SAFETY ANALYSIS REPORT

FOR

MODEL CNS 1-13C

TYPE "B" SHIPPING PACKAGE

REVISION 0

NOVEMBER 1987

Submitted By:

CHEM-NUCLEAR SYSTEMS, INC.

220 Stoneridge Drive

Columbia, SC 29210
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1.0 GENERAL INFORMATION

1.1 Introduction

This Safety Analysis Report describes a reusable shipping package designed to protect radioactive material from both normal conditions of transport and hypothetical accident conditions. The package is designated as the Model CNS 1-13C capable of transporting miscellaneous non-fissile or fissile exempt irradiated reactor components packaged in secondary containers.

1.2 Package Description

1.2.1 Packaging

(1) General

A steel encased lead shielded shipping cask. The packaging is a steel double-walled, lead-filled circular cylinder. A steel, plug-type, lead-filled lid is attached with twelve, 1-1/4" bolts; and a silicone gasket. Outer steel sheets are separated from the cask walls with small diameter wires. The lead shielding is 5" in the sides, 6" in the base and 5-3/4" in the lid. Two bolted-on steel lugs are for lifting only. The lid has a steel U-bar for lifting. The cavity drain line is closed with a plug. The cask is 26-1/2" in diameter and 54" long. The package weight is about 26,000 pounds.

The packaging is constructed in accordance with Chem-Nuclear Systems, Inc., Drawing Nos. C-110-E-0005, Sheets 1, 2, and 3, and C-112-B-006.
1.2.1 Packaging (continued)

(2) Cask Body
a. Outer Shell
   Steel plate is 1/2 inch thick, 67-1/16 inches high by 38-1/2 outer diameter with a 1/2 inch bottom plate and a 1/2 inch top flange.

b. Cavity
   1/2 inch stainless steel wall and bottom plate, 26-1/2 inches inner diameter by 54 inches deep.

c. Shielding Thickness
   5 inches of lead on sides, 6 inches of lead beneath cavity.

d. Penetration
   One, 1/2 inch outer diameter by 0.065 inch wall stainless steel tube gravity drain line from the center of cavity bottom to the side of the outer shell near the cask bottom, closed with a 1/2 NPT square head stainless steel pipe plug which protrudes 1/2 inch outside of shell surface. The drain line will be closed with a plug during transport.

e. Filters
   None.

f. Lifting Devices
   Two diametrically opposed ears bolted to sides of cask, removed during transport.
(3) Cask Lid
  a. Shape
     A conical cylinder attached to flat plates.

  b. Size
     Top plate is 38-1/2 inches diameter by 1/2 inch thick. Bottom
     plate is 30 inches diameter by 1/2 inch thick. The top
     conical cylinder diameter is 32-1/4 inches and the bottom
     conical cylinder diameter is 30 inches high. The cylinder is
     5-3/4 inches high.

  c. Construction
     Lead-filled steel clad conical cylinder welded to circular
     steel plates.

  d. Closure
     Twelve, 1-1/4 inch -7 UNC-2A steel bolts equally spaced 30°
     apart on a 35-3/8 inch diameter bolt circle.

  e. Closure Seal
     A minimum 3/16 inch thick flat silicone rubber or equivalent
     gasket between body and lid.

  f. Penetrations
     None.

  g. Shield Expansion Void
     None.

  h. Lifting Device
     Single steel loop, 1 inch diameter stainless steel rod located
     in center of lid top. Covered by bolted cap during transport.
(4) **Fire Shield**
Basically a right circular cylinder, 1/4 inch steel attached to, and separated 0.060 inch from, the cask outer shell. The 0.060 inch separation is maintained on the cask side with 0.060 inch diameter wire attached circumferentially to the cask shell 6 inches apart, and on the top and bottom with 0.060 inch diameter wire attached 2 inches apart. A cover plate is bolted to the fire shield over the drain during transport.

(5) **Tie-down Devices**
The tie-down system for the CNS 1-13C Cask consists of a carbon steel frame that fits over the top of the cask. The frame is an annular ring with an "L" shaped cross section, 6 inches high, and 6 inches in annular width, and 1-1/2 inches thick. Six lugs are attached to the ring to attach the tie-down cables. Two lugs will be located 90 degrees from the lifting ears. Two additional lugs are located on each side of each central lug at 45 degrees from the central lug.

### 1.2.2 Operational Features

(1) **Transportation**
The contents described in 1.2.3(b) shall be transported on a motor vehicle, railroad car, aircraft, inland water craft, or hold or deck of a seagoing vessel assigned for sole use of the licensee.

(2) **Cask Seal**
It is required that the drain plug be in place and only removed to drain liquid from the cask. A gasket is required for the seal between cask lid and the cask body; this gasket should be inspected each time lid is removed and replaced if it is defective.

(3) **Lid-Eye Bolt**
This eye is only to be used to lift lid. It is not designed to lift the entire cask. The cover plate for this eye bolt shall be in place and only removed for lifting of lid.

(4) **Cask**
Empty shipping weight of entire cask including tie-down device is approximately 21,200 pounds.
(5) Tie-Down Device
All shipments of the CNS 1-13C Cask will be tied-down to shipping bed by the CNS 1-13C Tie-Down Device. (See Figure I-A)
NOTE: Do not tie-down by the two diametrically opposed ears. They should have a cover plate attached at all times during shipment.

(6) Cask Lifting
The lifting of entire cask with or without lid is accomplished by using the two diametrically opposed ears protruding from the cask body.

(7) Cask Liner
No shipments will be made in the CNS 1-13C Cask without first placing a liner in cask cavity. 
NOTE: If the cask will be loaded under water, liner shall have adequate drain holes. Before loading liner, measure to assure it will fit properly in cask cavity.
MATERIAL: ASTM A-36

SECTION A-A

CASK TIE-DOWN RING

Figure I-A
1.2.3 Contents of Packaging

Type, form and maximum quantity of material per package

(a) Greater than Type A quantity of byproduct material as sealed sources or solid metal. Decay heat not to exceed 600 watts; or

(b) Decay heat not to exceed 5 watts, and:

Process solids, either dewatered, solid, or solidified in a secondary sealed container meeting the requirements for low specific activity material; or

Solid reactor components in secondary containers, as required, that meet the requirements for low specific activity material.
1.3 APPENDIX

1.3.1 Chem-Nuclear Systems, Inc. Drawings

The CNS I-13C Cask is fabricated in accordance with the following CNSI Drawings:

- Drawing No. C-110-E-0005, Rev. D
- Drawing No. C-112-B-0006, Rev. A
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Figure withheld under 10 CFR 2.390
FIGURE WITHHELD UNDER 10 CFR 2.390
NOTES:

1) FOR GENERAL NOTES AND BILL OF MATERIALS SEE SHEET 1 OF 3

2) WELDS SHALL BE LIQUID PENETRANT (PT) INSPECTED IN ACCORDANCE WITH ASME CODE SECTION III, DIV I, SUBSECTION NB, ARTICLE NB-5000 AND SECTION V, ARTICLE 6

CNS 1-13C
SHIPPING CASK
FIGURE WITHHELD UNDER 10 CFR 2.390
2.0 STRUCTURAL EVALUATION

2.1 Structural Design

2.1.1 Discussion
Analysis was performed to demonstrate that the CNS-1-13C Cask structural integrity complied with the applicable structural requirements of 10 CFR 71. The cask is constructed of 304 stainless components except where specifically noted. Primary structural support for the cask is provided by the 1/2 inch thick inner and outer shells. Additional stiffness support is provided to the outer shell by a ring 1 inch thick and 8 inches wide around the inside of the shell opposite the lifting lugs.

2.1.2 Design Criteria
The structural analysis was performed to comply with the appropriate paragraphs of 10 CFR 71 as they apply to the integrity of the cask body. Specifically, the following analysis demonstrates that the loading requirements for lifting devices and for tie-down devices will not yield the material of the cask containment structure. Further, the analysis shows the pressure loading and direct loading requirements defined in 10 CFR 71 will not produce excessive loads in the cask containment structure.

The structural analysis performed in conjunction with the 30 foot drop accident will show that the lid remains attached to the cask body to contain the cask cavity contents within the cask cavity. Deformation of the cask body produced by the 30 foot drop, as it pertains to loss of shielding, will be discussed in the shielding section of this report.

No loading analysis will be performed on the cask containment resulting from internal pressure. Preservation of the cask lid seal is not required as no liquids or loose powders will be transported uncontained within the cask cavity.
2.2 Weights and Centers of Gravity

2.2.1 Basic weight of empty cask = \( W_E \) = 19,950 pounds.

2.2.2 Weight of Payload - \( W_p \).
Assume the maximum cavity load to be used for the following analysis:
\( W_p = 5000 \) pounds.
This is in excess of loads normally transported in this cask by a factor of 5 - 10.

2.2.3 Weight of New Fire Shield - \( W_F \).
Basic cask outer dimensions:
Diameter = 38.5 inches,
Height = 68 inches.
Density = \( P \).
Fire shield dimension:
1/4 inch plate - 0.060 inch from cask surface.

\[
W_F = P \left[ V_{\text{top}} + V_{\text{bottom}} + V_{\text{side}} \right].
\]
\[
= P \left[ 2\pi R_s t H_s + (2)\pi R_s^2 t \right].
\]
\[
R_s = D/2 + 1/8 = \frac{38.5}{2} + 0.125 = 19.375 \text{ inches}.
\]
\[
H_s = H + 2(1/8 + 1/4) = 68 + 3/4 = 68.75 \text{ inches}.
\]
\[
W_F = (489)[2\pi\left(\frac{19.375}{12}\right)(0.25)(68.75) + (2)\pi\left(\frac{19.375}{12}\right)^2(0.25)].
\]
\[
= (489) [1.210 + 0.342].
\]
\[
= 759 \text{ pounds}.
\]
Assume wire and welds add to fire shield to give total weight of:
\( W_F = 1000 \) pounds.
2.2.4 Weight of Lid - $W_L$.

It is necessary to know the weight of the lid to evaluate lid closure bold stresses during dynamic loading.

(1) Lead:
Volume = $\frac{\pi}{3} [r_0^2 + r_0 r_i + r_i^2]h$.
- $r_0 = 15.625$ inches.
- $r_i = 14.5$ inches.
- $h_i = 5.75$ inches.
Volume = $\frac{\pi}{3} [244.1 + 226.6 + 210.3] (5.75)$
= 4100 in.$^3$
= 2.373 ft.$^3$

(2) Steel:
Volume = $V_{(top)} + V_{(bottom)} + V_{(side)}$.
= $\pi(19.25)^2(.75) + \pi(15)^2(.5) + \pi(\frac{16.125+15}{2})(.5)(5.75)$.
= 873.1 + 353.4 + 231.1
= 1508 in.$^3$
= 0.872 ft.$^3$

(3) Total Weight:
$P_{(lead)} = 710$ lbs./ft.$^3$
$P_{(steel)} = 489$ lbs./fts.$^3$
$W_L = (710)(2.373) + (489)(.872)$.
= 1684.7 + 426.6
= 2111 pounds.
2.2.5 Total Weight of Cask - $W$.

\[ W = W_E + W_P + W_F. \]
\[ W = 19,950 + 5000 + 1000. \]
\[ W = 25,950 \text{ pounds}. \]

2.2.6 Weight of outer shell - $W_{OS}$.

Volume

\[ \text{Volume} = 2\pi(18.75)(.5)(66.75) + \pi(19.25)^2(1.25). \]
\[ = 3931.9 + 1455.2. \]
\[ = 5387 \text{ in}^3. \]
\[ = 3.118 \text{ ft}^3. \]
\[ W_{OS} = 1524 \text{ pounds}. \]

2.2.7 Weight of inner shell - $W_{IS}$.

Volume

\[ \text{Volume} = 2\pi(13.25)(.5)(54) + \pi(14.25)^2(1.0). \]
\[ = 2248.8 + 637.9. \]
\[ = 2885.7 \text{ in}^3. \]
\[ = 1.670 \text{ ft}^3. \]
\[ W_{IS} = 817 \text{ pounds}. \]

2.2.8 Weight of Lead - $W_{PB}$.

Volume

\[ \text{Volume} = \pi(R_0^2 - R_1^2)H + \pi R_1^2(t_1 + t_2). \]
\[ R_0 = 18.75 \text{ inches}. \]
\[ R_1 = 13.75 \text{ inches}. \]
\[ H = 66.75 \text{ inches}. \]
\[ t_1 = 5.75 \text{ inches}. \]
\[ t_2 = 6.00 \text{ inches}. \]

\[ \text{Volume} = \pi[(18.75)^2 - (13.75)^2](66.75) + \pi(13.75)^2(11.75). \]
\[ = 34,076 + 6979. \]
\[ = 41,055 \text{ in}^3. \]
\[ = 23.76 \text{ ft}^3. \]
\[ W_{PB} = 16,869 \text{ pounds}. \]
2.3 Mechanical Properties of Materials

The following properties were utilized to evaluate the mechanical integrity of the CNS 1-13C Cask.

2.3.1 304 Stainless Steel - Cask Shells.
- Ultimate Tensile Strength \((1,2,3)\) 75,000 - 85,000 psi.
- Yield Strength \((1,2,3)\) 30,000 - 35,000 psi.
- Dynamic Flow Stress \((4)\) 30,000 - 45,000 psi.
- Modulus of Elasticity \((E) (5)\) at 200°F 27x10^6 psi.
- Poisson's Ratio \((\nu) (6)\) 0.30.
- Thermal Expansion \((\alpha) (7)\) at 200°F 9.5x10^{-6} in./in.-°F.
- Density \((\rho) (9)\) 489 lbs./ft.³.

2.3.2 Lead - Shielding.
- Ultimate Tensile Strength \((6)\) 2300 - 3000 psi.
- Yield Strength \((6)\) 1180 - 1330 psi.
- Dynamic Flow Stress \((9)\) 5000 - 10,000 psi.
- Modulus of Elasticity \((E) (6)\) 2x10^6 psi.
- Poisson's Ratio \((\nu) (6)\) 0.45.
- Thermal Expansion \((\alpha) (6)\) 1.61x10^{-5} in./in.-°F.
- Density \((\rho) (8)\) 710 lbs./ft.³.

2.3.3 SA-354, Type BD Bolts.
- Ultimate Tensile Strength \((10)\) 150,000 psi.

2.3.4 Carbon Steel, A-36 - Tie-down.
- Yield Strength \((11)\) 36,000 psi.
2.4 GENERAL STANDARDS FOR ALL PACKAGES

2.4.1 Minimum Package Size

The shielded cask is 39.13 inches outer diameter by 68.69 inches high.

2.4.2 Tamperproof Feature

A lock wire and seal of a type that must be broken if the package is opened is affixed to the cask closure.

2.4.3 Positive Closure

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

2.4.4 Chemical and Galvanic Reactions

There are no components of the packaging or its contents which are subject to chemical or galvanic reaction.
2.5 LIFTING AND TIE-DOWN STANDARDS FOR ALL PACKAGES

2.5.1 Lifting Devices

The CNS 1-13C Cask is provided with two lifting lugs attached to the side of the cask by which the cask and load can be lifted. The lid is provided with a lifting ring by which the lid may be removed from the cask. Neither the cask lifting lugs nor the lid lift ring will be used for tie-down and each will be provided with a cap or locking device to prevent such use.

The load requirements for lifting devices are defined in 10 CFR 71, Subpart E, Paragraph 71.45.

(1) Lifting Lugs

The load condition imposed on the lift lugs is as follows:

\[ W = 25,950 \text{ pounds.} \]

Impact Load = \(3W = 77,850 \text{ pounds.}\)

Therefore \(P = 38,925 \text{ pounds.}\)
2.5.1 Lifting Devices (continued)

a. Shear in Bolts - Each lifting lug is attached to the container with 4-1-8UNC-2A x 2-1/4 stainless steel bolts.

For each bolt: \[ A = \frac{\pi}{4}(1.0)^2 = 0.785 \text{ in.}^2. \]

\[ \sigma_s = \frac{(38,925) \text{ lbs.}}{4(.785) \text{ in.}^2} = 12,400 \text{ psi}. \]

The shearing yield stress will be taken as:

\[ \sigma_{ys} = \frac{\sigma_y}{\sqrt{3}} \quad \text{where } \sigma_y = \text{Tensile Yield Stress}. \]

This relationship is generally used for carbon steel:

\[ \sigma_{ys} = \frac{30,000}{\sqrt{3}} = 17,320 \text{ psi}. \]

Safety Factor \[ = \frac{\sigma_{ys}}{\sigma_s} = \frac{17,320}{12,400} = 1.40. \]

b. Tension in Bolts Due to Bending (21).

\[ P = 38,925 \text{ pounds.} \]

\[ M = (38,925) \text{ pounds (5) inch.} \]

\[ M = 194,625 \text{ in./lbs.} \]
2.5.1 Lifting Devices (continued)

Consider the following load condition between the bolts and plate. This loading will consist of tension in the lower bolts and a "bearing pressure" between the plate and the lifting ear.

\[ L = 5 \text{ inches.} \]
\[ b = 5.5 \text{ inches.} \]
\[ A_{\text{bolt}} = 0.785 \text{ in.}^2 \]

- Summation of Forces.
  \[ \Sigma F = 0. \]
  \[ 1/2 \, qb \, L = F. \]

- Summation of Moments.
  \[ \Sigma M = 0. \]
  \[ M = F\left(L - \frac{L}{3}\right). \]

Condition of Compatibility - Deflection Analysis.

\[ \frac{\delta_{\text{bolt}}}{\delta_{\text{plate}}} = \frac{\sigma_{\text{bolt}}}{E} \]
\[ \frac{q}{E} \]

Since both materials are 304 stainless steel:

\[ \frac{\delta_{\text{bolt}}}{\delta_{\text{plate}}} = \frac{\sigma_{\text{bolt}}}{q} = \frac{F}{2A_{\text{bolt}}} \]

\[ \frac{q}{q} \]
2.5.1 Lifting Devices (continued)

Also:

\[ \frac{6\text{bolt}}{6\text{plate}} = \frac{L-l}{L} \]

Therefore:

\[ \frac{L-l}{L} = \frac{F}{2A/q} \]

\[ F \cdot L = 2Aq(L-l). \]

The above three equations contain three unknowns: \( F \), \( q \), and \( L \). Substituting the appropriate values produces the following set of equations.

(i) Summation of Forces: \( F = 2.75qL \)

(ii) Summation of Moments: \( 15F - FL = 583,875 \).

(iii) Condition of Compatibility: \( FL = 7.85q - 1.57qL \)

Solve for \( L \) in equation (i) and substitute into equations (ii) and (iii).

\[ 15F - \frac{F^2}{2.75q} = 583,875. \]

\[ \frac{F^2}{2.75q} = 7.85q - \frac{(1.57)F}{2.75}. \]

Rearranging and Combining:

\[ 15F - 7.85q + 0.571F = 583,875. \]
Solve equation for "q" and substitute into:
\[ 21.59q^2 - 1.57qF = F^2 \]
gives: \( q = 1.93F - 74,379. \)
\[ 84.64F^2 - 6.36x10^6F - 3.11F^2 + 1.17x10^5F = F^2. \]
rearranging:
\[ 80.53F^2 - 6.24x10^6F - 1.194x10^{11} = 0. \]
\[ F^2 - 7.75x10^4F - 1.483x10^9 = 0. \]
Solve equation for "F" and substitute to obtain "q":
\[ F = 38,750 \pm (4310). \]
\( F_1 = 43,060 \) pounds \( F_2 = 34,400 \) pounds
\( q_1 = 10,880 \) psi \( q_2 = -6,188 \) psi

By sign convention, condition 2 will not satisfy the balance of forces in equation (i).

Therefore, the maximum bearing stress on the plate is:
\[ \sigma_b = 10,880 \text{ psi} \]
Safety Factor = \( \frac{30,000}{10,880} = 2.76. \)

The maximum tensile stress in the bolts will be:
\[ \sigma_t = \frac{F}{2A_{\text{bolt}}} \]
\[ = 27,430 \text{ psi}. \]
Yield strength of the bolt = 0.785 x 30,000 = 23,550 lbs.

The force exhibited on each bolt is \( F = \frac{43,060}{2} = 21,530 \) lbs.

Therefore:
Safety Factor = \( \frac{23,550}{21,530} = 1.09 \).

c. Shear in Bolt Insert

The insert is threaded into the lifting lug adapter plate, cask outer wall and lift lug backing ring and seal welded to the lift lug adapter plate of the cask. The inserts are drilled and tapped to accept the above mentioned bolts. Four inserts are mounted at each lift lug attachment point by drilling 1-1/2 inch diameter holes 1-3/4 inch deep and providing a 1/8 inch partial penetration by 45 degrees seal weld. Drawing C-110-E-0005, Sheet 3 of 3 shows the details of the insert mounting.

The following equation demonstrates the adequacy of the thread engagement to the cask body. No credit has been taken for the strength of the welds.

The shear strength of the threaded engagement of the insert (engagement length 1-3/8") is,

\[
F_{\text{MAX}} = x 1\ 1/2 \times 1\ 3/8 \times 0.577 \times 30,000
\]

\[
= 112,161 \text{ lbs.}
\]

Therefore, the strength of the insert (112,161 lbs) is much greater than the strength of the bolt (23,550 lbs., as shown previously).
2.5.1 Lifting Devices (continued)

d. Tension in Lug.

\[ \sigma_t = \frac{P}{A}. \]

\[ \sigma_t = \frac{38,925}{2(1.0 \times 1.0)} = 19,460 \text{ psi}. \]

Safety Factor \( \frac{\sigma_y}{\sigma_t} = \frac{30,000}{19,460} = 1.54. \)

e. Vertical Welding on Lug.

Assuming 3/8 inch fillet welds each side - continuous.

\[ A_w = (2)(17)(3/8)\sqrt{2} = 9.02 \text{ in.}^2 \]

Neglecting bottom plate.

(1) Shear Stress \( \sigma_s = \frac{P}{A_w}. \)

\[ \sigma_s = \frac{(38,925) \text{lbs.}}{(9.02) \text{in.}^2} = 4315 \text{ psi}. \]

Safety Factor \( \frac{\sigma_{ys}}{\sigma_s} = \frac{17,320}{4315} = 4.01. \)
2.5.1 Lifting Devices (continued)

f. Bending Stress - \( \sigma_b = \frac{Mc}{I} \).

\[ M = (P)l. \]

\[ I = 2 \left( \frac{bh^3}{12} \right) \quad \text{Two sides.} \]

For the weld - \( b = \frac{3}{8} \left( \frac{2}{2} \right) = 0.265 \) inch.

\[ h = 17 \text{ inches.} \]

\[ l = 5 \text{ inches.} \]

\[ c = h/2 = 8.5 \text{ inches.} \]

\[ I = 2 \left( \frac{.265)(17)^3}{12} \right) = 217 \text{ in.}^4. \]

\[ \sigma_b = \frac{(38,925)\text{lbs.}(5)\text{in.}(8.5)\text{in.}}{(217)\text{in.}^4} \]

\[ = 7620 \text{ psi.} \]

Safety Factor - \( \frac{30,000}{7,620} = 3.94. \)

(2) Welding on Cask Reinforcing Plate.

\[ \frac{P}{6.75^\circ} \]

3/8" FILLET WELD ALL AROUND
2.5.1 Lifting Devices (continued)

a. Shear Stress - $\sigma_s = P/A$.

\[ A = \text{(Perimeter)} \times \text{(Effective Weld Thickness)} = ((2)(8) + 2(5.5))(3/8 \times \sqrt{\frac{2}{2}}) = 7.16 \text{ in.}^2 \]

\[ \sigma_s = \frac{(38,925)\text{lbs.}}{7.16\text{in.}^2} = 5440 \text{ psi.} \]

Safety Factor $= \frac{17,320}{5,440} = 3.19$.

b. Bending Stress - $\sigma_b = Mc/I$.

\[ M = (P)(1). \]

\[ I = I_{\text{outer}} - I_{\text{inner}} = \frac{bh^3}{12}_0 - \frac{bh^3}{12}_1 \]

\[ b_0 = 6.03 \text{ in.} \quad b_2 = 5.50 \text{ in.} \]
\[ h_0 = 8.53 \text{ in.} \quad h_2 = 8.0 \text{ in.} \]
\[ l = 6.75 \text{ in.} \]
\[ c = h_0/2 = 4.265 \text{ in.} \]

\[ I = 1/12[(6.03)(8.53)^3 - (5.5)(8)^3] = 77.21 \text{ in.}^4 \]

\[ \sigma_b = \frac{(38,925)\text{lbs.}(6.75)\text{in.}(4.265)\text{in.}}{(77.21)\text{in.}^4} = 14,520 \text{ psi.} \]

Safety Factor $= \frac{30,000}{14,520} = 2.07$. 

