PROCEDURES, LICENSE AND SAFETY ANALYSIS REPORT

FOR

CHEM-NUCLEAR SYSTEMS, INC.

1-184-109

RADWASTE SHIPPING CONTAINERS

Chem-Nuclear Systems, Inc.

Corporate/Western Operations
P.O. Box 1866
Bellevue, WA 98009

March 11, 1983

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1. GENERAL INFORMATION

1.1 Introduction

This Safety Analysis Report describes a disposable, steel vessel used as a container for low-level radioactive material. These liners serve as the container both for transport and for burial.

1.1.1 References

a) CNSI - Design Control Procedures EN-AD-002

b) CNSI Quality Assurance Program QA-AD-001

c) Roark and Young, "Formulus for Stress and Strain", Fifth Edition, McGraw Hill, Inc. 1975

1.2 Package Description

1.2.1 Package

The 1-184-109 liners are disposable right circular cylinders (See drawing in section 1.3). The heads are fabricated from 5/16" carbon steel plate and the walls are 11 gauge carbon steel sheet. Access to this container is the top portion of a standard 17H 55 gallon drum welded to the liner top. Closure is accomplished using a 17H gasket lid and clamp ring. Optional access is through a 150 pound flange welded to the liner top with mating flange or pipe plug to accomplish closure.

1.2.2 Operational Features

The operational features of the 1-184-109 liners are shown on CNSI drawing number C-901-E-0025 in section 1.3.

1.2.3 Contents of Package

The 1-184-109 liners are designed for processed solids. These may be either dewatered, solid or solidified so long as they meet the requirements for Low Specific Activity (LSA) material. Also included are contaminated solid wastes and irradiated hardware.

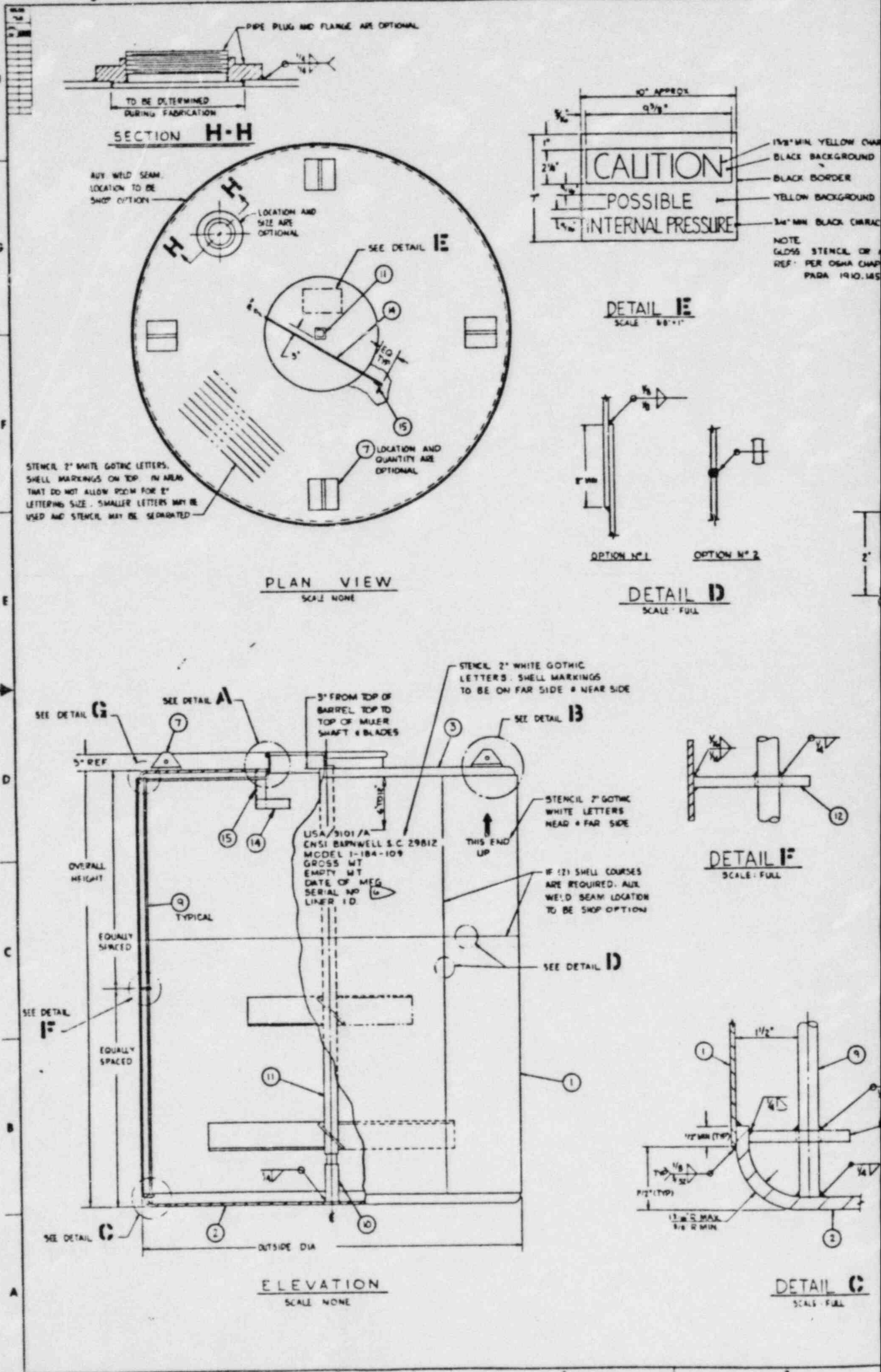
1.2.4 Q.A. Program

The 1-184-109 liners are designed, fabricated and handled using the CNSI Quality Assurance program (reference b).

