71-6058

PDR

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April 12, 1979

Mr. Charles E. MacDonald, Chief
U.S. Nuclear Regulatory Commission
Transportation Branch
Division of Fuel Cycle and Material Safety
Washington, D.C. 20555

Dear Chuck:

Enclosed are eight (8) copies each of the "Revision A Amendment to Safety Analysis for Shipment of Radioactive Waste Materials in the Modified NECO Shipping Cask Model B3-1", and the overall assembly drawing for this cask (Battelle Drawing No. 9958-8501-0001, Rev. C). The Amendment is being submitted on behalf of the Union Carbide Corporation, Tuxedo, New York. Mr. Marcus H. Voth of Union Carbide is sending you a letter requesting your review of this amendment and the granting of a certificate of compliance for use of two B3 casks having the changes indicated in this Amendment.

In letters to you dated March 12, 1979, and March 22, 1979, Mr. Voth described deviations in the configuration and materials in the two B3-1 casks recently obtained by Union Carbide. At Mr. Voth's request, Battelle's Columbus Laboratories has reviewed the deviations and made recommendations for corrective action.

The Amendment A Revision to the Safety Analysis Report (SARP) shows that the casks, as corrected, meet the regulatory requirements for all shipments for which this cask was previously certified. The introductory pages to the Amendment describe the deviations, the corrective action to be taken, and the portions of the SARP which are affected. The Amendment is in the normal format, i.e., replacement pages with the changed pages having a revision indication at the bottom. Where only part of a page is changed, that part is indicated by a vertical bar in the margin.

Any questions regarding the SARP can be directed to me at FTS 976-7502. Other questions should be directed to Mr. Voth at (914) 351-2131, Ext. 345.

Sincerely,

Richard J. Burian
Research Engineer
Nuclear and Flow Systems Section

RJB/sm

Enc.

cc: Mr. M. H. Voth

71-6058
w/ ltr
4/12/79

Revision A Amendment

to

Safety Analysis

for

Shipment of Radioactive Waste Materials
in the Modified NECO Shipping Cask
Model No. B3-1

Reference Documents

(1) Safety Analysis Report for the Shipment of Radioactive Waste Materials in the Modified NECO Shipping Cask Model No. B3-1, Battelle Memorial Institute, Columbus Laboratories, March 14, 1969.

(2) Battelle Design Drawing No. 9958-8501-0001, Revision B.

(3) Battelle Design Drawing No. 9958-8501-0001, Revision C (as built).

## Introduction

This amendment to the safety analysis of the design and proposed uses of the modified NECO Model B3-1 applies specifically to casks of this style owned by Union Carbide Corporation, Tuxedo, New York, and having the following identifying numbers: PPI Part No. D35136-1-02 and PPI Part No. D35136-1-03. These casks were constructed from materials other than those specified in Battelle Design Drawing Reference 2. In addition, the outer shell laminate (fire shell) was omitted from the side, cover and bottom. This amendment describes the corrective action taken by Union Carbide to rectify the deviations. The results of analyses are presented to show that these corrections and the use of alternate materials is acceptable and that the safe operation of the cask through all specified normal and accident conditions is assured. Battelle Design Drawing No. 9958-8501-0001, Revision C forms part of this amendment.

The as built cask, corrected to rectify the deviations in configuration, is shown in Reference 3. This drawing indicates that the cask with the corrections has the same configuration as the original design



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Drawing Reference 2, with three exceptions:

(1) The lugs penetrate the 1-inch thick doubler plate at the top of the cask and are welded to the 1/2-inch thick outer shell

(2) The drain plug boss penetrates the 1/4-inch thick fire shell laminate and is welded to the 1/2-inch thick outer shell

(3) The materials of construction are all Type 304 stainless steel and the weld metal is Type 309L stainless steel weld filler. In this configuration, the thermal, shielding, and criticality evaluations presented in Reference 1 are valid. In addition, some of the structural evaluations presented in Reference 1 also are valid. Those structural considerations which are no longer valid due to either the configuration of the lug and drain boss attachment or due to the use of stainless steel are re-evaluated below.

In order to facilitate review of the analysis the entire Description of Cask Section and the Structural Integrity Analysis Section from Reference 1 are reproduced with the appropriate changes. Analyses, or wording which has been changed are indicated by a vertical bar in the right margin and identification "Rev. A, April 9, 1979", in the bottom margin of that page.

Revision A Amendment
to

SAFETY ANALYSIS

for

THE SHIPMENT OF RADIOACTIVE WASTE MATERIALS IN
THE MODIFIED NECO SHIPPING CASK MODEL NO. B3-1

from

BATTELLE MEMORIAL INSTITUTE
Columbus Laboratories

April 9, 1979

## INTRODUCTION

This report presents a safety analysis of the design and proposed uses of the modified NECO Model No. B3-1 shipping cask for transporting large quantities of Fissile Class II radioactive materials to and from various sites at which assorted nuclear wastes are handled. Normal shipments of the radioactive materials are to be made by sole-use truck-trailer according to commercial conditions and regulations.

## SUMMARY

A safety evaluation has been made of the modified NECO Model B3-1 shipping cask (package) in accordance with § 71.23 of 10-CFR-Part 71. The results of the evaluation indicate that:

(a) The package satisfies the standards specified in Subpart C of 10-CFR-Part 71; and

(b) Five (5) similar packages (Fissile Class II) may be transported together in accordance with § 71.39 of 10-CFR-Part 71.

## PACKAGE DESCRIPTION

### Description of Cask

Cask Design Drawing No. 9958-8501-0001, Revision C, accompanying the Safety Analysis Report presents the configuration of the modified NECO Model B3-1 shipping cask. The modified cask has a calculated empty weight of 20,500 lb. The total envelope dimensions are 51.50 in. in diameter x 61.50 in. high.

The basic cask body is 41.00 in. in diameter x 57.00 in. high. It consists of two concentric stainless steel shells which form an annular region which is filled with chemical lead. The outer shell is of a laminated steel construction. The innermost layer of the two laminates is made of 1/2-in. stainless steel plate. The 1/4-in. outer layer of the laminated outer shell covers the bottom of the cask and the cylindrical sides to within 12 in. of the top. The upper 12 in. of the outer laminate layer is comprised of a 1-in.-thick band of stainless steel. The outer laminate layer is made of one, two, or three sections joined by longitudinal seam welds. The laminate is welded to the inner layer at the corners of the cask and at the point of intersection between the 1/4-in.-thick and 1-in.-thick outer laminate on the sides.

The inner shell is made of 1/2-in.-thick stainless steel plate and is unchanged from the original design. With the cover in place, the internal cavity dimensions are 26.50 in. in diameter x 43.00 in. long. The cover fits into a recess in the cask body formed by stepping the

internal cavity diameter to about 32 in. This recess is about 6.5 in. deep and has tapering sides. The top of the cask body is made of 1/2-in.-thick stainless steel plate welded to the inner and outer shells. Lead shielding consists of a 6-in. annulus on the sides and 6-in. slab sections on the bottom and top (cover).

A liquid drain line penetrates the inner cavity at about the center of the cavity bottom. The drain line terminates in the side of the shell about 3.25 in. from the bottom. A double pipe plug affords a closure of this drain. The closure is protected from mechanical damage by a 4-in.-diameter x 1-in.-thick stainless steel plate welded around the terminal hole of the drain line. A lead safety plug is welded in the side of the cask about 4 in. from the bottom. The outer and inner laminates of the outer shell are welded together to the drain line boss and safety plug assembly in the outer shell.