(0157W) 2-15
2.5.1 Lifting Devices (continued)

(3) Stresses in Outer Shell.
The CNS 1-13C Cask is designed with a reinforcing ring 8 inches high, 1 inch thick and located directly opposite the lifting lugs on the inside surface of the outer shell.

\[ P = \text{Radial Force.} \]
\[ M_L = \text{Moment in longitudinal direction to shell.} \]
\[ M_C = \text{Moment in circumferencial direction to shell.} \]

It will be necessary to determine the stress generated in the shell due to the loading transmitted by the lifting lug pad. The presence of the inner reinforcing ring will be accounted for.

The solution to this problem will be effected using a method accepted by Bechtel Corp. \(^{(12)}\) and is included as Appendix B for reference. This method provides a solution for local stresses in a cylindrical shell due to loading to attachments on that shell. Stresses resulting from unit loadings on the shell are tabulated for various \(C_2/C_1\) ratios and cylinder diameters. Only the tables including the range of interest for this problem have been included with the appendix.
2.5.1 **Lifting Devices (continued)**

Referring to the previous sketch, the maximum stresses in the shell will be:

\[ S_L = (A1)(P) + (A2)(M_L) \]
\[ S_C = (A1)(P) + (A3)(M_C) \]

*\( S_L \) - Maximum stress in shell in longitudinal direction.
*\( S_C \) - Maximum stress in shell in circumferential direction.

These bending stresses will be combined with inplace shear stress for this problem:

Radial Force - \( P = 0 \).

Longitudinal Moment - \( M_L = (38.93)\text{kips} \left( \frac{6.75}{12} \right) \text{ft.} \)

\[ = 21.90 \left( \text{ft./kips} \right) \]

Circumferential Moment - \( M_C = 0 \).

The inner reinforcing ring will be capable of resisting a portion of the longitudinal moment, thus reducing the moment exerted on the shell. 10 CFR 71, Subpart E, Paragraph 71.45 prohibits any condition where the stress level is in excess of the material yield strength. When a load is imposed on a system composed of two structural elements, the load redistribution begins as soon as the stress level in one of the elements reaches its yield point. As long as the total strength of the systems, calculated from the yield points, is greater than the applied loading, the stress level in the system will not exceed the respective yield points.

The maximum moment that may be taken by the reinforcing ring will either occur in bending or in torsion of the ring. The dead load distributed along the shell circumference is assumed to be taken by the shell itself.
For this analysis, the minimum yield stress ($\sigma_y = 30,000$ psi), available from the literature was used.

a. Bending - This stress will be resisted by the cross section of the ring.

\[ \sigma_a = \frac{M_R C}{I} \]

Therefore:
\[ M_R = \frac{\sigma_a I}{C} \]

\[ I = 2\left(\frac{bh^3}{12}\right) = 2\left(\frac{(1.0)(8.0)^3}{12}\right) \]

\[ = 85.33 \text{ in.}^4 \]

\[ \sigma_a = 30,000 \text{ psi} \quad \text{allowable stress.} \]

\[ C = 4.0 \text{ in.} \]

Therefore:
\[ M_R = \frac{(30,000) \text{ lbs.}(85.33) \text{ in.}^4}{\text{in.}^2(4.0)\text{ in.}} = 640,000 \text{ in./lbs.} \]

\[ = 53.36 \text{ ft./kips.} \]
2.5.1 Lifting Devices (continued)

b. Torsion - The cylinder will also resist a torque moment producing shear stress. This torque loading will be resisted by the longitudinal cross section of the ring.

Maximum shear occurs at midpoint of longer side.

From Roark (13).

\[ t = \frac{\tau (3a + 1.8b)}{8 a^2 b^2} \]

2a = 8.0 in. \quad a = 4.0 in.
2b = 1.0 in. \quad b = 0.5 in.

The maximum torque that can be taken by this ring without yielding will be:

\[ T = K_T \sigma_{ys} \]

\[ K_T = \frac{8 a^2 b^2}{3a + 1.8b} = \frac{8(4)^2(0.5)^2}{3(4) + 1.8(0.5)} = 2.48 \text{ in.}^3 \]

\[ \sigma_{ys} = \frac{\sigma_y}{\sqrt{3}} = 17,320 \text{ psi.} \]

Resisting torque will be:

\[ T_R = 2 K_T \sigma_{ys} \]

\[ = (2)(2.48)\text{in.}^3 (17,320) \text{ psi.} \]

\[ = 85,900 \text{ in./lbs.} \]

\[ = 7.16 \text{ ft./kips.} \]

Comparison of the bending and torsion loads at yield indicate that the torsion loading is the one that governs the maximum load the reinforcing ring can take.
2.5.1 Lifting Devices (continued)

The moment which the shell can resist will be the difference between the total moment and that taken by the reinforcing ring.

\[ M_S = M_L - M_R. \]
\[ = 21.90 - 7.16. \]
\[ = 14.74 \text{ ft.}/\text{kips}. \]

\[ \text{c. The maximum stress in the shell from the load applied by the lifting lug pad will be:} \]
\[ S_L = (A2)(M_S). \]
\[ S_C = 0. \]

\[ C_1 = 5.5 \text{ inches.} \]
\[ C_2 = 8.0 \text{ inches.} \]
\[ R = 19.0 \text{ inches.} \]
\[ t = 0.5 \text{ inches.} \]

\[ \frac{C_2}{C_1} = 1.45. \]
\[ D = 3.17 \text{ Ft.} \]

The tables in the attached Bectel Design Guide (Ref. 12) are formatted to present the stress coefficients as a function of shell diameter (D) and shell thickness (t) for various attachment size (C2). Separate tables have been prepared for square attachment (C2/C1 = 1.00) and rectangular attachment (C2/C1 = 3.00). To obtain the stress coefficient for this...
problem, interpolate linearly between vessel diameter $D = 3.0$, $t = 0.5$ and diameter $D = 3.5$, $t = 0.5$ for both the square attachment with $C_2 = 8.0$ and the rectangular attachment with $C_2 = 8.0$. Next make a linear extrapolation (which is considered within the accuracy of engineering design and recommended by the Bechtel Design Guide\(^{(12)}\)) between $C_2/C_1$ ratio to obtain the value of $A_2$ for this problem.

For: $C = 8.0$.

\[
\begin{array}{c|c|c}
C_2/C_1 & D = 3.0 & A_2 = 3.384 \\
D = 3.5 & A_2 = 3.416 \\
\end{array}
\begin{array}{c|c|c}
C_2/C_1 & D = 3.0 & A_2 = 5.836 \\
D = 3.5 & A_2 = 6.082 \\
\end{array}
\]

Therefore: $D = 3.17 : A_2 = 3.395$; $D = 3.17 : A_2 = 5.920$

For $C_2/C_1 = 1.45 : A_2 = 3.963$

The maximum longitudinal stress in the shell will be:
\[
S_L = (3.963)(14.74) = 58.40 \text{ ksi.} \\
= 58,400 \text{ psi.}
\]

d. The maximum inplane shear stress is determined by:

\[
\sigma_s = \frac{P}{A_s} \quad A_s = 2Ht, \quad H = \text{Shell Height}
\]

\[
= \frac{(38.925)}{2(68)\text{in.}(.5)\text{in.}} = 572 \text{ psi.}
\]
2.5.1 Lifting Devices (continued)

The maximum normal and shear stresses are found by combining the longitudinal stress and the inplane stress.

Maximum Normal Stress = \( \frac{S_L}{2} \pm \sqrt{\left(\frac{S_L}{2}\right)^2 + \sigma_s^2} \)

\[ = \frac{58,400}{2} \pm \sqrt{\left(\frac{58,400}{2}\right)^2 + (572)^2}. \]

\[ = 29,200 \pm 29,206. \]

\[ = 58,410 \text{ psi}. \]

Maximum Shear Stress = \( \sqrt{\left(\frac{S_L}{2}\right)^2 + \sigma_s^2} \)

\[ = \sqrt{\left(\frac{58,400}{2}\right)^2 + (572)^2}. \]

\[ = 29,210 \text{ psi}. \]

e. The allowable limits for longitudinal and circumferential stresses in a shell are determined based on maximum permissible secondary stresses (combined with primary stresses, if any) in the shell. The back characteristic of the secondary stress is that it is self-limiting, inasmuch as minor distortions can satisfy the discontinuity or thermal expansions that cause this stress to occur. Both the ASME, Section III and Division 2 of the ASME Section VIII have adopted a design philosophy, permitting the use of higher allowable stresses without a reduction in safety. From ASME Pressure Vessel Code, Section VIII, Division 2, Paragraph 4.130(14), this maximum allowable stress for operating conditions is:

\[ S_{\text{allowable}} \leq 2S_{\text{yield}}. \]

Therefore: \[ S_{\text{allowable}} = (2)(30,000) = 60,000 \text{ psi}. \]
2.5.1 Lifting Devices (continued)

Normal Stress:
Safety Factor $= \frac{50,000}{58,400} = 1.03$.

Shear Stress:
Safety Factor $= \frac{2(17,320)}{29,210} = 1.19$.

f. Lid Lifting Eye.
The maximum lifting load exerted on the lifting eye of the cask lid is based on:

$W_L = 2111$ pounds.

$P = 3 W_L$.

$P = (3)(2111)$ pounds.

$= 6333$ pounds.

(4) Tension in the Lifting Eye.

\[ \sigma_t = \frac{P}{2A}, \]
\[ A = \pi/4(1.0)^2 = 0.785 \text{ in.}^2 \]

\[ \sigma_t = \frac{(6333)\text{lbs.}}{2(.785)\text{in.}^2} \]

\[ = 4040 \text{ psi.} \]

Safety Factor $= \frac{35,000}{4,040} = 8.66$.

(5) Welding Around Lifting Eye.

\[ A_{\text{eff.}} = \pi D_{\text{eff.}} = \pi(1.0)(3/8)(\frac{\sqrt{2}}{2}) = 0.833 \text{ in.}^2 \]

\[ \sigma_s = \frac{P}{2A_{\text{eff.}}} = \frac{6,333}{2(.833)} = 3810 \text{ psi.} \]

Safety Factor $= \frac{20,200}{3,810} = 5.30$.

(0157W)
2.5.2 Tie-Down Devices.

The tie-down system for transporting the package is required to be designed to load conditions defined in 10 CFR 71, Paragraph 71.45(b)(1). This load condition is defined as follows: "... the system shall be capable of withstanding, without generating stress in any material of the package in excess of its yield strength, a static force applied to the center of gravity of the package having a vertical component of two times the weight of the package and its contents, a horizontal component along the direction in which the vehicle travels of 10 times the weight of the package with its contents."

The CNS 1-13C Cask has been provided with a tie-down frame that sets over the top of the cask. The tie-down geometry is shown on the following figure. It should be noted that this frame does not attach to the cask structure and therefore is not a structural part of the package.

The tie-down frame is designed for the loading conditions previously described. The effects of the load transmitted to the cask structure from the frame then are considered.

(1) Tie-down Forces - Stress in the frame are determined for the forces transmitted by the cables, in resisting the "g" loading, to the frame. Since the cask will be blocked at the base on the transporter to prevent sliding, the cable resisting forces will be those resisting tipping. For the purpose of this analysis assume the tie-down frame weighs 500 pounds for the "g" load evaluation.
TIEDOWN GEOMETRY

FIGURE 2.5-2
2.5.2 Tie-Down Devices (continued)

a. Forces due to 10g loading.

\[ P_c = 259,500 \text{ pounds} \]
\[ P_x^c = 5,000 \text{ pounds} \]
\[ l_c = 2.86 \text{ ft.} \]
\[ l_F = 5.83 \text{ ft.} \]
\[ \tan \alpha_1 = 1.00 \]
\[ \alpha_1 = 45^\circ \]
\[ \tan \alpha_2 = \frac{5.83}{4.00-1.15} = 2.05. \]
\[ \alpha_2 = 64.0^\circ \]
\[ l_2 = 1.63 + 1.15 = 2.78' \]
\[ l_1 = 1.63' \]
\[ F_6^x = F_2^x \]
\[ F_{2x}^x = F_{2x}^x \cos 64^\circ. \]
\[ F_{2xx}^x = F_{2x}^x \cos 45^\circ. \]

Summing Moments about Point "O".

\[ F_{1x} x (l_F) + 2(F_{2xx} x)(l_F) + F_{1z} x (2l_1) + \]
\[ 2(F_{2z} x)l_2 = P_x F_1 + P_x C l_c. \]
\[ F_{1z} x = F_{1x} x \tan 45^\circ = F_{1x}^x. \]
\[ F_{2z} x = F_{2x} x \left( \frac{5.83}{4.03} \right) = 1.45 F_{2x}^x. \]
\[ (5.83)F_{1x} x + (11.66)(\frac{1}{2})F_{2x} x + 3.26F_{1x} x. \]
\[ 8.06F_{2x} x = 771,320 \text{ in./lbs.} \]
This equation contains two unknowns. To resolve this, use deflection theory to resolve the forces:

\[ \Delta = \frac{P_1}{AE} \text{ for each cable.} \]

- **Cable #1** - For unit load in direction of 10g force:
  \[ P_u = 1 \text{ pound.} \]

  In direction of cable:
  \[ \Delta_1 = \frac{(\sqrt{2} P_u)(8.24)}{AE} = \frac{11.66}{AE} \]
  \[ \Delta_x = \sqrt{2} \Delta_1 = \frac{16.49}{AE} \]
  \[ K_1 = \frac{1}{\Delta x_1} = .0606 \text{ AE.} \]

- **Cable #2** - For unit load in direction of 10g force:
  \[ P_u = 1.0 \text{ pound.} \]

  \[ \Delta_2 = \frac{[(7.09/4.03) P_{Ru}]7.09}{AE} \]
  \[ P_{Ru} = \sqrt{2} P_u = \sqrt{2} \]
  Therefore:
  \[ \Delta_2 = \frac{\sqrt{2}(7.09/4.03)7.09}{AE} = \frac{17.64}{AE} \]
2.5.2 Tie-Down Devices (continued)

\[
\Delta R_2 = \left(\frac{7.09}{4.03}\right) \Delta_2
\]

\[
\Delta x_2 = \sqrt{2} \Delta R_2
\]

\[
k_2 = 0.0228 \text{ AE.}
\]
This system can be represented as a system of springs and masses as:

\[
\begin{align*}
F_1 &= \Delta_1 k_1, \\
F_2 &= \Delta_2 k_2, \\
\Delta_1 &= \Delta_2
\end{align*}
\]

Therefore:
\[
\frac{F_1}{F_2} = \frac{k_1}{k_2}
\]

Therefore:
\[
F_{2x} = \frac{k_2}{k_1} F_{1x} = (\frac{0.228}{0.0606}) F_{1x} = 0.376 F_{1x}.
\]

9.09 \(F_{1x} + (16.30)(0.376) F_{1x} = 771,320.
\]

15.22 \(F_{1x} = 771,320.
\]
\[
\begin{align*}
F_{1x} &= 50,680 \text{ pounds}, \\
F_{1z} &= 50,680 \text{ pounds}, \\
F_{2x} &= 19,060 \text{ pounds}, \\
F_{2z} &= 27,630 \text{ pounds}.
\end{align*}
\]
2.5.2 Tie-Down Devices (continued)

b. Forces due to 5g transverse load.

\[ P_y C = 129,750 \text{ pounds} \]
\[ P_y F = 2,500 \text{ pounds} \]

\[ l_C = 2.86. \]
\[ l_F = 5.83. \]

\[ \tan \alpha = \frac{5.83}{4.03} = 1.45. \]
\[ \alpha = 55.3^\circ. \]

\[ l_1 = 1.63. \]
\[ l_2 = 2.78. \]

\[ F_2 y = F_3 y. \]

\[ F_{2xx} y = F_{2x} y \cos 45^\circ. \]

\[ F_{2z} y = 1.45 F_{2x} y. \]

Summing moments about point "O".

\[ 2F_{2xx} y(L_F) + 2F_{2z} y(12) = P_y C \ l_C + P_y F \ l_F. \]

\[ 2(5.83)(\frac{1}{2})F_{2x} y + 2(1.45)(2.78)F_{2x} y = (129,750)(2.86) + (2500)(5.83). \]

\[ (8.24)F_{2z} y + (8.06)F_{2x} y = 385,660. \]

\[ 16.30 F_{2x} y = 385,660 \text{ lbs./in.} \]
\[ F_{2x} y = 23,660 \text{ lbs.} \]
\[ F_{2z} y = 34,310 \text{ lbs.} \]
2.5.2 Tie-Down Devices (continued)

**c. Forces due to 2g vertical load.**

\[ P_z^F = 2W_C - W_F = W_F = 500 \text{ lbs.} \]

\[ P_z^C = 2W_C - W_C = W_C = 25,950 \text{ lbs.} \]

\[ P_z^1 = P_z^4 \]

\[ P_z^2 = P_z^3 = P_z^5 = P_z^6 = P_z^1. \]

- Cable #1 & #4 - Unit load in direction of 2g Force:
  \[ P_u = 1 \text{ lbs.} \]

\[ \Delta_1 = \frac{(\sqrt{2}P_u)(\sqrt{2})(5.83)}{AE} = \frac{11.66}{AE} \]

\[ \Delta x_1 = \sqrt{2} \Delta_1 = \frac{16.49}{AE} \]

\[ k_1 = \frac{1}{\Delta k_1} = \frac{0.0606}{AE} \]

- Cables, #2, 3, 5, & 6:

\[ \Delta_2 = \frac{[(7.09)P_u](7.09)}{AE} = \frac{8.62}{AE} \]

\[ \Delta z_2 = \frac{(7.09)}{5.83}\Delta_2 = \frac{10.49}{AE} \]

\[ k_2 = 0.0954 \text{ AE.} \]

\[ \Sigma k = 2k_1 + 4k_2 = 0.5027AE. \]
2.5.2 Tie-Down Devices (continued)

\[ F_{1z} = \left( \frac{k_1}{Z_k} \right) P_z + \left( \frac{0.0606}{50.27} \right)(25,950) = 3130 \text{ pounds.} \]
\[ F_{1x} = F_{1z} = 3130 \text{ pounds.} \]
\[ F_{2z} = \left( \frac{k_2}{Z_k} \right) P_z = \left( \frac{0.0954}{50.27} \right)(25,950) = 4930 \text{ pounds.} \]
\[ F_{2x} = \left( \frac{4.03}{5.83} \right) F_{2z} = 3410 \text{ pounds.} \]

The load summary for each cable is as follows:

<table>
<thead>
<tr>
<th>Cable No.</th>
<th>( F_x ) - lbs.</th>
<th>( F_z ) - lbs.</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>53,810</td>
<td>53,810</td>
</tr>
<tr>
<td>2</td>
<td>46,030</td>
<td>66,870</td>
</tr>
<tr>
<td>3</td>
<td>26,970</td>
<td>39,240</td>
</tr>
<tr>
<td>4</td>
<td>3,130</td>
<td>3,130</td>
</tr>
<tr>
<td>5</td>
<td>3,410</td>
<td>4,930</td>
</tr>
<tr>
<td>6</td>
<td>22,470</td>
<td>32,560</td>
</tr>
</tbody>
</table>

Where the following sketch shows a representation of the force components \( F_x \) and \( F_z \) in a typical cable:
2.5.2 Tie-Down Devices (continued)

(2) Stress in circular Frame - Inspection of the load pattern around the frame indicates that the maximum stress would occur in the frame between Cable 6, 1 and 2. The maximum stress will be produced by the horizontal force \(F_x\). In order to use available formulae for obtaining the maximum stress, the load pattern is broken down into two cases: (1) Cable 1 with a horizontal load of 53,810 pounds at point "a", (2) Cables 2 & 6 with horizontal forces of 46,030 lbs. at points "b". The results are combined according to the principle of superposition.

Assume \(R = 20\) inches.

For loading at point "a" refer to Roark(15), Table 17, Case 1.

Point a. \(M_a = 0.3183 PR\).
\[= (0.3183)(53,810) \text{ lbs.}/(20) \text{ in.}\]
\[= 342,550 \text{ in.}/\text{lbs.}\]

Point c. \(T_c = 0.5 P\).
\[= 26,910 \text{ lbs.}\]

For loading at Point b refer to Roark(16), Table 17, case 5.

Point a. \(M_a = PR \left[ \sin 45^\circ (1 - \frac{45}{180}) - \frac{1}{\pi} (1 + \cos 45^\circ) \right]\).
\[= (46,030)(20) \left[ \frac{1}{\sqrt{2}} (1 - .25) - \frac{1}{\pi} (1 + \frac{1}{\sqrt{2}}) \right]\]
\[= - 14,100 \text{ in.}/\text{lbs.}\]
2.5.2 Tie-Down Devices (continued)

Point b. \( M_b = PR[1/\pi (1 + \cos 45^\circ + \frac{45}{180} \sin 45^\circ \cos 45^\circ) \right. \]
\[- \sin 45^\circ \cos 45^\circ].
\[= (46,030)(20)[.543 + .125 - .500]. \]
\[= 154,660 \text{ in./lbs}. \]

The maximum load combination occurs at point a.
\( M = 342,550 \text{ in./lbs}. \)
\( T = 24,410 \text{ lbs}. \)

The maximum stress in the ring will be determined as follows:

(1) Cross Sectional Area:
\( A = (6)(1.5) + (4.5)(1.5). \)
\[= 15.75 \text{ in.}^2 \]

(2) Centroid:
\[ \bar{x} = \frac{A_1 x_1 + A_2 x_2}{\sum A} \]
\[= \frac{(6)(1.5)(.75) + (4.5)(1.5)(4.5 + 1.5)}{15.75} \]
\[= 2.04 \text{ inches}. \]
2.5.2 Tie-Down Devices (continued)

\[ I_y = \frac{1}{12} bh^3 + Ad^2 \]
\[ = \frac{1}{12} [(6)(1.5)^3 + (1.5)(4.5)^3] + (9)(2.04-.75) + (6.75)(3.75-2.04) = 47.79 \text{ in.}^4 \]

Section Modulus:

\[ S_y = \frac{I_y}{6.0-x} = \frac{47.79 \text{ in.}^4}{6.0-2.04} = 12.07 \text{ in.}^3 \]

Bending Stress - \( \sigma_b = \frac{M}{S_y} \)

\[ = \frac{342,550 \text{ in.-lbs.}}{12.07 \text{ in.}^3} \]
\[ = 28,380 \text{ psi.} \]

Tensile Stress - \( \sigma_{ts} = \frac{T}{A} \)

\[ = \frac{24,410 \text{ lbs.}}{15.75 \text{ in.}^2} \]
\[ = 1550 \text{ psi.} \]

Total Tensile Stress - \( \sigma_t = 29,930 \text{ psi.} \)

For Carbon Steel A-36 - \( \sigma_y = 36,000 \text{ psi.} \)

Therefore: Safety Factor \( = \frac{36,000}{29,930} = 1.20 \).
2.5.2 Tie-Down Devices (continued)

(3) Bearing Stress between Tie-down Frame and Cask.

Again, assuming the following conservative loading.

The total load in the "X" direction is:

\[ P = (53,810) \text{ lbs.} + 2 \sin 45^\circ (46,030) \text{ lbs.} = 118,910 \text{ lbs.} \]

Assume the contact arc is 90\(^\circ\).

Chord length = (39.12)in. \times \left(\frac{90}{360}\right) = 30.72 \text{ in.}

Area = (30.72)(6.0-1.5) = 138.26 \text{ in.}^2

Bearing Pressure: \[ P = \frac{(118,910)\text{ lbs.}}{(138.26)\text{ in.}^2} = 860 \text{ psi.} \]
2.5.2 Tie-Down Devices (continued)

(4) Bending Stress at Tie-down Frame due to bearing pressure.

The cantilever moment per unit of circumferential length will be:

\[ M = (P)(A)I = (860)1 \text{lbs./in.}^2(4.5)(1.0) \text{in.}^2(4.5/2) \text{in.} \]

\[ = 8700 \text{ in./lbs.} \]

\[ I = \frac{1}{12} (bh^3) = \frac{1}{12}(1)(1.5)^3 \]

\[ = 0.281 \text{ in.}^4 \]

\[ S = \frac{I}{C} = \frac{0.281 \text{ in.}^4}{(1.5/2)} = 0.375 \text{ in.}^3 \]

Bending Stress:

\[ \sigma_b = \frac{M}{S} = \frac{8700}{0.375} \]

\[ = 23,210 \text{ psi.} \]

Safety Factor \( = \frac{36,000}{23,210} = 1.55 \).