1.3 Appendix

1-184-109 Liner Drawing

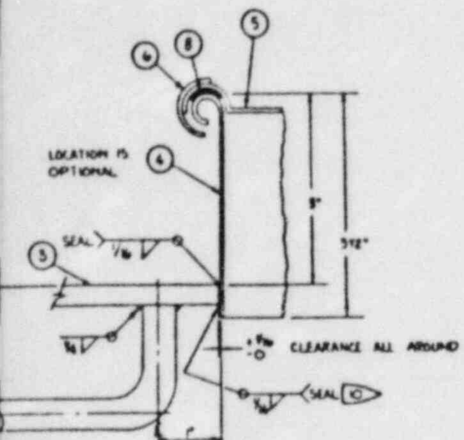
C-901-E-0025



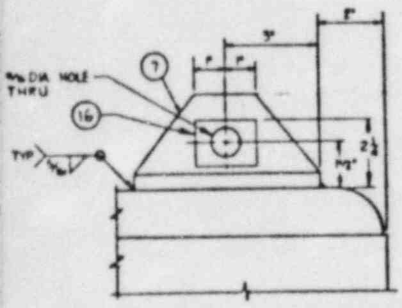
PIPE PLUG AND FLANGE ARE OPTIONAL
TO BE DETERMINED DURING FABRICATION
SECTION H-H
AUX WELD SEAM LOCATION TO BE SHOP OPTION
LOCATION AND SIZE ARE OPTIONAL
SEE DETAIL E
LOCATION AND QUANTITY ARE OPTIONAL
STENCIL 2" WHITE GOTHIC LETTERS. SHELL MARKINGS ON TOP. IN AREAS THAT DO NOT ALLOW ROOM FOR 2" LETTERING SIZE, SMALLER LETTERS MAY BE USED AND STENCIL MAY BE SEPARATED
PLAN VIEW
SCALE NONE
10" APPROX
CAUTION
POSSIBLE
INTERNAL PRESSURE
BLACK BACKGROUND
BLACK BORDER
YELLOW BACKGROUND
NOTE
DETAIL E
OPTION Nº 1
OPTION Nº 2
DETAIL D
SCALE: FULL
SEE DETAIL G
SEE DETAIL A
3" FROM TOP OF BARREL TOP TO TOP OF MIXER SHAFT & BLADES
STENCIL 2" WHITE GOTHIC LETTERS. SHELL MARKINGS TO BE ON FAR SIDE & NEAR SIDE
SEE DETAIL B
STENCIL 2" GOTHIC WHITE LETTERS NEAR & FAR SIDE
THIS END UP
USA/9101/A
CNSI BARNWELL S.C. 29812
MODEL 1-184-109
GROSS WT
EMPTY WT
DATE OF MFG
SERIAL NO
LINER I.D.
OVERALL HEIGHT
TYPICAL
EQUALLY SPACED
IF (2) SHELL COURSES ARE REQUIRED, AUX WELD SEAM LOCATION TO BE SHOP OPTION
SEE DETAIL D
SEE DETAIL F
DETAIL F
SCALE: FULL
SEE DETAIL C
OUTSIDE DIA
ELEVATION
SCALE NONE
DETAIL C
SCALE: FULL

LEGEND DISPOSABLE LINER

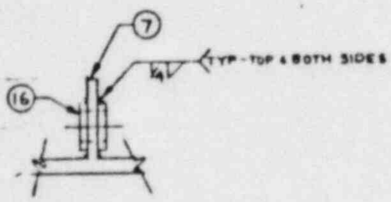
LINER IDENT	HEIGHT IN	DIA IN	WT EMPTY LBS (11)	CALCULATED CAPACITY FT3	GROSS WT MAX LBS
L6-80	54	58	950	81	10100
L4-85	97	44	900	84	10200
L6-75	69	52	767	84.8	10267
L7-100	57	74½	1250	96	11600
L8-120	71½	61	1100	118	14500
L14-125	49	76	1400	128.6	15500
L14-170	69¾	74½	1550	170	20750
L14-195	75½	76	1650	196	23700
L71-235	79	82	1800	241	28500
L21-300	104½	82	2200	317	32000
L18-450	97	83½	2100	303	32000

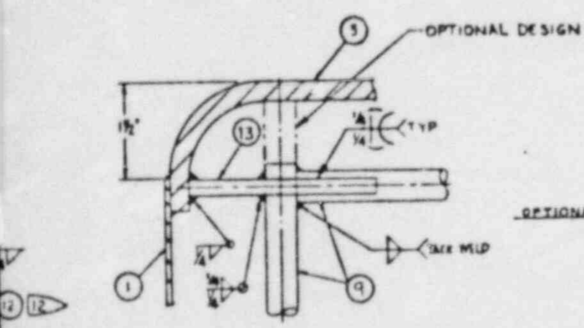


DETAIL A
SCALE: FULL

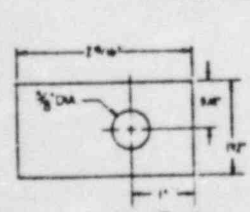


DETAIL B
SCALE: HALF

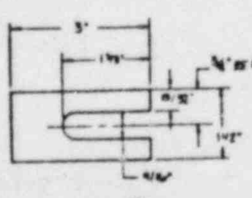




DETAIL G
SCALE: FULL



ITEM 12
SCALE: FULL



ITEM 13
SCALE: HALF SIZE

NOTES

1. BREAK AND DEBURR ALL SHARP EDGES.
2. WELDING SHALL BE PERFORMED BY WELDERS QUALIFIED PER ASME SECTION IX. WELD PROCEDURES SHALL BE SUBMITTED AND APPROVED PRIOR TO FABRICATION.
3. CLEANLINESS: INTERIOR/EXTERIOR SURFACES TO BE FREE OF WELD SPATTERS, WELD SCABS, WELD FREE OF FLUX AND ARC STRIKES. SWEEP OR VACUUM INTERIOR CLEAN.
4. LEAK TEST: PNEUMATIC TEST AT 3 - 5 PSIG WITH SOAP AND WATER SOLUTION (OR EQUIVALENT). APPLIED TO EXTERIOR WELD SEAMS AND SEAL. NO LEAKS ARE PERMITTED.
5. LUBRICATE CLAMP RING BOLT WITH LIGHT COAT OIL AND INSTALL FINGER TIGHT ONLY.
6. SERIAL NO. WILL BE CNSI PURCHASE ORDER NO. WITH SEQUENTIAL DASH NUMBERS FROM NO. 1 TO QUANTITY ORDERED.
7. LOCKWIRE BOLT ON CLAMP RING WHEN USED AS AN LSA TRANSPORT CONTAINER.
8. WHEN USED AS AN LSA TRANSPORT CONTAINER, LIFTING EYES SHALL BE PLUGGED TO PREVENT USE AS TIE-DOWN LUGS.
9. ALL DIMENSIONS ARE REFERENCE ONLY.
10. WELD REQUIRED ONLY WHEN INTERIOR EPOXY COATING IS SPECIFIED.
11. DOES NOT INCLUDE MIXER, SHAFT AND BLADE ASSEMBLY.
12. ITEM 12 TO BE COPED TO FIT BOTTOM HEAD (ITEM 2).

NOT FOR FABRICATION
LICENSING DWG ONLY

ITEM	QTY	DESCRIPTION	MATERIAL OR PART NO.	MAT'L SPEC	
16	A/R	PLATE 1½ X 2 X ¼ THK	C/STL	A36	
15	2	ANGLE 2 × 2 × ¼ × 5" LG.	C/STL	A36	
14	1	FLAT BAR ¼ THK × 2" × 27" × 2" LG			
13	A/R	PL 1½ × 3 × ¼ THK (SEE DETAIL)			
12	A/R	PL 1½ × 2⅞ × ¼ THK (SEE DETAIL)	C/STL	A36	
11	1	MIXER SHAFT AND BLADES			
10	1	PIPE 2" × 7" LG SCH 80	C/STL	[illegible]	
9	A/R	ROD ½" DIA	C/STL	A36	
8	1	GASKET HALF ROUND	NEOPRENE RUBBER	60 DUR	
7	A/R	TEE WT 3 × 12.5# × 6" LG	C/STL	A36	
6	1	55 GAL DRUM BOLTED CLAMP RING HEAVY DUTY		—	
5	1	55 GAL DRUM LID #16 GA SHT		—	
4	1	MODEL 17H DRUM TOP W/NO SWAGES		—	
3	1	TOP HEAD 5/16 PLATE		A36	
2	1	BOTTOM HEAD 3/16 PLATE		A36	
1	1	WALL: SHEET 11 GA	C/STL	A569	

BILL OF MATERIAL

UNLESS OTHERWISE NOTED DIMENSIONS ARE IN INCHES
DO NOT SCALE PRINT

FILE NO. 84643

CHEM-NUCLEAR SYSTEMS, INC.