Six lugs, equally spaced, penetrate the 12-in.-wide x 1-in.-thick outer laminate band at the top of the cask and are welded to both the 1/2-in. thick outer shell and the laminate band. These lugs provide both a means for lifting the cask and tying it down to a vehicle. The lugs are nominally 5.50 in. high x 5.25 in. long x 1.5 in. thick. They have an elliptical hole 2.5 in. long x 1.5 in. wide cut in the lug. The top of the lug is positioned 2.50 in. from the top of the cask. Attachment to the cask body is accomplished with full penetration welds.

Twelve bosses, made of stainless steel, are welded in the top of the cask so that the top of the boss is flush with the top of the cask. Each boss is tapped to accommodate 1-1/4-in.-7 x 2-in. long used to secure the cover to the cask body. The bolts are of the ASTM

A325 high-strength type. A tapered surface is machined on the circular edge at the joint between the inner cavity shell and the top plate of the cask. This surface is the seat for the O-ring used to provide secondary containment of the cask contents.

The cover of the cask is nominally 32 in. in diameter X 7.25 in. thick. The sides are tapered to fit the recess in the cask body. The sides and bottom of the cover are made of 1/2-in. stainless steel plate. The top plate of the cover is laminated. The inner layer is 1/2-in.-thick stainless steel and the outer layer is 1/4-in.-thick stainless steel. The 1/4-in. layer is cut out around penetrations through the top plate including the bolt holes, a lifting eye, and a safety plug. The two layers are welded together at the edges and around all penetrations. Lifting of the cover is provided by a U-shaped eye made of 3/4-in.-diameter steel bar. It is approximately 3.75 in. high and has an internal opening width of about 2.5 in. The chemical lead-filled section between the top and bottom plates of the cover is 6.0 in. thick.

There are no materials in the cask which are specifically designed or used as nonfissile neutron absorbers or moderators. Neither is the cask provided with any internal or external structures or protecting receptacles except as discussed above. All heat rejection is accomplished by conduction through the cask walls and radiation and convection from the cylindrical walls of the cask. The cask is designed to operate dry, i.e., gaseous air is the only heat-transfer medium from the contents to the inner cavity wall of the cask.

## Description of Cask Contents

In accordance with the requirements of § 71.22(b) of 10-CFR-71 - Subpart B, the materials planned for shipment in the NECO Model No. B3-1 cask are described as follows:

### (1) Radioactive Constituents - Identification and Maximum Radioactivity

The radioactive contents of the cask include any radionuclide(s) classified according to the transport grouping in Appendix C of 10-CFR-71. Quantities (in curies) of the respective radionuclides will be equal to or less than any one of the following group limits:

| Transport Group* | Quantity (in curies) |
|---|---|
| I | 100 |
| II | 590 |
| III General | 800 |
| Co-60 | 28,000 |
| Cs-137 | 80,000 |
| IV | 1,430 |
| V | 12,000 |
| VI and VII | 100,000 |

### (2) Identification and Maximum Quantities of Fissile Constituents

Fissile constituents planned for shipment in the cask along with respective quantities are as follows:

U-233 . . . . . 200 grams
Pu-239 . . . . . 200 grams
U-235 . . . . . 350 grams

* As defined in § 173.390 of 49 CFR and Appendix C of 10-CFR-71.

(3) Chemical and Physical Form

The chemical and physical form of the package contents cannot be explicitly defined since the latter will be primarily radioactive wastes.

(4) Extent of Reflection, Neutron Absorbers, and H/X Atomic Ratios

Reflection, absorption, and atomic characteristics of the package contents are summarized as follows:

Extent of Reflection . . . . . . . . Maximum Reflection

Nonfissile Neutron Absorbers Present . . . . None Assumed (although various types would be present)

Atomic Ratio of Moderator to Fissile Constituents:

| Isotope | H/X |
|---|---|
| U-233 | 450 |
| Pu-239 | 800 |
| U-235 | 500 |

(5) Maximum Weight

The maximum weight of the package contents is 9500 lb based on a density equivalent to that of lead.

(6) Maximum Amount of Decay Heat

A decay heat load of 400 watts is the maximum analyzed for the package contents although subsequent calculations indicate that this value could safely be extended to 750 watts.

## Structural Integrity Analysis

The structural integrity analysis of the modified NECO Model B3-1 shipping casks, ID Nos. PPI Part No. D35136-1-02 and PPI Part No. D35136-1-03 was performed to show compliance with the applicable structural requirements designated in the Code of Federal Regulations, 10-CFR-Part 71. Basically the casks consist of AISI Type 304 stainless steel plates and shells. The geometry is as presented in Battelle Drawing No. 9958-8501-0001, Revision C. The structural components of the cask are made of AISI Type 304 stainless steel and Type 309L stainless steel weld filler.

All materials have been certified to their composition and properties. (The 1/4-inch plate which has been ordered to be used for the laminate (fire shell) was ordered to specifications of minimum structural properties.) In cases where some properties (such as bearing strength) were not specified in the material certifications, these properties were obtained from the Aerospace Structural Metals Handbook* and MIL-HDBK-5A**. In cases where property data were not specified, the values were estimated by referring to properties of similar materials. The ASTM A325 bolts specified in the cask design correspond to Type 4 fasteners included in MIL-HDBK-5A. The surface temperature of the cask was taken as 130 F, (from thermal analyses) and all structural material properties were degraded accordingly by the use of data presented in MIL-HDBK-5A. Table 1 summarizes the properties of the materials utilized in the design.

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* Aerospace Structural Metals Handbook, Fourth Revision, Vol. I, Ferrous Alloys, Code 1101, March, 1967.

** Metallic Materials and Elements for Aerospace Vehicle Structures, MIL-HDBK-5A, Change Notice 2, Sections 2.2 and 8.1, July 24, 1967.

TABLE 1. MATERIAL PROPERTIES UTILIZED IN
NECO MODEL NO. B3-1 CASK DESIGN

| Material | Property | Value, psi[(a)] |
|---|---|---|
| AISI Type 304 | | |
| 1/4- and 1/2-in. plate[(b)] | Tensile yield stress | 37,300 |
| | Tensile ultimate stress | 81,400 |
| | Shear ultimate stress | 54,300 |
| 1-in. plate[(b)] | Tensile yield stress | 34,000 |
| | Tensile ultimate stress | 78,000 |
| 1-1/2-in. plate[(b)] | Tensile yield stress | 31,900 |
| | Tensile ultimate stress | 74,100 |
| | Shear yield stress | 21,300 |
| | Bearing stress | 48,000 |
| 3/4-in. round[(b)] | Tensile yield stress | 66,000 |
| | Shear yield stress | 44,000 |
| AWS 308L/309L Weld Filler[(c)] | Tensile yield | 31,000 |
| | Tensile ultimate | 72,000 |
| | Shear yield | 20,700 |
| | Shear ultimate | 48,000 |
| ASTM-A325 bolts[(d)] (Type 4 fasteners) | Tensile ultimate stress | 120,000 |
| | Shear ultimate stress | 89,000 |

(a) At 130 F.
(b) Material certification.
(c) AWS Specifications.
(d) ASTM Specification.