(5) Stresses in Lug.

Assume all welds = 3/8 in.

\[ P = 60,670 \text{ lbs.} \]
2.5.2 Tie-Down Devices (continued)

a. Stress across lug area:

\[ \sigma_s = \frac{P}{A} = \frac{(53,810) \text{lbs.}}{(1.5)(2)(.75)} = 23,920 \text{ psi.} \]

Safety Factor \( \frac{36,000}{23,920} = 1.51. \)

b. Shear Stress in Weld:

\[ \sigma_s = \frac{P}{A_s} \]

Shear Area of Weld: \( A = \left( (2)(6) + 2(1.5) \right) \left( \frac{3}{8} \times \frac{\sqrt{2}}{2} \right) = 3.977 \text{ in.}^2. \)

\[ \sigma_s = \frac{(53,810) \text{lbs.}}{(3.977) \text{in.}^2} = 13,530 \text{ psi.} \]

Safety Factor \( \frac{36,000}{13,530} = 2.66. \)

c. Bending in lug:

\[ M = Pe \]

\[ M = (53,810)(.5) = 26,905 \text{ in.-lbs.} \]

\[ I = \frac{bh^3}{12} = \frac{(1.5)(1.5)^3}{12} = 0.422 \text{ in.}^4. \]
2.5.2 Tie-Down Devices (continued)

\[ S = \frac{I}{C} = \frac{0.422}{(1.5/2)} = 0.562 \text{ in.}^3 \]

Bending Stress:

\[ \sigma_b = \frac{M}{2S} = \frac{26,905}{(2)(0.562)} = 23,940 \text{ psi.} \]

Safety Factor = \frac{36,000}{23,940} = 1.50.

d. Bending in Weld:

\[ \sigma_b = \frac{M}{C/I}. \]

\[ I = \frac{1}{12}[b_0h_0^3 - b_1h_1^3]. \]

\[ b_0 = 2.03 \text{ in.} \quad h_0 = 6.53 \text{ in.} \]

\[ b_1 = 1.50 \text{ in.} \quad h_1 = 6.00 \text{ in.} \]

\[ I = \frac{1}{12}[(2.63)(6.53)^3 - (1.50)(6.00)^3] = 20.11 \text{ in.}^4 \]

\[ M = (53,810)(1.25) = 67,260 \text{ in.} / \text{lbs.} \]

\[ \sigma_b = \frac{(67,260)(3.265)}{20.11} = 10,920 \text{ psi.} \]

Safety Factor = \frac{36,000}{10,920} = 3.30.
2.5.2 Tie-Down Devices (continued)

(6) Longitudinal Load on the Cask Body:
The forces transmitted to the cask body will result from the vertical loads on the frame.

\[ R = 18.75 \text{ in.} \]
\[ t = 0.50 \text{ in.} \]

\[ F_z = \sum F_1 z. \]

\[ F_1 z = 53,810. \]
\[ F_2 z = 66,870. \]
\[ F_3 z = 39,240. \]
\[ F_4 z = 3,130. \]
\[ F_5 z = 4,930. \]
\[ F_6 z = 32,560. \]

\[ F_z = 200,540 \text{ lbs.} \]

\[ \sigma_a = \frac{F_z}{A} = \frac{200,540}{2\pi(18.75)(.50)} = 3400 \text{ psi}. \]

Safety Factor \( \frac{30,000}{3400} = 8.8. \)
2.6 Normal Conditions of Transport

2.6.1 Heat

The effect on the package of heat, as defined in 10 CFR 71, is to be determined. The temperatures in the package for these conditions are determined in Section 3.4.2. The component temperatures were found to be:

- Fire Shield: $\bar{T} = 203^\circ F$.
- Outer shell: $\bar{T} = 228^\circ F$.
- Lead: $\bar{T} = 230^\circ F$.
- Inner shell: $\bar{T} = 232^\circ F$.

These temperatures will be used to determine the radial dimensional changes that occur from the $68^\circ F$ ambient steady state condition. The coefficient of thermal expansion is:

- Lead: $\alpha = 1.61 \times 10^{-5}/^\circ F$.
- Steel: $\alpha = 9.5 \times 10^{-6}/^\circ F$ outer.
  $\alpha = 9.6 \times 10^{-6}/^\circ F$ inner.

The dimensional changes that will occur are summarized in the following table:

<table>
<thead>
<tr>
<th>LOCATION</th>
<th>R-in</th>
<th>$\Delta T$</th>
<th>$\Delta R$</th>
<th>EFFECT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inner Shell</td>
<td>13.75 in.</td>
<td>164$^\circ F$</td>
<td>.022 in.</td>
<td></td>
</tr>
<tr>
<td>Lead</td>
<td>13.75 in.</td>
<td>164$^\circ F$</td>
<td>.036 in.</td>
<td>.014 in. gap</td>
</tr>
<tr>
<td>Lead</td>
<td>18.75 in.</td>
<td>160$^\circ F$</td>
<td>.048 in.</td>
<td></td>
</tr>
<tr>
<td>Outer Shell</td>
<td>18.75 in.</td>
<td>160$^\circ F$</td>
<td>.029 in.</td>
<td>Interference</td>
</tr>
<tr>
<td>Outer shell</td>
<td>19.25 in.</td>
<td>160$^\circ F$</td>
<td>.030 in.</td>
<td>.005 in. deflection</td>
</tr>
<tr>
<td>Fire shield</td>
<td>19.31 in.</td>
<td>135$^\circ F$</td>
<td>.025 in.</td>
<td>on wire spacers</td>
</tr>
</tbody>
</table>

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2.6] Heat (continued)

Check the interference between the lead and outer shell to insure the shell will not yield and effect the thermal gap between outer shell and fire shield.

Two concentric annuli of dissimilar materials will expand in the radial direction by different amounts when subjected to a change in temperature due to the different coefficient of thermal expansion. In the case where the inner annulus has a greater coefficient of thermal expansion, this annulus will expand into the outer shell thus producing a bearing pressure on the outer shell. This pressure is in turn resisted by hoop stress in the outer shell.

The expressions for stress in a cylinder under pressure are:\(^{(22)}\)

\[
\text{Radial: } \sigma_r = \frac{a^2 b^2 (P_0 - P_1)}{b^2 - a^2} \frac{1}{r^2} + \frac{P_2 a^2 - P_0 b^2}{b^2 - a^2}
\]

\[
\text{Tangential: } \sigma_\theta = \frac{a^2 b^2 (P_0 - P_1)}{b^2 - a^2} \frac{1}{r^2} + \frac{P_1 a^2 - P_0 b^2}{b^2 - a^2}
\]

The displacement expressions are:

\[
\text{Radial: } U = \frac{1}{E} \left[ -\frac{(1+v)}{r} \frac{a^2 b^2 (P_0 - P_1)}{b^2 - a^2} + (1-v) \frac{P_1 a^2 - P_0 b^2}{b^2 - a^2} \right]
\]

\[
\text{Tangential: } v = 0
\]
Consider the displacement at the interface radius for the following sketch with the addition of thermal expansion.

**Lead Ring at** $r_2$:

- $P_1 = 0$; $P_0 = P_B$
- $a = r_1$; $b = r_2$

**U_{pb}(r_2) = \frac{1}{E_{pb}} \left[ - \frac{(1+u_{pb})}{r_2} \left( \frac{r_1^2 r_2^2}{r^2} \right) P_B + \frac{r^3}{r_2^2 - r_1^2} \right] \left( 1-u_{pb} \right) r_2 + a_{pb} \Delta T r_2. $$

**Stainless Ring at** $r_2$:

- $P_1 = P_B$; $P_0 = 0$
- $a = r_2$; $b = r_3$

**U_{ss}(r_2) = \frac{1}{E_{ss}} \left[ - \frac{(1+u_{ss})}{r_2} \left( \frac{r_2^2 r_3^2}{r_3^2 - r_2^2} \right) P_B + \frac{r^3}{r_3^2 - r_2^2} \right] \left( 1-u_{ss} \right) r_2 + a_{ss} \Delta T r_2. $$

At the interface radius $U_{pb}(r_2) = U_{ss}(r_2)$.

**Let:**

- $K_{pb} = \frac{1}{E_{pb}} \left[ - (1+u_{pb}) \left( \frac{r_1^2 r_2^2}{r_2^2 - r_1^2} \right) \left( 1-u_{pb} \right) \right].$
- $K_{ss} = \frac{1}{E_{ss}} \left[ (1+u_{ss}) \left( \frac{r_2^2 r_3^2}{r_3^2 - r_2^2} \right) \left( 1-u_{ss} \right) \right].$

**Pb** $K_{pb} + a_{pb} \Delta T r_2 = P_B K_{ss} + a_{ss} \Delta T r_2.$

**Pb** \[ K_{pb} - K_{ss} \] = \[ a_{ss} - a_{pb} \] $\Delta T r_2.$
2.6.1 Heat (continued)

The Bearing Pressure at the interface is:

\[ P_B = \frac{(\alpha_{ss} - \alpha_{Pb})}{(K_{Pb} - K_{ss})} \Delta T \ r_2. \]

**Lead:**
\[ r_1 = 13.75 \text{ in.} \]
\[ r_2 = 18.75 \text{ in.} \]
\[ \Delta T = 160^\circ \text{F.} \]
\[ \alpha_{Pb} = 1.61 \times 10^{-5} \text{ in./in.}^0 \text{F.} \]
\[ \nu_{Pb} = 0.45. \]
\[ E_{Pb} = 2 \times 10^6 \text{ psi.} \]

**Stainless:**
\[ r_2 = 18.75 \]
\[ r_3 = 19.25 \]
\[ \Delta T = 160^\circ \text{F.} \]
\[ \alpha_{ss} = 9.5 \times 10^{-6} \text{ in./in.}^0 \text{F.} \]
\[ \nu_{ss} = 0.30. \]
\[ E_{ss} = 27 \times 10^6 \text{ psi.} \]

\[ K_{Pb} = -2.70 \times 10^5 \text{ in.}^3/\text{lbs.} \]
\[ K_{ss} = 8.15 \times 10^{-6} \text{ in.}^3/\text{lbs.} \]

Substituting these values to solve for the Bearing Pressure:

\[ P_B = \frac{(0.95-1.61) \times 10^{-5} \text{ in.}^0 \text{F}^{-1} - 1 \text{ lb.}}{(-2.70-0.82) \times 10^{-5} \text{ in.}^3} (160)^0 \text{F} (18.75) \text{ in.} \]

\[ P_B = 563 \text{ psi.} \]

Substitute this value into the expressions for stress in the steel shell at \( r_3 \):

\[ \sigma_r = -\frac{r_2^2 P_B}{r_3^2-r_2^2} + \frac{r_2^2 P_B}{r_3^2-r_2^2} = 0. \]
\[ \sigma_r = \frac{r_2^2 P_B}{r_3^2-r_2^2} + \frac{r_2^2 P_B}{r_3^2-r_2^2} = \frac{r_2^2 P_B}{r_3^2-r_2^2}. \]

\[ \sigma_r = 2(563) \text{ psi} \left( \frac{18.75^2}{(19.25)^2 - (18.75)^2} \right). \]
\[ \sigma_r = 20,830 \text{ psi}. \]

The Safety Factor will be:

\[ SF = \frac{30,000}{20,830} = 1.44. \]
2.6.2 Cold

The effect on the package of cold is also to be considered. This is condition is described in 10 CFR 71. Temperatures for this condition are determined in Section 3.4.3. Average region temperatures are:

- Fire Shield: \( T = 52^\circ\text{F} \)
- Outer Shield: \( T = 75^\circ\text{F} \)
- Lead: \( T = 77^\circ\text{F} \)
- Inner Shell: \( T = 79^\circ\text{F} \)

The summary of dimensional changes in going from 100°F ambient conditions will be for \( \alpha = 9.1 \times 10^{-5}/^\circ\text{F} \) — stainless.

<table>
<thead>
<tr>
<th>Location</th>
<th>R - in.</th>
<th>( \Delta T )</th>
<th>( \Delta R )</th>
<th>Effect</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inner Shell</td>
<td>13.75</td>
<td>-87°F</td>
<td>-.011 in.</td>
<td>Interference</td>
</tr>
<tr>
<td>Lead</td>
<td>13.75</td>
<td>-87°F</td>
<td>-.064 in.</td>
<td></td>
</tr>
<tr>
<td>Lead</td>
<td>18.75</td>
<td>-88°F</td>
<td>-.087 in.</td>
<td></td>
</tr>
<tr>
<td>Outer Shell</td>
<td>18.75</td>
<td>-88°F</td>
<td>-.015 in.</td>
<td>Gap</td>
</tr>
<tr>
<td>Outer Shell</td>
<td>19.25</td>
<td>-88°F</td>
<td>-.015 in.</td>
<td>.001 in. Deflection</td>
</tr>
<tr>
<td>Fire Shield</td>
<td>19.21</td>
<td>-91°F</td>
<td>-.016 in.</td>
<td>on wide spacers.</td>
</tr>
</tbody>
</table>

In this case the interference occurs between the lead shield and the cask cavity liner. For this condition the bearing pressure will be given by:

\[
P_B = \left( \frac{\alpha_{\text{Pb}} - \alpha_{\text{ss}}}{k_{\text{ss}} - k_{\text{Pb}}} \right) \Delta T r_2.
\]

Stainless:
- \( r_1 = 13.25 \text{ in.} \)
- \( r_2 = 13.75 \text{ in.} \)
- \( \Delta T = -87^\circ\text{F} \)
- \( \alpha_{\text{ss}} = 9.1 \times 10^{-5} \text{ in.}/^\circ\text{F} \)
- \( v = 0.30 \)
- \( E_{\text{ss}} = 27 \times 10^6 \text{ psi} \)

Lead:
- \( r_2 = 13.75 \text{ in.} \)
- \( r_3 = 18.75 \text{ in.} \)
- \( \Delta T = -87^\circ\text{F} \)
- \( \alpha_{\text{Pb}} = 1.61 \times 10^{-5} \text{ in.}/^\circ\text{F} \)
- \( v = 0.45 \)
- \( E_{\text{Pb}} = 2 \times 10^6 \text{ psi} \)
2.6.2 Cold (continued)

\[ K_{ss} = \frac{1}{E_{ss}} \left[ -(1+v_{ss}) \frac{r_1^2 r_2}{r_2^2 - r_1^2} - \frac{r_2^3}{r_2^2 - r_1^2} (1-v_{ss}) \right]. \]

\[ = -1.36 \times 10^{-5} \text{ in.}^3/\text{lbs}. \]

\[ K_{pb} = \frac{1}{E_{pb}} \left[ (1+v_{pb}) \frac{r_2^2 r_3}{r_3^2 - r_2^2} - \frac{r_2^3}{r_3^2 - r_2^2} (1-v_{pb}) \right]. \]

\[ = 4.66 \times 10^{-6} \text{ in.}^3/\text{lbs}. \]

Substituting these values to solve for the Bearing Pressure:

\[ P_B = \frac{(1.61-0.95)10^{-5}}{(-1.36-0.47)10^{-5}} (-87)(13.75) \]

\[ = 432 \text{ psi}. \]

Substituting this value into the expressions for stress in the steel shell at \( r_1 \):

\[ \sigma_r = \frac{P_B r_2}{r_2^2 - r_1^2} - \frac{P_B r_2}{r_2^2 - r_1^2} = 0 \]

\[ \sigma_\theta = -\frac{P_B r_2}{r_2^2 - r_1^2} - \frac{P_B r_2}{r_2^2 - r_1^2} = -2p_b \frac{r_2}{r_2^2 - r_1^2} \]

\[ \sigma_\theta = -12,100 \text{ psi}. \]

Safety Factor = \( \frac{30,000}{12,100} = 2.47. \)
2.6.3 Reduced External Pressure

10 CFR 71.71 (c)(3) requires that the package should be able to withstand a reduced external pressure of 3.5 psia. Conversely, the package should be able to withstand a 14.7 - 3.5 = 11.2 psi internal pressure. Assume the inner shell is supported by the lead in resisting the internal pressure.

(1) End Plates _ From Roark (17)

\[ \sigma_f = \frac{3}{32}(D/t)^2 P(3 + v) \]  
\(D = \text{Mean Diameter} = 27 \text{ in.}\)
\(P = 11.2 \text{ psig}\)

**Steel**: \(t = 0.5 \text{ in.}; v = 0.3\)

**Lead**: \(t = 5.75 \text{ in.}; v = 0.45\)

\[ \sigma_{\text{yield}} = \frac{3}{32}(27/5.75)^2(11.2)(3 + 0.45) = 79.87 \text{ psi for lead}\]

For the lead and steel shells in contact, the yield of the steel plate will not be exceeded as entire pressure can be taken by the lead without yield.
2.6.4 Increased 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. Assume the outer shell is supported by the lead in resisting the external pressure.

(1) End Plates - From Roark (17)

\[ \sigma_f = \frac{3}{32}(D/t)^2P(3+v) \]

(free ends)

\[ D = \text{mean diameter} = 37.5 \text{ inches.} \]
\[ P = 25 \text{ psig} = 0.50 \text{ in.} \]
\[ \text{Steel: } t = 0.50 \text{ in.; } v = 0.30. \]
\[ \text{Lead: } t = 5.75 \text{ in.; } v = 0.45. \]

Lead: \( \sigma_f = 3/32(37.5)^2(25)(3 + .45) = 344 \text{ psi.} \)
\[ \sigma_{y\text{ield}} = 1160 \text{ psi for lead}. \]

For the lead and steel shells in contact, the yield of the steel plate will not be exceeded as entire pressure can be taken by the lead without yield.

(2) Cylindrical Shell - Buckling. From Roark (18).

\[ P_2 = \frac{2t}{D} \left( \frac{\sigma_y}{1 + \frac{\sigma_y}{E}(D/t)} \right) \]
\[ E = \text{Modulus of Elasticity} = 28 \times 10^6 \text{ psi.} \]
\[ \sigma_y = \text{Yield Strength} = 30,000 \text{ psi.} \]
\[ D = 37.5 \text{ in.} \]
\[ t = 0.50 \text{ in.} \]
\[ P_2 = \frac{(2)(.50)}{(37.5)} \left( \frac{30,000}{1 + \frac{30,000}{28 \times 10^6}(37.5)^2} \right) \]
\[ = 114 \text{ psi.} \]
\[ \text{Safety Factor: } SF = \frac{114}{25} = 4.6. \]
2.6.5 **Vibration**

Inspection of casks similar to the CNS Model 1-13C (i.e. GE Model 1600) since 1962 reveals no evidence of damage of significance to transport safety.

2.6.6 **Water Spray**

Since the container is constructed of metal, there is no damage to containment resulting from dropping the container through the standard drop heights after being subjected to water spray.

2.6.7 **Free Drop**

Since the container is constructed of metal, there is no damage to containment resulting from dropping the container through the standard drop heights after being subjected to water spray.

2.6.8 **Corner Drop**

This requirement is not applicable since the package is fabricated of steel and weighs more than 110 lbs.

2.6.9 **Compression**

The loaded container is capable of withstanding a compressive load equal to five times its weight with no change in spacing.

2.6.10 **Penetration**

There is no effect on containment or overall spacing from dropping a thirteen pound by 1-1/4 inch diameter bar from four feet onto the most vulnerable exposed surface of the packaging.
2.7 Hypothetical Accident Conditions

2.7.1 Free Drop

The cask must withstand a 30 foot fall onto a flat, unyielding surface.

The stresses associated with the drop will be evaluated by assuming that the kinetic energy of the cask will be equal to the energy of deformation of the cask.

Kinetic Energy = HW.
Deformation Energy = Vk.

\[ H = \text{Drop Height} = 360 \text{ inches.} \]
\[ W = \text{Cask Weight} = 25,950 \text{ pounds.} \]
\[ k = \text{Dynamic Flow Pressure} = 10,000 \text{ psi (lead)(9).} \]
\[ V = \text{Volume of Material Displaced, - in}^3 \]

\[ V = \frac{hW}{k}. \]

\[ V = \frac{(360)(25,950)}{10,000} = 934 \text{ in}^3. \]

The value of \( k = 10,000 \text{ psi} \) for lead was taken as the value that would produce the minimum deformation, and hence the maximum "g" loading transmitted to structural members.
(1) Corner Drop

For impact on a corner, the volume of deformed lead will be as the sketch.

The shaded region represents the volume of lead displaced dissipating the kinetic energy of the 30 foot drop.

$$V = R^3 \tan \alpha (\sin \theta - \frac{\sin^3 \theta}{3} - \cos \theta).$$

Assume the drop angle is formed by a vertical line from the cask center of gravity through the corner of the lead. Assume all the kinetic energy is dissipated by lead deformation. Assume the center of gravity of the cask is at the vertical midpoint of the cask.

$$\alpha = \tan^{-1} \frac{R}{h}$$

R (lead) = 18.75 in.

h (including fire shield) = 34.875 in.

$$\alpha = 23.3^\circ.$$
$F(\theta) = \sin \theta - \frac{\sin^3 \theta}{3} - \theta \cos \theta$

$F(\theta) = \theta - \sin \theta$

FIGURE 2.7-1.
Substituting these values into the expression for displacement volume leaves $\theta$ as the remaining unknown.

$$F(\theta) = 0.263$$
$$\theta = 70.6^\circ$$

The distance along the radius undergoing deformation will be:

$$S = (1 - \cos \theta) R.$$  

Upon substitution, this value is:

$$S = 12.51 \text{ inches}.$$  

To evaluate the stresses in various components resulting from impact loading, it is necessary to determine the effective deceleration of the impact.

$$F_I = G_I W.$$  

Where:

- $F_I$ = impact force.
- $G_I$ = impact acceleration.
- $W$ = cask weight.

This impact force will be equal to the 'impact' or dynamic flow pressure times the impact area.

$$F_I = k A_I.$$  

During impact, the dynamic flow pressure will be constant and the impact area will vary from zero at initial contact to a maximum upon completion of the deformation.

The exact nature of the change in impact area, and hence impact force, with time is not easily determined.
2.7.1 Free Drop (continued)

However, it is clear that the maximum impact force occurs when the impact area is a maximum. This will occur when all the kinetic energy of the system has been absorbed.

A section through the cylinder at AA will be an ellipse with major axis $a$ and minor axis $b$ as follows:

\[ a = \frac{R}{\cos \theta} = 21.30. \]
\[ b = \frac{R}{\cos \alpha} = 18.75. \]

The area $A_1$ will then be the area of the sector of an ellipse.

\[ A_1 = ab\left(\frac{\pi}{2} - \sin^{-1}\frac{x}{a}\right) - xy. \]

Where:
\[ y = \frac{b}{a}\sqrt{a^2 - x^2} = 17.69. \]
\[ x = a - \Delta = 7.08. \]
\[ \Delta = \frac{S}{\cos \alpha} = 14.22. \]

Solution of the above relationships gives:

\[ A_1 = 366.8 \text{ in.}^2 \]

Solving now for the impact acceleration:

\[ G_1 = \frac{F_I}{W} = k\frac{A_1}{W}. \]

\[ = \frac{(10,000) \text{ lbs./in.}^2(366.8)\text{in.}^2}{25,950} \]

\[ = 141.3. \]
2.7.1 Free Drop (continued)

If the cask were to impact on the top edge of the cask, the weight of the cover and contents would produce both shear and tensile stresses in the bolts. Assume the weight of contents acts at the center of the inside surface of the lid.

\[ W_I = (W_L + W_P) G_I. \]

\[ W_L = 2110 \text{ lbs.} \]

\[ W_P = 5000 \text{ lbs.} \]

\[ W_I = 1.00 \times 10^6 \text{ lbs.} \]

\[ t_c = 7.00 \text{ inches} \]

\[ t_L = 3.50 \text{ inches.} \]

* Bolts will not bear on fireshield.

a. Tensile Stress - Bolts

Tensile forces will be introduced into the bolts in resisting the moments resulting from the impact load. Summation of moments about "O".

\[ \Sigma M_O = W_I R \cos \alpha - W_L G_I t_L \sin \alpha. \]

\[ = (1.00 \times 10^6)(18.75)(.881) - (2110)(141.3)(3.50)(.474). \]

\[ = 1.66 \times 10^7 - 4.95 \times 10^5. \]

\[ = 1.71 \times 10^7 \text{ in./lbs.} \]
This moment must be resisted by an equal moment exerted by the bolts to preserve equilibrium.

\[ \Sigma M_{0-0} = \Sigma P_n a_n. \]

Where: \( P_n \) - Tensile force in Bolt \( n \).
\( a_n \) - Distance from Bolt \( n \) to axis of rotation \( 0-0 \).

