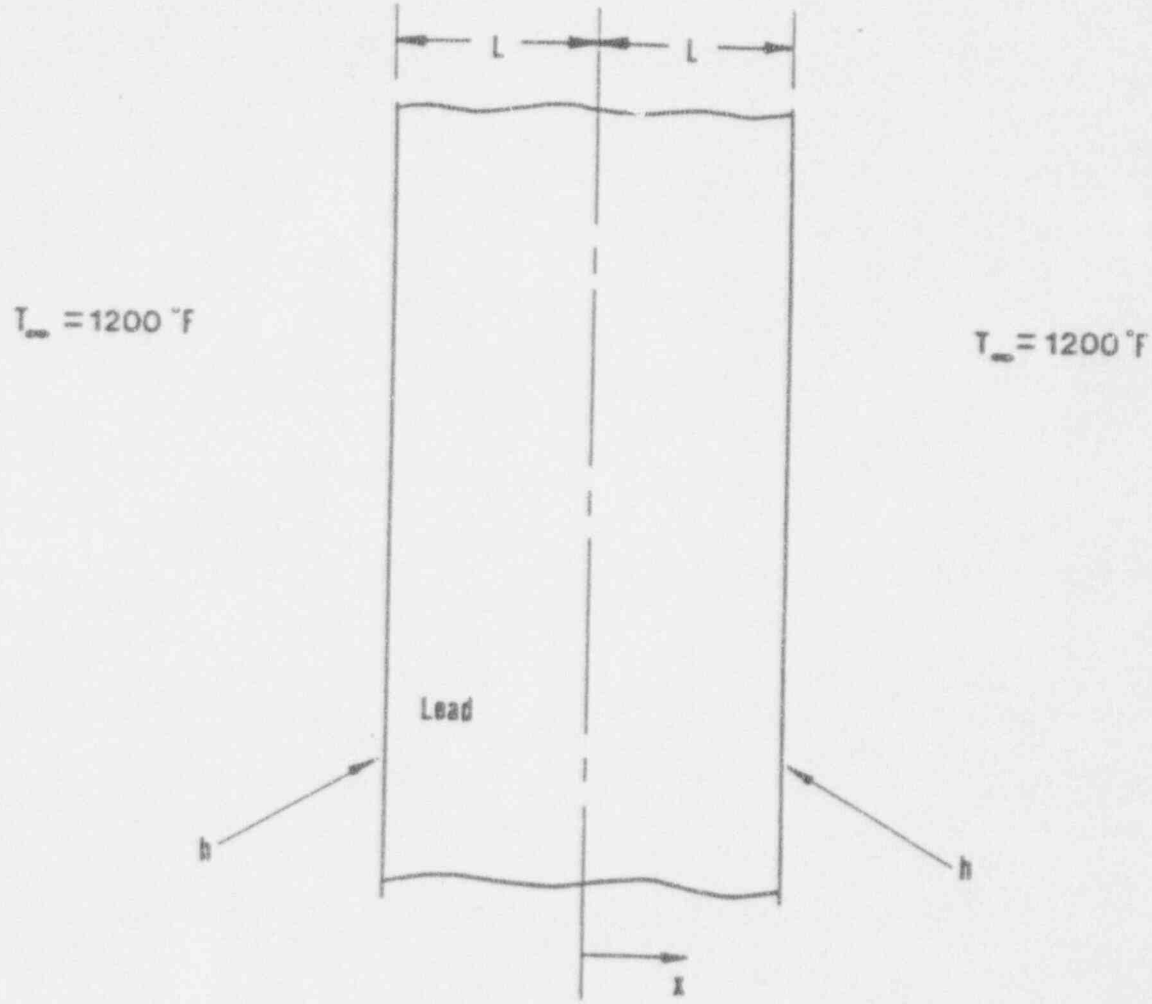
$$Q = B(T_1^4 - T_\infty^4)$$

where B is a coefficient which may include the Stefan-Boltzmann constant, surface areas, and emissivities.

Time integration is carried out using the explicit finite difference technique. The size of the time step is limited by the stability criteria.

3.5.2 Verification of Computer Program

The accuracy of the thermal analyzer program was determined by comparison with known theoretical solutions contained in the literature. An example is the transient heat conduction in an infinite flat plate as shown in Figure 3.5.2-1. The flat plate is initially at a uniform temperature of $100^{o}F$ and is immersed in a fluid at a temperature of $1200^{o}F$. The plate is four inches thick and the material is lead. Because the temperature distribution is symmetric about the centerline, only one-half of the plate is analyzed.



ρ = 710 lb/ft³

Cp = 0.031 Btu/lb-°F

k = 20 Btu/hr-ft-°F

h = 40 Btu/hr-ft²-°F

T_i = 100°F

L = 2 in

FIGURE 3.5.2-1 Thermal conditions used in verification of thermal analyzer

Figure 3.5.2-2 shows the theoretical temperature obtained from Holman [5] and temperatures calculated using the thermal analyzer. The individual data points are the temperatures calculated by the thermal analyzer and the solid line is the theoretical temperature distribution. The temperature distribution shown in Figure 3.5.2-2 is at a time of 0.1 hour. The number of nodes used in the calculation was five and the time increment was 0.001 hour. The maximum error of approximately $5^{O}F$ would be decreased if the number of nodes were increased. However, the results obtained are reasonably accurate.