General Standards (§ 71.31 of 10-CFR-71)

a. No Internal Reactions. The materials used--steel and lead, do not react with each other in such a way as to cause deleterious amounts of corrosion products.

b. Positive Closure. Closure of the cask is accomplished by 12 ASTM Type A325 bolts. These bolts provide positive closure of the cask during normal shipping conditions. The closure with respect to accident conditions is analyzed in a subsequent section.

c. Lifting Devices.

c.1. Support Three Times the Loaded Weight. The cask is provided with six lugs equally spaced. These devices afford a means of tiedown as well as lifting of the cask. For purposes of analysis, it is assumed that only two of the six lugs will be used at any one time for lifting the loaded cask. Therefore, the total load per lug is:

$$P_L = 3 \times \frac{W}{2} = \frac{3}{2}(30,000) = 45,000 \text{ lb} .$$

It is further assumed that a 1-1/2-in. clevis pin will be used to engage the lug. When used as a lifting device, the lug can fail in any one of five modes; the analyses for these failure modes are presented below.

c.1.1. Shear in the Lug Welds. The shear stress in the welds between the lug and the cask shell is:

$$\sigma_{sh} = \frac{P_L}{A} = \frac{45,000}{2(0.707)(0.75)(5.5)} = \frac{45,000}{5.84} = 7700 \text{ psi} .$$

The margin of safety is calculated to be:

$$MS = \frac{F_{sy}}{\sigma_{sh}} - 1 = \frac{20,700}{7,700} - 1 = 1.68 \ .$$

<u>c.1.2. Fiber Failure in the Lug Weld at the Cask Shell</u>. The fiber stress in the weld is produced by the moment of the vertical load on the lug and is represented by:

$$\sigma_f = \frac{Mc}{I_{Top}} \ ,$$

where

$$I_{Top} = I_o + Ad^2 = 2\left[\frac{bh^3}{12} + (bh)\left(\frac{h}{2}\right)^2\right]$$

$$= 2\left[\frac{(0.707)(0.75)(5.5)^3}{12} + \frac{(0.707)(0.75)(5.5)^3}{4}\right] = 58.7 \text{ in.}^4$$

$$M = (P_L)(e) = (45,000)(2) = 90,000 \text{ in.-lb}$$

$$c = h = 5.5 \text{ in.}$$

The fiber stress is, therefore:

$$\sigma_f = \frac{(90,000)(5.5)}{58.7} = 8400 \text{ psi} \ .$$

The margin of safety is:

$$MS = \frac{F_{ty}}{\sigma_f} - 1 = \frac{31,000}{8,400} - 1 = 2.69 \ .$$

c.1.3. Shear Through the Eye of the Lug. The shear stress developed in the eye by the clevis is:

$$\sigma_{sh} = \frac{P_L}{A} = \frac{45,000}{(1.5)(2.25 + 2.12)} = \frac{45,000}{6.55} = 6900 \text{ psi} .$$

The margin of safety is:

$$MS = \frac{F_{sy}}{\sigma_{sh}} -1 = \frac{21,300}{6,900} -1 = 2.08 .$$

c.1.4. Tensile Failure of the Eye of the Lug. The minimum area of the lug in tension is that corresponding to a horizontal plane through the eye which is:

$$A = t(W - d) = 1.5(4.25 - 1.5) = 4.125 \text{ in.}^2 .$$

The corresponding stress is:

$$\sigma_t = \frac{P_L}{A} = \frac{45,000}{4.125} = 10,900 \text{ psi} ,$$

and the margin of safety is:

$$MS = \frac{F_{ty}}{\sigma_t} -1 = \frac{31,900}{10,900} -1 = 1.92.$$

c.1.5. Bearing in the Eye of the Lug. The area for bearing of the clevis pin in the eye of the lug is the projected area of the clevis pin on the ear of the lug; therefore, the bearing stress is:

$$\sigma_{br} = \frac{45,000}{(1.5)(1.5)} = 20,000 \text{ psi} .$$

The margin of safety is:

$$MS = \frac{F_{bry}}{\sigma_{br}} - 1 = \frac{48,000}{20,000} - 1 = 1.4.$$

<u>c.2. Support Three Times Weight of the Lid</u>. A single U-shaped eye is provided for lifting the cover of the cask. Material properties of the eye and the weld which secures the eye to the cover of the cask were considered to be those of AISI 1025 steel. The lifting device (U-shaped eye) can fail by any one of three modes; analyses corresponding to each of these modes are presented below.

<u>c.2.1. Tensile Failure of the U-Eye</u>. The load is assumed equally supported by both legs of the U-eye. Therefore, for a total cover weight ̄ 2260 lb, the load on each leg is:

$$P_L = 3(\frac{W}{2}) = \frac{3}{2}(2260) = 3390 \text{ lb} .$$

The area resisting this load is:

$$A = \frac{\pi D^2}{4} = \frac{(\pi)(0.75)^2}{4} = 0.441 \text{ in.}^2 ,$$

and the stress is:

$$\sigma_t = \frac{P_L}{A} = \frac{3390}{0.441} = 7700 \text{ psi} .$$

Thus, the margin of safety is:

$$MS = \frac{F_{ty}}{\sigma_t} -1 = \frac{66,000}{7,700} -1 = \text{Large.}$$

<u>c.2.2. Shear Failure of the U-Shaped Eye</u>. Shear stresses will develop in the U-shaped eye due to forces caused by crane hooks or similar mechanisms during lifting of the cover. Furthermore, the maximum shear stress will occur at the top of the U-shaped eye where the cross-sectional area resisting the shearing force is a minimum. Accordingly, the maximum shear stress is:

$$\sigma_{sh} = \frac{P_L}{A_{min}} ,$$

where as above,

$$P_L = 3390 \text{ lb}$$

and $A_{min} = 0.441 \text{ in.}^2$ .

Therefore,

$$\sigma_{sh} = \frac{3390}{0.441} = 7700 \text{ psi} ,$$

and the margin of safety is:

$$MS = \frac{F_{sy}}{\sigma_{sh}} -1 = \frac{44,000}{7,700} -1 = \text{Large.}$$

<u>c.2.3. Shear in the Weld Between the U-Shaped Eye and the Cover</u>. The shear load in each weld is $P_L$, whereas the area subjected to the shear load is:

$$A = \pi d(0.707)(t) .$$

If the diameter is conservatively taken as the diameter of the U-shaped eye and the weld thickness as the thickness of the top plate of the cover, the resulting area is:

$$A = (\pi)(0.75)(0.707)(0.5) = 0.833 \text{ in.}^2 ,$$

and the corresponding stress is:

$$\sigma_{sh} = \frac{P_L}{A} = \frac{3390}{0.833} = 4070 \text{ psi} .$$

Thus, the margin of safety is:

$$MS = \frac{F_{sy}}{\sigma_{sh}} -1 = \frac{20,700}{4,070} -1 = \text{Large.}$$

<u>c.3. Nonlifting Attachments Covered or Locked</u>. The U-shaped eye on the cover and the cover closure are not designed to permit its use as a cask-lifting device. Therefore, a C-plate which bolts onto the eye is provided to prevent inadvertent use of the component as a cask-lifting device.

The drain plug is recessed in the side wall of the cask. This adequately protects it from damage by normal contact of the cask with other objects which might occur during handling and transit.

c.4. Failure of the Lifting Device Would Not Impair Containment or Shielding. Impairment of containment or shielding due to failure of the lifting device would be less severe than in the case of the 30-ft drop which is considered in a subsequent section.

d. Tiedown Devices.

d.1. No Yielding With 10G Longitudinal, 5G Transverse, and 2G Vertical Forces. The six lugs provided for lifting the cask are also designed for tiedown of the cask to the bed of the transport vehicle. For purposes of analysis, it was assumed that the cask was positioned on a bed 8 ft wide (a common width of truck beds). It was further assumed that the tiedown cables extend in a radial direction from the cask to the vehicle bed (see Figures 1 and 2).

The forces on the tiedown lugs were evaluated for two orientations of the cask on the vehicle bed. In the first (Figure 1), the cask was positioned so that the 10G longitudinal force through the center of gravity of the cask was directed through two opposite lugs (Numbers 1 and 4 in Figure 1). In the second case (Figure 2), the cask was rotated 30 degrees with respect to the first case so that the 10G longitudinal force was directed midway between adjacent lugs. It was assumed that those cables which are not attached to the sides of the bed (e.g., Cables 1 and 4 in Figure 1) make an angle of 45 degrees with the axis of the cask. However, for those cables which are assumed to be attached to the side of the bed, the angles were calculated. Cables 2, 3, 5, and 6 in Figure 1 form an angle of about 33 degrees, whereas Cables 3 and 6 in Figure 2 form an angle of about 26.5 degrees.