\( R_{BC} \) - Bolt circle radius = 17.6875 in.
\( R \) - Lid Radius = 19.25 in.

If we assume the lid is a rigid body, each bolt load will be proportional to its distance from the axis of rotation.

\[ \frac{P_2}{P_1} = \frac{a_2}{a_1}, \text{ etc.} \quad P_2 = P_1 \left( \frac{a_2}{a_1} \right). \]

Therefore:

\[ \Sigma M_{0-0} = P_1 a_1 + P_2 a_2 + \ldots + P_n a_n. \]

\[ = P_1 a_1 + P_1 \left( \frac{a_2}{a_1} \right) a_2 + \ldots + P_1 \left( \frac{a_n}{a_1} \right) a_n. \]

\[ = P_1 (a_1 + \frac{a_2^2}{a_1} + \ldots + \frac{a_n^2}{a_1^2}). \]

\[ = P_1 a_1 \left( 1 + \frac{a_2^2}{a_1^2} + \ldots + \frac{a_n^2}{a_1^2} \right). \]

\[ = P_1 a_1 \left( 1 + k_1^2 + \ldots + k_n^2 \right). \]

Therefore:

\[ P_1 = \frac{\Sigma M_{0-0}}{a_1 (1 + k_1^2 + \ldots + k_n^2)}. \]

Where: \( P_1 \) - Tensile Force in bolt farthest from axis of rotation.
\( a_1 \) - Distance from axis of rotation to farthest bolt.

\[ k_n = \frac{a_n}{a_1}. \]
2.7.1 Free Drop (continued)

\[ z_1 = R_{BC} \sin 30^\circ = 8.84 \text{ in.} \]
\[ z_2 = R_{BC} \sin 60^\circ = 15.32 \text{ in.} \]

\[ a_1 = R + R_{BC} = 36.94 \]
\[ a_2 = R + X_2 = 34.57 \]
\[ a_3 = R + X_1 = 28.09 \]
\[ a_4 = R \quad = 19.25 \]
\[ a_5 = R - X_1 = 10.41 \]
\[ a_6 = R - X_2 = 3.93 \]
\[ a_7 = R - R_{BC} = 1.56 \]

\[ k_1 = .936, \quad k_1^2 = .376 \]
\[ k_2 = .760, \quad k_2^2 = .578 \]
\[ k_3 = .521, \quad k_3^2 = .272 \]
\[ k_4 = .282, \quad k_4^2 = .079 \]
\[ k_5 = .106, \quad k_5^2 = .011 \]
\[ k_6 = .042, \quad k_6^2 = .002 \]

\[ 1 + k_1^2 + \ldots + k_n^2 = 1 + 2 \sum_1^5 k_n^2 + k_0 \]
\[ = 1 + 3.632 + .002 \]
\[ = 4.634. \]

\[ P_1 = \frac{(1.71 \times 10^7) \text{in.-lbs.}}{(36.94)(4.634) \text{in.}} = 9.99 \times 10^4 \text{ lbs.} \]

For 1-1/4-7UNC bolts, the effective stress area is:
\[ A_{\text{eff}} = 0.9684 \text{ in.}^2 \quad (19). \]
\[ \sigma_t = P_1/A_{\text{eff}} = 103,000 \text{ psi.} \]

The ultimate tensile strength for the bolt material is:
\[ \sigma_{tu} = 150,000. \]
Safety Factor = \( \frac{103,000}{150,000} = 1.46. \)
b. Shear Stress - Bolts

Shear Stresses will be introduced into the bolts in resisting the lateral loads resulting from the corner drop. This shear stress is expressed by:

$$\sigma_s = \frac{W_t}{n A_{\text{eff}}} = \frac{W_t \sin \alpha}{n A_{\text{eff}}}$$

For 12 bolts with $A_{\text{eff}} = 0.9684$ in.$^2$:

$$\sigma_s = \frac{(1.00 \times 10^6) \text{lbs.} \times (0.474)}{(12)(0.9684) \text{in.}^2}$$

$$= 40,990 \text{ psi}.$$  

The shear ultimate stress for the bolt material is:

$$\sigma_{su} = \sigma_t \sqrt{3} = 86,600 \text{ psi}.$$  

Safety Factor $= \frac{86,600}{40,990} = 2.11$.  

(0157W)
2.7.1 Free Drop (continued)

c. Loading in Lid Structure

\[ R = 18.75 \text{ in. (lead radius).} \]
\[ R_{BC} = 17.6875 \text{ in.} \]
\[ S = 12.52 \text{ in. (lead deformation).} \]
\[ X = R(1 - \cos 60^\circ). \]
\[ = 9.37 \text{ in.} \]

The sketch shows that the deformation of the lid from the corner drop will include a significant portion of the seal and 5 of the 12 lid bolts. Since this container will transport only solid irradiated materials, leakage of liquids or powders from the container after the drop will not be a consideration. It must be shown that the lid will remain on the container to confine the irradiated components within the container cavity. Consider now the tensile stress that will occur in the highest loaded of the remaining seven bolts. This loading may be expressed as:

\[
P_1 = \frac{M_{0-0}}{a_1(1 + 2 \sum k_n^2)}
\]

\[
a_1(1 + 2 \sum k_n^2) = (36.94)[1 + 2(.876 + .578 + .272)] = (36.94)(4.452).
\]

Therefore: \[ P_1 = \frac{(1.71 \times 10^7) \text{ in.-lbs.}}{(36.94)(4.452) \text{ in.}} \]

\[ = 1.04 \times 10^5 \text{ lbs.} \]
2.7.1 Free Drop (continued)

The effective stress area of the bolt is:

\[ A_{\text{eff}} = 0.9684 \text{ in.}^2 \]

Therefore:

\[ \sigma_t = \frac{(1.04\times10^5) \text{ lbs.}}{(0.9684) \text{ in.}^2} = 107,400 \text{ psi.} \]

Safety Factor \( \frac{150,000}{107,400} = 1.40 \).
(2) Side Drop

For impact of the cask, with centerline parallel to the impact surface, the volume of deformed lead will be as shown.

![Diagram of cask with angle of deformation and volume calculation](image)

The shaded region represents the volume of material displaced:

\[ V = \frac{R^2}{2} (\theta - \sin \theta)H. \]

For cask: \( R = 19.25 \) inches.
\( H = 68.0 \) inches.

The displacement for the side drop of a cask that accounts for the steel sides and end plates is described as follows.

The angle of deformation can be found from the expression: (23)

\[
\frac{Wh}{t_s Rhk_s} = \left[ F_1(\frac{\theta}{2}) \right] \left[ \frac{R}{t_s} \left( \frac{k_{pb}}{k_s} \right) + 2 \left( \frac{R}{H} \right) \left( \frac{t_c}{t_s} \right) \right] + F_2(\frac{\theta}{2})
\]

Where:
\[ F_1(\frac{\theta}{2}) = \frac{1}{2}(\theta - \sin \theta). \]
\[ F_2(\frac{\theta}{2}) = \sin \left( \frac{\theta}{2} \right) \left( 2 - \cos \frac{\theta}{2} \right) - \frac{\theta}{2}. \]

\( h = 360 \) in.
\( t_s = \) outer shell thickness = 0.5 in.
\( t_c = \) end plate thickness = 0.5 in.
\( k_s = \) dynamic stress of stainless = 45,000 psi.
\( k_{pb} = \) dynamic stress of lead = 10,000 psi.
2.7.1 Free Drop (continued)

Solution of the above expression yields for the angle of deformation:
\[ \theta = 41.0^\circ. \]

The width of the deformation is:
\[ c = 2R \sin \theta/2. \]
\[ c = 13.48 \text{ in.} \]

The impact area will be:
\[ A_I = CH = (68)(13.48) = 916.6 \text{ in.}^2 \]

The deformation volume is:
\[ V = \frac{1}{2} R^2 (\theta - \sin \theta) H. \]
\[ = 749.3 \text{ in.}^3 \]

The deformation volume thus derived may be used to obtain an effective dynamic flow stress for the composite:
\[ V = hW/k. \]

Therefore:
\[ k = \frac{hW}{V} = \frac{(360)\text{in.}(25,950)\text{lbs.}}{749.3\text{in.}^3} \]
\[ = 12,470 \text{ psi.} \]

From this value of dynamic stress the impact acceleration may be determined:
\[ G_I = \frac{kA_I}{W} = \frac{(12,470)(916.6)}{(25,950)} = 440. \]
This impact loading applied to the lid of the cask will produce a shear stress in the bolts.

\[
\sigma_s = \frac{G_L W_L}{n A_{eff}}
\]

Where:  

- \( W_L \) = lid weight = 2110 lbs.  
- \( n \) = number of bolts = 12.  
- \( A_{eff} \) = effective shear area of bolts = 0.9684 in.

\[
\sigma_s = \frac{(440)(2110)}{(12)(0.9684)}
\]

\[
= 79,960 \text{ psi.}
\]

The shear ultimate stress for the bolt material is:

\( \sigma_{su} = 86,600 \text{ psi.} \)

Safety Factor = \( \frac{86,600}{79,960} = 1.08 \).
2.7.2 Puncture

The cask container must be shown to resist a 40 inch drop onto a 6 inch diameter cylinder without puncture. An empirical equation is given for lead-filled casks developed by ORNL.\(^{20}\)

\[
t = (\frac{W}{S})^{0.71}.
\]

Where: 
- \(t\) = shell thickness
- \(W\) = cask weight - pounds.
- \(S\) = ultimate tensile strength of outer shell - psi.

\[
t = \left(\frac{25,950}{75,000}\right)^{0.71} = 0.471 \text{ inch}.
\]

For the puncture accident, the 1/4 inch fire shield will contribute to the overall thickness that must be breached. This total thickness is:

\[
t_s = 0.75 \text{ inches}.
\]

This design satisfies the requirements for puncture drop.

Next consider bending in the outer shell resulting from impact loading onto the 6 inch diameter cylinder.

Bending in the outer shell will be produced by the reaction loading \(F_{1/2}\) acting through the centroid of the half-cask. The moment arm for this reaction is \(X_c\), the distance from the cask centerline to the center of gravity of 1/2 of the cask.

The impact force will be determined as before, where the impact area is equal to the area of the impact cylinder.

\[
F_I = k_s A_I.
\]

Where: 
- \(k_s\) - dynamic flow pressure of stainless = 45,000 psi.
- \(A_I = \frac{\pi}{4}(R_c)^2 = \frac{\pi}{4}(6.0)^2 = 28.27 \text{ in.}^2\)
- \(F_I = (45,000)(28.27) = 1.272 \times 10^6 \text{ lbs.}\)
2.7.2 Puncture (continued)

The centroid distance was determined for the following geometry and symmetry was then assumed for the cask about its axial centerline. The greatest centroid distance results with no load in the cask cavity.

\[
\bar{X}_C = \frac{\sum_i M_i X_{C_i}}{\sum_i M_i}
\]

<table>
<thead>
<tr>
<th>Volume</th>
<th>Weight - lbs.</th>
<th>(X_C) in.</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2500</td>
<td>13.5</td>
</tr>
<tr>
<td>2</td>
<td>324</td>
<td>13.75</td>
</tr>
<tr>
<td>3</td>
<td>78</td>
<td>27.25</td>
</tr>
<tr>
<td>4</td>
<td>5770</td>
<td>13.75</td>
</tr>
<tr>
<td>5</td>
<td>2724</td>
<td>30.50</td>
</tr>
<tr>
<td>6</td>
<td>856</td>
<td>17.125</td>
</tr>
<tr>
<td>7</td>
<td>234</td>
<td>33.875</td>
</tr>
</tbody>
</table>

Without the cask cavity load:

\[
\sum_i M_i X_{C_i} = 1.916 \times 10^5 \text{ in.} / \text{lbs.}
\]

\[
\sum_i M_i = 9986 \text{ lbs.}
\]

Therefore: \(X_C = 19.19\) inches.
2.7.2 Puncture (continued)

The bending stress in the outer shell will be:

\[ \sigma_B = \frac{Mc}{I}. \]

Where: \( M = \frac{F_1}{4} \); \( I = 2\tilde{\chi}^2 \).

\[ C = R_0. \]
\[ I = \pi/4 (R_0^4 - R_i^4). \]

For: \( R_0 = 19.25 \) in.
\( R_i = 18.75 \) in.
\( I = \pi/4[(19.25)^4 - (18.75)^4] = 1.078 \times 10^4 \) in.\(^4\)

\[ \sigma_B = \frac{(1.272 \times 10^6) \text{lbs.}(38.4) \text{in.}(19.25) \text{in.}}{4(1.078 \times 10^4) \text{in.}^4} \]

\[ \sigma_B = 21,810 \text{ psi}. \]
Safety Factor = \( \frac{30,000}{21,810} = 1.38. \)
2.7.3 Thermal

See Section 3.5 Hypothetical Accident Thermal Evaluation.

2.7.4 Immersion - Fissile Material

The requirement of 10CFR71.73 (c)(4) is not applicable.

2.7.5 Immersion - All Packages

10CFR71.73 (c)(5) requires immersion in water with a pressure of 21 psig for eight hours. Review of the stresses in Section 2.6.4 for a 25 psig pressure indicates the stresses are low, and this test will have no significant effect on the package.

2.8 Special Form

Not applicable.

2.9 Fuel Rods

Not applicable.
2.10 APPENDIX

2.10.1 Appendix A - References

2.10.2 Appendix B - Local Stresses in Cylindrical Shells Due to External Loadings
2.10.1  Appendix A - References

1. ASME Boiler and Pressure Vessel Code, Section VIII, Division 2, 1974 Ed., Table AHA-1, p. 54.


10. ASME Boiler and Pressure Vessel Code, Section II, Division 1, 1974 Ed., Table 1-7.3, p. 128.


15. Roark and Young, Op. cit., Table 17, Case 1.

16. Ibid, Table 17, Case 5.


2.10.1 Appendix A - References (continued)


LOCAL STRESSES IN CYLINDRICAL SHELLS
DUE TO EXTERNAL LOADINGS

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LOCAL STRESSES IN CYLINDRICAL SHELLS DUE TO EXTERNAL LOADINGS

INTRODUCTION

These tables present a quick method of designing or checking a rectangular or circular attachment to a cylindrical shell. They are based on a paper 'Local Stresses in Spherical and Cylindrical Shells due to External Loadings' by Wichman, Hopper & Hershon, published in Welding Research Council Bulletin No. 107, August 1965. Values from the curves are obtained by interpolation. The analytical portion of the W.R.C. Bulletin was done by P. P. Bijlaard.

RESULTS

There are four sets of tables given for attachments of different shapes and different ratios of width to length. In each set, i.e. for each particular shape and each particular \((C_2/C_1)\) ratio, are tabulated different vessel diameters on each page. Maximum principal stresses due to a radial load of one kip, a longitudinal moment and a circumferential moment, each of one ft. kip, are given for a range of vessel thicknesses after corrosion loss and for different attachment sizes corresponding to each particular vessel diameter. These stresses are designated as \(A_1, A_2\) and \(A_3\) respectively.

Maximum stresses present in a shell for a given loading (neglecting shear forces) can be computed as follows:

\[
S_L = A_1 \times P + A_2 \times M_L
\]

\[
S_C = A_1 \times P + A_3 \times M_C
\]

where

- \(S_L\) = Maximum stress occurring in the longitudinal direction at the outside of the shell due to the combination of a radial load and a longitudinal moment. (ksi)
- \(S_C\) = Maximum stress in the circumferential direction at the outside of the shell due to the combination of a radial load and a circumferential moment. (ksi)
- \(P\) = Concentrated or total distributed radial load. (kips)
- \(M_L\) = External overturning moment in the longitudinal direction with respect to the shell. (ft-kips)
- \(M_C\) = External overturning moment in the circumferential direction with respect to the shell. (ft-kips)
- \(A_1\) = Maximum principal stress in the longitudinal and the circumferential directions due to a radial load of one kip. (ksi/kip)
A2 = Maximum principal stress due to a longitudinal moment of one ft-kip. (ksi/ft-kip)

A3 = Maximum principal stress due to a circumferential moment of one ft-kip. (ksi/ft-kip)

and C1 = Maximum length of attachment in circumferential direction. (in)

C2 = Maximum length of attachment in longitudinal direction. (in)

If a desired case is not given in these tables, it may be interpolated. However, if greater accuracy and information are desired, the singular program called 'LUGS' should be used. Present tables should not be used if shear stresses are a substantial part (say, more than 15%) of the allowable stresses. Shear stresses may be obtained from the following formulas.

\[ \tau_L = \frac{2V_L}{\pi C_1 V_T} \quad \tau_C = \frac{2V_C}{\pi C_1 V_T} \]

for a circular attachment.

\[ \tau_L = \frac{V_L}{2C_2 V_T} \quad \tau_C = \frac{V_C}{2C_1 V_T} \]

for a rectangular attachment.

where \( \tau_L \) = Shear stress in longitudinal direction. (ksi)
\( \tau_C \) = Shear stress in circumferential direction. (ksi)
\( V_L \) = Concentrated shear load in the longitudinal direction. (kips)
\( V_C \) = Concentrated shear load in the circumferential direction. (kips)
\( V_T \) = Wall thickness, (after corrosion) of cylindrical shell. (in)

Only maximum stresses occurring at the outside of the shell are printed in these tables since the stresses at the outside are always greater than those at the inside.

Values should not be extrapolated much outside the given tabulations. For these cases, the 'LUGS' program should be used.

After finding the maximum stresses in the longitudinal and the circumferential direction, they should be checked to ensure that they are within the allowable limits. Allowable stresses in the longitudinal and circumferential directions are denoted by \( S_L, \text{allow.} \) and \( S_C, \text{allow.} \) respectively. A good rule to follow is:

\[ S_L, \text{allow.} = \frac{(2 \times S - 0.5 \times Sp)}{1000} \] (ksi)

\[ S_C, \text{allow.} = \frac{(2 \times S - Sp)}{1000} \] (ksi)
where $Sp =$ stress due to pressure, occurring in the circumferential direction (psi)

$$Sp = \frac{\text{Internal Pressure (psig)} \times \text{Vessel Radius (in)}}{\text{Corroded Vessel Thickness (in)}}$$

If pressure is unknown, let $Sp = S$. In which case $S_L, \text{ allow.} = 1.5 \frac{S}{1000}$ and $S_C, \text{ allow.} = \frac{S}{1000}$.

where $S =$ Maximum allowable stress value from Subsection C of the ASME Boiler and Pressure Vessel Code, Section VIII, 'Unfired Pressure Vessels' 1965. (psi)

For example, for metal temperatures between -20 and +650°F,

<table>
<thead>
<tr>
<th>Material</th>
<th>$S$(psi)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A-201A (or A-515-55)</td>
<td>13,750</td>
</tr>
<tr>
<td>A-212B (or A-515-70)</td>
<td>17,500</td>
</tr>
<tr>
<td>A-283C</td>
<td>12,650</td>
</tr>
<tr>
<td>A-285C</td>
<td>13,750</td>
</tr>
<tr>
<td>A-204C</td>
<td>18,750</td>
</tr>
</tbody>
</table>

**Determination of $C_1$ & $C_2$ for different shapes:**

For I beams, WF beams, channels, etc., $C_1$ & $C_2$ correspond to the width of the flange and the depth of the section. For moments applied on the weaker axis, stresses given in the tables should be multiplied by 1.2.
Note that in general reinforcing pads should not be used with structural members, including pipes, except in the case of nozzle connections. When additional strength is required the attachment should be made larger.

The tables are given for a square and for a 3:1 attachment. For other sizes, values may be interpolated. For a 2:1 ratio, stresses may be computed as 60% of those for the 3:1 ratio (using the maximum length) plus 40% of those for the square (using the maximum length).

Example 1:

Check the shell stresses for a lug attachment using the following conditions:

| Vessel diameter | 7' - 6" |
| Vessel thickness | 1" |
| Corrosion allowance | 3/16" |
| Design pressure | 230 psig |
| Design temperature | 550°F |
| Material | A-285-C, F.B. |
| Lug | 16 \( \frac{W}{4} \) 58 |
| Radial load | 6,600 lbs. |
| Longitudinal moment | 55,200 in-lbs. |
| Circumferential moment | 42,750 in-lbs. |

Solution

1.1 Checking the shell stresses:

\[
t - c = 1.0 - 0.1875 = 0.8125"
\]
\[
C_2 = 16.0; C_1 = 8.5"
\]

Since \( C_2/C_1 \neq 2 \), it will have to be interpolated between a 3:1 rectangular and a square attachment.

From Page 2.13 & 3.13, using \( C_2 = 16" \),

<table>
<thead>
<tr>
<th>3:1 Rect. Attach. (long)</th>
<th>Square</th>
</tr>
</thead>
<tbody>
<tr>
<td>A1</td>
<td>1.2664</td>
</tr>
<tr>
<td>A2</td>
<td>1.123</td>
</tr>
<tr>
<td>A3</td>
<td>2.2947</td>
</tr>
</tbody>
</table>

For 2:1 attachment,

\[
A_1 = 0.6 \times 1.2664 + 0.4 \times 0.734 = 1.053
\]
\[
A_2 = 0.6 \times 1.123 + 0.4 \times 0.5726 = 0.903
\]
\[
A_3 = 0.6 \times 2.2947 + 0.4 \times 1.09 = 1.813
\]

\[
S_L = A_1 \times P + A_2 \times M_L
\]
\[
= 1.053 \times 6.6 + 0.903 \times 55.2
\]
\[
= 11.10 \text{ ksi}
\]
\[ S_c = \left[ A_1 \times P + A_3 \times M_c \right] \times 1.2 \quad \text{(For moment applied on the weak axis)} \]
\[ = \left[ 1.053 \times 6.6 + 1.813 \times \frac{42.75}{12} \right] \times 1.2 \]
\[ = 16.09 \, \text{ksi} \]

\[ S = 13,750 \, \text{psi} \quad \text{(from ASME Code, Sec. VIII)} \]

\[ S_{L, \text{allow}} = \frac{25 - 0.5 \, \text{Sp}}{1000} \]
\[ = \frac{2 \times 13,750 - 0.5 \times 230}{0.8125} \times \frac{45}{1000} \]
\[ = 21.13 \, \text{ksi} \quad \Rightarrow S_L = 11.10 \quad \therefore \text{O.K.} \]

\[ S_{C, \text{allow}} = \frac{25 - \text{Sp}}{1000} \]
\[ = \frac{27,500 - 12,740}{1000} \]
\[ = 14.76 \, \text{ksi} \quad \ll S_C = 16.09 \quad \therefore \text{Not O.K.} \]

Attachment: should be redesigned. Since the tables are given for 1:1 and 3:1, it will be convenient to select a size from one of those tabulated.

1.2 Redesigning the lug:

Try a 12" x 12" square attachment

From page 2.13, at t-c = 0.8125",

\[ A_1 = 0.9847 \]
\[ A_2 = 0.9891 \]
\[ A_3 = 1.6322 \]

\[ S_L = A_1 \times P + A_2 \times M_L \]
\[ = 0.9847 \times 6.6 + 0.9891 \times \frac{55.2}{12} \]
\[ = 11.05 \, \text{ksi} \quad \ll S_{L, \text{allow}} = 21.13 \, \text{ksi} \quad \therefore \text{O.K.} \]

\[ S_C = \left[ A_1 \times P + A_3 \times M_c \right] \times 1.2 \]
\[ = \left[ 0.9847 \times 6.6 + 1.6322 \times \frac{42.75}{12} \right] \times 1.2 \]
\[ = 14.78 \, \text{ksi} \quad \ll S_{C, \text{allow}} = 14.76 \, \text{ksi} \quad \therefore \text{O.K.} \]

Use 12 WF 72 shape.
Example 2:

Check the shell stresses for a nozzle attachment using the following information.

- Vessel diameter = 10'-0"
- Vessel thickness = 5/16"
- Corrosion allowance = 1/8"
- Design pressure = 35 psig
- Design temperature = 400°F
- Material = A-285-C, F.B.
- Pipe diameter = 0'-10 3/4"
- Reinforcement pad = 1'-10" Ø & 0.1875" thk.
- Radial load = 1,250 lbs.
- Longitudinal moment = 17,500 in-lbs.
- Circumferential moment = 5,300 in-lbs.
- Longitudinal shear = 1,400 lbs.