DISPOSABLE LINER
SUBMITTAL DRAWING

SIZE E — C-901-E-0025 — REV —

2. STRUCTURAL EVALUATION

2.1 Structural Design

2.1.1 Discussion

The 1-184-109 liners are designed with 5/16" carbon steel plate top and bottom. The cylindrical walls are 11 gauge sheet. The top penetration/access is a standard 17H 55 gallon drum top or a 150 pound flange. Lifting eyes are welded to the liner top. All parts are welded construction.

2.1.2 Design Criteria

The design capacity for each vessel is listed in the table in CNSI drawing C-901-E-0025. The maximum gross weights shown reflect the design criteria based on maximum material densities, and assumed uniform or homogeneous material, and a safety factor of 3 on material yield strength.

2.2 Weights

The weight of each vessel empty and loaded has been calculated and shown on CNSI drawing C-901-E-0025 (see section 1.3).

2.3 Mechanical Properties of Materials

All materials of fabrication are carbon steel as specified in CNSI drawing C-901-E-0025.

2.4 General Standards For All Packages

2.4.1 Chemical and Galvanic Action

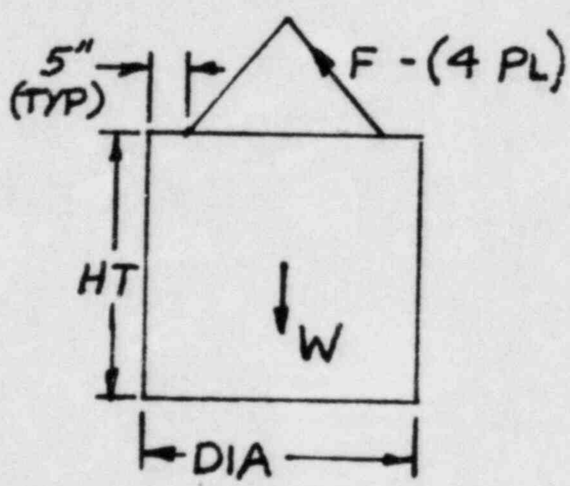
These vessels are constructed from a single material, they are intended to be used as one-time shipping containers of solidified or dry wastes, therefore chemical and galvanic action will be minimal.

2.4.2 Positive Closure

The closure system for all liners is a gasketed 17H drum lid fastened with the specified bolt ring or a mating flange with gasket or pipe plug if required.

2.4.3 Lifting Devices

Lifting cables for each liner are specified in CNSI drawing B-121-D-0001.



Shackle Loads on Lifting Eyes

$$4F \cos(\theta) = W$$
$$F = W/4\cos(\theta)$$

L4-85 Liner (opposite padeye attachment)

$$F = \frac{10,200}{4 \cos 26.9°}$$

F = 2860 lb.

L4-85 uses 5/8" shackle, maximum allowed load = 7380 lb.

L6-80 Liner (opposite padeye attachment)

$$F = \frac{10,100 \text{ lb.}}{4 \cos 28.7°}$$

F = 2880 lb.

L6-80 uses 5/8" shackle, maximum allowed load = 7380 lb.

Note: The L6-75 liner has approximate dimensions similar to the L6-80 and thus has safe lifting lugs.

L7-100 Liner (opposite padeye attachment)

$$F = \frac{11,600 \text{ lb.}}{4 \cos 29.75°}$$

F = 3340 lb.

L7-100 uses 5/8" shackle, maximum allowed load = 7380 lb.

L8-120 Liner (adjacent padeye attachment)

$$F = \frac{14,500 \text{ lb.}}{4 \cos 23.1°}$$

F = 3941 lb.

L7-100 uses 5/8" shackle, maximum allowed load = 7380 lb.

L14-195 Liner (adjacent padeye attachment)

$$F = \frac{23,700 \text{ lb.}}{4 \cos 21.04°}$$

F = 6348 lb.

L14-195 uses 5/8" shackle, maximum allowed load = 7380 lb.

Note: The L14-125 is the same diameter as the 14-195 but shorter and lighter and thus has safe lifting lugs.

L14-170 Liner (adjacent padeye attachment)

$$F = \frac{20,750 \text{ lb.}}{4 \cos 20.54°}$$

F = 5550 lb.

L14-170 uses 5/8" shackle, maximum allowed load = 7380 lb.

L18-450 Liner (adjacent padeye attachment)

$$F = \frac{32,000 \text{ lb.}}{4 \cos 21.8°}$$

F = 8610 lb.

L18-450 uses 3/4" shackle, maximum allowed load = 8610 lb.

L21-300 Liner (adjacent padeye attachment)

$$F = \frac{32,000 \text{ lb.}}{4 \cos 21.32°}$$

F = 8610 lb.

L21-300 uses 3/4" shackle, maximum allowed load = 8610 lb.

L21-235 Liner (adjacent padeye attachment)

$$F = \frac{28,500 \text{ lb.}}{4 \cos 21.32°}$$

F = 7648 lb.

L21-235 uses 3/4" shackle, maximum allowed load = 8610 lb.

Lifting eye strength:

15/16" diameter hole

.82 steel thickness (bearing)

Referenced from Roark and Young, Page 523

$$\sigma_{allowed} = 12000 \text{ psi}$$

For 5/8" shackle size - 3/4" pin

$$F_{allowed} = \sigma_{allowed} A$$

where $A = \text{Area} = 3/4" \times .82"$

$$F_{allowed} = 7380 \text{ lbs.}$$

For 3/4" shackle size - 7/8" pin

$$F_{allowed} = \sigma_{allowed} A$$

where $A = \text{Area} = 7/8" \times .82"$

$$F_{allowed} = 8610 \text{ lbs.}$$

Lifting Eye Weld Strength:

Weld around eye.
1-1/4" ϕ x 1/4 weld

$$\text{Area}_{weld} = \frac{.25}{\sqrt{2}} \times 1.25\,\pi = .6942 \text{ in}$$

$$\text{Load per weld} = F_{allowed} \times \frac{.25}{.82}$$

$$= 8610 \text{ lbs} \times \frac{.25}{.82} = 2625 \text{ lbs.}$$

$$\sigma_{weld} = \frac{2625 \text{ lbs}}{.6942 \text{ sq. in}} = 3781 \text{ psi}$$

Weld around "T" section

$$A_{weld} = \frac{15/16}{\sqrt{2}} \times 12 = 7.95 \text{ sq. in}$$

$$\sigma_{weld} = \frac{\text{load per weld}}{\text{Area}_{weld}}$$

$$\sigma_{weld} = \frac{8610 \text{ lbs}}{7.95 \text{ sq. in}}$$

$$\sigma_{weld} = 1083 \text{ psi}$$

The lifting eye strength is calculated for 12,000 psi yield. Since the lifting eye weld stress is only 1083 psi, the eye will fail before liner integrity is lost.