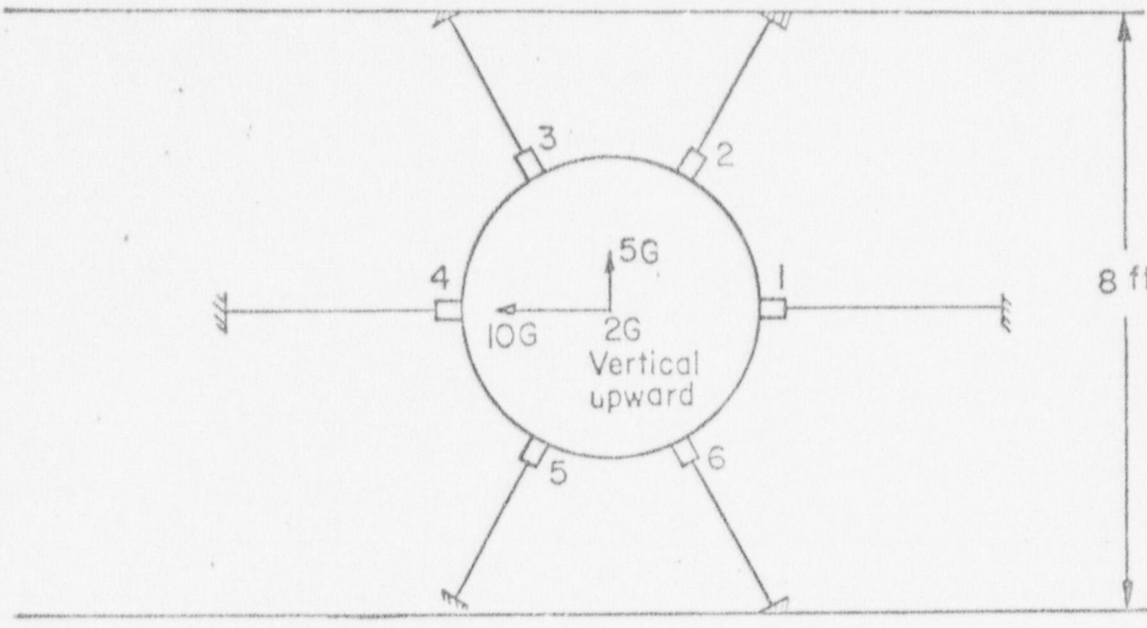



FIGURE 1. CASK ORIENTATION FOR CASE OF 10G
LOAD PASSING THROUGH TWO LUGS

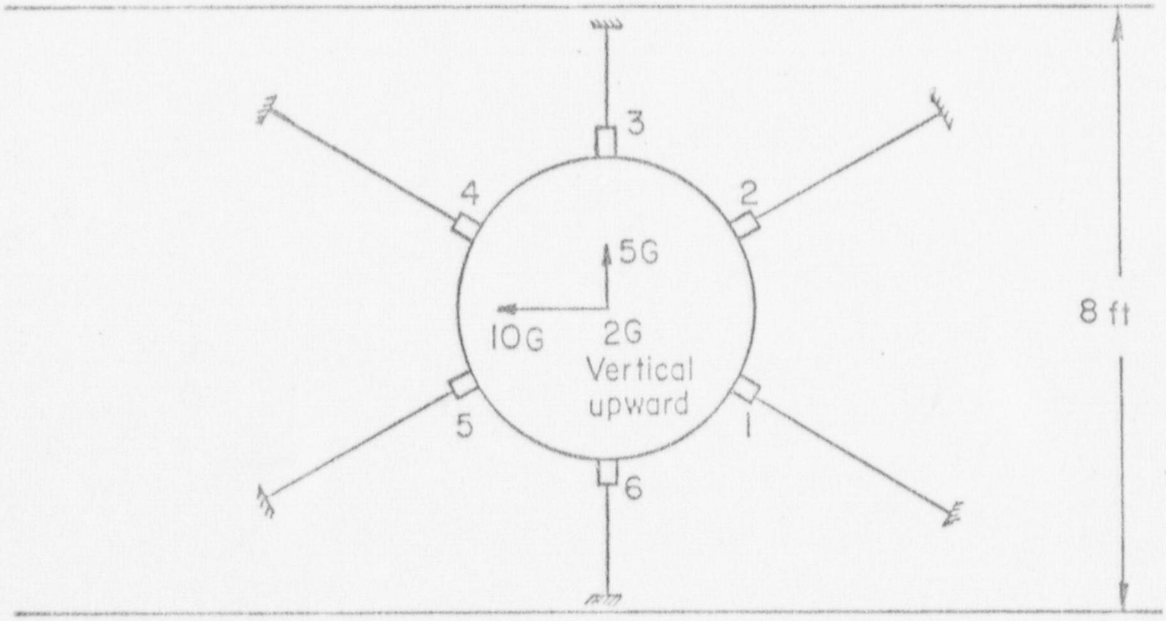



FIGURE 2. CASK ORIENTATION FOR CASE OF 10G LOAD
PASSING MIDWAY BETWEEN ADJACENT LUGS

The analysis of the forces on the lugs was performed assuming all three imposed G-forces to be acting simultaneously. Also, as is customary, it was assumed that the cask is adequately blocked at the base so that tipping rather than sliding, or sliding and tipping is impending.

Analytical results are presented in Table 2:

TABLE 2. FORCES ON TIEDOWN LUGS FOR CASK ORIENTATION CASES 1 AND 2*

| | Force, lb | |
|---|---|---|
| Lug No. | Case 1 | Case 2 |
| 1 | 80,700 | 81,200 |
| 2 | 43,400 | 62,200 |
| 3 | -- | 19,700 |
| 4 | -- | -- |
| 5 | 38,000 | 15,300 |
| 6 | 78,000 | 57,800 |

* Shown in Figures 1 and 2, respectively.

These data indicate that for Case 1 about 66 percent of the load is almost equally divided between the two lugs with the remainder being almost equally divided between two other lugs, leaving a negligible force on the remaining two lugs. In Case 2, about 86 percent of the load is applied to three lugs with the remaining load being shared by two other lugs.

The maximum load on one lug was found to be for the Case 2 orientation, i.e., 81,200 lb. This load was used in the following analyses of stresses in the lug when the latter was utilized as a tiedown device.