Solution:

2.1 At nozzle to pad junction:

\[ t - c = 0.3125 - 0.125 = 0.1875" \]

Effective corroded thickness = \( t_{\text{shell}} + t_{\text{pad}} = 0.1875" + 0.1875" = 0.375" \)

From page 1.18, by interpolation,

\[ A_1 = \frac{(5.0528 + 4.2602)}{2} = 4.657 \]
\[ A_2 = \frac{(6.709 + 4.634)}{2} = 5.672 \]
\[ A_3 = \frac{(10.471 + 8.267)}{2} = 9.369 \]

\[ S_L = A_1 \times P + A_2 \times M_L \]
\[ = 4.657 \times 1.25 + 5.672 \times 17.5\]
\[ = 14.1 \text{ ksi} \]

\[ S_C = A_1 \times P + A_3 \times M_C \]
\[ = 4.6565 \times 1.25 + 9.369 \times 5.3\]
\[ = 9.96 \text{ ksi} \]

now \( S = 13,750 \text{ psi} \) for A-285-C below 650°F

\[ S_{L, \text{allow.}} = \frac{(25 - 0.5 \times S_p)}{1000} \]
\[ = \frac{(2 \times 13,750 - 0.5 \times 35 \times 60)}{0.1875} / 1000 \]
\[ = (27,500 - 5,600) / 1000 \]
\[ = 21.9 \text{ ksi} \]

\( S_L > S_{L, \text{allow.}} \) \( \therefore \) O.K.
\[ S_c, \text{ allow.} = \frac{(25 - Sp)}{1000} \]
\[ = \frac{(27,500 - 11,200)}{1000} \]
\[ = 16.3 \text{ ksi} > S_c = 9.96 \therefore \text{O.K.} \]

2.2 At junction of pad to shell:

\[ t - c = 0.1875 \]

From page 1.18, values at 0.1875" thickness may be obtained by extrapolation as shown in Figure 2.

EVALUATION OF "A" VALUES FOR REQUIRED THICKNESS \( V_T \)

![Graphs showing evaluation of A values for VT thickness]

\[ S_L = A1 \times P + A2 \times H_L \]
\[ = 5.7 \times 1.25 + 4.0 \times \frac{17.5}{12} \]
\[ = 12.96 \text{ ksi} < S_L, \text{ allow.} = 21.9 \text{ ksi} \therefore \text{O.K.} \]

\[ S_C = A1 \times P + A3 \times M_c \]
\[ = 5.7 \times 1.25 + 11.5 \times \frac{5.3}{12} \]
\[ = 12.2 \text{ ksi} < S_C, \text{ allow.} = 16.3 \text{ ksi} \therefore \text{O.K.} \]
The shear stress is given by:

\[ \tau_L = \frac{2 \times 1.4}{\pi \times 1 \times 0.1875} = 0.44 \text{ ksi (\sim 4\% of } \sigma_c, \text{ allow.)} \]

\[ \therefore \text{ Use of tables is justified.} \]

## 2.3 Adequacy of pad:

Nozzle to pad and pad to shell connections in accordance with the ASME Code Section VIII will generally be found adequate to transmit the applied moments and forces from external loadings.

For connections other than nozzles, and transmitting structural loads only, and where a pad is used, the connection from attachment to pad to shell should be checked to avoid overstressing the pad locally below the attachment.
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<th>5.0</th>
<th>6.0</th>
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**NOTE:** The table continues with more values, but the pattern is not clearly visible due to the layout of the image. The values in the table represent some form of measurement or data, but without further context, it's difficult to interpret the specific nature of the data.
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</tbody>
</table>
3.0 THERMAL EVALUATION

3.1 Discussion

The thermal analysis presented in this section is performed, first for normal transport conditions and then, for the hypothetical fire transient as described in 10 CFR 71. The purpose of this analysis is to determine the thermal response of the cask resulting from the design modifications to the fire shield.

3.2 Summary of Thermal Properties of Materials

The thermal properties used in the following evaluations are summarized in the tables below:

3.2.1 Air (1)

The thermo-physical properties of air used here are summarized on the following Figure 3.2-1.

3.2.2 Lead

Density = 710 lbs./ft.³
Melting Temperature = 621°F

<table>
<thead>
<tr>
<th>Temperature - °F</th>
<th>k - Btu/hr.-ft.-°F</th>
<th>Cp - Btu/lb.-°F</th>
</tr>
</thead>
<tbody>
<tr>
<td>32</td>
<td>20.1</td>
<td>0.0303</td>
</tr>
<tr>
<td>212</td>
<td>19.6</td>
<td>0.0315</td>
</tr>
<tr>
<td>572</td>
<td>13.0</td>
<td>0.0338</td>
</tr>
<tr>
<td>621</td>
<td>8.8</td>
<td>0.0337</td>
</tr>
<tr>
<td>900</td>
<td>8.9</td>
<td>0.0326</td>
</tr>
</tbody>
</table>
**Density**

- lb/ft³ (at 1 atm) \( \rho \)

**Specific Heat**

- Btu/(lb)(deg. F)(at 1 atm) \( c_p \)

**Viscosity**

- lb/hr(ft³)(ft²) \( \mu \)

**Conductivity**

- Btu/(hr)(ft²)(°F/ft) \( k \)

**Prandtl No.**

- dimensionless \( N_p \)

*These conductivity data do not apply at very low pressures, i.e., microns of mercury. For reduced pressure data, see p. 3.*

**Table: Specific Heat and Density Data**

<table>
<thead>
<tr>
<th>Property</th>
<th>Temp Range Deg. F</th>
<th>Reference</th>
<th>Evidence</th>
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<td>1</td>
<td>Test</td>
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<tr>
<td>Specific Heat</td>
<td>280 to 4940</td>
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<tr>
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<td>Conductivity</td>
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<td>1340 to 4040</td>
<td>2</td>
<td>Theory</td>
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**Footnotes:**

3.2.3 Stainless Steel

Density = 489 lb./ft.\(^3\)
Melting Temperature = 1800\(^\circ\)F
Latent Heat = 120 Btu/lb.

<table>
<thead>
<tr>
<th>Temperature - (^\circ)F</th>
<th>(k) - Btu/hr.-ft.-(^\circ)F</th>
<th>(C_p) - Btu/lb.-(^\circ)F</th>
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<td>0.110</td>
</tr>
<tr>
<td>212</td>
<td>9.4</td>
<td>0.120</td>
</tr>
<tr>
<td>572</td>
<td>10.9</td>
<td>0.133</td>
</tr>
<tr>
<td>932</td>
<td>12.4</td>
<td>0.140</td>
</tr>
<tr>
<td>1800</td>
<td>15.8</td>
<td>~0.150</td>
</tr>
</tbody>
</table>
3.3 Technical Specifications of Components

3.4 Thermal Evaluation for Normal Conditions of Transport

3.4.1 Thermal Model
The cask system shall next be analyzed for normal conditions of transport to determine the effects of hot day (ambient temperature = 130 F), and cold day (ambient temperature = -40 F) conditions as defined in 10 CFR 71.

Thermal properties for the materials of the cask are given in Section 2.6. The geometry of the cask is taken as follows:

<table>
<thead>
<tr>
<th>Region</th>
<th>Material</th>
<th>Dimension</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cavity</td>
<td>Void</td>
<td>13.25 in.</td>
</tr>
<tr>
<td>Inner Shell</td>
<td>Stainless</td>
<td>13.75 in.</td>
</tr>
<tr>
<td>Shield</td>
<td>Lead</td>
<td>18.75 in.</td>
</tr>
<tr>
<td>Outer Shell</td>
<td>Stainless</td>
<td>19.25 in.</td>
</tr>
<tr>
<td>Gap</td>
<td>Air</td>
<td>19.31 in.</td>
</tr>
<tr>
<td>Fire Shield</td>
<td>Stainless</td>
<td>19.56 in.</td>
</tr>
</tbody>
</table>

1 = 68.62 inches = 5.718 ft.
D = 39.12 inches = 3.260 ft.

The steady state heating on a body exposed to atmospheric conditions may be found from the following relationship:

\[ q_s + q_a + q_t + q_c + q_k - q_r + q_i = 0 \]
3.4.1 Thermal Model (continued)

This condition expresses the heat loading on the surface of the body where:

- $q_s$ - direct solar load absorbed, Btu/hr.-ft.$^2$
- $q_a$ - atmospheric heat absorbed, Btu/hr.-ft.$^2$
- $q_t$ - terrestrial heat absorbed, Btu/hr.-ft.$^2$
- $q_r$ - radiation emitted from body, Btu/hr.-ft.$^2$
- $q_c$ - conduction to body, Btu/hr.-ft.$^2$
- $q_v$ - convection to body, Btu/hr.-ft.$^2$
- $q_I$ - Internal heat generated within body, Btu/hr.-ft.$^2$

The temperature profile will be determined for the radial direction from the cask cavity. For this computation, the ends of the cask shall be neglected from the total heat transfer area.

3.4.2 Maximum Temperatures

(1) Direct Solar Load

The solar heat loading on the surface of a vertical cylinder is a function of the solar heating and the projected area of the cylinder with the sun. The maximum solar heating occurs at approximately noon, however, the projected area of the cylinder is minimum at this time.

$$q_s = q_o f_1(\theta) f_2(\theta)$$

Where:

- $f_1(\theta) = T_a \sec (90-\theta)$
- $f_2(\theta) = \cos \theta$
- $q_o$ - solar constant = 442 Btu/hr.-ft.$^2$
- $T_a$ - transmission coefficient for air = 0.7
3.4.2 Maximum Temperatures (continued)

The diagram shows that, as the sun is near its zenith, \( f_1(\theta) \) maximizes resulting in maximum solar load. However, \( f_2(\theta) \) maximizes as the sun approaches normal with the surface of the cylinder. The maximum solar load therefore occurs somewhere between vertical and horizontal. Solar load is also affected by the orientation of the receptor surface with the compass but this effect will be neglected for a cylinder. Other factors that affect the solar load are time of year and earth latitude. The maximum heat load on a vertical cylinder that incorporates these factors is found to be: (3)

\[
q_s = 225 \text{ Btu/hr.-ft.}^2
\]

This value includes the contribution from diffuse atmospheric heating.

The projected heat transfer for solar heating neglecting the ends of the cask is:

\[
A_{s/l} = D = 3.26 \text{ ft.}^2/\text{ft.}
\]

(2) Atmospheric

The heating on the cask surface resulting from diffuse atmospheric heating is presented in the same reference as the solar heating. This value is taken as:

\[
q_a = 45 \text{ BTU/hr.-ft.}^2
\]

The effective heat transfer area, neglecting the ends of the cask is:

\[
A_{a/l} = \pi D = 10.24 \text{ ft.}^2/\text{ft.}
\]

(3) Terrestrial

The terrestrial heating results from radiation from the ground to the cask surface. It will be assumed that the cask on the transporter will not "see" the ground.

\[
q_t = 0
\]
3.4.2 Maximum Temperatures (continued)

(4) Conduction to the Body

It will be assumed that conduction paths from the cask surrounding to the cask surface are negligible.

\[ q_k = 0 \]

(5) Convection to the Body

Heat transfer by convection to the body will be with the surrounding air. This is expressed by:

\[ q_c = h_c A_c (T_a - T_s) \text{ Btu/hr.-ft.}^2 \]

Where:
- \( T_a \) - Air temperature
- \( T_s \) - Surface temperature
- \( h_c = 0.19 \Delta T^{1/3} \) for vertical cylinders in air

The heat transfer area is expressed by:

\[ A_{a/l} = \pi D = 10.24 \text{ ft.}^2/\text{ft.} \]

(6) Radiation from Body

The heat transfer from the body by radiation to the air is given by:

\[ q_r = E_o A_r (T_s - T_a) \]

Where:
- \( E \) = emissivity of the radiating surface
- \( E_o = 0.171 \times 10^{-8} \) Btu/hr./ft.\(^2/\circ R^4 \)

The heat transfer area is given by:

\[ A_{r/l} = \pi D = 10.24 \text{ ft.}^2/\text{ft.} \]

(7) Internal Heating

Internal heating will come from activity in the cask cavity. The current heat load limit for the cavity is:

\[ q_I = 600 \text{ watts} \]

Assume the heating occurs over \( 1/2 \) the cavity length:

\[ l_I = 1/2(54) \text{ inches} = 2.25 \text{ feet} \]
3.4.2 Maximum Temperatures (continued)

(8) Summary

\[ \frac{Q_s}{1} = (q_s + q_a) \frac{A_s}{1} = \frac{(225) \text{Btu/hr.-ft.}^2 (3.26) \text{ft.}^2/\text{ft.}}{225} \times 733.50 \text{ Btu/hr.-ft.} \]

\[ \frac{Q_a}{1} = (q_a) \frac{A_a}{1} = (45) \text{Btu/hr.-ft.}^2 (10.24) \text{ft.}^2/\text{ft.} = 460.80 \text{ Btu/hr.-ft.} \]

\[ \frac{Q_t}{1} = 0 \]

\[ \frac{Q_k}{1} = 0 \]

\[ \frac{Q_c}{1} = (0.19)(T_s - T_a)^{1.333} \text{ Btu/hr.-ft.}^2 (10.24) \text{ft.}^2/\text{ft.} = 1.9456(T_s - T_a)^{1.333} \text{ Btu/hr.-ft.} \]

\[ \frac{Q_r}{1} = E(0.171) \text{ Btu/hr.-ft.}^2 \text{ - } \frac{0.1R^4[(T_s/100)^4 - \frac{T_a}{100})^4]}{10.24} \text{ft.}^2/\text{ft.-\text{R}} \]

\[ \frac{Q_1}{1} = (q_1)/1 = \frac{(600) \text{watts} (3.413) \text{Btu}}{\text{hr.-watt} (2.25) \text{ft.}} = 910.10 \text{ Btu/hr.-ft.} \]

(9) Ambient Temperature = 100°F, No Solar Load

a. Surface Temperature of Cask

The steady state equation describing the heating at the cask surface will be:

\[ \frac{Q_I}{I} = \frac{Q_r}{I} - \frac{Q_c}{I} \]

Where:

\[ Q_I = 600 \text{ watts} \]

\[ \frac{Q_r}{I} = 1.751 E[(T_s/100)^4 - (T_a/100)^4] \]

\[ \frac{Q_c}{I} = 1.9456(T_s - T_a)^{1.333} \]

\[ I = \frac{2.25 \text{ Ft.}}{1} \]

\[ T_a = 100^\circ \text{F} = 560^\circ \text{R} \]

\[ T_s = 0.85(4) \text{ weathered stainless} \]

Substituting these values in the above equation gives:

\[ 2373.9 = (1.4884)(T_s/100)^4 + (1.9456)(T_s - 560)^{1.333} \]

\[ T_s = 143^\circ \text{F} \]
3.4.2 Maximum Temperatures (continued)

b. Temperature Profile in Cask - \( T_a = 100^\circ F \)

\[
\begin{align*}
R_1 &= 13.25 \text{ in.} = 1.1042 \text{ ft. cavity} \\
R_2 &= 13.75 \text{ in.} = 1.1458 \text{ ft. stainless} \\
R_3 &= 18.75 \text{ in.} = 1.5625 \text{ ft. lead} \\
R_4 &= 19.25 \text{ in.} = 1.6042 \text{ ft. stainless} \\
R_5 &= 19.31 \text{ in.} = 1.6092 \text{ ft. air} \\
R_6 &= 19.56 \text{ in.} = 1.6300 \text{ ft. stainless} \\
T_s &= 143^\circ F \\
Q/I &= 910.1 \text{ Btu/hr.-ft.} \\
\end{align*}
\]

- Across fire shield - stainless

\[
Q/I = \frac{2\pi k_s}{\ln(R_6/R_s)} (T_5 - T_6)
\]

At \( 150^\circ F \), \( k_s = 8.92 \text{ Btu/hr.-ft.}^\circ F \)

\[
910.1 = \frac{2\pi (3.92)}{\ln(1.6300/1.6092)} \Delta T = 4363 \Delta T
\]

\( \Delta T = 0.2^\circ F \)

\( T_5 = 143.2^\circ F \)

- Across air gap

\[
Q/I = (Q/I)_{\text{conduction}} + (Q/I)_{\text{radiation}}
\]

\[
= \frac{2\pi k_a}{\ln(R_5/R_4)} (T_4 - T_5) + A_4 F_4 \sigma (T_4^4 - T_5^4)
\]

Air at \( 160^\circ F \), \( k_a = 0.0166 \text{ Btu/hr.-ft.-}^\circ F \)

(U157W)
3.4.2 Maximum Temperatures (continued)

Steel: $E_4 = 0.95(5)$ Rough steel plate at $200^\circ F$

$E_5 = 0.94(5)$ Rough steel plate at $100^\circ F$

\[
A_{445} = \frac{1}{\frac{1 - E_4}{A_4 E_4} + \frac{1 - E_5}{A_5 E_5}}
\]

\[
= \frac{1}{\left(\frac{1 - .95}{2\pi(1.6042)(.95)} + \frac{1}{2\pi(1.6042)} + \frac{1 - .94}{2\pi(1.6032)(.94)}\right)}
\]

\[
= \frac{1}{(0.0052 + 0.0992 + 0.0063)}
\]

\[
= \frac{1}{0.1107}
\]

\[
= 9.03 \text{ ft.}^3/\text{ft.}
\]

\[
Q/1 = \frac{2\pi(0.0166)}{\ln(1.6092/1.6042)} (t_4 - 603) + (9.03)(.171)
\]

\[
[(T_4/100)^4 - (603/100)^4]
\]

\[
23164 = 33.52 T_4 + (1.5441)(T_4/100)^4
\]

The right-hand side of this equation is shown graphically on Figure 3.4-1. From this Figure:

$T_4 = 163^\circ F$

- Outer Shell - Stainless

\[
Q/1 = \frac{2\pi k_s}{\ln(R_4/R_3)} (T_3 - T_4)
\]

\[
k_s = 9.02 \text{ Btu/hr.-ft.}^2\cdot \text{OF at } T = 163^\circ F
\]

\[
910.1 = \frac{2\pi(9.02)}{\ln(1.6042/1.5625)} \Delta T = 2195 \Delta T
\]

\[
\Delta T = 0.4^\circ F
\]

$T_3 = 163.4^\circ F$
FIGURE 3.4-1

$F(T_4) = 33.52 T_4 + (1.5541)(T_4/100)^4$

$T_4 = \text{oR}$

$T_4 = 163 \text{°F}$
Lead Shielding

\[ Q/l = \frac{2\pi k_L}{\ln(R_3/R_2)} (T_2 - T_3) \]

\[ k_L = 19.1 \text{ Btu/hr.-ft.-}^\circ\text{F at } T = 163^\circ\text{F} \]

\[ 910.1 = \frac{2\pi(19.1)}{\ln(1.5625/1.1458)} \Delta T = 386.9 \Delta T \]

\[ \Delta T = 2.4^\circ\text{F} \]
\[ T_2 = 165.8^\circ\text{F} \]

Inner Shell

\[ K_S = 9.05 \text{ Btu/hr.-ft.-}^\circ\text{F at } T = 165^\circ\text{F} \]

\[ 910.1 = \frac{2\pi(9.05)}{\ln(1.1458/1.1042)} \Delta T = 1539 \Delta T \]

\[ \Delta T = 0.6^\circ\text{F} \]
\[ T_1 = 166.4^\circ\text{F} \]

Summary

\[ T_1 = 166.4^\circ\text{F} \]
\[ T_2 = 165.8^\circ\text{F} \]
\[ T_3 = 163.4^\circ\text{F} \]
\[ T_4 = 163.0^\circ\text{F} \]
\[ T_5 = 143.2^\circ\text{F} \]
\[ T_6 = 143.0^\circ\text{F} \]
3.4.2 Maximum Temperatures (continued)

(10) Hot Day Conditions - \( T_a = 130^\circ F \)

The evaluated condition is conservative compared to the condition described in 10CFR71.

Therefore: \[
\frac{Q_s}{1} + \frac{Q_i}{1} = \frac{Q_r}{1} - (-\frac{Q_c}{1}).
\]

\[
733.5 + 910.1 = 1.751 E[(T_s/100)^4 - (T_a/100)^4] + 1.9456(T_s - T_a)^{1.333}
\]

\[ E = 0.85\text{ weathered stainless steel} \]

\[ T_a = 130^\circ F = 590^\circ R \]

Substituting these values in the above equation gives:

\[ 3447.1 = (1.4384)(T_s/100)^4 + (1.9456)(T_s - 590) \]

This equation is solved by trial and error as shown on the following curve, Figure 3.4-2. The resulting surface temperature is:

\[ T_s = 203^\circ F. \]

The analysis in Section 3.4.2(9)b. shows that the temperature change across the stainless steel shells is negligible due to the high thermal conductivity. In this analysis, assume the average steel shell temperature is equivalent to the surface temperature. The first significant temperature change will be across the air gap.

\[ Q/1 = \frac{2\pi k_a}{\ln(R_s/R_4)} (T_4 - T_5) + A_4F_{4-5} \sigma(T_4^4 - T_5^4). \]

For air at 210°F; \( k_a = 0.0180 \text{ Btu/hr.-ft.-}^\circ F \)

\[ A_4F_{4-5} = 9.03 \text{ ft.}^2/\text{ft.} \]

\[ T_5 = 203^\circ F = 663^\circ R. \]
FIGURE 3.4-2

\[ F(T_s) = 1.4884 \left( \frac{T_s}{100} \right)^4 + 1.9456(T_s - 560) \]

\( T_s - ^\circ R \)

- \( T_s \approx 203^\circ F \)
- \( T_s \approx 193^\circ F \)
- \( T_s = 167^\circ F \)
- \( T_s = 143^\circ F \)

Surf. Temperature - °F

- 150
- 160
- 170
- 180
- 190
- 200
- 210
3.4.2 Maximum Temperatures (continued)

\[
3.4.2.2\text{ Maximum Temperatures (continued)}
\]

\[
910.1 = \frac{2\pi(0.0180)}{\ln(1.6092/1.6042)} (T_4 - 663) + (9.03)(.171)[(T_4/100)^4 - (663/100)^4].
\]

\[
27,989 = 36.34 T_4 + (1.5441)(T_4/100)^4.
\]

This equation is plotted on Figure 3.4-3. The solution to this equation is:

\[
T_4 = 228^\circ F.
\]

The temperature rise across the lead region will be given by:

\[
Q/1 = \frac{2\pi k_L}{\ln(R_3/R_2)} (T_2 - T_3).
\]

For lead at 230°F; \( k_L = 19.5 \text{ Btu/lb.} \cdot \text{°F} \)

\[
T_3 = T_4 = 228^\circ F
\]

\[
1643.6 = 395.0 \Delta T
\]

\[
T = 4.2^\circ F;
\]

\[
T_3 = 232^\circ F.
\]
FIGURE 3.4-3.

\[ F(T_4) = 30.28(T_4) + 1.5441(T_4/100)^4 \]

\( T_4 \) - °F

- \( F(T_4) = 18.000 \) when \( T_4 = 75^\circ F \)
- \( F(T_4) = 228^\circ F \) when \( T_4 = 228^\circ F \)

**OUTER SHELL TEMPERATURE - °F**

- 80
- 100
- 120
- 140
- 160
- 180
- 200
- 220
- 240

- 15,000
- 17,000
- 19,000

- 26,000
- 27,000
- 28,000
- 29,000
3.4.3 Minimum Temperatures

Revision 0

(1) Cold Day Conditions - $T_a = -40^\circ F$

This condition is described in 10 CFR 71.71 as "An ambient temperature of -40 F in still air and shade".

Therefore: 

$$
\frac{Q_a}{T} + \frac{Q_I}{T} = \frac{Q_r}{T} - \left( - \frac{Q_c}{T} \right).
$$

$$
460.8 + 910.1 = 1.751 E[(T_s/100)^4 - (T_a/100)^4] + (1.9456)(T_s - T_a)^{1.333}
$$

$E = 0.85(3)$ weathered stainless steel

$T_a = -40^\circ F = 420^\circ R$

Substituting these values into the above equation gives:

$$
1834.0 = (1.4884)(T_s/100)^4 - (1.9456)(T_s - 420)^{1.333}.
$$

This equation is solved by trial and error to give the following result:

$$
T_s = 52^\circ F.
$$

The temperature across the air gap will be found from the expression:

$$
Q_{I/1} = \frac{2\pi k_a}{\ln(R_5/R_4)} (T_4 - T_5) + A_4 F_{4-5}^a (T_4^4 - T_5^4)
$$

For air at 70$^\circ F$; $k_a = .0150$ Btu/hr-ft-$^\circ F$

$$
T_5 = 52^\circ F = 512^\circ R
$$

910.1 = \frac{2\pi(.0150)}{\ln(1.6092/1.6042)} (T_4 - 512) +

(9.03)(.171)[(T_4/100)^4 - (512/100)^4].

17,476 = (30.28)T_4 + (1.5441)(T_4/100)^4.