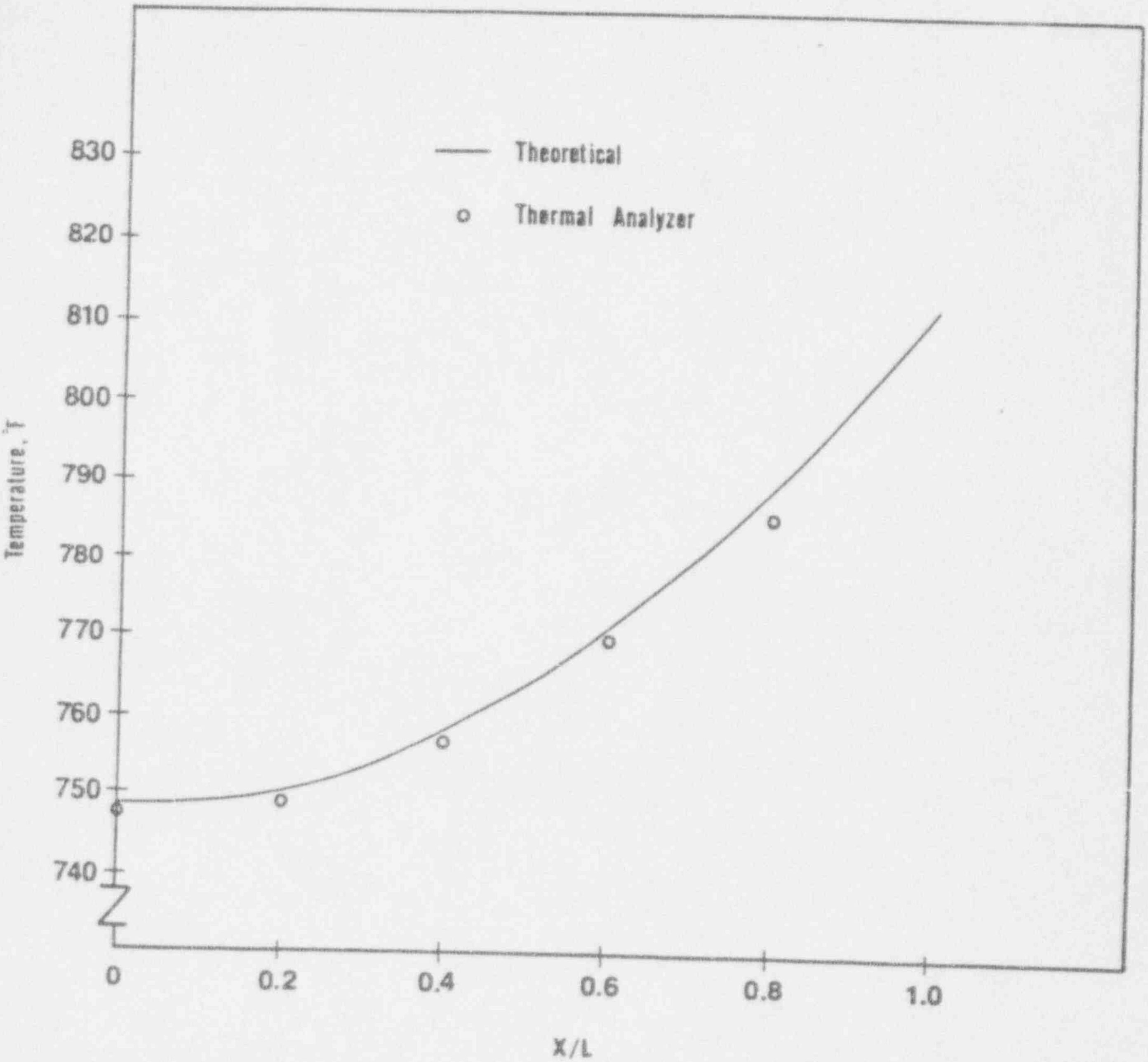


FIGURE 3.5.2-2 Comparison of thermal analyzer calculation with the theoretical temperatures for infinite flat plate

3.5.3 References

1. Metals Handbook, American Society for Metals, 8th Edition, Vol. 1, 1961.

2. Modern Plastics Encyclopedia, McGraw-Hill, Vol. 50, No. 10A, October, 1973.

3. Eckert, E.R.G. and Drake, Jr., R.M., Heat and Mass Transfer, McGraw-Hill, 2nd Edition, 1959.

4. Siegel, R. and Howell, J.R., Thermal Radiation Heat Transfer, Hemisphere Publishing Corp., 2nd Edition, 1981.

5. Holman, J.P., Heat Transfer, McGraw-Hill, 5th Edition, 1981.

4. CONTAINMENT

This chapter identifies and discusses the package containment for the normal conditions of transport.

4.1 Containment Boundary

The containment boundary claimed for the package is the 10-142A transport cask described in Section 1.2 and Drawing STD-02-107, Rev. 0, sheets 1 and 2 of 2, attached to this report.

4.1.1 Containment Vessel

The 10-142A cask will be used to carry a heavy gauge steel liner with a capacity of approximately 125 cubic feet of ion exchange resin. The liner is a cylindrical steel container with 11 gauge walls and 5/16 inch thick heads. Each liner is pressure tested to 3 to 5 psig.

During transport the liner will contain a maximum of 125 cubic feet of resin from the reactor letdown purification system. The resins are typically 40 to 60 mesh and are a mixture of cation and anion ionic forms.

The 10-142A cask is designed to contain the radioactive material during normal transport and hypothetical accident conditions, with no containment credit taken for the liner. The containment analysis contained in this report considers only the cask.

4.1.2 Containment Penetration

The only penetration of the containment vessel is a 0.40 inch diameter vent hole in the container primary lid. The vent hole is used as a test portal during leak testing of the container. A detail of this vent hole is shown in Detail C, Sheet 1 of Drawing STD-02-107, Rev. 0. A copy of this drawing is attached to this report. During transport this vent hole is sealed off by a standard threaded piped plug and thread sealant. Inspection of this plug location is specified in the operating procedures for the cask.

4.1.3 Seals and Welds

The top of the cask is provided with a combination of a primary lid and a secondary lid. The arrangement is shown schematically in Figure 1.2.1-1 and is described in Section 1.2. Both the primary and secondary lids are fitted with silicon and/or neoprene gaskets at the sealing interfaces. Specific details of the cask lid arrangement and the gaskets involved in sealing the lids are shown in Drawing STD-02-107, Rev. 0, sheets 1 and 2 of 2, attached to this report.

With the exception of the attachment of the primary and secondary lids, the cask is an all welded construction. Details and specification regarding welding of the cask structure are shown in Drawing STD-02-107, Rev. 0, sheets 1 and 2 of 2.

4.1.4 Closure

The cask primary and secondary lids are fastened to the cask body by a system of ratchet binders and bolting, respectively, as described in Section 2.1 and as shown in detail in Drawing STD-02-107, Rev. 0, sheets 1 and 2 of 2, attached to this report.