The lug can fail by any one of six modes. Analyses corresponding to each of these failure modes are presented below.

d.1.1. Shear in the Weld Between the Lug and the Cask Shell. The shear in the welds between the ear of the lug and the shell of the cask is:

$$\sigma_{sh} = \frac{F_y}{A} ,$$

where $F_y$ is the vertical component of the load on the lug. Then,

$$F_y = (\cos\alpha)(F) = (0.707)(81,200) = 57,400 \text{ lb} ,$$

and

$$A = 2(0.707)(t)(\ell) = (2)(0.707)(0.75)(5.5) = 5.84 \text{ in.}^2 ,$$

which result in a stress of:

$$\sigma_{sh} = \frac{F_y}{A} = \frac{57,400}{5.84} = 9800 \text{ psi} .$$

The corresponding margin of safety is:

$$MS = \frac{F_{sy}}{\sigma_{sh}} -1 = \frac{20,700}{9,800} -1 = 1.11.$$

d.1.2. Fiber Failure in the Weld of the Lug to the Cask Shell. The fiber stress is produced by the moment of the vertical and horizontal components of the load on the lug. Thus,

$$M = (F_y)(e_y) + (F_x)(e_x)$$

$$M = (57,400)(2) + 57,400 \ (2.25) = 241,600 \text{ in.-lb} ,$$

and the stress is:

$$\sigma_f = \frac{Mc}{I_{Bot}} \quad ,$$

where

$$c = h = 5.5 \text{ in.}$$

and

$$I_{Bot} = I_o + Ad^2 = 2\left[\frac{bh^3}{12} + bh\left(\frac{h}{2}\right)^2\right] .$$

From Section c.1.2.,

$$I = 58.7 \text{ in.}^4 .$$

Therefore,

$$\sigma_f = \frac{(241,600)(5.5)}{58.7} = 22,600 \text{ psi} \quad ,$$

and the margin of safety is:

$$MS = \frac{F_{ty}}{\sigma_f} -1 = \frac{31,000}{22,600} -1 = 0.37.$$

<u>d.1.3. Shear Through the Eye of the Lug</u>. The shear of the tiedown clevis through the eye of the lug is:

$$\sigma_s = \frac{F}{A} \quad ,$$

where

$$F = 81,200 \text{ lb}$$

and

$$A = 2\ t\ d = 2\ (1.5)(2.12) = 6.36 \text{ in.}^2 .$$

Therefore,

$$\sigma_s = \frac{81,200}{6.36} = 12,800 \text{ psi} .$$

The margin of safety is:

$$MS = \frac{F_{sy}}{\sigma_s} -1 = \frac{21,300}{12,800} -1 = 0.66.$$

d.1.4. Tensile Failure of the Eye of the Lug. The load on the lug tends to cause a tensile failure of the eye. For a minimum stress area of:

$$A = \left(\frac{w - d}{\cos\alpha}\right)t ,$$

where

$w$ = width of the lug = 4.25 in.

$d$ = width of the eye = 1.5 in.

$\alpha$ = angle of the area plane with the horizontal = 45 degrees

$t$ = thickness of the ear = 1.5 in.

and

$$A = \frac{4.25 - 1.5}{0.707} (1.5) = 5.84 \text{ in.}^2 .$$

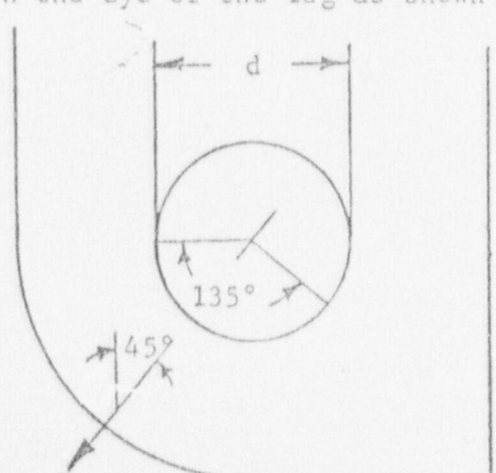
The stress is:

$$\sigma_t = \frac{F}{A} = \frac{81,200}{5.84} = 13,900 \text{ psi} ,$$

which results in a margin of safety of:

$$MS = \frac{F_{ty}}{\sigma_t} - 1 = \frac{31,900}{13,900} - 1 = 1.29.$$

d.1.5. Bearing in the Eye of the Lug When the Lug is Used as a Tiedown Device. The clevis imposes a pressure over a 135-degree arc of contact with the eye of the lug as shown in the sketch below.



The bearing area is:

$$A = t(1 + 0.707)\frac{d}{2} = 1.5(1.707)(\frac{1.5}{2}) = 1.92 \text{ in.}^2 ,$$

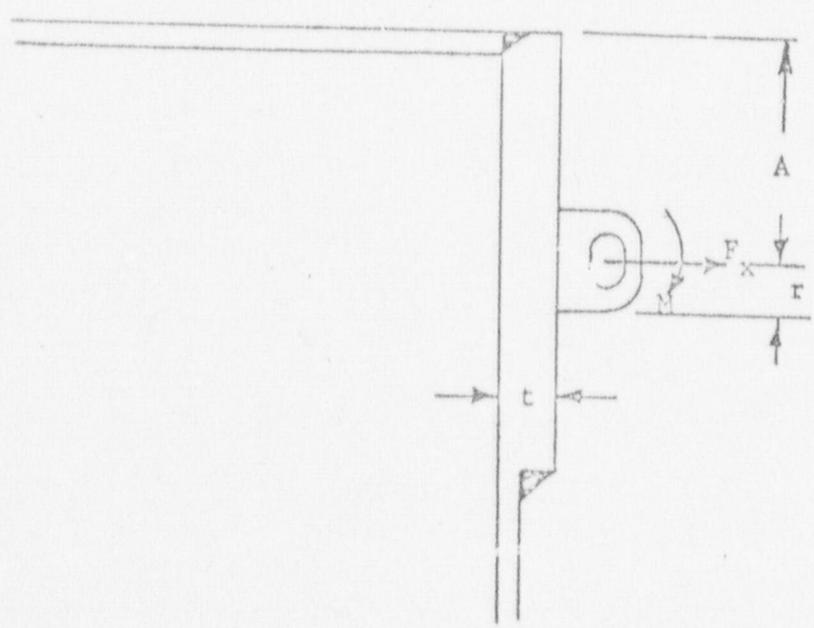
and the bearing stress is:

$$\sigma_{br} = \frac{F}{A} = \frac{81,200}{1.92} = 42,300 \text{ psi} ,$$

which results in a margin of safety of:

$$MS = \frac{F_{bry}}{\sigma_{br}} - 1 = \frac{48,000}{42,300} - 1 = 0.13.$$

d.1.6. Fiber Failure of the Cask Shell Adjacent to the Lug. The lug was assumed to act as a trunnion imparting both a bending moment and a pull-out force on the shell of the cask as shown in the sketch below:



Also, the shell was conservatively assumed to be a flat plate 12 in. in diameter. The ef... on the stresses in the shell by the applied loads was examined for both simply supported and fully fixed conditions at the edge of the 12-in.-diameter plate.

For the case of the applied moment, the severest stress condition exists when the edges of the plate are assumed to be simply supported. In accordance with Roark*, Case 5, the stress is defined as:

$$\sigma_r = \frac{3M}{4\pi t^2 r}\left\{1 + (\nu + 1)\ln\left[\frac{2(A - r)(r + 0.7A)^2}{0.49\ A^3}\right]\right\} .$$

The moment is:

$$M = (F_y)(e) = (57,400)(2) = 114,800 \text{ in.-lb} ,$$

and

$t = 1.5$ in.

$r = \frac{5.5}{2} = 2.75$ in.

$\nu = 0.3$

$A = 6$ in.

Therefore, the maximum fiber stress is:

$$\sigma_{rM} = 14,700 \text{ psi} .$$

For the case of the pull-out force, $F_y$, the worst stress condition exists when the edges of the 12-in.-diameter plate are assumed to be fully fixed. Accordingly, from Roark**, Case 20, the stress is defined as:

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* Roark, R. J., Formulas for Stress and Strain, Fourth Edition, McGraw-Hill Book Company, New York, Chapter 10, page 217, 1965.