Stress on liner top from lifting forces. Assume load on 6" diameter circle.

From Roark and Young Table 24 Case 18

$$M_{max} = \frac{W_{max}}{4\pi} 1 + (1+.31) \ln \frac{5}{3} - \frac{(1-.31)(3)^2}{(4)(5)^2}$$

$$W_{max} = 8000 \text{ lbs.}$$

$$M_{max} = 250 \text{ in lbs/in}$$

$$\sigma_{max} = 15356 \text{ psi} < 36000 \text{ psi}$$

Note: Anticipated variations in lifting devices will require some modification to the lifting arrangement shown on drawing C-901-E-0025. These modifications will require a lifting eye stress not greater than 12000 psi, maximum height = 3", and minimum weld to the liner top of 12". The above analysis therefore applies to these other possible lifting arrangements.

2.4.4 Tiedown Devices

There are no tiedown devices which are a structural part of these packages. Lifting eyes will be securely covered during transportation in such a manner as to prevent their use as tiedowns.

2.5 Standards for Type B and Large Quantity Packaging

Not applicable for Type A packages

2.6 Normal Conditions of Transport

2.6.1 Heat

The liner is fabricated from one material and will therefore not be subject to thermal stresses. Internal partial pressures of gases at 130°F will not total greater than 7.3 psi limit determined in section 2.6.3.

2.6.2 Colu

The liner is contructed of one material and will therefore not be subject to thermal stresses.

2.6.3 Pressure

Pressure is worst for largest container

Geometry Diameter 90" maximum
Height 104-1/2" maximum

p = 7.3 psi - effective interior pressure

Top and Bottom - assume unsupported except at walls
fixity 5/16" plate with .105 walls --- 1/4 fixity

Roark and Young
Table 24 Case 10

$$S.S. - M_c = \frac{qa^2(3+\nu)}{16} = \frac{.0075x(41.75)^2(3.3)}{16} = 2.70 \text{ in-k/in}$$

$$Fixed\ M_c = \frac{qa^2(1+\nu)}{16} = \frac{.0075x(41.75)^2(1.3)}{16} = 1.06 \text{ in-k/in}$$

3/4 s.s + 1/4 fixed = 2.70x.75 + 1.06 x .25 = 2.29 in-k/in

Edge $\frac{-qa^2}{8} = \frac{-.0075x(41.75)^2}{8} = 1.63$ in-k/in

$.25x1.63 = .41$ in-k/in

Stress $\frac{m}{s} = \frac{2.29}{.01628} = 140.5$ ksi   Have to use membrane forces:

Check edge shear

$\frac{A}{C} = \frac{\pi D^2}{4} \quad x \quad \frac{1}{\pi D} = \frac{D}{4}$

$\frac{PD}{4} = \frac{.0075}{5/16} x \frac{83.5}{4} = .501$ ksi

This is OK

Roark and Young pg 406

$\frac{qa^4}{Et^4} = k_1 \frac{y}{t} + k_2 \frac{y}{t}^3 = \frac{.0075 \times 43.5^4}{29000x.3125^4} = 1.45 \frac{y}{.3125} + .376 \left(\frac{y}{.3125} \right)^3$

$\frac{\sigma a^2}{Et^2} = k_3 \frac{y}{t} + k_4 \frac{y}{t}^2 = \frac{\sigma \times 43.5^2}{29000x.3125^2} = 1.77 \frac{y}{.3125} + .294 \left(\frac{y}{.3125} \right)^2$

$K_1 = \frac{1.016}{1-\nu} = \frac{1.016}{1-.3} = \frac{1.016}{.7} = 1.45 \quad K_2 = 3.76$

$K_3 = \frac{1.238}{1-\nu} = \quad = \frac{1.238}{.7} = 1.77 \quad K_4 = 284$

Solving 1st Equation for y by trial: $y = 1.927$

$\sigma x.715 = 5.664 y + .254 (y/.3125)^2 = 20.57$

$\sigma = 20.57/.715 = 28.77 < 36$ ksi

Top and bottom are o.k. under pressure

Walls-

Longitudinal stress $\frac{qr}{2t} = \frac{.0075 \times 43.5}{2x.105} = 1.55$ ksi

Longitudinal stress $\frac{qr}{t} = \frac{.0075 \times 43.5}{.105} = 3.11$ ksi

$<< 36$ ksi

Wall strength is satisfactory

Lid - cap is standard DOT 17H drum lid which meets these and DOT requirements

2.6.4 Vibration

All containers shown in drawing have natural frequencies much greater than frequencies normally incident to transport. Sample calculations are included as Appendix 2.10.1.

2.6.5 Water Spray

All containers included in this report are welded steel construction and as such will not be affected by water spray.

2.6.6 Analysis Free Drop Test

A corner drop oriented with the center of gravity over the point of impact results in the greatest deformation. In both corner and end drops (top down) the liner will crush into the void intentionally left in the top of the liner. Steel will yield into the plastic region, but all energy is absorbed prior to reaching the ultimate rupture strength of the container.

All other orientations with solidified product inside the liner at the point of impact will result in some reduced deformation of the liner in the plastic region. The side drop and bottom corner and bottom end drop are thus safe.

Weight of Container:

For L18-450 height = 97" = 8.0833'
diameter = 83.5" = 6.96'
empty weight = 1950 lb.

$$\text{Volume} = \frac{\pi d^2}{4}(h) = \frac{\pi(6.96')^2(8.0833')}{4} \quad \text{Capacity} = 307.5\ ft^3$$

Weight of contents = Density x Volume

$$= (110\ lb/ft^3)(307.5\ ft^3) = 33{,}829\ lb.$$

Total estimated gross weight = 33,829 lb + 1950 lb.

= 35,779 lb. or 35.8 K.