4.2 Requirements for Normal Conditions of Transport

The following is an assessment of the package containment under normal conditions of transport based in part on the analyses performed in Chapters 2 and 3.

4.2.1 Containment of Radioactive Material

4.2.1.1 Structural and Containment Integrity - Normal transport conditions will not compromise the structural or containment integrity of the cask. Transport conditions as specified in 10 CFR 71 will result in an increase in temperature and internal pressure of the container contents. These conditions of transport and their influence on the release of radioactive contents from the container are considered in the following section.

4.2.1.2 Containment Criteria - 10 CFR 71 Section 51 (a) specifies that there be no loss or dispersal of radioactive contents, as demonstrated to a sensitivity of $A_2 x 10^{-6}$ per hour. The package will be loaded with solid radioactive material, including ion exchange resins, filters, etc., in a medium of air occupying the voids in the package. The cask closure is designed to contain the radioactive material within the cask during normal conditions of transport and hypothetical accident conditions. The particle size of the resins, 40 to 60 mesh, is sufficiently large to prevent escape through the gasket seal under normal conditions of transport.

The most plausible condition for the release of radioactive material is the release of gaseous activity generated during transit. Prior to sealing the cask, the radioactive material will be vented to remove radioactive gases. This is typically done at the plant site during storage in the spent resin storage tank, which is vented to the offgas system, and during transfer to the vented cask liner. During transport, however, gaseous activity may be generated by decay of isotopes absorbed onto the ion exchange resin. A review of the isotopes which may be present in resin wastes reveals that only radioiodine (I-131) would produce significant amounts of gaseous radioactivity, in the form of xenon isotopes. The other isotopes of iodine are either not present in sufficient quantities or decay to stable isotopes. In normal power plant practice, spent resins are to be stored until the short-lived radioactivity, such as I-131 (8.07 days) and I-133 (20.9 hours), have decayed away. Thus the assumption that significant iodine will be present at the time of shipment is considered conservative.

An expression for permissible leak rate from the container under normal transport conditions is written as follows:

$$L_N = A_2 \times 10^{-6}/C$$

where L_N = permissible leak rate from container for transport condition (atm - m^3/hr)

$A_2 \times 10^{-6}$ = activity limit for normal conditions of transport (Ci/hr)

C = specific activity of medium in container (Ci/m^3)

The I-131 decays to Xe-131m.

A_2 = 100 (from 10 CFR 71, Table A-1)

C = 5.23 (from Section 4.5.1 of this report)

Therefore, $L_N = 100 \times 10^{-6}/5.23 = 1.9 \times 10^{-5}$ atm - m^3/hr

= 19 atm - cm^3/hr

= 5.3×10^{-3} atm - cm^3/sec

4.2.2 Pressurization of Containment Vessel

Prior to transport, the package must be vented to eliminate any gases which have accumulated. These gases may include radiolytically generated hydrogen and very small amounts of radioactive gases resulting from isotopic decay. Gases are generally vented from ion exchange resins during storage in the spent resin tank, which is vented to the station offgas system, and during transfer to the vented cask liner prior to shipment.

The volume of gas generated due to isotopic decay, such as the decay of iodine to zenon, will be insignificant, but the potential exists for combustible quantities of hydrogen to be generated radiolytically from wet wastes such as dewatered resins. For any package containing materials with a radioactivity concentration exceeding that for low specific activity material, the hydrogen generation rate must be determined. If the hydrogen concentration will exceed 5% by volume, the secondary container and cask cavity must be inserted with a dilutent to assure that oxygen is limited to 5% by volume. (Refer to IE Information Notice No. 84-72, "Clarification of Condition for Waste Shipments Subject to Hydrogen Gas Generation.")

If the internal gas pressure does increase up to the 5% limit for hydrogen, the cask will not be adversely affected. A 5% increase in the gas volume in the package will result in an approximate 5% or 0.74 psi increase in the internal pressure of the cask:

Pressure increase = (0.05) (14.7 psi) = 0.74 psi

Analysis of the cask for a much larger differential pressure of 24.6 psi has been conducted in Sections 2.6.1.3, and the container was shown to be adequate to withstand that pressure.

4.2.3 Containment Criterion

A leak test is specified to verify containment under conditions of normal transport. This leak test would typically be calculated either at the facility where the cask is domiciled or at the shipper's plant site.

The leak test procedure which will be employed will be detection of a leak using a soap film. The procedure is described in Chapter 8. The expected temperature applied to the cask at the time of the test is standardized at 77^{o}F (25^{o}C). The specified internal pressure of the cask is 8 psig.

From Section 4.2.1.2, the permissible leak rate was:

$$L_N = 5.3 \times 10^{-3} \text{ atm - cm}^3\text{/sec}$$

The required test sensitivity is:

$$S = L_N/2 = 2.65\text{x}10^{-3} \text{ atm - cm}^3\text{/sec}$$

The soap bubble leak test used for the 10-142A cask is sensitive to 10^{-3} atm - cm^3/sec, therefore containment criteria is satisfied.

4.2.4 Coolant Loss

Not applicable since there are no coolants involved.

4.3 Containment Requirement for the Hypothetical Accident Condition

This section is not applicable.

4.4 Special Requirements

This section is not applicable.