** Ibid., page 222.

$$\sigma_r = \frac{3F}{2\pi t^2}\left[1 - \frac{2A^2}{A^2 - r^2}\left(\ln \frac{A}{r}\right)\right] ,$$

where

$$F = F_x = 57,400 \text{ lb} ,$$

and the other dimensions are the same as above. Therefore, the maximum fiber stress is:

$$\sigma_{rf} = 11,900 \text{ psi} .$$

The total maximum stress in the shell is the sum of these two stresses. That is,

$$\sigma_f = \sigma_{rM} + \sigma_{rf} = 19,700 + 11,900 = 26,600 \text{ psi} .$$

This stress occurs on the surface of the shell at the top of the lug. The margin of safety is:

$$MS = \frac{F_{ty}}{\sigma_f} - 1 = \frac{34,000}{26,600} - 1 = 0.28 .$$

d.2. Nontiedown Devices Covered or Locked. The nontiedown devices will be covered as described above in Section c.3.

d.3. Failure of the Tiedown Device Would Not Impair Meeting Other Requirements. Failure of the tiedown device would not impair meeting other requirements of the cask as described above in Section c.4. and in the subsequent section on accident conditions.

Structural Standards for Large-Quantity Packaging (§ 71.32 of 10-CFR-71)

a. Load Resistance. The requirement for load resistance is that, when simply supported at its ends, the cask must be able to withstand a uniformly distributed load equal to five times the cask weight. Conservatively, the outer shell alone is assumed to support this load. Accordingly, the stress is:

$$\sigma_f = \frac{Mc}{I} ,$$

where

$$M = \frac{1}{8} W \ell = (5)(\frac{1}{8})(30{,}000)(57.5) = (1.08)(10^6) \text{ in.-lb}$$

$$c = \frac{D}{2} = \frac{41}{2} = 20.5 \text{ in.}$$

$$I = \pi \frac{d_o^4 - d_i^4}{64} = \frac{\pi}{64} (41^4 - 39.5^4) = (1.94)(10^4) \text{ in.}^4$$

and the corresponding stress is:

$$\sigma_f = \frac{Mc}{I} = \frac{(1.08)(10^6)(20.5)}{(1.94)(10^4)} = 1140 \text{ psi} ,$$

which results in a margin of safety of:

$$MS = \frac{F_{ty}}{\sigma_f} -1 = \frac{37{,}300}{1{,}140} -1 = \text{large} .$$

b. External Pressure. The requirement for external pressure is that the cask must be able to withstand an external pressure of 25 psig without loss of contents. The outer shell was conservatively assumed to withstand this pressure with no assistance from the lead in which case the shell could fail by stress failure of the end plates, stress failure of the cylindrical shell, or collapse of the outer shell. These cases are analyzed individually below.

b.1. Stress Failure of End Plates. The severest stress condition exists when the edges of the end plate are assumed to be simply supported. According to Roark*, Case 1, the maximum stress in the end plate may be described as:

$$\sigma_f = \frac{3}{32} \left(\frac{D}{t}\right)^2 p(3 + \nu) ,$$

where

D = mean diameter = 40.25

t = 0.75 in.

p = 25 psig

$\nu$ = 0.3.

$$\therefore \sigma_f = \frac{3}{32} \left(\frac{40.25}{0.75}\right)^2 (25)(3 + 0.3) = 2300 ,$$

and the corresponding margin of safety is:

$$MS = \frac{F_{ty}}{\sigma_f} - 1 = \frac{37,300}{2,300} - 1 = \text{large} .$$

b.2. Stress Failure of Cylindrical Shell. The stress in the shell is given by Roark**, Case 1, as:

$$\sigma_{hoop} = \frac{pD}{2t}$$

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* Ibid., page 216.

** Ibid., Chapter 12, page 298.

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where the dimensions are the same as above. Therefore, the fiber stress is:

$$\sigma_f = \frac{(25)(40.25)}{(2)(0.75)} = 670 \text{ psi} ,$$

and the margin of safety is:

$$MS = \frac{F_{ty}}{\sigma_f} - 1 = \frac{37,300}{670} - 1 = \text{large} .$$

<u>b.3. Collapse of the Cylindrical Shell.</u> The critical collapsing pressure of a shell is given by Roark*, Case 1, as:

$$p_c = \frac{2t}{D}\left(\frac{F_{ty}}{1 + \frac{F_{ty}}{E}\left(\frac{D}{t}\right)^2}\right) ,$$

where

$E$ = elastic modulus = $29 \times 10^6$ psi.

$$\therefore \quad p_c = \frac{(2)(0.75)}{40.25}\left(\frac{37,300}{1 + \frac{33,800}{(29)(10^6)}\left(\frac{40.25}{0.75}\right)^2}\right) = 320 \text{ psi} .$$

and the margin of safety is:

$$MS = \frac{p_c}{p} - 1 = \frac{320}{25} - 1 = \text{large}.$$

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* Ibid., Chapter [illegible], page 298.

Evaluation of a Single Package (§ 71.34 of 10-CFR-71)

a. Effect of Transport Environment on Safety of Cask.

a.1. Normal Transport Conditions (Appendix A of 10-CFR-71).

The structural requirements of the cask for normal transport conditions as specified in § 71.35 of 10-CFR-71 are less severe than those analyzed in previous sections as well as those analyzed in subsequent sections for accident conditions.

a.2. Accident Conditions (Appendix B of 10-CFR-71).

a.2.1. Thirty-Foot Free Drop onto a Flat Surface.

The first condition which the cask must withstand in the hypothetical accident sequence is a 30-ft fall onto a flat, unyielding surface. There are three critical orientations which the cask can assume at the moment of impact. These include direct impact on an end, direct impact on the cylindrical side, and impact on an edge at such an angle that the reaction force is directed through the center of mass of the cask. These conditions are evaluated individually below.

a.2.1.1. End Impact. In the case of a direct end impact, the force is evenly distributed over the end of the cask. Furthermore, the kinetic energy of the cask at the moment of impact must be absorbed by deformation of the cask shell and shielding material; this quantity is defined as:

$$KE = hW ,$$

where

h = the drop height = 30 ft = 360 in.

W = the loaded cask weight = 30,000 lb.

The energy absorbed by the cask during deformation is:

$$E = V k ,$$

where

$V$ = volume of material displaced, in.$^3$

$k$ = energy absorbed per unit volume, in.-lb/in.$^3$.

By equating the above equations, the volume of material displaced is found to be:

$$V = \frac{hW}{k} .$$

On the basis of data from tests conducted on casks and cask materials by ORNL, it can be shown that a conservative value for the energy absorption of lead is:

$$k = 10{,}000 \text{ in.-lb/cu. in.}$$

If energy absorption in the steel shell of the cask is conservatively neglected, the volume of lead which must be deformed is:

$$V = \frac{hW}{k} = \frac{(360)(30{,}000)}{10{,}000} = 1080 \text{ in.}^3 .$$

From geometric considerations, the volume of lead deformed is:

$$V = \frac{\pi d^2}{4} \delta ,$$

where

$\delta$ = the depth of deformed lead

$d$ = the diameter of the lead shielding = 39.5 in.