Energy of Drop:

The drop height was 12" as specified for a liner of this weight

Energy = wh = (35.779K)(12") = 429.3 in-k

Volume Deformed Steel Required:

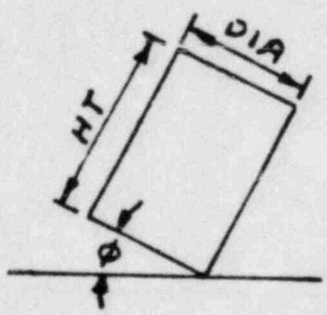
Assuming the steel will yield at 36 ksi,

$$\frac{429.3\ \text{in-k}}{36\ \text{ksi}} = 11.93\ in^3$$

for 11 gauge steel sheet, thickness is

$$A = \frac{11.93\ in^3}{.12\ in} = 99.39\ in^2 \text{ of skin}$$

Geometry:



$$\phi = \tan^{-1}(83.5/97) = 40.72°$$

$$\sin\phi = .7579$$

$$\cos\phi = .6524$$

Amount of Crush Required:

Using the calculated equation for Area:

and A = 99.393 in^2, R = 83.5"/2 = 41.75", sinø = .6524, cosø = .7579

$$A = \frac{4R\delta}{3\cos\phi}\cos^{-1}\left(1-\frac{\delta}{R\sin\phi}\right) = \frac{4(41.75")\delta}{3(.7579)}\cos^{-1}\left(1-\frac{\delta}{(41.75)(.6524)}\right)$$

$A = 99.39$ in $= 73.45\ \delta\cos\ (1- \frac{\delta}{27.24})$

$\delta = 2.9"$

Check Bottom Weld:

Maximum G-Force, from previously calculated equation:

$C = 2R\cos^{-1}(1-\frac{\delta}{R\sin\phi})$

$C = 2(41.75")\cos^{-1}(1- \frac{2.9"}{(41.75)(.6524)})$

$C = 38.9"$

Maximum Force: (38.9")(.12")(36 ksi) = 167.97k

Maximum Force = $\frac{167.97\ k}{35.779\ k}$ = 4.695 G

Where 35.779 k was the calculated weight force of the liner

Pressure on Bottom:

Where density = 110 lb/ft^3 and h = 8.083'

$p = (4.695\ G)(8.083')(110\ lb/ft^3)$

$p = 4{,}174\ lb/ft^2 = 28.99$ psi

The shear on the weld, $\frac{P(D)}{4} = \frac{(28.99)(83.5")}{4}$ = 605 lb/in

Therefore, the weld is adequate

END DROP

Liner: 18-450

Diameter = 83.5 inches

Height = 97 inches

Weight = 32000 pounds

Height = 12 inches

Potential Energy = weight x drop height

PE = 384000 inch lbs.

Required Volume = Energy/Yield stress

Vol. Req. = 10.6 cu.in.

Deflection = Vol/(Cir. xTh)

Defl. = .32 in

"G" Load = Drop Height/Deflection

"G" LD. = 37.5 G

Weight of Container:

For L21-300 height = 104.5" = 8.708'

diameter = 82" = 6.833'

empty weight = 1961 lb.

Note: Since the 21-235 is the same diameter as the 21-300 but shorter and lighter, this analysis applies to these liners.

$$\text{Volume} = \frac{\pi d^2}{4}(h) = \frac{\pi(6.833')^2(8.708')}{4} \overset{\text{Capacity}}{=} 319.35\ ft^3$$

Weight of contents = Density x Volume

$$= (110\ lb/ft^3)(319.35\ ft^3) = 35{,}129\ lb.$$

Total estimated gross weight = 35,129 lb + 1961 lb.

= 37,090 lb. or 37.09 K.

Energy of Drop:

The drop height was 12" as specified for a liner of this weight

Energy = wh = (37.09K)(12") = 445.08 in-k

Volume Deformed Steel Required:

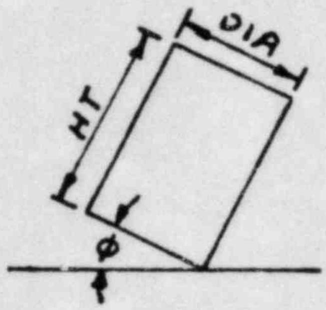
Assuming the steel will yield at 36 ksi,

$$\frac{445.08\ \text{in-k}}{36\ \text{ksi}} = 12.36\ in^3$$

for 11 gauge steel sheet, thickness is .12"

$$A = \frac{12.36\ in^3}{.12\ in} = 103\ in^2 \text{ of skin}$$

Geometry:



$\phi = \tan^{-1}(82/104.5) = 38.12°$

$\sin\phi = .6173$

$\cos\phi = .7867$

Amount of Crush Required:

Using the calculated equation for Area:

and $A = 103\ in^2$, $R = 82"/2 = 41"$, $\sin\phi = .6173$, $\cos\phi = .7867$

$$A = \frac{4R\delta}{3\cos\phi}\cos^{-1}\left(1-\frac{\delta}{R\sin\phi}\right) = \frac{4(41")\delta}{3(.7867)}\cos^{-1}\left(1-\frac{\delta}{(41)(.6173)}\right)$$

$$A = 103\ in^2 = 69.49\ \delta\cos\ \left(1-\frac{\delta}{25.31}\right)$$

$$\delta = 3.0"$$

Check Bottom Weld:

Maximum G-Force, from previously calculated equation:

$$C = 2R\cos^{-1}\left(1-\frac{\delta}{R\sin\phi}\right)$$

$$C = 2(41")\cos^{-1}\left(1-\frac{3"}{(41)(.6173)}\right)$$

$$C = 40.33"$$

Maximum Force: (40.33")(.12")(36 ksi) = 174.2 k

$$\text{Maximum Force} = \frac{174.2\ k}{37.09\ k} = 4.698\ G$$

Where 37.09 k was the calculated weight force of the liner

Pressure on Bottom:

Where density = 110 lb/ft^3 and h = 8.708 ft

$p = (4.697\ G)(8.709')(110\ lb/ft^3)$

$p = 4{,}499.6\ lb/ft^2 = 31.25\ psi$

The shear on the weld, $\frac{P(D)}{4} = \frac{(31.25\ psi)(82")}{4} = 640.6\ lb/in$

Therefore, the weld is adequate

END DROP

Liner: 21-300

Diameter = 82 inches
Height = 104.5 inches
Weight = 32000 pounds
Drop Height = 12 inches

Potential Energy = weight x drop height
PE = 384000 inch lbs.

Required Volume = Energy/Yield stress
Vol. Req. = 10.6 cu.in.

Deflection = Vol/(Cir. x Th)
Defl. = .33 in

"G" Load = Drop Height/Deflection
"G" LD. = 36.2 G

Weight of Container:

For L8-120 height = 71.5" = 5.958'

diameter = 61" = 5.0833'

empty weight = 1072 lb.

$$\text{Volume} = \frac{\pi d^2}{4}(h) = \frac{\pi(5.0833')^2(5.958')}{4} = \begin{matrix}\text{Capacity}\\ 120.9 \text{ ft}^3\end{matrix}$$

Weight of contents = Density x Volume

$$= (110 \text{ lb/ft}^3)(120.9 \text{ ft}^3) = 13{,}301 \text{ lb.}$$

Total estimated gross weight = 13,301 lb + 1072 lb.

= 14,373 lb. or 14.373 K.