4.5 Appendix

4.5.1 Calculation of Activity of Medium in Containment System

For the purpose of this analysis, it is assumed that 5000 Ci of I-131 are present in the waste at the time of shipment. The peak quantity of the resulting xenon isotope is then calculated. (Ref. 4)

Radioactive generation and decay occurs in the following sequence:

$$A \xrightarrow{\lambda_A} B \xrightarrow{\lambda_B} C$$

where λ_A and λ_B are the decay constants of the respective isotopes. The rate of change of isotope B at any time t is given by:

$$dN_B/dt = \lambda_A N_A - \lambda_B N_B \qquad (1)$$

where N_A = number of atoms of A

where N_B = number of atoms of B

But $N_A = N_{Ao}\, e^{-\lambda At}$ (2)

where N_{Ao} = number of atoms of A at t = 0

Substituting (2) into (1) gives:

$$dN_B/dt = \lambda_A N_{Ao}\, e^{-\lambda At} - \lambda_B N_B \qquad (3)$$

The solution for (3) is written as follows:

$$N_B e^{\lambda Bt} = [1/(\lambda_B - \lambda_A)]\lambda_A N_{Ao} e^{(\lambda B - \lambda A)t} + C \qquad (4)$$

To solve for C, apply the boundary condition at t=0, $N_B = 0$:

$$C = -\lambda_A\, N_{Ao}/(\lambda_B - \lambda_A) \qquad (5)$$

Combining (4) and (5) gives the following expression for N_B:

$$N_B = \lambda_A N_{Ao}(e^{-\lambda At} - e^{-\lambda Bt})/(\lambda_B - \lambda_A) \quad (6)$$

The activity of isotope B would then be as follows:

$$Q_B = \lambda_B N_B \quad (7)$$

The time at which nuclide B reaches maximum activity is calculated by differentiating (6) and setting the result equal to zero:

$$dN_B/dt = \lambda_A N_{Ao}(-\lambda_A e^{-\lambda At} + \lambda_B e^{-\lambda Bt})/(\lambda_B - \lambda_A) = 0 \quad (8)$$

$$\lambda_A e^{-\lambda At} = \lambda_B e^{-\lambda Bt} \quad (9)$$

$$\ln(\lambda_B/\lambda_A) = (\lambda_B - \lambda_A)t \quad (10)$$

$$t_{max} = t = \ln(\lambda_B/\lambda_A)/(\lambda_B - \lambda_A) \quad (11)$$

The decay constant of any one isotope is calculated as follows:

$$\lambda_i = \ln 2/(t_{1/2})i$$

where $(t_{1/2})i$ = half life of isotope i

$t_{1/2}$ (I-131) = 8.040 days

$t_{1/2}$ (Xe-131m) = 11.92 days

["Chart of Nuclides," 12th ed., General Electric Company, GET-6504, 1983. (Ref. 3)].

λI-131 = (ln2)/8.040 = 0.0862/day

λXe-131m = (ln2)/11.92 = 0.0581/day

Using equation (11), calculate the time for Xe-131m to reach maximum activity:

t_{max} for Xe-131m = 14.04 days

To calculate the maximum activity for Xe-131m, the appropriate branching ratio must be considered:

$$\text{A: I-131} \xrightarrow[\text{8.04 days}]{0.6\%} \text{Xe-131m} + \beta^- \xrightarrow[\text{11.92 days}]{} \text{Xe-131}$$

Using equation (7) and the branching ratio, the peak activity may be calculated:

$$Q_B(max) = 0.006\ Q_B = 9\ Ci$$

The available volume of the cask is 142 ft^3. The volume of the resin in the cask is 125 ft^3. Thirty-five percent of the resin volume is void. Therefore, the free volume in the cask occupied by a gas is calculated as follows:

$$V_f = 142 - 125 + 0.35\ (125) = 60.75\ ft^3$$
$$= 1.72\ m^3$$

The specific activity of medium is therefore:

$$C = Q_B(max)/V_f = 9/1.72 = 5.23\ Ci/m^3$$

4.5.2 References

1. IE Information Notice No. 84-72, "Clarification of Conditions for Waste Shipments Subject to Hydrogen Gas Generation."

2. ANSI N41.5, "Leakage Tests on Packages for Shipment of Radioactive Materials," American National Standards Institute, New York, 1977.

3. "Chart of the Nuclides," 13th ed., General Electric Company, GET-6504, 1983.

4. Introduction to Health Physics, Cember, H., Pergammon Press, 1983.

5. SHIELDING EVALUATION

5.1 Discussion

The shielding package of the 10-142A Cask consists of a cylindrical container which is a built-up composite structure of lead and steel. The container consists of an inner steel shell surrounded by a layer of lead shielding and an exterior steel shell. The primary structural component is the exterior shell which is 1.0 inch thick. The inner steel liner is 0.5 inch thick and lead shielding is 3.5 inches thick. The general arrangement of the cask has been described previously in Chapter 1 and is shown sketched in Figure 1.2.1-1. In addition, details of construction are shown in Drawing No. STD-02-107, Rev. 1, sheets 1 and 2 of 2. A copy of this drawing is attached to this report.

The analyses in Chapter 2 of this report have demonstrated that structural integrity of the cask will not be compromised in normal transport conditions. Since the cask is integral with the cask structure, the analyses in Chapter 2 likewise demonstrate that transport conditions will not compromise shielding integrity.

The typical radiological product which will be placed in the cask for shipment is spent ion exchange resin. The range of possible contents is listed in Section 1.2.3 of this report. It is noted that, for an individual shipment involving the 10-142A cask, the shipper has the responsibility for verifying that radiation readings external to the cask are in compliance with 10 CFR 71 Section 47. The cask shielding, however, is more than adequate for the expected range of radiological content. The shielding performance of the cask is demonstrated by the analysis in the following section.

5.2 Shielding Analysis

It is the shipper's responsibility to verify allowable radiation limits for the cask. The external radiation is a direct function of the radiological content of the cask. To aid the shipper in assessing permissible radiological content and to demonstrate the performance of cask shielding, a pair of example radiological loads are analyzed for two common isotopes characteristic of spent ion exchange resin. The isotopes selected for analysis are Co-60 and Cs-137. Both of these isotopes are beta and gamma emitters, however, due to the extensive lead shielding of the cask, beta transmission through the lead would not be significant. The analysis, therefore, considers only gamma radiation.

The analysis considers allowable radiation limits and then, based on these limits, calculates a corresponding radiological content of either an entire load of Co-60 or an entire load of Cs-137. The shipper is thereby able to use the results of this analysis as a guide in establishing loading limits on the basis of allowable radiation limits.

The objective of this analysis is to develop a relationship between the Curie content of the cask and the exposure dose rate at a location 2 meters from the cask vertical surface. These expressions will then be used to determine a maximum Curie content for a limiting exposure dose rate of 10 mR/hr at 2 meters.