Therefore,

$$\delta = \frac{4V}{\pi d^2} = \frac{(4)(1080)}{\pi d^2} = 0.88 \text{ in.} ,$$

and the thickness of lead shielding which remains is:

$$t_L = t_{Pb} - \delta = 6.00 - 0.88 = 5.12 \text{ in.}$$

a.2.1.2. Side Impact. In the case of direct impact on the side, the volume of lead deformed is:

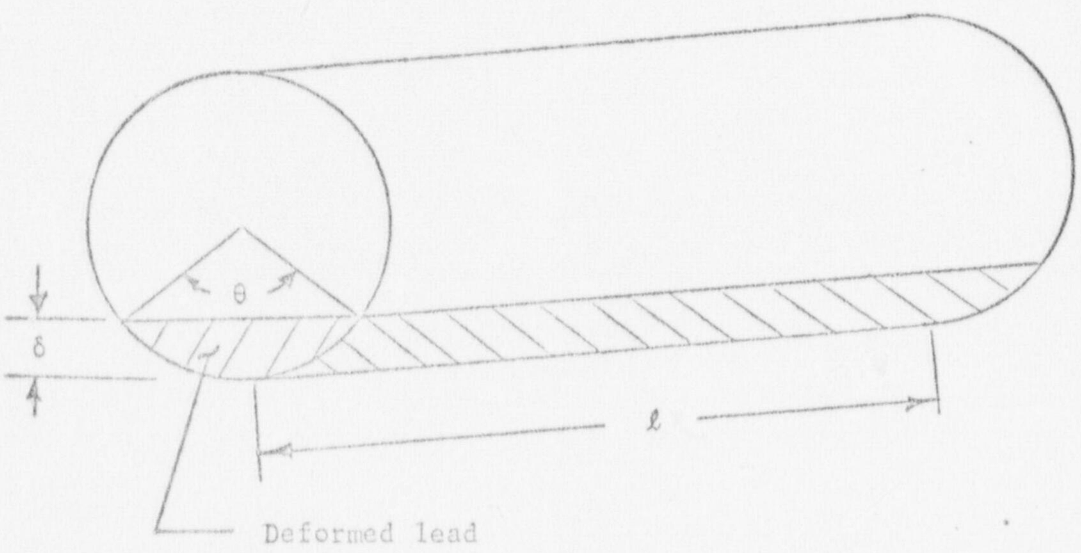
$$V = \frac{d^2}{8} (\theta - \sin\theta)\ell ,$$

where

$\theta$ = the angle subtended by the deformed area (see sketch below)

$\ell$ = the longitudinal length of the deformed lead section

= 55.5 in.




Therefore,

$$\theta - \sin\theta = \frac{8V}{\ell d^2} = \frac{(8)(1080)}{(55.5)(39.5)^2} = 0.100 ,$$

and

$\theta$ = 49.0 degrees.

The corresponding depth of the deformed lead is:

$$\delta = (1 - \cos\frac{\theta}{2})\frac{d}{2} = (1 - \cos\frac{49}{2})(\frac{39.5}{2})$$

$$= 1.75$$

which results in a residual lead thickness of:

$$t_L = t_{Pb} - \delta = 6 - 1.75 = 4.25 \text{ in.}$$

The average impact force during deformation is:

$$F_I = \frac{E}{\delta} = \frac{EK}{\delta} = \frac{hW}{\delta} \quad ,$$

and the equivalent "g" load is:

$$G_I = \frac{F_I}{W} = \frac{hW}{W\delta} = \frac{h}{\delta} = \frac{360}{1.75} = 206 \text{ "g's"} \ .$$

When applied to the cask cover, this g-load must be resisted in shear by the 12 cover bolts, the resultant stress of which is determined by:

$$\sigma_{sh} = \frac{(G_I)(W_c)}{(A)(n)} \quad ,$$

where

$W_c$ = weight of the cover = 2260 lb

A = the effective area of each bolt = 0.6331 in.$^2$

n = number of bolts.

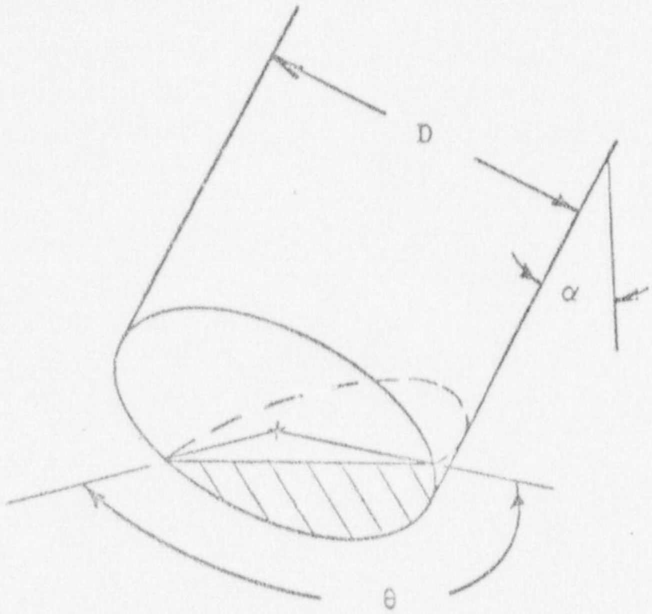
Therefore,

$$\sigma_{sh} = \frac{(206)(2260)}{(0.6331)(12)} = 61{,}300 \text{ psi} \ .$$

The ultimate shear stress of the ASTM Type A325 bolts specified is 89,000 psi; this value results in a margin of safety of:

$$MS = \frac{F_{su}}{\sigma_{sh}} -1 = \frac{89{,}000}{61{,}300} -1 = 0.45 \ .$$

a.2.1.3. Edge Impact. In the case of impact on an edge, the deformed lead may be represented as shown in the following sketch.




Accordingly, the volume of lead displaced is:

$$V = \left(\frac{D}{2}\right)^3 \tan\alpha\left(\sin\theta - \frac{\sin^3\theta}{3} - \theta\cos\theta\right) .$$

For the edge drop,

$$\alpha = 35.5 \text{ degrees} ,$$

and, by trial and error:

$$\theta = 64.8 \text{ degrees} .$$

The depth of deformed lead, $\delta$, measured along a line from the edge of the cask through the cask's center of gravity is:

$$\delta = 6.83 \text{ in.}$$

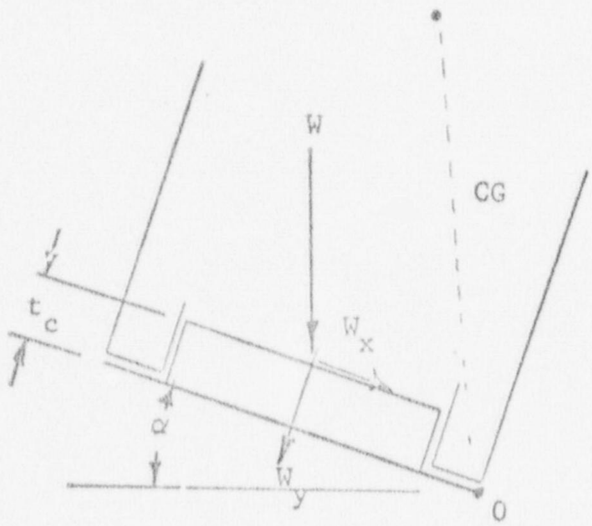
Therefore, the thickness of lead remaining between the edge of the inner cavity and the deformed surface is:

$$t_L = 1.54 \text{ in.}$$

Also, the impact load in "g's" is:

$$G_I = \frac{h}{\delta} = \frac{360}{6.83} = 53 \text{ g} .$$

If the cask were to impact on a top edge of the cask, the weight of the cover and contents would produce both shear and tensile stresses in the bolts. Furthermore, if the combined weight of the cover and contents are assumed to act at the center of the bottom face of the cover as shown in the sketch below, the maximum load on the bolts can be evaluated.




The maximum tensile stress in the bolts will occur in the bolt farthest away from the point of impact, O, and is evaluated by the following equation:

$$\sigma = \left(\frac{Mc}{I}\right)_0 \quad ,$$

where

$$M = [(W_y)\frac{D}{2} - (W_x)t_c]G = WG(\frac{D}{2}\cos\alpha - t_c\sin\alpha)$$

$$c = \frac{1}{2}(D + D_{BC})$$

$$I_o = \Sigma(I_c + Ad^2)$$

where

$W$ = the weight of the cover and contents = 11,760 lb

$G$ = the "g" impact load = 53 g

$D$ = the cask diameter = 41 in.

$t_c$ = the cover thickness = 10.5 in.

$D_{BC}$ = the bolt circle diameter = 37.0 in.