Energy of Drop:

The drop height was 36" as specified for a liner of this weight

Energy = wh = (14.373K)(36") = 517.4 in-k

Volume Deformed Steel Required:

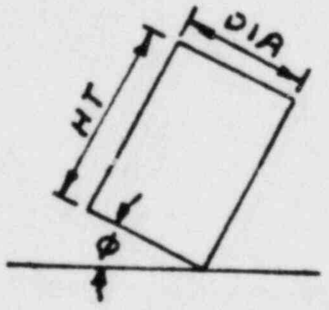
Assuming the steel will yield at 36 ksi,

$$\frac{517.4 \text{ in-k}}{36 \text{ ksi}} = 14.37 \text{ in}^3$$

for 11 gauge steel sheet, thickness is .12"

$$A = \frac{14.37 \text{ in}^3}{.12 \text{ in}} = 119.8 \text{ in}^2 \text{ of skin}$$

Geometry:



$\phi = \tan^{-1}(61/71.5) = 40.47°$

$\sin\phi = .761$

$\cos\phi = .649$

[illegible]nt of Crush Required:

Using the calculated equation for Area:

and $A = 119.8\ in^2$, $R = 61"/2 = 30.5"$, $\sin\phi = .649$, $\cos\phi = .761$

$$A = \frac{4R\delta}{3\cos\phi}\cos^{-1}\left(1-\frac{\delta}{R\sin\phi}\right) = \frac{4(30.5")}{3(.761)}\cos^{-1}\left(1-\frac{\delta}{(30.5)(.649)}\right)$$

$$A = 53.44\ \delta\cos^{-1}\left(1-\frac{\delta}{19.79}\right) = 119.8\ in^2$$

$$\delta = 3.6"$$

Check Bottom Weld:

Maximum G-Force, from previously calculated equation:

$$C = 2R\cos^{-1}\left(1-\frac{\delta}{R\sin\phi}\right)$$

$$C = 2(30.5")\cos^{-1}\left(1-\frac{3.6"}{(30.5)(.649)}\right)$$

$$C = 37.37"$$

Maximum Force: $(37.37")(.12")(36\ ksi) = 161.4\ k$

Maximum Force $= \frac{161.41\ k}{14.373\ k} = 11.23\ G$

Where 14.373 k was the calculated weight force of the liner

Pressure on Bottom:

Where density = 110 lb/ft^3 and h = 71.5/12 = 5.958 ft

$p = (11.23)(110\ lb/ft^3)(5.958')$

$p = 7361.5\ lb/ft^2 = 51.12\ psi$

The shear on the weld, $\frac{P(D)}{4} = \frac{(51.12\ psi)(61")}{4} = 779.6\ lb/in$

Therefore, the weld is adequate

END DROP

Liner: 8-120

Diameter = 61 inches
Height = 71.5 inches
Weight = 18500 pounds
Drop Height = 36 inches

Potential Energy = weight x drop height
PE = 666000 inch lbs.

Required Volume = Energy/Yield stress
Vol. Req. = 18.5 cu.in.

Deflection = Vol/(Cir. x Th)
Defl. = .77

"G" Load = Drop Height/Deflection
"G" LD. = 46.61

Force to yield walls = cir. x th. x yield stress
Fy = 862000

"G" Load = Fy/Wt
"G" LD. = 46.6 G

Weight of Container:

For L14-170 height = 69-3/8" = 5.7813'

diameter = 74-1/2" = 6.2083'

empty weight = 1428 lb.

Volume $= \frac{\pi d^2}{4}(h) = \frac{\pi(6.2083')^2(5.7813')}{4} = $ Capacity 175 ft^3

Weight of contents = Density x Volume

$= (110\ lb/ft^3)(175\ ft^3) = 19{,}251$ lb.

Total estimated gross weight = 19,257 lb + 1428 lb.

= 20,679 lb. = 20.68 k

Energy of Drop:

The drop height was 24" as specified for a liner of this weight

Energy = wh = (20,679 K)(24") = 496.3 in-k

Volume Deformed Steel Required:

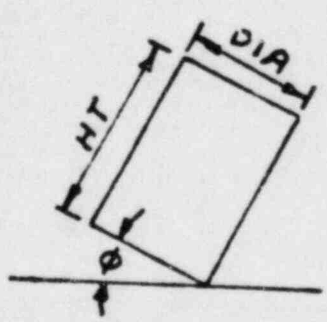
Assuming the steel will yield at 36 ksi,

$$\frac{496.3\ \text{in-k}}{36\ \text{ksi}} = 13.79\ \text{in}^3$$

for 11 gauge steel sheet, thickness is .12"

$$A = \frac{13.79\ \text{in}^3}{.12\ \text{in}} = 114.9\ \text{in}^2 \text{ of skin}$$

Geometry:



$\phi = \tan^{-1}(74.5/69.375) = 47.04°$

$\sin\phi = .7318$

$\cos\phi = .6815$

Amount of Crush Required:

Using the calculated equation for Area:

and $A = 114.9 \text{ in}^2$, $R = 74.5"/2 = 37.25"$, $\sin\phi = .7318$, $\cos\phi = .6815$

$$A = \frac{4R\delta}{3\cos\phi}\cos^{-1}\left(1-\frac{\delta}{R\sin\phi}\right) = \frac{4(37.25")\delta}{3(.6815)}\cos^{-1}\left(1-\frac{\delta}{(37.25)(.7318)}\right)$$

$$A = 114.9 \text{ in}^2 = 72.88\delta\cos^{-1}\left(1-\frac{\delta}{27.26}\right)$$

$$\delta = 3.2"$$

Check Bottom Weld:

Maximum G-Force, from previously calculated equation:

$$C = 2R\cos^{-1}\left(1-\frac{\delta}{R\sin\phi}\right)$$

$$C = 2(37.25")\cos^{-1}\left(1-\frac{3.2"}{(37.25)(.7318)}\right)$$

$$C = 36.46"$$

Maximum Force: (36.46")(.12")(36 ksi) = 157.511 k

$$\text{Maximum Force} = \frac{157.51\text{k}}{20.679\text{k}} = 7.62 \text{ G}$$

Where 20.679 k was the calculated weight force of the liner

Pressure on Bottom:

Where density = 110 lb/ft^3 and h = 5.7813 ft

$p = (7.62 \text{ G})(110 \text{ lb/ft}^3)(5.7813')$

$p = 4{,}844 \text{ lb/ft}^2 = 33.64 \text{ psi}$

The shear on the weld, $\frac{P(D)}{4} = \frac{(33.64 \text{ psi})(74.5")}{4} = 626.5 \text{ lb/in}$

Therefore, the weld is adequate

END DROP

Liner: 14-170

Diameter = 74.5 inches
Height = 69.5 inches
Weight = 20,760 pounds
Drop Height = 24 inches

Potential Energy = weight x drop height
PE = 498,000 inch lbs.

Required Volume = Energy/Yield stress
Vol. Req. = 13.84 cu.in.

Deflection = Vol/(Cir. x Th)
Defl. = .47

"G" Load = Drop Height/Deflection
"G" LD. = 50.73

Force to yield walls = cir. x th. x yield stress
Fy = 1,053,000

"G" Load = Fy/Wt
"G" LD. = 50.73

Weight of Container:

For L14-195 height = 75-1/2" = 6.3'

diameter = 76" = 6.333'

empty weight = 1650 lb.

Note: Since the 7-100 and 14-125 liners are the same diameter as the 14-195 but shorter and lighter, this analysis applies to these liners

$$\text{Volume} = \frac{\pi d^2}{4}(h) = \frac{\pi(6.333')^2(6.3')}{4} = \text{Capacity } 198.5\ ft^3$$

Weight of contents = Density x Volume

$$= (110\ lb/ft^3)(198.5\ ft^3) = 21{,}830\ lb.$$

Total estimated gross weight = 21,830 lb + 1650 lb.