The model employed in this analysis represents the contents of the cask as a cylindrical source. The cask shielding is represented as an infinite slab. A sketch of this model is shown in Figure 5.2.1-1. The activity is assumed to be uniformly distributed. The exposure dose rate considered by the model would be that of measured at a point located at one-half height of the container. This analysis is based on that contained in Mathematical Theory of Radiation Dosimetry, Fitzgerald [Ref. 1].

The dose rate from a radioactive source may be calculated from the energy flux according to the following relationship:

$$R = \mu_a(air)\ I_o/\rho_{air} \quad (MeV/g/sec) \tag{1}$$

where R = dose rate (MeV/g/sec)

I_o = energy flux ($MeV/cm^2/sec$)

$\mu_a(air)$ = total linear absorption coefficient (1/cm)

ρ_{air} = density of air (g/cm^3)

To express the dose rate in terms of R/hr, (1) becomes:

$$R = 6.58 \times 10^{-5}\ \mu_a(air)\ I_o/\rho_{air} \quad (R/hr) \tag{1b.}$$

The energy flux at a field position P exterior on the side of a right cylinder, with an infinite slab shield and uniform activity distribution, $\theta_1 = \theta_2 = \theta$ (see Figure 5.2.1-1) is given by:

$$I_o = 2.96 \times 10^9\ C_v\ E\ (2\Pi R_o^2)\ [F(\theta, b_2)]/(a + Z) \tag{2}$$

where $F(\theta, b) = \int_0^\theta e^{-b.\sec\theta'}\, d\theta'$

The values for the function are given in Fitzgerald, Figure 5.14B, page 298.

b_2 = effective total attenuation

= $b + \mu_s Z$

b = attenuation from the cask boundary to the point of interest, P

$\mu_s(i)$ = total linear scattering coefficient in material i

Z = effective self absorption distance (Z is a function of R_o, a and b. It is solved empirically in Fitzgerald, Figures 5.26 B and C, pages 323 and 324.)

R_o = radius of cylinder

a = distance between the cylinder and the point of interest, P

E = energy per disintegration

C_v = specific activity of radiation

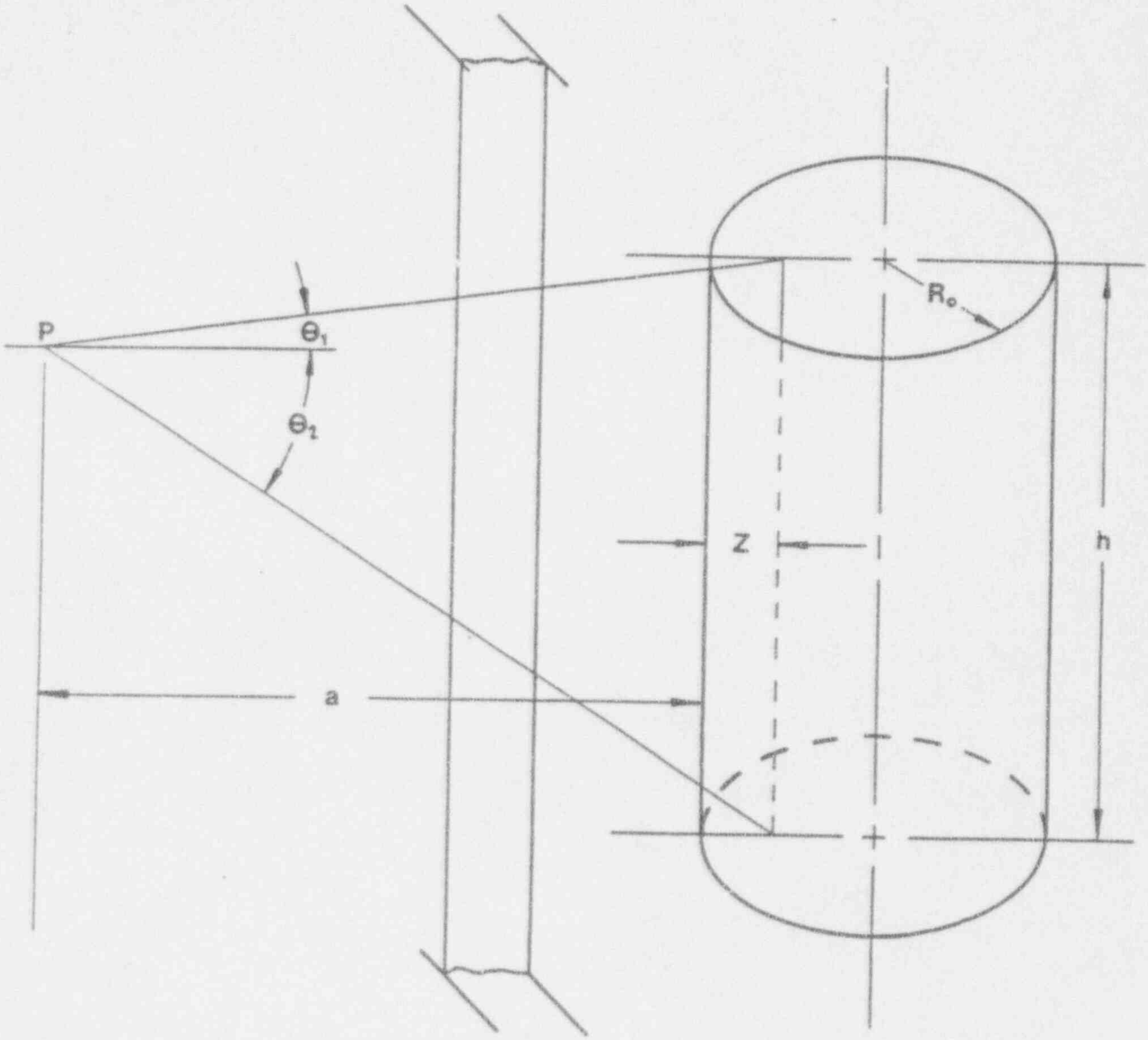


FIGURE 5.2.1-1 Sketch showing a radiation source modeled as a cylindrical source and shielding modeled as an infinite slab

The first step in the solution is to solve for Z:

$$Z = Z(R_0, a, b,)$$
$$b = \Sigma \mu(i).x_i \qquad (3)$$

where $\mu(i)$ = total linear attenuation of material i (cm^{-1})
x_i = thickness of material i (cm)

For the 10-142A cask, a combination of steel and lead is used in the side walls. This combination of materials may be related to an equivalent lead thickness:

1.70 in. steel + 3.50 in. lead = 4.30 in. lead equivalence
= 11 cm lead equivalence

[From A Guide for Design, ..., ORNL-NSIC-68, Figure 7.3, page 223.]