This function is shown on Figure 3.4-3. The solution to the above equation is:

$$
T_4 = 75^\circ F.
$$
The temperature rise across the lead region will be as before where:

\[ k_L = 20.0 \text{ Btu/hr.-ft.-°F at } T_L = 75{}^\circ\text{F}. \]
\[ 
\Delta T_L = 4.1{}^\circ\text{F}. 
\]
\[ T_3 = 79{}^\circ\text{F}. 
\]
3.4.4 Maximum Internal Pressures

Section 2.6.1 identifies normal condition temperature within the containment vessel to be $T=232^\circ F$.

To find the maximum internal pressure, assume the cask is loaded at $70^\circ F$ and 14.696 psia. From the saturated water tables *(Page 649), the partial pressure of water is 0.3631 psia. Therefore, the partial pressure of air at $70^\circ F$ is:

$$P_{\text{atm}} - P_{\text{water}} = P_{\text{air}}$$

$$14.696 - 0.3631 = 14.333 \text{ psia} = P_{\text{air}}$$

From the saturated water tables *(Page 650), the partial (vapor) pressure of water at $232^\circ F$ is 21.618 psia.

The partial pressure of air at $232^\circ F$ may be found from the perfect gas law:

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

In this case, $T_1 = 70^\circ F$, $P_1 = 14.333$ psia, $T_2 = 232^\circ F$. However, the perfect gas relation requires all temperatures to be absolute temperatures.

\[
\frac{14.333}{530} = \frac{P_2}{692} \quad T_1 = 70^\circ F = 530^\circ R \\
T_2 = 232^\circ F = 692^\circ R
\]

$P_2 = 18.714$ psia = partial pressure of air at $232^\circ F$.

The absolute pressure will be the sum of the partial pressures:

\[
P_{2\text{absolute}} = P_{\text{water}} + P_{\text{air}} = 21.618 + 18.714 = 40.332 \text{ psia. (25.6 psig)}
\]

The predicted pressure value conservatively assumes a sufficient quantity of free water is present, thus all pressure predictions are based upon the properties of saturated water. These conservative predictions of pressure and associated temperatures are used to evaluate integrity of the CNS 1-13C package. None of these conditions reduce the effectiveness of the package containment.

3.4.5 **Maximum Thermal Stress**

The temperature gradient through the side wall under normal conditions of transport is due to the decay heat of 600 watts. The resulting temperature difference between the outside surface of the outer steel shell and the inside surface of the inner steel shell is 3.4 degrees F. Stresses resulting from this temperature gradient are far below the yield point of the cask materials. Section 2.6.1 discusses the effect of thermal stresses in detail.
3.5 Hypothetical Accident Thermal Evaluation

3.5.1 Thermal Model

The analysis in this section demonstrates the thermal response of the CNS 1-13 C cask when subjected to the environmental fire transient discussed in 10 CFR 71.

3.5.2 Package Conditions and Environment

This transient is defined as exposure of the entire package to a thermal radiation environment of 1475°F for 30 minutes with an emissivity coefficient of 0.9, and assuming the surfaces of the package have an absorption coefficient of 0.8.

3.5.3 Package Temperatures

Radiation to a small gray body in black surroundings may be expressed by:

\[ Q_r = \sigma A_1 E_1 (E_0 T_0 - T_1) \]

Where:
- \( E_0 = 0.90 \) emissivity of flame
- \( E_1 = 0.80 \) emissivity of package
- \( T_0 = 1475°F = 1935^0R \)

The thermal response of the radial profile for this cask was determined using the graphical "Schmidt Plot" method discussed in Kreith (6), Chapter 4. This method permits an algebraic solution to the transient heat transfer problem including the problem where the boundary condition varies with time. The solution is obtained for an effective unit-surface conductance, which is equivalent to a convection heat transfer coefficient.

\[ Q_r = h_r A_1 (T_0 - T_1) \]

Where:
- \( h_r \) - effective surface conductance
- \( T_0 \) - effective flame temperature

Take: \( \bar{T}_0 = (0.9)^{1/4} T_0 \)

Equate the two heat transfer equations and solve for \( h_r \):

\[ h_r = \frac{E_1 \sigma (T_0^4 - T_1^4)}{\bar{T}_0 - T_1} \]

(0157W)
3.5.3 Package Temperatures (continued)

Substituting in the given values results in an expression for the surface conductance in terms of the surface temperature \(T_1\).

At the surface of the body:

\[
\frac{q}{A_1} = h_r(T_0 - T_1) = -k_s \frac{dT}{dX}.
\]

In finite difference form at any time step \(t\):

\[
\frac{dT}{dX} = \frac{T_1^t - T_0^t}{ks/h_r} = \frac{T_1^t - T_2^t}{\Delta X}
\]

For the algebraic solution, this relationship shows the slope of the temperature between 0 and 1 equal to that between 1 and 2 with an effective \(\Delta X_0 = k_s/h_r\).

The unit-surface conductance in finite difference form will be:

\[
h_r^t = \frac{(1.726 \times 10^4) - (0.1363)(\frac{T_1^{t-1}}{100})^4}{1885 - T_1^{t-1}}
\]
3.5.3 Package Temperatures (continued)

The temperature profile within the material is determined from the unsteady conduction equation in one dimension.

\[ \frac{1}{a} \frac{\partial T}{\partial \theta} = \frac{a}{\partial x^2} T \]

\[ a = \frac{k}{C_P \rho} \] of material

\( \theta \) - time

In finite difference form:

\[ \frac{1}{a} \frac{\Delta a T}{\Delta \theta} = \frac{\Delta x^2 T}{\Delta x^2} \]

Adopting subscript notation \( n \) in \( x \)-direction and \( t \) in time direction:

\[ \frac{1}{a} \frac{\Delta \theta T}{\Delta \theta} = \frac{1}{a} \frac{T_{n+1} - T_n}{\Delta \theta} \]

\[ \frac{\Delta x^2 T}{\Delta x^2} = \frac{\Delta x (\frac{\Delta T}{\Delta x})}{\Delta x} = \frac{T_{n+1}^t - T_n^t}{\Delta x} - \frac{T_n^t - T_{n-1}^t}{\Delta x} \]

Combining these equations into the finite difference equation gives:

\[ \frac{1}{a} \frac{T_{n+1}^t - T_n^t}{\Delta \theta} = \frac{T_n^t + 2T_{n+1}^t + T_{n-1}^t}{\Delta \theta} \]

\[ \frac{\Delta x^2 (T_{n+1}^t - T_n^t)}{a \Delta \theta} = T_{n+1}^t - 2T_n^t + T_{n-1}^t \]

To solve the equation algebraically, \( \Delta x^2 \) and \( \Delta \theta \) will be chosen such that:

\[ \frac{\Delta x^2}{a \Delta \theta} = 2 \]

Therefore:

\[ 2T_n^t + 1 - 2T_n^t = T_{n+1}^t - 2T_n^t + T_{n-1}^t \]

or,

\[ T_n^{t-1} = \frac{T_{n+1}^t + T_{n-1}^t}{2} \]

The Figure on page 3-22 shows this.
3.5.3 Package Temperatures (continued)

Having selected a method to solve the transient problem the question remains as to applying it to a system of multiple regions in the direction of interest. This shall be accomplished by two modifications to the previous theory.

1. The fire shield - gap - outer shell of the cask will be replaced by a dummy material that behaves the same thermally as the three materials.

2. The second region intervals will be determined from selection of the interval size in the first region and keeping the time steps constant.

3. The temperature at the interface between the two regions shall be determined by the boundary conditions at that point.

4. The temperature change across the inner stainless shell is approximately constant, and the temperature of the shell is equal to the inner lead temperature.

The previous conditions may be stated algebraically.

\[ \frac{2 E}{\ln(R_1/R_2)} (T_1 - T_2) = U (T_1 - T_2). \]

Where: U - overall heat transfer coefficient of the region.

\[ \Delta X_2 = \Delta X_1 \sqrt{\frac{a_2}{a_1}} \]

\[ k_1 \frac{\Delta T_1}{\Delta X_1} = k_2 \frac{\Delta T_3}{\Delta X_2} \]

\[ \frac{\partial T}{\partial X_3} = 0 \]
3.5.3 Package Temperatures (continued)

a. Effective conductivity of fire shield/outer shell.

\[ q/l = \frac{2\pi E}{\ln(R_1/R_4)} (T_1 - T_4). \]
\[ q/l = \frac{2\pi k_s}{\ln(R_1/R_2)} (T_1 - T_2). \]
\[ q/l = \frac{2\pi k_a}{\ln(R_2/R_3)} (T_2 - T_3) + \sigma A_2 F_{2-3} (T_2^4 - T_3^4). \]
\[ q/l = \frac{2\pi k_s}{\ln(R_3/R_4)} (T_3 - T_4). \]

\( k_s \) - thermal conductivity of steel
\( k_a \) - thermal conductivity of air

\[ A_2 F_{2-3} = 1/ \frac{P_2}{A_2 E_2} + \frac{1}{A_2} + \frac{P_3}{A_3 E_3} \]
\[ p = 1 - \frac{E}{E_2} \]

For weathered stainless, take \( E_2 = E_3 = 0.85^{(3)} \)

\[ A_2 F_{2-3} = \frac{P_2}{E_2} + \frac{P_3 R_2}{E_3 R_3} \]
\[ = 0.739 A_2 \]

Let:
\[ \alpha A_2 F_{2-3} (T_2^4 - T_3^4) = A_2 h_r (T_2 - T_3) \]
\[ h_r = \frac{(0.739)\sigma (T_2^4 - T_3^4)}{T_2 - T_3} \]

(0157W)
Since the rate of heat flow through this system is constant the overall heat transfer coefficient may be solved by solution of each of the intermediate temperatures.

Therefore:

$$U = \frac{1}{2\pi k_s} \ln\left(\frac{R_1}{R_2}\right) + \frac{1}{2\pi k_a} + \frac{1}{2\pi k_s} \ln\left(\frac{R_3}{R_4}\right)$$

$$\bar{k} = \frac{\ln\left(\frac{R_1}{R_2}\right)}{k_s} + \frac{1}{k_a} + \frac{1}{k_s} \ln\left(\frac{R_3}{R_4}\right)$$

To solve this equation, some estimate of the temperature characteristics of the system during the transient must be known. An analysis has been performed on a similar cask using the computer code THT-D by Battelle Memorial Institute in Columbus (7). This cask had a 1/4 inch stainless fire shield, a 0.060 inch air gap, and a 1/2 inch stainless outer shell wall. These characteristics are identical with the system here. The radial temperature profile for this system resulted in the following average temperatures during the transient.

$$T_{\text{surface}} = 1100^\circ F$$
$$T_{\text{shell}} = 440^\circ F$$

Since the temperature change across the steel is negligible, the same values will be used for the surface temperatures across the gap.

$$T_2 = 1100^\circ F = 1560^\circ R$$
$$T_3 = 440^\circ F = 900^\circ R$$

Substituting these values into the expression for effective radiation conductance gives:

$$h_r = 10.05 \text{ Btu/hr.-ft.}^2\cdot\text{O.R.}$$
3.5.3 Package Temperatures (continued)

The following values of thermal conductivity are chosen:

- Air: \( k_a = 0.030 \text{ Btu/hr.-ft.-°R} \)
- \( k_s = 11.0 \text{ Btu/hr.-ft.-°R} \)

Substituting all of these values into the expression for effective thermal conductivity gives:

\[ k = 0.998 \text{ Btu/hr.-ft.-°R} \]

Additional property changes for the composite include:

\[ \bar{P} = P_s \left( \frac{t_s}{t_c} \right) \]

- \( P_s = 489 \text{ lbm/ft.}^3 \)
- \( t_s = 0.75 \text{ inch} \)
- \( t_c = 0.81 \text{ inch} \)

\[ \bar{P} = 452.8 \text{ lb./ft.}^3 \]

For \( C_p \) use the value for stainless:

\( C_p = 0.125 \text{ Btu/lbm.-°F} \)

The effective thermal diffusivity constant for the composite will be:

\[ \bar{a} = \frac{k}{\rho C_p} \]

\( \bar{a} = 0.01763 \text{ ft.}^2/\text{hr.} \)
3.5.3 Package Temperatures (continued)

b. Interval Widths

To use the Schmidt Plot Method, it is normally sufficient to separate the region into some number of equal intervals and solve for the corresponding time step length.

For the composite fire shield/outer shell:
\[ X = 0.81 \text{ inches} \]
\[ a = 0.01763 \text{ ft}^2/\text{hr.} \]

Chose 3 intervals:
\[ \Delta X = 0.27 \text{ inches} \]

\[ \Delta \theta = \frac{\Delta X^2}{2a} = \frac{(0.27)^2}{(2)(0.01763)(144)} \text{in}^2 \text{-hr.-ft.}^2 \]

\[ = 0.0144 \text{ hr.} \]
\[ = 0.86 \text{ min.} \]

The time step will be the same for the lead region. Use this value to determine the corresponding interval width:

\[ \Delta X_2 = \Delta X_1 \sqrt{\frac{a_2}{a_1}} \]

For Lead: \[ a = 0.883 \text{ ft}^2/\text{hr.} \]

\[ \Delta X_2 = 0.27 \sqrt{\frac{0.883}{0.01763}} \]

\[ = 1.911 \text{ inches} \]
c. Temperature at Interface

The temperature at the interface will be determined by solving the boundary condition at the interface.

\[ k_1 \frac{\partial T_1}{\partial x_1} = k_2 \frac{\partial T_2}{\partial x_2} \]

In finite difference form:

\[ k_1 \frac{T_{n-1} - T_n}{\Delta x_1} = k_2 \frac{T_n - T_{n+1}}{\Delta x_2} \]

It can be shown by manipulation of the finite difference equation for temperature within the homogeneous regions that:

\[ T_{n-1}^t = T_{n-1}^{t-1} \]

\[ T_{n+1}^t = T_{n+1}^{t-1} \]

This now permits solution of the interface temperature at time step \( t \) based upon a knowledge of the interval temperatures on either side of the interface in the preceding time step.

Let: \((k_1/k_2)(\Delta x_2/\Delta x_1) = \bar{K} \) constant

\[ KT_{n-1}^{t-1} - KT_n^t = T_n^t - T_{n+1}^{t-1} \]
3.5.3 Package Temperatures (continued)

Rearranging, and solving for interface temperature \( T_n \):

\[
T_n = \frac{k_1 T_{n-1}^{t-1} + T_{n+1}^{t-1}}{1 + k}
\]

\( k_1 = 0.998 \ \text{Btu/hr.-ft.-°F} \) composite

\( k_2 = 18.6 \ \text{Btu/hr.-ft.-°F} \) lead

\( \Delta X_1 = 0.27 \ \text{in.} \)

\( \Delta X_2 = 1.911 \ \text{in.} \)

\( \bar{R} = 0.380. \)

\text{d. Radial Transient Temperature Solution}

It is now possible to solve the transient heat transfer problem using the Schmidt Plot Method. The plotting was made using the following relationships.

\[
h_r^t = \frac{17,260 - (0.1368) \left( \frac{T_1^{t-1}}{100} \right)^4}{1885 - T_0^{t-1}}.
\]

\[
T_3^{t+1} = \frac{(0.380)T_3^t + T_5^t}{1.380}.
\]

The following table shows the values for the first six time steps used to make the plot.

<table>
<thead>
<tr>
<th>( \Delta \theta )</th>
<th>( T_1^{t-1} (^{\circ}R) )</th>
<th>( h_r^t )</th>
<th>( \left( \frac{k}{h_r} \right)^{(12)} )</th>
<th>( T_3^t )</th>
<th>( T_5^t )</th>
<th>( T_4^{t+1} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>625</td>
<td>13.58</td>
<td>.385</td>
<td>625</td>
<td>625</td>
<td>624</td>
</tr>
<tr>
<td>2</td>
<td>915</td>
<td>16.31</td>
<td>.713</td>
<td>700</td>
<td>625</td>
<td>645</td>
</tr>
<tr>
<td>4</td>
<td>1090</td>
<td>13.23</td>
<td>.621</td>
<td>770</td>
<td>640</td>
<td>676</td>
</tr>
<tr>
<td>6</td>
<td>1210</td>
<td>21.23</td>
<td>.564</td>
<td>840</td>
<td>655</td>
<td>706</td>
</tr>
</tbody>
</table>

(0157W)
3.5.3 Package Temperatures (continued)

The complete Schmidt Plot for 36 time steps (T = 30.96 min.) is shown on Figure 3.5-1.

The temperatures at the surface of the fire shield (T₁), at the outer shell/lead interface (T₄), and at the inside surface of the lead (T₇), were taken from the Schmidt and plotted against time as shown on Figure 3.5-2. These results are then compared to the results obtained by Battelle(7) for the similar system using the THT-D computer code.

Comparison of the results indicate that the Schmidt Plot Method used here gives a reasonable approximation of the thermal behavior across the radial profile during the fire transient. The surface temperature profile of the CNS 1-13 cask, initially lagging and finally leading, results from assuming a constant effective thermal conductivity (k̄) during the transient when compared to the computer solution. During the fire, radiation across the gap will increase from an initially small value which would increase the surface temperature at the beginning of the transient. During the latter stages of the transient, the effects of radiation would be expected to be slightly higher than the assumed average which would, in turn, lower the final surface temperature slightly.

The temperature profile of the outside surface of the lead correlates well with the computer solution. The approximately constant T between the two methods during the transient is consistent with the T at the start of the transient. The lower T across the lead region for the CNS 1-13 cask (ΔT = 100°F) in comparison to that for the NECO Cask (ΔT = 140°F) is due primarily to the difference in lead region thickness.

CNS-1600: \[ \Delta T / \Delta x = 100^\circ F / 5 \text{ in.} = 20^\circ F / \text{in.} \]
NECO: \[ \Delta T / \Delta x = 140^\circ F / 6 \text{ in.} = 23^\circ F / \text{in.} \]
FIGURE 3.5-2.

RADIAL TEMPERATURE PROFILE
- THT-D ANALYSIS - NECø CASK
- SCHMIDT PLOT - CNS 1-136 CASK

TEMPERATURE - °F

OUTSIDE LEAD

INSIDE LEAD

TIME - MINUTES
e. Volume of Lead Melt

The primary objective of the fire transient analysis is to determine the behavior of the shield. Sufficient shielding material must survive the fire transient, in place, to maintain dose rates in the vicinity of the cask within the limits specified in 10CFR71.

The results on Figure 2.4-1 indicate that the melting temperature of lead (621°F) is not reached in the 30 minute transient. Further, the Battelle analysis(7), extending the transient into the cooldown period for the similar cask geometry showed that the maximum lead temperature along the radial profile occurs at T = 30 min. Therefore, based upon uniform heat transmission, it could be concluded that no lead melt occurred. However, uniform heat transmission does not occur, specifically at the corners of the cask and at points where lifting lugs, tie-downs, etc. are connected to the cask outer shell.

The analysis performed by Battelle was based upon a finite cylinder with uniform material thickness in both the radial and axial directions. This analysis indicates that lead melting started in the corners of the cylinder after 27.5 minutes in the transient.

For the purposes of this study, assume that lead melting in the corners will occur when the temperature at the surface of the lead reaches the same point at which lead melt started in the Battelle analysis. Local melting at bolt connections, etc. will start earlier in the transient but the extent of melting will be minimized by the lower average temperature in the lead mass and the high thermal conductivity transferring the heat away. The assumed model here is based upon the premise that when the average lead temperature reaches a certain value, conduction away from local heat zones is no longer sufficient to prevent melting.
3.5.3 Package Temperatures (continued)

Inspection of Figure 3.5-2 shows that melting at the corners of the cask in the Battelle analysis began at an outside lead temperature of 515°F. This same temperature is reached in this analysis after 26 minutes in the transient.

The heat balance of the cask system based upon average radial temperatures during the final 4 minutes of the transient shall be used to determine the mass of lead melt.

\[
\frac{Q}{A} = \frac{\sum M_n C_{pn} \Delta T_n}{At} + H_L \frac{M_L}{At}
\]

Where:
- \(M_n\) - Mass of individual regions
- \(C_{pn}\) - Specific heat of each region
- \(\Delta T_n\) - Temperature change during time interval \(\Delta t\)
- \(H_L\) - Latent heat of lead = 10.55 Btu/lb.
- \(M_L\) - Mass of lead melt during time interval \(\Delta t\)
- \(Q/A\) - Average surface heating
- \(A_T\) - Total area of surface

Assume the Battelle analysis results describe the temperature behavior on the surface of the CNS-1600 cask during the last 4 minutes of the transient.

\[
\frac{Q}{A} = 0.171(0.8)[(0.9)(1935/100)^4 - (1580/100)^4]
\]

\[
= 8735 \text{ Btu/hr.-ft.}^2
\]
3.5.3 Package Temperatures (continued)

The total surface area of the cask is:

\[ A = 2\pi R_0^2 + 2\pi R_0 H \]

\[ R_0 = 19.56 \text{ in.} \]
\[ H = 68.62 \text{ in.} \]

\[ A = 2\pi(19.56)^2 + 2\pi(19.56)(68.62) \]
\[ = 10,837 \text{ in.}^2 \]
\[ = 75.26 \text{ ft.}^2 \]

The total heat into the cask in the last 4 minutes of the transient will be:

\[ Q_T = (Q/A)A \Delta t \]
\[ = (8735)\text{Btu/hr.-ft.}^2(75.26)\text{ft.}^2(4.0)\text{min.}(1/60)\text{hr./min.} \]
\[ = 43,826 \text{ Btu} \]

The heat balance equation will now be solved as follows:

\[ Q_T = (MC_p\Delta T)_{OS} + (MC_p\Delta T)_{IS} + (M - M_L)C_p\Delta T)_{lead} + H_L M_L. \]

Where:

\[ M_{OS} = 2283 \text{ lbs.} \text{ (mass outer shell + fire shield)} \]
\[ M_{IS} = 817 \text{ lbs.} \text{ (mass inner shell)} \]
\[ M = 16,869 \text{ lbs.} \text{ (mass lead)} \]
\[ C_p = 0.125 \text{ Btu/lbm.-°F} \text{ (stainless steel)} \]
\[ C_p = 0.0325 \text{ Btu/lbm.-°F} \text{ (lead)} \]
\[ H_L = 10.55 \text{ Btu/lbm.} \text{ (latent heat - lead)} \]

The temperature change for the last 4 minutes of the transient shall be taken an follows:

- Fire Shield + Outer Shell - For conservatism, take the average temperature change between the surface of the fire shield and the outer shell/lead interface.

\[ \Delta T_{OS} = 27.5^\circ \text{F} \]
3.5.3 Package Temperatures (continued)

- The average bulk temperature change of the lead will be taken as the difference between the average lead temperature at 26 minutes and the average lead temperature at 30 minutes.

\[
T_{30} = \frac{560 + 460}{2} = 510^\circ F
\]

\[
T_{26} = \frac{515 + 410}{2} = 462.5^\circ F
\]

\[
\Delta T_{\text{lead}} = 510 - 462.5 = 47.5^\circ F
\]

- Inner Shell - The temperature change for this component will be taken as the same as the inside surface of the lead.

\[
\Delta T_{\text{IS}} = 460 - 410 = 50^\circ F
\]

Substituting into the heat balance equation:

\[
(43,826)\text{Btu} = (2233)\text{lbs.}(0.125)\text{Btu/lb.-}^\circ F(27.5)^\circ F + \\
(317)\text{lbs.}(0.125)\text{Btu/lb.-}^\circ F(50)^\circ F + \\
(16,869 - M_L)\text{lbs.}(0.0325)\text{Btu/lb.-}^\circ F(47.5)^\circ F + \\
(10.55)\text{Btu/lb.}(M_L)\text{lb.}
\]

This equation can be solved for \(M_L\):

\[
43,826 = 7848 + 5106 + 26,042 - 1.54 M_L + 10.55 M_L
\]

\[4830 = 9.01M_L\]

\[M_L = 536 \text{ lbs.}\]

The total melt volume will be:

\[
\text{Volume} = \frac{(536)\text{lbs.}}{(710)\text{lbs.-ft.}^3} = 0.755 \text{ ft.}^3
\]

\[= 1305 \text{ in.}^3\]
f. Shielding Displacement

The most serious consequence of the lead melt during the fire transient is loss of effective shielding if the molten lead can escape its confinement. For conservatism assume all the lead melt volume is around the top corner of the cask to compensate for the presence of the bolt circle for the lid.

Assume that the melting occurs uniformly radially and axially such that the area of lead melt in the corners forms a 45° triangle.

The volume of molten lead will be represented by a ring around the cylinder with cross-section shown by the shaded region.