= 23,500 lb. or 23.5 K

Energy of Drop:

The drop height was 24" as specified for a liner of this weight

Energy = wh = (23.5 K)(24") = 564 in-k

Volume Deformed Steel Required:

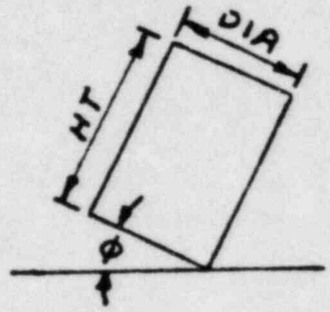
Assuming the steel will yield at 36 ksi,

$$\frac{564\ in\text{-}k}{36\ ksi} = 15.67\ in^3$$

for 11 gauge steel sheet, thickness is .12"

$$A = \frac{15.67\ in^3}{.12\ in} = 128.8\ in^2 \text{ of skin}$$

Geometry:



$\phi = \tan^{-1}(76/49) = 57.2°$

$\sin\phi = .8405$

$\cos\phi = .5419$

Amount of Crush Required:

Using the calculated equation for Area:

and $A = 128.8\ in^2$, $R = 76"/2 = 38"$, $\sin\phi = .8405$, $\cos\phi = .5419$

$$A = \frac{4R\delta}{3\cos\phi}\cos^{-1}\left(1-\frac{\delta}{R\sin\phi}\right) = \frac{4(38")\delta}{3(.5419)}\cos^{-1}\left(1-\frac{\delta}{(38)(.8405)}\right)$$

$$A = 128.8\ in^2 = 93.58\delta\cos^{-1}\left(1-\frac{\delta}{31.94}\right)$$

$\delta = 3.1"$

Check Bottom Weld:

Maximum G-Force, from previously calculated equation:

$$C = 2R\cos^{-1}\left(1-\frac{\delta}{R\sin\phi}\right)$$

$$C = 2(38")\cos^{-1}\left(1-\frac{3.1"}{(38)(.8405)}\right)$$

$C = 33.76"$

Maximum Force: (33.76")(.12")(36 ksi) = 145.85 k

Maximum Force = $\frac{145.85k}{15.467k}$ = 9.436 G

Where 15.67 k was the calculated weight force of the liner

Pressure on Bottom:

Where density = 110 lb/ft^3 and h = 4.0833 ft

p = (9.436 G)(110 lb/ft^3)(6.3') = 6,539 lb/ft^2

p = 45.4 psi

The shear on the weld, $\frac{P(D)}{4} = \frac{(45.4\ psi)(76")}{4}$ = 863 lb/in

Therefore, the weld is adequate

<u>END DROP</u>

Liner: 14-195

Diameter = 76 inches

Height = 75.5 inches

Weight = 23500 pounds

Drop Height = 24 inches

Potential Energy = weight x drop height

PE = 564000 inch lbs.

Required Volume = Energy/Yield stress

Vol. Req. = 15.4 cu.in.

Deflection = Vol/(Cir. x Th)

Defl. = .518 in

"G" Load = Drop Height/Deflection

"G" LD. = 46 G

Weight of Container:

For L4-85 height = 97" = 8.0833'

diameter = 44" = 3.6667'

empty weight = 800 lb. (my calculation)

Volume $= \frac{\pi d^2}{4}(h) = \frac{\pi(3.6667')^2(8.0833')}{4} =$ Capacity 85.35 ft^3

Weight of contents = Density x Volume

= (110 lb/ft^3)(85.35 ft^3) = 9389 lb.

Total estimated gross weight = 9389 lb + 800 lb.

= 10,189 lb.

or 10.189 K

Energy of Drop:

The drop height was 48" as specified for a liner of this weight

Energy = wh = (10.189 K)(48") = 489.1 in-k

Volume Deformed Steel Required:

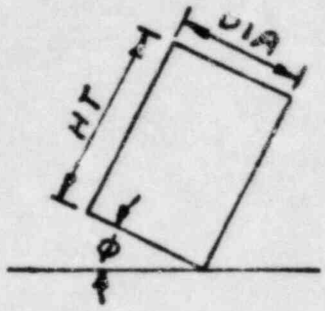
Assuming the steel will yield at 36 ksi,

$$\frac{489 \text{ in-k}}{36 \text{ ksi}} = 13.59 \text{ in}^3$$

for 12 gauge steel sheet, thickness is .1"

$$A = \frac{13.59 \text{ in}^3}{.105 \text{ in}} = 129.4 \text{ in}^2 \text{ of skin}$$

Geometry:



$\phi = \tan^{-1}(44/96) = 24.62°$

$\sin\phi = .417$

$\cos\phi = .909$

Amount of Crush Required:

Using the calculated equation for Area:

and $A = 129.4\ in^2$, $R = 44"/2 = 22"$, $\sin\phi = .417$, $\cos\phi = .909$

$$A = \frac{4R\delta}{3\cos\phi}\cos^{-1}\left(1-\frac{\delta}{R\sin\phi}\right) = \frac{4(22")\delta}{3(.909)}\cos^{-1}\left(1-\frac{\delta}{(22)(.417)}\right)$$

$$A = 129.4\ in^2 = 32.27\delta\cos^{-1}\left(1-\frac{\delta}{9.174}\right)$$

$$\delta = 4.1"$$

Check Bottom Weld:

Maximum G-Force, from previously calculated equation:

$$C = 2R\cos^{-1}\left(1-\frac{\delta}{R\sin\phi}\right)$$

$$C = 2(22")\cos^{-1}\left(1-\frac{4.1"}{(22)(.417)}\right)$$

$$C = 43.33"$$

Maximum Force: (43.33")(.105")(36 ksi) = 163.8 k

Maximum Force $= \frac{163.8k}{10.189k} = 16.07$ G

Where 10.189 k was the calculated weight force of the liner

Pressure on Bottom:

Where density = 110 lb/ft^3 and h = 96 ft./12 = 8

$p = (16.07)(8')(110\ lb/ft^3)$

$p = 14{,}142\ lb/ft^2 = 98.21$ psi

The allowed shear on the weld, $\frac{P(D)}{4} = \frac{(98.2\ psi)(44")}{4} = 1081$ lb/in

Therefore, the weld is adequate

END DROP

Liner: L4-85

Diameter = 44 inches

Height = 97 inches

Weight = 10200 pounds

Drop Height = 36 inches

Potential Energy = weight x drop height

PE = 367200 inch lbs.

Required Volume = Energy/Yield stress

Vol. Req. = 10.2 cu.in.

Deflection = Vol/(Cir. x Th)

Defl. = .59 in

"G" Load = Drop Height/Deflection

"G" LD. = 60.98 G

Force to yield walls = Cir x Th. x yield stress

Fy = 622000 lbs.

"G" Load = Fy/Wt

"G" LD. = 60.98 G

Weight of Container:

For L6-80 height = 54" = 4.50'

diameter = 58" = 4.833'

empty weight = 888 lb.