The relationship between the linear and mass attenuation coefficients for material i is given by the following expression:

$$\mu(i) = \mu'(i)\ \rho_i \qquad (4)$$

where μ'(air) = mass attenuation coefficient of material i (cm^2/g)
ρ_i = density of material i (g/cm^3)

The gamma energy of Co-60 is conservatively approximated at 1.5 MeV. Hence μ' is evaluated at this energy:

$\mu'(air) = 0.0518$	$\rho_{air} = 1.293 \times 10^{-3}$	$\mu(air) = 6.7 \times 10^{-5}$
$\mu_a'(air) = 0.0255$		$\mu_a(air) = 3.3 \times 10^{-5}$
$\mu'(H_2O) = 0.0575$	$\rho_{H_2O} = 1.0$	$\mu(H_2O) = 5.8 \times 10^{-2}$
$\mu_a'(H_2O) = 0.0283$		$\mu_a(H_2O) = 2.8 \times 10^{-2}$
$\mu'(Pb) = 0.0517$	$\rho_{Pb} = 11.35$	$\mu(Pb) = 5.9 \times 10^{-1}$

[From Radiological Health Handbook, Tables 5.1 and 5.4, pages 122-124, 126.]

$\rho_{resin} = 0.83\ g/cm^3$

[From J.W. Bland, Consultants, "10 CFR 61 Waste Classification ...", Section 4.13.]

Therefore, (3) can be solved as follows:

$$b = \mu(Pb)\ x_{Pb} + \mu(air)\ x_{air}$$
$$= (5.9 \times 10^{-1})\ (11) + (6.7 \times 10^{-5})\ (200)$$
$$= 6.5$$
$$R_0 = 84\ cm$$
$$a = 200 + 13 = 213\ cm$$ (distance of 2 m + thickness of cask wall)

To find Z, the number of mean free path lengths between the cylinder center and point P must be determined:

$$\mu_s(resin)\ (a + R_0)$$

$\mu'_s(resin)$ has been approximated by using $\mu'_s(H_2O)$:

$$\mu'_s(resin) = \mu_s'(H_2O)$$

$$\mu'_s(H_2O) = \mu'(H_2O) - \mu_a'(H_2O)$$

$$= 0.0575 - 0.0283$$

$$= 0.0292\ cm^2/g$$

and multiplying by the density of resin to get the total linear scattering coefficient.

$$\mu_s(resin) = (0.0292)(0.83)$$
$$= 0.0242\ cm^{-1}$$

Therefore,

$$\mu_s(\text{resin})\ (a + R_0) = (0.0242)(213 + 84)$$
$$= 7.2$$

$$a/R_0 = 2.5$$

From Fitzgerlad, Figure 5.26 B, m = 1.18 where m is a variable used in determining Z. From Fitzgerald, Figure 5.26 C, for b = 6.5 and $a/R_0 = 2.5$:

$$(1/m)\mu_s(\text{resin})\ (Z) = 1.15$$

$$Z = (1.15)(1.18)/(.0242)$$
$$= 56.1 \text{ cm}$$

To evaluate the function F(θ, b2), b2 and θ must be determined. As stated previously:

$$b_2 = b + \mu_s(\text{resin})\ Z$$
$$= 6.5 + (.0242)(56.1)$$
$$= 7.9$$

From basic principles of geometry:

$$\theta = \tan^{-1}[h/(2)(a + Z)]$$
$$= \tan^{-1}[183/(2)(213 + 56)]$$
$$= 19^{\circ}$$

From Fitzgerald, Figure 5.14 B:

$$F(19^{\circ}, 7.9) = 1.0 \times 10^{-4}$$

For Co-60, $E = E_1 + E_2$ (two gammas emitted per disintegration)

$$E = 1.17 + 1.33 = 2.5 \text{ MeV}$$

[From Chart of the Nuclides, page 26.]

Also, $C_v = C/V$, where:

C = total activity in Curies

V = volume of the cask

= 125 ft^3

= 3.5×10^6 cm^3

Therefore, the desired relationship for $I_o = I_o(C)$ is evaluated as follows:

$$I_o = 2.96 \times 10^9 \ (C/3.5 \times 10^6) \ (2.5) \ (2.\Pi.84^2) \ (1.0 \times 10^{-4})/(213 + 56) \qquad (5)$$
$$= 34.8(C) \ MeV/cm^2/sec$$

Combining (1b) and (5) and knowing the values for μ_a(air) and I_o determined previously, the following expression is developed:

$$R = (6.58 \times 10^{-5}) \ (3.3 \times 10^{-5}) \ (34.8xC)/(1.293 \times 10^{-3})$$
$$= 5.84 \times 10^{-5}(C) \ R/hr$$

For a limiting exposure dose rate of 10 mR/hr at 2 meters, the maximum Curie load of the cask for Co-60 alone would be:

$$C = (10 \times 10^{-3})/(5.84 \times 10^{-5})$$
$$= 1.7 \times 10^2 \ Ci$$

Therefore, a loading of 170 Ci of Co-60 will produce a 10 mR/hr field at 2 meters from the cask.

The above analysis for Co-60 has also been conducted for Cs-137. The results of the analysis show that for a dose rate of 10 mR/hr, the maximum Curie load of the cask for Cs-137 alone would be 8.24×10^4 Curies.

5.3 Shielding Analysis - Hypothetical Accident Conditions

This section not applicable.

5.4 Other Considerations

The maximum Curie contents of Co-60 and Cs-137, absorbed on ion exchange resin and placed into the 10-142A cask, are calculated in the preceding section. The shipper, however, must consider other factors which can effect the amount of radioactivity which may be placed into the cask, i.e., waste form, mixtures of radionuclides, and decay heat generation.