Expanding the corner as follows:

at $x = 0; \ y = a$
\[ a = o + b \] which gives: $b = a$

at $y = 0; \ x = a$
\[ o = ma + a \] which gives $m = -1$

therefore: $y = -x + a$. 

---

3.5.3 Package Temperatures (continued)

Revision 0
3.5.3 Package Temperatures (continued)

\[ dA = (a - y)dx \]
\[ dV = 2\pi rdA = 2\pi[(R - a) + x]dA \]
\[ = 2\pi[(R - a) + x](a - y)dx \]
\[ = 2\pi(R - a + x)(a + x - a)dx \]
\[ = 2\pi(R - a + x)xdx \]
\[ = 2\pi(R - a)xdx + x^2dx \]

\[ V = \int_0^a (R - a)xdx + \int_0^a x^2dx \]
\[ = (R - a)x^2/2 + x^3/3 \bigg|_0^a 2\pi \]
\[ = [(R - a)a^2/2 + a^3/3] 2\pi \]
\[ V = [Ra^2/2 - a^3/6] 2\pi \]
\[ V = a^2/2(R - a/3) 2\pi \]

The distance \( a \) can be related to the displacement \( \delta \) by the following:

\[ b = \sqrt{a^2 + a^2} = a\sqrt{2} \]
\[ \delta = \sqrt{a^2 - (b/2)^2} = \sqrt{a^2 - 2a^2/4} = \sqrt{a^2/2} = a/\sqrt{2} \]

Substituting into the expression for volume gives the relationship between lead melt volume and shielding displacement.

\[ V = \delta^2 (R - \frac{\sqrt{2}}{3} \delta) 2\pi \]

This relationship is shown on Figure 3.5-3.
VOLUME = \( 8^2 \left( R - \frac{\sqrt{2}}{3} S \right) 2\pi \)

\( R = 18.75 \text{ in.} \)
3.6 Appendix
3.6.1 Appendix A - References


4. Ibid, p. 133.


4.0 CONTAINMENT

This chapter describes the containment configuration of the CNSI 1-13C Package for normal transport and hypothetical accident conditions.

4.1 CONTAINMENT BOUNDARY

4.1.1 Containment Vessel
The package containment vessel is defined as the inner shell of the shielded transport cask, together with the associated lid seals and lid closure bolts. The inner shell of the cask, or containment vessel, consists of a right circular cylinder of 26 inches inner diameter and 54 inches inside height. The shell is fabricated of 1/2 inch thick stainless steel plate, Type 304 (ASTM A-240). At the base, the cylindrical shell is welded to a 1/2 inch thick stainless steel circular end plate. At the top, similar construction techniques are used for the removable lid. The lid is attached to the cask body with twelve equally spaced 1-1/4 inch bolts in a 35.38 inch diameter bolt circle.

4.1.2 Containment Penetration
The drain line is the only penetration of the containment vessel. At the base, the drain line consists of a 1/2 inch O.D. by 0.065 inch wall stainless steel tube gravity line from the center of the cavity bottom to the side of the outer shell near the cask bottom.

4.1.3 Welds and Seals
The containment vessel components are all joined by full penetration groove welds or full penetration groove and fillet welds. The lid seal is a high temperature flat silicone gasket.

4.1.4 Closure
The top closure consists of a shielded lid with tapered sidewalls to assist in positioning and sealing. The lid is attached to the cask body by twelve (12) equally spaced 1-1/4 inch - 7 UNC x 2-1/2 inch long bolts. These bolts are fabricated of ASTM A-354, Grade BD material.
4.2 Requirements for Normal Conditions of Transport

4.2.1 Containment of Radioactive Material

The CNS 1-13C cask is designed to assure no release of radioactive material in excess of limits prescribed in N.R.C. Regulatory Guide 7.4, "Leakage Test on Packages for the Shipment of Radioactive Materials", under normal conditions of transport.

4.2.2 Pressurization of Containment Vessel

Section 2.6.1 identifies normal condition temperature within the containment vessel to be $T=232^\circ F$.

To find the maximum internal pressure, assume the cask is loaded at $70^\circ F$ and 14.696 psia. From the saturated water tables *(Page 649)*, the partial pressure of water is 0.3631 psia. Therefore, the partial pressure of air at $70^\circ F$ is:

$$P_{\text{atm}} - P_{\text{water}} = P_{\text{air}}$$

$$14.696 - 0.3631 = 14.333 \text{ psia} = P_{\text{air}}$$

From the saturated water tables*(Page 650)*, the partial (vapor) pressure of water at $232^\circ F$ is 21.618 psia.

The partial pressure of air at $232^\circ F$ may be found from the perfert gas law:

$$\frac{P_1}{T_1} = \frac{P_2}{T_2}$$
In this case, \( T_1 = 70^\circ F \) \( P_1 = 14.333 \) psia, \( T_2 = 232^\circ F \).

However, the perfect gas relation requires all temperatures to be absolute temperatures.

\[
\begin{align*}
\frac{14.333}{530} &= \frac{P_2}{692} \\
T_1 &= 70^\circ F = 530^\circ R \\
T_2 &= 232^\circ F = 692^\circ R
\end{align*}
\]

\( P_2 = 18.714 \) psia = partial pressure of air at \( 232^\circ F \).

The absolute pressure will be the sum of the partial pressure.

\[
P_{\text{absolute}} = P_{\text{water}} + P_{\text{air}} = 21.618 + 18.714 = 40.332 \text{ psia. (25.6 psig)}
\]

The predicted pressure value conservatively assumes a sufficient quantity of free water is present, thus all pressure predictions are based upon the properties of saturated water. These conservative predictions of pressure and associated temperatures are used to evaluate integrity of the CNS 1-13C package. None of these conditions reduce the effectiveness of the package containment.

4.2.3 Containment Criterion

Table 4.2.1 shows the radiological limitations placed on a releasable medium that could transport radioactivity through leaks, if any exist, in the containment system. Appendix 4.4 summarizes the derivation of the limits given in the table. The limits are to be applied with special consideration of (1) the chemical and physical forms of the radioactive materials within the containment system and (2) the possible leakage modes, such as diffusion of gases, airborne transportation of powders or particulates, reactions with water, and solubility. Provided these limits are not exceeded, compliance of the CNS 1-13C package with the requirements of NRC Regulatory Guide 7.4 is assured. In accordance with Regulatory Position, Paragraph C of this guide, compliance with the requirements of 10CFR71 for no release of material from the containment vessel is demonstrated.

Table 4.2.1

<table>
<thead>
<tr>
<th>Content Description</th>
<th>Releasable Contents</th>
</tr>
</thead>
<tbody>
<tr>
<td>Single Knowns Radionuclide</td>
<td>$A^2_x \times 1.4 \times 10^{-1}$</td>
</tr>
<tr>
<td>Mixture of Known Radionuclides</td>
<td>$F_n^{**} \times 1.4 \times 10^{-1}$</td>
</tr>
<tr>
<td>Mixture of Unknown Radionuclides</td>
<td>$5.6 \times 10^{-2}$</td>
</tr>
<tr>
<td>(no alpha emitters)</td>
<td></td>
</tr>
<tr>
<td>Mixture of Unknown Radionuclides</td>
<td>$2.8 \times 10^{-4}$</td>
</tr>
<tr>
<td>(including alpha)</td>
<td></td>
</tr>
</tbody>
</table>


** $F_n^{**}$ Values are determined by the method of mixtures given in Paragraph 408 of Safety Series No. 6 (referenced in *, above).
4.3 Containment Requirements for the Hypothetical Accident Conditions

Section 2.7 covers accident condition damages to the CNS 1-13C. Although the cask structure remains intact, it will be assumed that the closure seal will leak gases due to localized deformation of the closure flange. Based on such a risk of a release under accident conditions, no integrity will be assumed for the containment of the releasable portion of the cask contents. Table 4.3.1 give the limits that must be complied with. These limits assure that no more than the tabulated value of material can be released from the containment. This complies with the NRC Regulatory Guide 7.4 limit of A2 per week for a B(U) type package and with paragraph 71.51(a) of 10 CFR Part 71.

Table 4.3.1

LIMITATIONS ON CASK CONTENTS AVAILABLE FOR RELEASE WITH GASEOUS CASK MEDIA UNDER ACCIDENT CONDITIONS

<table>
<thead>
<tr>
<th>Content Description</th>
<th>Releasable Contents</th>
</tr>
</thead>
<tbody>
<tr>
<td>Single Known Radionuclide</td>
<td>$A_2^*$</td>
</tr>
<tr>
<td>Mixture of Known Radionuclides</td>
<td>$F_n^{**}$</td>
</tr>
<tr>
<td>Mixture of Unknown Radionuclides (no alpha emitters)</td>
<td>4.0x10^{-1}</td>
</tr>
<tr>
<td>Mixture of Unknown Radionuclides (including alpha emitters)</td>
<td>2.0x10^{-3}</td>
</tr>
</tbody>
</table>

The contents must also comply with the following:

Releasable contents must be less than 0.1 percent of the total package contents; but must not exceed:

1. 0.01 Ci of Group I radionuclides,
2. 0.5 Ci of Group II radionuclides,
3. 10 Ci of Group III radionuclides,
4. 10 Ci of Group IV radionuclides,
5. 1.0 Ci of inert gases.


** $F_n$ Values are determined by the method of mixtures given in Paragraph 408 of Safety Series No. 6 (reference in *, above).
4.4 Appendix
4.4 APPENDIX - Normal and Accident Radioactive Material Release Limits for the CNS 1-13C Cask

Tables 4.2.1 and 4.3.1 define limits for the portion of the total cask activity that can be released as defined in Paragraph 5.3.2 of ANSI Standard 14.5 - 1977. For the CNS 1-13C Package the medium is assumed to be a small quantity of residual water in the vapor phase along with the air inside the cask cavity for both normal and accident conditions of transport.

4.4.1 Normal Transport Limits

A soap bubble leak test as outlined in Section 8.2.2 is used to verify leaktightness of the package at a leak/rate of $3.24 \times 10^{-3} \text{ atm-cm}^3/\text{sec}$ (Standard Conditions) for normal conditions of transport. (Reference Section 8.3 for derivation of leak rate limits.)

The quantity, $L_N$, represents the permissible leak rate of the medium (steam) at temperatures and pressures associated with normal transport conditions. Correlation of this quantity with the demonstrated leak rate at standards conditions, $L_S$, is achieved via use of Equation (B.5) of ANSI N14.5:

$$L_N = \frac{L_S \ n_S (P_u^2 - P_d^2)N}{n_N (P_u^2 - P_d^2)S}$$

Where:

- $L_S = 3.24 \times 10^{-3} \text{ atm-cm}^3/\text{sec}$
- $n_S = 0.0185 \text{cP}$, air viscosity
- $P_{us} = 1 \text{ atm}$
- $P_{ds} = 0 \text{ atm}$
\[ \eta_N = 0.2536 \text{ cP (steam at 252°F)} \]
\[ P_{unN} = (25.6 \text{ psig} + 14.7)/14.7 = 2.741 \text{ atm} \]
\[ P_{dN} = 1 \text{ atm} \]

Therefore:

\[ L_N = \frac{3.24 \times 10^{-3}(0.0185)(2.741^{2-12})}{0.2536 (1^{2-0^2})} \]
\[ L_N = 1.539 \times 10^{-3} \text{ cm}^3/\text{sec} \]

Using the calculational methods from ANSI N14.5 - 1977, for normal conditions of transport:

\[ L_N = \frac{R_N}{C_N} \]

Where:

\[ R_N = 2.78 \times 10^{-10} A_2 \text{ Ci/sec} \]
\[ C_N = \text{Permissible Activity of the Releasable Medium, Ci/m}^3 \]

Therefore,

\[ C_N = \frac{R_N}{L_N} = \frac{(2.78 \times 10^{-10}) \times A_2 \text{ Ci}^3}{1.539 \times 10^{-3} \text{ cm}^3} = (0.181)(A_2) \frac{\text{Ci}}{\text{m}^3} \]

As the volume of the CNS 1-13C cask is 17.24 ft.\(^3\) = 0.49 m\(^3\), the total releasable material limit is:

\[ (0.49)(0.181)(A_2) = (0.089)(A_2) \text{ Ci}. \]

In the case where \( A_2 \) cannot be determined, IAEA Safety Series No. 6, Paragraph 411 gives values of \( A_2 \) for unknown nuclide mixtures with or without alpha emitters as 0.002 Ci and 0.4 Ci respectively.

Therefore, the CNS 1-13C cask can carry a releasable 0.0356 Ci of mixed unknown nuclide with no alpha emitters and be in compliance with NRC Regulatory Guide 7.4.
4.4.2 Accident Condition Limits
From ANSI 14.5 and IAEA Safety Series 6, non venting B(u) packages must limit releases under accident conditions of transport to one $A_2$ value per week. This amounts to 0.4 Ci/week for a mixture of unknown nuclides with no alpha emitters. As the integrity of gasket seal is not verifiable under accident conditions and a quantitative leakage rate not available, it is assumed that the total releasable quantity will be released within a one week period after the accident. Therefore the total amount that can be transported as a releasable portion of the cask contents will be limited to an $A_2$ value or to those values given in 10 CFR Part 71.

4.4.3 Example For Determining Compliance To Normal And Accident Transport Limits.
An irradiated component shipment is to be made in the CNS 1-13C. Surface contamination has been shown to be

$$2 \times 10^6 \text{ dpm} \text{ over a } 10 \text{ m}^2 \text{ surface area. The nuclide inventory is unknown but does not contain alpha emitters. The total shipment contains 2000 Ci of Co-60. Can the shipment be made under the limits of Tables 4.2.1 and 4.3.1 of the SAR?}$$

For unknown, non alpha emitter, nuclide mixtures, the releasable contents are given as:
Normal Transport, 0.0356 Ci
Accident Transport, 0.40 Ci or 0.1 percent of total package contents.

For $10 \text{m}^2$, there are 1000 areas of 100 cm$^2$. If 0.0356 Ci is distributed over this $10 \text{m}^2$ area,

$$\frac{0.0356}{1000} = 3.56 \times 10^{-5} \text{Ci}/(100 \text{ cm}^2)$$

$$3.56 \times 10^{-5} \text{Ci} \times 3.7 \times 10^{10} \frac{\text{dps}}{\text{Ci}} \times 60 \frac{\text{sec}}{\text{min}} = 7.90 \times 10^7 \frac{\text{dpm}}{100 \text{cm}^2}.$$
Therefore, the $2 \times 10^6 \frac{dpm}{100 \text{cm}^2}$ on the component of the example is within the Ci limit.
The accident limit for such a shipment would be $8.9 \times 10^8 \frac{dpm}{100 \text{cm}^2}$ (calculated by the same method shown above).

or,

$0.1 \text{ percent} \times 2000 \text{ Ci} = 2 \text{ Ci}.$

Both of the above limits are complied with. The shipment can be made.
The package shielding must be sufficient to satisfy the conditions of 10CFR71, paragraph 71.73 for the hypothetical accident conditions. It must be shown that shielding loss resulting from either the 30 foot drop or the fire transient will not increase the external radiation dose rate to more than 1,000 mRems/hr at 3 feet from the external surface of the cask.

This cask will be operated such that the radioactive inventory within the cask will not result in dose rates exceeding 200 mRem/hr on the package surface, or 10 mRem/hr at 1 meter from the surface of the package.

5.2 Source Specification

The equivalent point source, assuming Co$^{60}$ energy, will be determined for the normal geometry. This equivalent source will then be used to evaluate the effects of the hypothetical accidents.

5.2.1 Gamma Source

Equivalent Point Source

The point source is determined as follows:

$$\phi_Y = \frac{B_s e^{-b_1}}{4\pi r^2}$$  \hspace{1cm} (1)

$$\phi_Y = \text{Photon flux} \frac{Y}{cm^2 \cdot S}$$

$$S_0 = \text{Equivalent source} \frac{Y}{S}$$

$$b_1 = \Sigma f u t$$ for shielding

$$B = \text{Buildup factor}$$

$$r = \text{distance from source to dose point}$$

$$D = K \phi_Y$$

$$K = 2.3 \times 10^{-6} \frac{R/hr}{\phi_Y} \text{ for Co}^{60}$$  \hspace{1cm} (2)
5.2.1 Gamma Source (continued)

Through the side of the cask the following values are used: (3)

Lead: \( t = 5 \text{ in.} = 12.7 \text{ cm}; \ \mu/p = .0600 \text{ cm}^2/\text{gm.} \)

Steel: \( t = 1-1/4 \text{ in.} = 3.175 \text{ cm}; \ \mu/p = .0515 \text{ cm}^2/\text{gm.} \)

For these values:

\( b_1 = 10.0 \)
\( B = 4.0 \) (4)

For the two dose conditions:

\( D_1 = 10 \text{ mRem/hr.}; \quad r = 6.31 + 36 = 42.31 \text{ inch} \)
\( D_2 = 200 \text{ mRem/hr.}; \quad r = 6.31 \text{ inches - distance to surface of cavity} \)

\[ S_0 = \frac{4\pi r^2 D}{B Ke^{-b_1}} \]

Substituting into the above expression:

(1) \( D = 10 \text{ mRem/hr. at 3 feet.} \)

\[ S_0 = 3.475 \times 10^{12} \text{ y/S.} \]

(2) \( D = 200 \text{ mRem/hr. on the surface.} \)

\[ S_0 = 1.546 \times 10^{12} \text{ y/S.} \]

The dose rate on the surface governs and will be used in the accident analysis.

Shield displacements will result from either the 30 foot drop or from the lead melt in the fire transient. The maximum displacement for the drop will occur using the minimum dynamic flow pressure for lead given in Section 2.3.2. This value is:

\( K = 5000 \text{ psi} \)

The shielding deformation resulting from the 30 foot drop will be developed for each impact mode using this value.

The lead volume displacement for the fire transient was determined in Section 3.5.3.

\( VF = 1305 \text{ in} \)
5.2.2 Neutron Source

Not applicable.
5.3 Model Specification

5.3.1 Description of the Radial and Axial Shielding Configuration

(1) Lead Displacement - Corner

The shielding displacement for the 30 foot corner drop will be determined for the combined displacement of the lead shield and the steel shell and fire shield.

Referring to the Figure on Page 2-51 the volume of the ungula of a cylinder is:

\[ V = R^3 \tan \alpha[f(\theta)] \]

Lead Displacement:

\[ V_L = R_L^3 \tan \alpha[f(\theta_L)] \]

Total Displacement:

\[ V_T = R_O^3 \tan \alpha[f(\theta_T)] \]

For: \( \theta_L = \theta_T \),

The steel displaced volume is:

\[ V_S = V_T - V_L = (R_O^3 - R_L^3) \tan \alpha[f(\theta)] \]

The total displaced volume from kinetic energy considerations is:

\[ V_T = \frac{hW}{k} \quad \text{Where } k \text{ is the effective dynamic flow stress of the combined lead and steel.} \]

Assume: \( k = \frac{k_s V_S + k_L V_L}{V_S + V_L} \)
Then:
\[ V_T = \frac{h W (V_s + V_L)}{k_s V_s + k_L V_L} = \frac{h W V_T}{k_s V_s + k_L V_L} \]

\[ h W = k_s V_s + k_L V_L \]
\[ = k_s (R_0^3 - R_L^3) \tan \alpha [f(\theta)] + k_L R_L^3 \tan \alpha [f(\theta)]. \]
\[ = [k_s R_0^3 + R_L^3 (k_L - k_s)] \tan \alpha [f(\theta)]. \]

Therefore:
\[ f(\theta) = \frac{h W}{[k_s R_0^3 + R_L^3 (k_L - k_s)] \tan \alpha} \]

Let:
\[ R_L = \text{Lead outer radius} = 18.75 \text{ inches} \]
\[ R_0 = \text{Cask outer radius} = 19.50 \text{ inches (with fire shield)} \]
\[ k_s = \text{Steel dynamic flow stress} = 45,000 \text{ psi} \]
\[ k_L = \text{Lead dynamic flow stress} = 5000 \text{ psi} \]
\[ \alpha = 28.3^0 \]
\[ h = 360 \text{ inches} \]
\[ W = 25,950 \text{ lbs.} \]

\[ f(\theta) = \frac{(360) \text{in.}(25,950) \text{lbs.-in.}^2}{(.538)[(45,000)(19.50)^3 - (40,000)(18.75)^3]} \text{ lbs.-in.}^3 \]
\[ = \frac{1.73 \times 10^7}{(3.337 - 2.637)10^8} \]
\[ = .243 \]

From Figure 2.7-1, page 2-52
\[ \theta = 1.225 \text{ Radians} \]
\[ = 70.2^0 \]

The shielding geometry for lead displacement in the corner for the two cases is as shown:
5.3.1 (continued)

a. Impact

\[ \theta = 70.2^\circ \text{ (Figure 2.7-1).} \]
\[ \alpha = 28.3^\circ \]
\[ R = 19.50 \text{ inches} \]

\[ S = (1-\cos \theta)R = 12.89 \text{ inches} \]
\[ \delta = S \tan \alpha = 6.94 \text{ inches} \]
\[ t_s = 1.0 + .50/\cos \alpha = 1.57 \text{ inch} \]

b. Fire

\[ R = 18.75 \text{ inches} \]
\[ \delta = 3.45 \text{ inches} \]
5.3.1 (continued)

c. Impact

\[ \Delta r = (6.75 \tan \alpha = 3.63 \text{ inches} \]
\[ r = 13.75 + \Delta r = 17.38 \text{ inches} \]
\[ \Delta = 19.50 - r = 2.19 \text{ inches} \]
\[ S' = S - \Delta = 10.77 \text{ inches} \]

\[ \delta' = \delta(S'/S) = (6.94)(\frac{10.77}{12.89}) = 5.80 \text{ inches}. \]

\[ X_I = 6.75/\cos \alpha - \delta' = (\frac{6.75}{3.80}) - 5.80 = 1.87 \text{ inches}. \]

d. Fire

\[ \delta' = \delta - \frac{\Delta t}{2} \]
\[ \Delta t = 5.75 - 5.00 = .75 \text{ in.} \]
\[ X_F = \sqrt{2} \cdot t - \delta' \]
\[ = \sqrt{2} \cdot (5.00) - 3.45 + \frac{0.75}{\sqrt{2}} \]
\[ = 4.15 \text{ inches}. \]
5.3.1 (continued)

(2) Lead Displacement - Side
The lead displacement for the two geometries along the side of the cask are shown below. The displacement for the fire analysis assumes all the lead melts opposite the reinforcing ring.

a. Impact

\[ \theta = 59.5^\circ \text{ (Figure 2.7-1)} \]
\[ R = 18.75 \text{ inches} \]
\[ \delta = (1 - \cos \theta/2)R \]
\[ \delta = 2.50 \text{ inches} \]
\[ t = 5.00 \text{ inches} \]
\[ X_1 = t - \delta = 2.50 \text{ inches} \]
b. Fire

\[ V_M = 1305 \text{ in.}^3 \text{ from page 3-36.} \]

\[ \frac{V_M}{\pi R_F} = 1305 \text{ in.}^3, \]

\[ H_R = 8.00 \text{ inches} \]

\[ R_F = 17.75 \text{ inches} - \delta \]

Therefore:

\[ \delta^2 - 17.75\delta + \frac{V_M}{2\pi H_R} = 0 \]

\[ \delta = 1.61 \text{ inch} \]

\[ X_F = 4.00 - 1.01 \]

\[ X_F = 2.39 \text{ inches.} \]
5.3.1 (continued)

(3) Lead Displacement - Ends

Consider the amount of lead displacement for the 30 foot free drop on both the top and the bottom of the cask. The displacement will be determined as follows:

\[
\Delta H = \frac{RWH}{\pi(R^2 - r^2)(t_s\sigma_s + R\sigma_{PB})}
\]

Where:
- \( R \) - outer radius of lead = 18.75 inches
- \( r \) - inner radius of lead = 13.75 inches
- \( W \) - cask weight = 25,950 lbs.
- \( H \) - drop height = 360 inches
- \( \sigma_s \) - steel dynamic flow stress = 45,000 psi
- \( \sigma_{PB} \) - lead dynamic flow stress = 5,000 psi
- \( t_s \) - Steel shell thickness = 0.50 in.