$I_c$ = area moment of inertia for one bolt about its own neutral axis = 0.0319 in.$^4$

$A$ = the effective area of one bolt = 0.633 in.$^2$

$d$ = the distance of each bolt from a horizontal axis through "O"

$\alpha$ = 35.5 degrees.

Therefore,

$M = (8.00)(10^6)$ in.-lb

$c = 39.0$ in.

$I = 4490$ in.$^4$

and

$$\sigma_t = \frac{Mc}{I} = \frac{(8)(10^6)(39.0)}{4416} = 69{,}500 \text{ psi} .$$

The corresponding margin of safety is:

$$MS = \frac{F_{tu}}{\sigma_t} - 1 = \frac{120{,}000}{69{,}500} - 1 = 0.73 .$$

In addition, the shear stress is:

$$\sigma_{sh} = \frac{W_n}{nA} = \frac{W\sin\alpha}{nA} = \frac{(11{,}760)(\sin 35.5)}{(12)(0.633)} = 47{,}400 \text{ psi} ,$$

which results in a margin of safety of:

$$MS = \frac{F_{su}}{\sigma_{sh}} - 1 = \frac{89{,}000}{47{,}400} - 1 = 0.88 .$$

a.2.2. Puncture.

a.2.2.1. Forty-Inch Drop on Six-Inch Steel Cylinder. Second in the sequence of hypothetical accident conditions to which the cask must be subjected is the 40-in. drop onto a 6-in.-diameter cylinder. An empirical equation for the minimum steel shell thickness required for lead-filled casks has been developed by the Oak Ridge National Laboratory.* The equation has the form:

$$t = \left(\frac{W}{F_{tu}}\right)^{0.71} ,$$

where

$t$ = minimum shell thickness, in.

$W$ = weight of lead-lined cask, lb

$F_{tu}$ = ultimate tensile strength, psi.

Therefore, the required shell thickness is:

$$t = \left(\frac{W}{F_{tu}}\right)^{0.71} = \left(\frac{30,000}{78,000}\right)^{0.71} = 0.51 \text{ in.}$$

On the basis of an outer shell thickness of 0.75, the present cask design is shown to comply with the regulatory puncture criteria.

a.2.2.2. Drop on Lifting Lug. In the event of a drop on the lifting lug, the cask shell could be penetrated by the lug. The aforementioned empirical equation developed by ORNL for 6-in.-diameter penetrators is not applicable to the rectangular-shaped lug.

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* Nelms, H. A., "Structural Analysis of Shipping Casks, Vol. 3, Effects of Jacket Physical Properties and Curvature on Puncture Resistance", Oak Ridge National Laboratory, ORNL-TM-1312, Vol. 3, June, 1968.

For calculational purposes, it is assumed that the shell would fail by pure shear of the lug through the 1/2-in. shell. The contribution of the weld of the 1-in. doubler to the lug is conservatively neglected. Shear area in the shell is given by:

$$A = 2t(W + h) = (2)(0.5)(1.5 + 5.50)$$

$$A = 7.0 \text{in.}^2$$

and the force to cause shear failure is:

$$F = (F_{su})(A) = (54,300)(7.0)$$

$$F = 380,100 \text{ lb} .$$

Furthermore, the maximum force required to cause compressive yielding in the lug is:

$$F = F_{cy} A = F_{ty} A ,$$

where

$$A = (W)(h)$$

$$\therefore \; F = (31,900)(1.5)(5.50) = 263,200 \text{ lb.}$$

Hence, the lug will yield in compression before it will penetrate the outer shell of the cask.

a.2.2.3. Drop on the Cover of the Cask. A drop on the cover of the cask must be analyzed to determine if the U-shaped eye (lifting device) on the cover would penetrate the top plate. Accordingly, the force required to cause one weld to shear is calculated by:

$$F = (F_{su})(A) = (F_{su})(\pi)(d)(t)(0.707) ,$$

where

d = the U-eye diameter = 0.75 in.

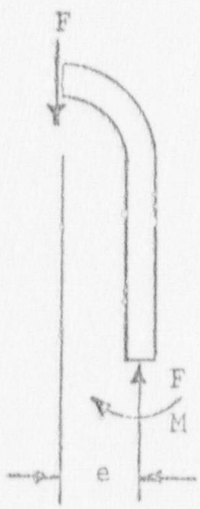
t = the weld thickness = 0.50 in.

Therefore,

$$F = (48,000)(\pi)(0.75)(0.5)(0.707)$$

$$F = 40,000 \text{ lb.}$$

In addition, however, the U-shaped eye could possibly fail by bending as illustrated in the sketch below.




The resisting moment M is developed to counteract the couple produced by the bending force F. Accordingly, the fiber stress developed in the U-shaped eye is:

$$\sigma_f = -\frac{F}{A} \pm \frac{Mc}{I} = -\frac{F}{A} \pm \frac{(Fe)(c)}{I}$$

$$= F\left(-\frac{1}{A} \pm \frac{ec}{I}\right)$$

where

$$A = \frac{\pi d^2}{4} = 0.441 \text{ in.}^2$$

$$e = 1.625 \text{ in.}$$

$$c = d/2 = 0.375 \text{ in.}$$

$$I = \frac{\pi d^4}{64} = 0.01558 \text{ in.}^4 .$$

Therefore,

$$\sigma_f = F\left(- \frac{1}{0.441} \pm \frac{(1.625)(0.375)}{0.01558}\right)$$

$$= F(- 2.26 \pm 39.15)$$

$$= + 36.89\ F \text{ or } - 41.41\ F$$

and

$$F = \frac{\sigma_f}{+ 36.89} \text{ or } \frac{\sigma_f}{- 41.41} .$$

If the fibe. design stress, $\sigma_f$, is taken as the yield stress:

$$\sigma_f = F_{ty} = F_{cy} = 66{,}000 \text{ psi} ,$$

and

$$F = \frac{66{,}000}{+ 36.89} \text{ or } \frac{- 66{,}000}{- 41.41}$$

$$= 1800 \text{ lb or } 1600 \text{ lb.}$$

Therefore, the U-shaped eye will fail in bending before the weld will shear.

a.2.2 4. Drop on Lug and Drain Boss. For a drop on the side in which the impact occurs on the lug and drain boss (i.e., one of the six lugs will be aligned with the drain boss), the lug and boss would tend to puncture the shell. The case of the lug was analyzed above and found to yield before puncture would occur. In the case of the boss, the puncture condition can be evaluated by referring to the basic derivation of the puncture equation by Nelms* for the case of a drop onto a 6-in.-diameter cylinder. The general empirical equation is:

$$\frac{E_F}{F_{tu}} = 2.4\ d^{1.6}\ t^{1.4}$$

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* Ibid., Chapters VI, VII, and VIII.

where

$E_F$ = the kinetic energy of the cask at the moment of impact, in.-lb

$F_{tu}$ = the tensile ultimate strength of the 1/2-in. shell = 81,400 psi

d = the diameter of the penetrator = 4 in.

t = the minimum permissible shell thickness, in.

For a drop on the lug and boss, it is assumed that half of the kinetic energy would be taken by each member. Therefore,

$$E_F = \frac{1}{2}Wh = \frac{1}{2}(30{,}000)(40) = 600{,}000 \text{ in.-lb} ,$$

and

$$\frac{600{,}000}{81{,}400} = (2.4)(4^{1.6})(t^{1.4})$$

$\therefore$ t = 0.46 in.

Since the shell is 0.50 in. thick, it will not puncture.

b. Shipment May Be Evaluated Together With or Without Transport Vehicle. All of the foregoing structural analyses have been based on a shipment without transport vehicle.

c. Other Transport Conditions May Be Approved by the Commission. Not applicable.

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