5.4.1 Waste Form

In general, higher density waste forms will provide greater self shielding and allow greater amounts of activity to be placed into the cask without exceeding radiation limits on the outside of the cask. For example, cement solidified wastes with a density of 90-150 lb./ft.^{3}, will provide greater self shielding than the dewatered ion exchange resins, with a density of 50-52 lb./ft.^{3}, assumed for the calculations in Section 5.2. Radiation dose rates would be a factor of approximately two to three less for a given amount of activity.

5.4.2 Mixtures of Radionuclides

Waste shipments from power stations are generally a mixture of nuclides rather than a single specific isotope. While a single nuclide such as Co-60 or Cs-137 may predominate, the dose from all the various nuclides contained in the waste must be considered prior to loading the cask to ensure that cask shielding and other limits are not exceeded.

5.4.3 Decay Heat Generation

For the heat transfer calculations presented in Chapter 2, a normal decay heat generation rate of 400 watts was used as a basis for analysis. The user of the cask must ensure that the 400 watt value is not exceeded during shipment. The calculations for decay heat from Co-60 and Cs-137, indicate that decay heat will be a significant factor for Cs-137, relative to the dose rate limitations external to the cask. Cask loadings for cesium are limited by decay to 5.8×10^4Ci, which is lower than the 8.24×10^4Ci calculated in the shielding analysis in Section 5.2. Co-60 loadings, however, are limited to a maximum of 170 Ci due to dose rate limits.

5.5 Appendix

5.5.1 References

1. Mathematical Theory of Radiation Dosimetry, Fitzgerald, J., Gordon and Breach, 1967.

2. Shappert, L.B., ıl., "A Guide for the Design Fabrication and Operation of Shipping Casks for Nuclear Applications," ORNL-NSIC-68, Oak Ridge National Laboratory, February, 1970.

3. The Health Physics and Rad ical Health Handbook, Schleien et al., editors, Nuclear Lectern A...iates, 1984.

4. "10 CFR 61 Waste Classification Program -- Davis Besse Nuclear Power Station", J. Stewart Bland Consultants, Annapolis, Maryland, 1987.

5. "Chart of the Nuclides," th ed., General Electric Company, GET-6504, 1983.

6. "Perry's Chemical Engineers' Handbook", McGraw-Hill, 5th Ed., 1973.

6. CRITICALITY EVALUATION

Fissile materials to be contained in the 10-142A cask are limited to the amounts as exempted under 10 CFR 71.53. As a result, criticality evaluation is not applicable for the 10-142A cask.

7. OPERATING PROCEDURES

This chapter of the report describes the operating procedures to be used in the preparation for and performance of loading and unloading the 10-142A cask. The procedures have been developed to ensure that occupational radiation exposures are maintained as low as is a reasonable achievable as required by paragraph 20.1(c) of 10 CFR Part 20, "Stand.:ds for Protection Against Radiation."

7.1 Procedures for Loading the Cask

Section 6.1 of STD-P-02-040 specifies the radiation surveys and inspections to be performed on the 10-142A cask. These surveys and inspections are specified to ensure that the package is not damaged and that surface contamination levels are within the allowable limits of the regulations. Upon receipt of the cask, the following inspections and survey must be performed.

(a) Radiation and external contamination surveys on both the cask and vehicle.

(b) Inspection of tiedown lugs and shackles on cask and trailer for cracks and wear.

(c) Inspection of cask primary lid ratchet binders and tiedown ratchets/ turnbuckles and cables to verify proper working condition.

(d) Verification that impact limiter and secondary lid lifting lug covers are present.

After removal of the upper impact limiter, the following are performed:

(e) Inspection of the primary lid test port plug for the presence of thread sealant.

After removal of the cask primary lid, the following are performed:

(f) Inspection of the primary lid gasket for cracks of tears which would affect proper sealing.

(g) Inspection of the cask interior for standing water. Water must be removed prior to shipment.

(h) Inspection of the cask for obstructions to loading.

(i) Inspection of the cask interior for defects which might affect the cask integrity.

(j) Inspection of the secondary lid holddown nuts to ensure that all are present and not damaged.

If the secondary lid is to be removed for loading or if the secondary lid security seal has not been broken or is not installed, the following must be performed:

(k) Inspection of the secondary lid outer and inner gaskets for cracks, nicks or tears which would affect proper sealing.

After removal of the secondary lid from the primary cask lid, the following must be performed:

(l) Inspection of the secondary lid holddown studs for damage.

(m) Inspection of the two secondary lid gaskets for cracks or tears which would affect proper sealing.

Procedure for replacing damaged studs or gaskets are provided in STD-P-02-039, 10-142A Cask Maintenance .

7.1.1 Loading Instructions

The instructions for loading the cask are provided in Section 6.3 of STD-P-02-040 . The cask may be loaded with waste contained in either a liner or ten 55-gallon drums. Pallets are used to facilitate the loading of drums into the cask. The loading procedure is summarized below:

(a) The raincover, if so equipped, is removed.

(b) The upper impact limiter is removed.

(c) The primary lid is removed from the cask.

(d) Ten drums (on pallets) or a liner is loaded into the cask. Five drums may be placed on each pallet.

(e) Shoring, if necessary, is installed to secure the liner in position.

(f) The primary lid is installed. Detailed instructions are provided to ensure proper positioning, minimize the potential for damage to the cask or sealing surfaces and for securing the ratchet binders. A wire security seal is then installed through an eyelet on the primary lid lug, to the impact limiter tie down tab.

(g) If removed, the secondary lid is installed. As with the primary lid, detailed instructions are provided to ensure proper installation and a security wire is installed as the final installation step.

Throughout the loading procedure, special precautions are noted to minimize the spread of radioactive contamination and damage to the cask equipment. The requirements for coating threads with antiseize compound and torquing fasteners are stated in the procedure.

Users of the cask must be registered as users in accordance with 10 CFR Part 71 and 10 CFR Part 49 and are responsible for operating the cask under a quality assurance program provided by the USNRC. The users are responsible for ensuring that the radioactive material shipments comply with all of the applicable requirements of the Department of Transportation, the USNRC and disposal site regulations. Specifically, users of the cask are responsible for complying with the requirements of 10 CFR Part 71.47 and paragraph 71.87(i)(1) and (2), which specify limits for radiation and external non-fixed contamination, prior to release of the package.