The thickness of the steel shell has been taken as the thickness of the cask outer shell. The displacement of the 0.25 inch thick fire shield has been neglected for conservatism.

a. Bottom displacement

\[ \text{Diagram of bottom displacement} \]
5.3.1 (continued)

\[
\Delta H = \frac{(18.75)\text{in.}(25,950)\text{lbs.}(360)\text{in.-in.}^2}{\pi[(18.75)^2 - (13.75)^2]((.5)(45,000) + (18.75)(5000))\text{in.}^2\text{-lbs.-in.}}
\]

\[
= \frac{(1.75 \times 10^8)\text{in.}}{\pi(162.5)(1.16 \times 10^5)}
\]

\[
= 2.96 \text{ in.}
\]

\[
X_{IB} = t_{Pb} - \Delta H
\]

\[
= 3.04 \text{ inches}
\]

b. Top Displacement

Assume only the lid does not deform and all deformation occurs in the cask body.

\[
\Delta H = \frac{(18.75)\text{in.}(25,950)\text{lbs.}(360)\text{in.-in.}^2}{\pi[(18.75)^2 - (13.75)^2]((1.0)(45,000) + (5.0)(5000))\text{lbs.-in.}}
\]

\[
= \frac{(1.75 \times 10^8)\text{in.}}{\pi(162.5)(7.0 \times 10^4)}
\]

\[
= 4.90 \text{ in.}
\]

\[
X_{IT} = t_{Pb} - \Delta H
\]

\[
= 0.85 \text{ inch.}
\]
5.3.1 (continued)

The deformation stops short of the cask cavity lip for this case. If the lid also deforms, the deformation model will be the same as for the bottom end drop.

\[ \Delta H = 2.96 \text{ inches} \]
\[ X_{IT} = t_{Pb} - \Delta H = 2.79 \text{ inches}. \]

(4) Shielding Effect of Lead Displacement

To determine the lead displacement having the greatest effect on dose rate compare the attenuation for each case as follows:

\[ A = \frac{B e^{-b_1}}{4\pi r^2}; \quad \text{where: } b_1 = \sum u_i t_i \]

\( r \) = distance from inside surface of cask cavity to a dose point 3 feet from the outside surface of the cask.

A summary of the pertinent data is presented in the following table.

<table>
<thead>
<tr>
<th>CASE</th>
<th>r (cm)</th>
<th>t-steel (cm)</th>
<th>t-lead (cm)</th>
<th>b_1</th>
<th>e-b_1</th>
<th>B(4,5)</th>
<th>A</th>
</tr>
</thead>
<tbody>
<tr>
<td>Corner-impact</td>
<td>100.17</td>
<td>3.93</td>
<td>4.75</td>
<td>4.89</td>
<td>7.531-3</td>
<td>2.5*</td>
<td>1.493x10^{-7}</td>
</tr>
<tr>
<td>Corner-fire</td>
<td>112.73</td>
<td>3.18</td>
<td>10.54</td>
<td>8.52</td>
<td>1.995-4</td>
<td>3.6*</td>
<td>4.497x10^{-9}</td>
</tr>
<tr>
<td>Side-impact</td>
<td>100.97</td>
<td>3.18</td>
<td>6.35</td>
<td>5.65</td>
<td>3.505-3</td>
<td>2.8*</td>
<td>7.660x10^{-8}</td>
</tr>
<tr>
<td>Side-fire</td>
<td>107.47</td>
<td>5.72</td>
<td>6.07</td>
<td>6.509</td>
<td>1.491-3</td>
<td>9.0**</td>
<td>9.246x10^{-8}</td>
</tr>
<tr>
<td>Top-impact</td>
<td>102.34</td>
<td>3.81</td>
<td>7.09</td>
<td>6.419</td>
<td>1.630-3</td>
<td>3.0*</td>
<td>3.715x10^{-8}</td>
</tr>
<tr>
<td>Bottom-impact</td>
<td>102.34</td>
<td>3.175</td>
<td>7.72</td>
<td>6.59</td>
<td>1.376-3</td>
<td>3.0*</td>
<td>3.136x10^{-8}</td>
</tr>
</tbody>
</table>

* Use buildup for lead
** Use buildup for iron

The case of 30 foot impact on the corner will be limiting.

\[ D = K A S_0 \]
\[ K = 2.3x10^{-6} \text{ R/hr} \]
\[ S_0 = 1.546x10^{12} \text{ y/s} \]
\[ D = 0.530 \text{ R/hr. less than 1.0 R/hr}. \]

The shielding displacement satisfies the criteria.
BASIC DATA

DOSE BUILD-UP FACTOR IN LEAD FOR A POINT ISOTROPIC SOURCE

RELAXATION LENGTH, μ₀R

DOSE BUILD-UP FACTOR, B

E₀ = 2.0 MEV

E₀ = 3.0 MEV

E₀ = 5.0 MEV

B.0

B.0

B.0
5.3.2 Shield Regional Densities

The manual method used to calculate shielding in this analysis does not require input of material densities or atomic number densities. Instead, the parameters $b_1 (= \sum \mu_i t_i)$ and $B$ (buildup) are utilized as discussed (and tabulated) in Section 5.2 and 5.3.1.

5.4 Shielding Evaluation

A manual shielding analysis method was applied as discussed in Sections 5.2 and 5.3.1. The method is based on point-kernel techniques described in Reference 1.
5.4.1 References


5. Ibid, p. 432.
6.0 CRITICALITY EVALUATION

Not applicable.
7.0 OPERATING PROCEDURES

7.1 Procedures for Loading the Package

7.1.1 Prepare to remove the tie-down ring:

(1) Loosen the binders on the cables/chains.
(2) Remove the cable/chains from the shackles on the tie-down ring.
(3) Attach the crane hook to the tie-down ring.
(4) Remove the tie-down ring and place it on absorbent material or plastic sheeting.
(5) Remove the crane hook.


NOTE: THIS CASK MAY BE LOADED WITH EITHER A 55-GALLON DRUM OR A LINER. AN APPROPRIATE LIFTING DEVICE MUST BE ATTACHED TO THE DRUM OR THE LINER. IF THE CASK IS LOADED UNDER WATER, FOLLOW THE PROCEDURE FOR WET LOADING; SECTION 7.1.3.

7.1.2 Procedure for Dry Load the Cask:

CAUTION: DO NOT LIFT THE CASK BY THE LIFTING LUG ON THE CASK LID. KEEP CRANE CABLE VERTICAL AT ALL TIMES TO AVOID LATERAL MOVEMENT OF THE CASK.

(1) Prepare and remove the cask from the trailer, if necessary:

NOTE: POSITION THE CASK ON A LEVEL SURFACE TO FACILITATE LOWERING THE LINER STRAIGHT INTO THE CASK.

a. Attach the 2 lifting lugs to the cask using the eight (8) 1-8 UNC bolts. Torque the bolts to 200 ft.-lbs. ± 10%.

b. Attach the lifting sling to the round lifting holes on the cask lifting lugs.

c. Attach the crane hook to the lifting sling.

d. Move the cask to a level loading area.
e. Remove the crane hook.

(2) Prepare and remove the cask lid:
   a. Remove the twelve 1-1/4 inch bolts from the lid, using a star pattern.
   b. Remove the lifting lug cover plate from the lid lifting lug and retain for reinstallation.
   c. Attach the crane hook to the lid lifting lug or to a sling attached to the lid lifting lug.
   d. Lift the lid straight up off the cask and place it on absorbent material or plastic sheeting.

   CAUTION: BE ALERT THAT THE CASK LID GASKET MAY LIFT OFF WITH THE CASK LID: DO NOT DAMAGE THE GASKET SEATING SURFACES, THE SIDE OF THE CASK, OR INNER WALLS AT ANY TIME.

   e. Remove the crane hook.

(3) Prepare and remove the liner or the drum from the cask, if necessary:
   a. Attach the crane hook to the lifting device on the liner or the drum.
   b. Lift out the liner or drum and place it on absorbent material or plastic sheeting.
   c. Remove the crane hook.

(4) Fill the liner or the drum, if necessary.

(5) Prepare and load the liner or drum into the cask, if necessary:

   CAUTION: AS THE LINER OR DRUM IS LOWERED INTO THE CASK, THE AIR IN THE CASK WILL CUSHION AND SLOW THE LINER OR DRUM. BE ALERT TO THE POSSIBILITY OF AIRBORNE CONTAMINATION ESCAPING FROM THE CASK DURING THIS PROCEDURE.
7.1.2 Cask Dry Loading (continued)

NOTE: Clean the liner or drum before placing it in the cask. Treat debris removed as contaminated. Do not damage the gasket seating surfaces of the cask when placing liner or drum into the cask.

a. Attach the crane hook to the lifting device on the liner or the drum.

b. Lower the liner or the drum straight into the cask.

c. Remove the crane hook.

d. Ensure that the liner lifting device swings clear to allow proper installation of the cask lid.

NOTE: Shore the liner or drum if necessary to prevent movement inside the cask during normal transport conditions.

(6) Prepare and replace the cask lid:

a. Visually inspect the lid gasket for cracks or tears that would prevent the gasket from forming a seal. Replace or repair the gasket if required. Contact CNSI Transportation Department for instructions to replace gasket. Inspect and clean the gasket seating surfaces.

b. Attach the crane hook to the lid lifting lug or to a sling attached to the lid lifting lug.

NOTE: Clean the bottom surface of the lid, treating all debris removed as contaminated.

c. Position the lid over the cask using the alignment pin.

d. Lower the lid onto the cask.

e. Replace the twelve 1-1/4 inch bolts on the cask lid. Torque to 420 ± 42 ft.-lbs. (320 ± 32 ft.-lbs. if lubricated), using a star pattern.

NOTE: Tighten all the bolts hand-tight before starting the torque sequence.
7.1.2 Cask Dry Loading (continued)

f. Remove the crane hook.
g. Replace the lifting lug cover on the cask lid.

(7) Refer to Sections 7.1.4 and 7.1.5 for replacing the cask on the trailer, removing the lifting lugs and replacing the tie-down ring.

(8) Leak test the package as described in Section 8.2.2.

7.1.3 Procedure to Wet Load the Cask:

CAUTION: DO NOT ATTEMPT TO LIFT THE CASK BY THE LIFTING LUG ON THE CASK LID. KEEP CRANE CABLES VERTICAL AT ALL TIMES TO AVOID LATERAL MOVEMENT OF THE CASK.

(1) Prepare and remove the cask from the trailer:

NOTE: The cask shall be replaced on the trailer in the same position and orientation as received.

a. Remove the twelve 1-1/4 inch bolts from the lid, using a star pattern.
b. Remove the lifting lug cover plate from the lid lifting lug and retain for reinstallation.
c. Attach a lifting sling to the lid lifting lug.
d. Attach the crane hook to the lifting sling.
e. Lift the lid straight off the cask and place it on absorbent material or plastic sheeting.

CAUTION: BE ALERT THAT THE CASK LID GASKET MAY LIFT OFF WITH THE CASK LID. DO NOT DAMAGE THE GASKET SEATING SURFACES, THE SIDE OF THE CASK, OR INNER WALLS AT ANY TIME.
f. Remove the crane hook.
7.1.3 Cask Wet Loading (continued)

Visually inspect the lid gasket for cracks or tears that would prevent the gasket from forming a seal. Replace or repair the gasket if it is required. Contact CNSI Transportation Department for instructions to replace gasket. Inspect and clean the gasket seating surfaces.

(2) Prepare and lower the cask into the pool:

NOTE: TREAT ANY LIQUID FROM THE DRAIN AS CONTAMINATED. IF THE CASK SLING IS TO BE DISCONNECTED FROM THE CRANE HOOK, CONFIRM THAT THE SLING HAS REMOTE CONNECTING/DISCONNECTING CAPABILITY.

a. Remove the drain plug from the cask, clean the threads and retain for reinstallation.
b. Attach the 2 lifting lugs to the cask using the eight (8) 1-8 UNC bolts. Torque the bolts to 200 ft. lbs. ± 10%.
c. Attach the lifting sling to the round holes on the cask lifting lugs if necessary.
d. Attach the crane hook to the lifting sling.
e. Lift the cask with the crane.
f. Position the cask over the pool.
g. Lower the cask into the pool to a sufficient depth to ensure safe operating conditions for all personnel.
h. Detach the crane hook from the lifting sling, if necessary. Confirm that the cask is resting securely in the pool before disconnecting.

(3) Fill the liner, if necessary.

(4) Load the filled liner into the cask, if necessary.

(5) Prepare and replace the cask lid while the cask is in the pool:
a. Attach the crane hook to the lid lifting sling.
b. Position the lid over the cask using the alignment pin.
c. Lower the lid onto the cask.
7.1.3 Cask Wet Loading (continued)

d. Remove the crane hook from the lid lifting sling.

(6) Prepare and remove the loaded cask from the pool:
   a. Attach the crane hook to the cask lifting sling.
   b. Lift the cask out of the pool. Allow the cask to remain over the pool until all the water has drained from the cask.
   c. Replace the cask drain plug. Ensure that the drain plug does not leak.
   d. Move the cask to a set-down area.
   e. Replace the twelve 1-1/4 inch bolts on the cask lid. Torque to 420 + 42 ft.-lbs. (320 + 32 ft.-lbs if lubricated), using a star pattern.

NOTE: Tighten all bolts hand-tight before starting the torque sequence.

f. Decontaminate all external surfaces of the cask.
   g. Remove the crane hook, if necessary.
   h. Remove the lifting sling from the cask lid.
   i. Leak test the package as described in Section 8.2.2
   j. Attach wire seals to the two adjacent bolts designated for sealing.

7.1.4 Prepare and replace the cask on the trailer, if necessary:

NOTE: The cask shall be replaced on the trailer in the same position and orientation as received.

(1) Attach the crane hook to the cask lifting sling, if necessary.
(2) Place the cask on the trailer, confirming that cask is properly positioned for transportation.
(3) Remove the crane hook from the lifting sling.

(4) Detach the lifting sling from the cask lifting lugs.

(5) Remove the 2 cask lifting lugs from the cask.

7.1.5 Prepare and replace the tie-down ring:

(1) Attach the crane hook to the tie-down ring.

(2) Lift the tie-down ring onto the cask and set it in position.

(3) Remove the crane hook.

(4) Attach the cables/chains to the shackles on the tie-down ring.

(5) Tighten the binders on the cables/chains.

7.1.6 Replace the lid lifting lug cover.

7.1.7 Before the cask leaves the facility, the following shall be confirmed:

(1) That any external lifting lugs are properly covered for transport.

(2) That trailer placarding and ask labeling meet DOT Specifications (CFR Title 49, Part 172).

(3) That exterior radiation levels do not exceed 200 mR./hr. on contact, 10 mR./hr. at 2 meters and 2 mR./hr. in the tractor cab, in accordance with 49 CFR 173.441 (b).

(4) That the outer package is sealed with anti-tamper seals.

(5) That the drain plug is securely installed and sealed.

(6) That the cask lifting lugs have been removed from the package.

7.1.8 Complete the USER CHECK-OFF SHEET before the cask leaves the facility and send a copy with the shipment.
7.2 Procedures for Unloading the Package

NOTE: All personnel handling filled liner or filled drums shall observe established site radiation protection procedures.

7.2.1 Position the unloading crane at an optimum distance to facilitate off-loading and to minimize operator exposure.

7.2.2 Prepare and remove the tie-down ring:

NOTE: Tie-down using the rectangular slots on the cask lifting lugs is PROHIBITED.

(1) Loosen the binders on the cables/chains.
(2) Remove the cables/chains from the shackles on the tie-down ring.
(3) Attach the crane hook to the tie-down ring.
(4) Remove the tie-down ring and place it on absorbent material or plastic sheeting.
(5) Remove the crane hook.

7.2.3 Prepare and remove the cask lid:


(1) Remove the twelve 1-1/4 inch bolts from the lid, using a star pattern.
(2) Remove the lifting lug cover plate from the lid lifting lug and retain for reinstallation.
(3) Attach the crane hook to the lifting lug.
(4) Lift the lid straight up off of the cask and place it on absorbent material or plastic sheeting.

CAUTION: BE ALERT THAT THE CASK LID GASKET MAY LIFT OFF WITH THE CASK LID.
CAUTION: DO NOT DAMAGE THE GASKET SEATING SURFACES, THE SIDE OF THE CASK, OR INNER WALLS AT ANY TIME.
7.2.3 Prepare and remove the cask lid: (continued)

(5) Remove the crane hook.

7.2.4 The health physics technician shall conduct a radiation and contamination survey to determine off-loading precautions.

7.2.5 If directed by the health physics technician, vacate all personnel from the immediate area except the crane operator and a rigger. The rigger shall stand in clear view of the crane operator.

7.2.6 Prepare and remove the contents of the cask:

(1) Attach the crane hook to the lifting device on the liner or the drum.
(2) Lift the liner or drum straight up out of the cask and allow any liquid to drip off into the cask.
(3) Place the liner in position for disposal or future handling.
(4) Detach the crane hook from the liner or drum lifting device.

7.2.7 The health physics technician shall survey the interior of the cask for radiation and contamination levels. Decontaminate if acceptable levels (as per site operations) are exceeded.

CAUTION: TREAT ANY LIQUID IN THE CASK OR USED IN THE DECONTAMINATION PROCESS AS CONTAMINATED.

7.2.8 Visually inspect the inside of the cask for damage or for liquid accumulation. Contact Health Physics Department for instructions to remove any liquid or foreign material from cask. If the inside surfaces of the cask are damaged, remove the cask from service.

7.2.9 Place a new liner in the cask, if required:
CAUTION: DO NOT DAMAGE THE GASKET SEATING SURFACES, THE SIDE OF THE CASK, OR INNER WALLS AT ANY TIME.
NOTE: Clean the liner or drum before placing it into the cask. Treat debris removed as contaminated.
7.2.9 Placing New Liner (continued)

(1) Attach the crane hook to the attachment on the liner.
(2) Carefully lower the liner into the cask and remove the crane hook.
   **DO NOT** damage the gasket seating surfaces, the side of the cask, or inner walls.
(3) Ensure that the liner lifting device swings clear to allow proper installation of the cask lid.

7.2.10 Prepare and replace the cask lid:

(1) Visually inspect the lid gasket for cracks or tears that would prevent the gasket from forming a seal. Replace or repair the gasket if required. Contact CNSI Transportation Department for instructions to replace gasket. Inspect and clean the gasket seating surfaces.
(2) Attach the crane hook to the lid lifting lug or to a sling attached to the lid lifting lug.

**NOTE:** Clean the bottom surface of the lid, treating all debris removed as contaminated.

(3) Position the lid over the cask using the alignment pin.
(4) Lower the lid onto the cask.
(5) Replace the twelve 1-1/4 inch bolts on the cask lid. Torque to 420 \(+ 42\) ft.-lbs. (320 \(+ 32\) ft.-lbs. if lubricated, using a star pattern.

**NOTE:** Tighten all the bolts hand-tight before starting the torque sequence.

(6) Remove the crane hook.
(7) Replace the lug cover on the cask lid.

7.2.11 Prepare and replace the tie-down ring.

(1) Attach the crane hook to the tie-down ring.
(2) Lift the tie-down ring onto the cask and set it in position.
7.2.11 Prepare and replace the tie-down ring. (continued)

(3) Remove the crane hook.
(4) Attach the cables/chains to the shackles on the tie-down ring.
(5) Tighten the binders on the cables/chains.

7.2.12 Replace the lid lifting lug covers.

7.2.13 The health physics technician shall survey all exterior surfaces of the cask for contamination and radiation levels. Decontaminate if required to meet the limits set forth in Section 173.397 of CFR 49.

7.2.14 Before the cask leaves the facility, the following shall be confirmed:

(1) That any external lifting lugs are properly covered for transport.
(2) That trailer placarding and cask labeling meet DOT Specifications (CFR Title 49, Part 172).
(3) That exterior radiation and contamination levels conform to requirements as established in site radiation and contamination release procedures and DOT requirements.
(4) That the outer package is sealed with anti-tamper seals.
(5) That the drain plug is securely installed and sealed.
(6) That the cask lifting lugs have been removed from the package.
8.1 Acceptance Tests

8.1.1 Visual Inspection

The package will be examined visually for any adverse conditions in materials or fabrication using applicable codes, standards and drawings.

8.1.2 Structural Tests

8.1.2.1 Testing of the lifting devices attached to the package, primary lid shall be accomplished to meet the standards of 10 CFR 71.31.

8.1.2.2 Visual examinations during fabrication will identify the integrity of structural welding and proper fabrication techniques.

8.1.3 Leak Tests

Leak tests shall be performed as specified in 8.2.2.

8.1.4 Component Tests

There are no auxiliary components on the package.

8.1.5 Test for Shielding Integrity

Newly fabricated packages will be gamma scan examined to verify poured lead shield.

All packages will be routinely surveyed prior to shipment to assure adequate shield integrity.

8.1.6 Thermal Acceptance Test

Not applicable for this package.
8.2 Maintenance Program

CNSI is committed to an ongoing preventative maintenance program for all shipping packages. The 1-13C package will be subjected to routine and periodic inspections and tests as outlined in this section and CNSI approved procedures.

8.2.1 Structural and Pressure Tests

Routine visual examinations will be performed to detect damage or defects significant to package condition. Exterior stencils, nameplates, seals and bolts will be verified in place.

8.2.2 Leak Test

The CNS 1-13C package is pressurized to 4 PSIG and soap bubble leak tested at the perimeter of the lid seal prior to each shipment. Leak test pressure is discussed in Appendix 8.3.

8.2.3 Subsystem Maintenance

The cask does not have any subsystems.

8.2.4 Valves and Gaskets on Containment Vessel

Annual replacement will be made of all seals and gaskets.

8.2.5 Shielding

No tests are required for shielding performance other than normal transportation compliance surveys.

8.2.6 Thermal

No thermal tests are required.
8.3 Appendix
8.3 Determination Of Leak Test Pressures

8.3.1 Periodic Leak Tests

Permissable leak rates for normal conditions of transport were given in Section 4.4.1 as:

\[ L_N = 1.539 \times 10^{-3} \text{ cm}^3/\text{sec} \text{ (normal conditions)} \]

The required charge pressure at test conditions, required to verify leaktightness for this leak rate at normal conditions may be determined by use of equation (B.5) of ANSI N14.5:

\[ L_N = \frac{L_T \eta_T (P_u^2 - P_d^2)N}{\eta_N (P_u^2 - P_d^2)T} \]

Rearranging terms to solve for \( P_{ut} \):

\[ P_{ut} = \sqrt{\frac{L_T \eta_T (P_u^2 - P_d^2)N}{L_N \eta_N} + P_d^2} \]

Where:

- \( P_{ut} \) = Cask Cavity Charge Pressure
- \( P_d \) = 1 atm
- \( \eta_T \) = 0.0185 cP
- \( L_T \) = 2x10^{-3} (cm^3/sec)  
  - Soap bubble test sensitivity of 1x10^{-3} cm^3/sec Table A1
  - ANSI N14.5 (1/2 Procedure sensitivity included)

- \( P_{UN} \) = (25.6 + 14.7)/14.7
- \( P_d \) = 1 atm
- \( \eta_N \) = 0.2536 cP
- \( L_N \) = Permissable Leak rate at normal conditions (cm^3/sec)

Assumed test Conditions of dry air at 25°C

Normal conditions steam at 232°F and 25.6 psig
Normally leak rates are expressed in terms of standard conditions. The quantity, \( L_N \), represents the permissible leak rate of the medium (steam) at temperatures and pressures associated with normal transport conditions. Correlation of this quantity with the demonstrated leak rate at standards conditions, \( L_S \), is achieved via use of Equation (B.5) of ANSI N14.5:

\[
L_S = \frac{L_N \eta_N (P_u^2 - P_d^2) S}{\eta_S (P_u^2 P_d^2) N}
\]

Where:
- \( L_N = 1.539 \times 10^{-3} \text{ cm}^3/\text{sec} \)
- \( \eta_N = 0.2536 \text{ cP (steam at 232°F)} \)
- \( P_uN = (25.6 \text{ psig} + 14.7)/14.7 = 2.741 \text{ atm} \)
- \( P_dN = 1 \text{ atm} \)
- \( \eta_S = 0.0185 \text{ cP, air viscosity} \)
- \( P_uS = 1 \text{ atm} \)
- \( P_dS = 0 \text{ atm} \)

Therefore:

\[
L_S = \frac{(1.539 \times 10^{-3})(0.2536)(1^2 - 0^2)}{(0.0185)(2.741^2 - 1^2)}
\]

\( L_S = 3.24 \times 10^{-3} \text{ atm-cm}^3/\text{sec}. \)

8.3.2 Assembly Verification Leak Test

Leak tests for this type of package are generally performed prior to each shipment to \( 1 \times 10^{-1} \text{ atm-cm}^3/\text{sec} \) (standard conditions) to verify that the package has been assembled properly. The periodic leak test achieves a sensitivity of \( 3.24 \times 10^{-3} \text{ atm-cm}^3/\text{sec} \) (standard conditions) and shall be used for assembly verification prior to each use of the package.