7.2 Procedures for Unloading the Cask

In unloading the cask, the same steps as described in Section 7.1 of this report must be performed, i.e., radiation and contamination surveys, removal of raincover, upper impact limiter and primary lid, etc., in addition to removing the load contained in the cask.

Since the cask will not contain waste with fissile material in excess of the amounts exempted under 10 CFR 71.53, fission gases will not be generated and are not considered. Contaminated coolant materials are not considered as a coolant is not used with the 10-142A cask.

Decontamination of the cask may be performed if necessary with conventional decontamination procedures. The cask is internally lined with polished stainless steel to facilitate decontamination processes.

As required by 10 CFR 71.89, consignees who will open and unload the cask must be registered users of the cask. SEG will provide all users with controlled procedures and other documentation necessary to open the cask safely. The consignee (user) must ensure that the appropriate documentation is available prior to opening the cask.

7.3 Preparation of the Empty Package for Transport

The same procedures for preparing a loaded cask for shipment apply to the preparation of empty packages. Users of the cask are responsible for complying with the requirements of paragraphs 71.87(i)(1) and (2), which specify limits for external non-fixed contamination, prior to release of the package.

7.4 Appendix

The detailed operating procedures for loading and unloading the 10-142A cask are contained in STD-P-02-040. Refer to this procedure, which is provided as an attachment to this report.

8. ACCEPTANCE TESTS AND MAINTENANCE PROGRAM

8.1 Acceptance Tests

The 10-142A cask is inspected and tested by qualified personnel in accordance with approved procedures prior to being released for service. Inspection and acceptance requirements for welds include visual inspection, magnetic particle, penetrant examination or radiographic examination. All completed shipping casks are inspected for correct dimensions and surface finish conditions. The following sections describe the inspections and tests to be performed.

8.1.1 Visual Inspection

Visual inspection according to ASME Section V is performed on all welds which are in final finished form. Personnel conducting visual weld inspections are qualified inspectors. A dimensional check will be performed to verify conformance with SEG Drawing STD-02-107, Rev. 0, sheets 1 and 2 of 2.

8.1.2 Nondestructive Examination

As required on the engineering drawings attached to this report, penetrant examination(PT) and magnetic particle examination(MT) of welds and weld areas is complete on finished welds. Examination personnel are qualified and certified in accordance with ASNT SNT-TCIA. Acceptance criteria are as specified in Section III of the ASME Code.

8.1.3 Leak Test

Completed and assembled casks are leak tested using air as the test medium. The leak testing procedure is specified in STD-P-02-038, Soap Bubble Leak Test. This procedure is included as an attachment to this report. The leak test sensitivity analysis is provided in the Appendix, Section 8.3.

8.1.4 Gamma Scan Test

The lead shielding is tested by a gamma scan test performed prior to the attachment of linings and impact limiters to verify the absence of voids and proper load thickness. The gamma scan testing procedure is performed in accordance with SEG Procedure STD-P-02-037, Gamma Scanning of Lead Shielding for SEG Casks attached to this report.

8.2 Maintenance Program

This section describes the maintenance program required to ensure continued performance of the 10-142A cask. The maintenance program, which is provided in STD-P-02-038, STD-P-02-039, and STD-P-02-040 includes periodic inspection, testing and gasket replacement schedules as well as criteria for replacement and repair.

8.2.1 Inspection

Inspections must be performed on cask gaskets, stud bolts and nuts, turnbuckles, and other critical components prior to each shipment. The inspection requirements are discussed in Chapter 7 and presented in detail in STD-P-02-040, Operating Instructions for Loading and Unloading the 10-142A Cask. This procedure is provided as an attachment to this report.

8.2.2 Gasket Replacement

Primary and secondary lid gaskets must be replaced whenever a defect such as a nick, fray or cut occurs which could adversely affect the containment integrity of the cask.

As a minimum, the primary and secondary lid gaskets must be replaced every year, as specified in STD-P-02-039, 10-142A Cask Maintenance. This procedure, which is provided as an attachment to this report, provides the instructions for performing and documenting the gasket replacement.

8.2.3 Leak Tests

A soap bubble leak test to insure containment integrity must be performed whenever a primary or secondary lid gasket is repaired or replaced. This includes performing the test following the annual replacement of primary and secondary gaskets discussed in Section 8.2.2. The leak test procedure is described in STD-P-02-038, Soap Bubble Leak Test, which is attached to this report.

The sensitivity of the leak test is 1×10^{-3} atm-cm^3/sec, well below the maximum permissible sensitivity of 2.65×10^{-3} atm-cm^3/sec for the 10-142A Cask. Refer to Section 8.3.1 for the calculation of the maximum permissible sensitivity of the leak test.

8.2.4 Shielding

The steel and lead which provide shielding for the cask are not expected to degrade over the life of the cask, thus a routine maintenance schedule is not required for the shielding.

8.2.5 Thermal

The stainless steel thermal shield is not expected to degrade over the life of the cask, thus a routine maintenance schedule is not required for the thermal shield.

8.3 Appendix

8.3.1 Permissible Leak Test Sensitivity

An expression for permissible leak test sensitivity, S, is written as follows:

$$S = 0.5\ L_T \quad atm\text{-}cm^3/sec$$

[ANSI 14.5-1977, "American National Standard for Leakage Rates on Packages for Shipment of Radioactive Materials, Section 7.2.2."]

In this expression, L_T is the lowest value for equivalent leak rate as determined for the normal transport conditions (Section 4.2.3).

$$L_T = 5.3x10^{-3} \quad atm\text{-}cm^3/sec \quad \text{(normal accident conditions)}$$

Therefore:

$$S = 2.65x10^{-3} \quad atm\text{-}cm^3/sec$$

8.3.2 References

1. ANSI 14.5-1977, "American National Standard for Leakage Rates on Packages for Shipment of Radioactive Materials". American National Standards Institute, New York, 1977.