Volume $= \frac{\pi d^2}{4}(h) = \frac{\pi(4.833')^2(4.50')}{4} =$ Capacity $82.55\ ft^3$

Weight of contents = Density x Volume

$= (110\ lb/ft^3)(82.55\ ft^3) = 9{,}081$ lb.

Total estimated gross weight = 9,081 lb + 888 lb.

= 9,970 lb.

or 9.97 k

Energy of Drop:

The drop height was 48" as specified for a liner of this weight

Energy = wh = (9.97 K)(48") = 478.6 in-k

Volume Deformed Steel Required:

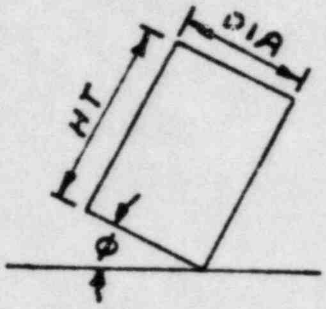
Assuming the steel will yield at 36 ksi,

$$\frac{478.6\ \text{in-k}}{36\ \text{ksi}} = 13.29\ \text{in}^3$$

for 12 gauge steel sheet, thickness is .105"

$$A = \frac{13.29\ \text{in}^3}{.105\ \text{in}} = 126.6\ \text{in}^2 \text{ of skin}$$

Geometry:



$\phi = \tan^{-1}(58/54) = 47.05°$

$\sin\phi = .7319$

$\cos\phi = .6814$

Amount of Crush Required:

Using the calculated equation for Area:

and $A = 126.6\ in^2$, $R = 58"/2 = 29"$, $\sin\phi = .7319$, $\cos\phi = .6814$

$$A = \frac{4R\delta}{3\cos\phi}\cos^{-1}\left(1 - \frac{\delta}{R\sin\phi}\right) = \frac{4(29")\delta}{3(.6814)}\cos^{-1}\left(1 - \frac{\delta}{(29)(.7319)}\right)$$

$$A = 126.6\ in^2 = 56.75\delta\cos^{-1}\left(1 - \frac{\delta}{21.22}\right)$$

$\delta = 3.7"$

Check Bottom Weld:

Maximum G-Force, from previously calculated equation:

$$C = 2R\cos^{-1}\left(1 - \frac{\delta}{R\sin\phi}\right)$$

$$C = 2(29")\cos^{-1}\left(1 - \frac{3.7"}{(29)(.7319)}\right)$$

$C = 34.76"$

Maximum Force: (34.76")(.105")(36 ksi) = 131.4 k

Maximum Acceleration = $\frac{131.4\ k}{9.97k}$ = 13.18 G

Where 9.97 k was the calculated weight of the liner

Pressure on Bottom:

Where density = 110 lb/ft^3 and h = 54 ft/12 = 4.5 ft

p = (13.18 G)(4.5')(110 lb/ft^3)

p = 6,524 lb/ft^2 = 45.3 psi

The shear on the weld, $\frac{P(D)}{4} = \frac{(45.32 \text{ psi})(58")}{4}$ = 656.9 lb/in

Allowed Shear 6.36 kips/inch

Therefore, the weld is adequate

END DROP

Liner: 6-80

Diameter = 58 inches
Height = 54 inches
Weight = 9900 pounds
Drop Height = 48 inches

Potential Energy = weight x drop height
PE = 475200 inch lbs.

Required Volume = Energy/Yield stress
Vol. Req. = 13.2 cu.in.

Deflection = Vol/(Cir. x Th)
Defl. = .58 in

"G" Load = Drop Height/Deflection
"G" LD. = 82.8 G

Force to yield walls = Cir x Th. x yield stress
Fy = 820,000 lbs.

"G" Load = Fy/Wt
"G" LD. = 82.8 G

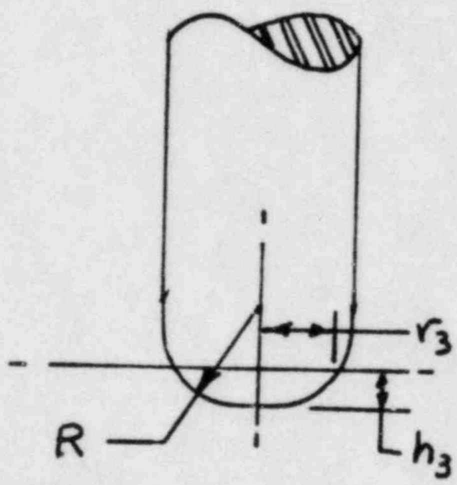
2.6.7 Corner Drop

All containers evaluated in this report are of welded steel construction, weigh in excess of 110 pounds and will not contain fissile material. For this reason the corner drop, from a height of 1 foot onto a flat, unyielding, horizontal surface, is not required.

2.6.8 Penetration

Spherical Penetration Geometry

Volume spherical segment of one base



$$V = 1/6\pi h_3\ (3r_3^2 + h_3^2)$$

$$(R-h_3)^2 + r_3^2 = R^2$$

$$r_3^2 = R^2 - (R-h_3)^2$$

$$= R^2 - (R^2-2Rh_3+h_3^2)$$

$$= R^2-R^2+2Rh_3-h_3^2 = 2Rh_3-h_3^2$$

Substituting in equation from above:

$$V = 1/6\pi h_3(3(2Rh_3 - h_3^2)+h_3^2)$$

$$= 1/6\ \pi h_3\ (6Rh_3-3h_3^2+h_3^2)$$

$$= 1/6\pi h_3\ (6Rh_3 - 2h_3^2)$$

$$= \pi h_3^2\ (R - \frac{h_3}{3}) = \pi h_3^2\ (D/2 - \frac{h_3}{3})$$

$$r_3 = \sqrt{(2Rh_3 - h_3^2)}$$

Penetration:

13 lb wt with hemispherical end 1-1/4" ø falling 40" into side.

Worst case is smallest diameter of container

45" ø container R/r = 45/1.25 = 36.

Look at case of flat sheet first, consider curvature effects later.

Energy:

wh = 13x40 = 520 in lbs.

Volume stl. = 520/36000 = .0144 in^3

Volume of spherical segment πd^2 (r - d/3)

d = depth of penetration of missile into steel plate

Check .0884" penetration

$V = (.0884)^2\ \pi(\frac{1.25}{2} - \frac{.0884}{3})$ = .0146 in^3 compared with .0144 in^3 rqd.

.0884" penetration vs. .125 thickness

not enough energy to penetrate

set of "Dimples" $r = \sqrt{[2Rh_3 - h_3^2]}$

$= \sqrt{[1.25 \times .0884 - .0884^2]} = 0.320"$

$A = \pi R^2 = \pi x.320^{-2} = .322\ in^2$

Force = .322x36 = 11.61 kips

Effects of shell curvature

$R\text{-}h = d = \sqrt{[22.5^2 - .322^2]} = 22.498$

$h = R\text{-}d = 22.5 - 22.498 = .002"$

Does not affect results.

Stress at point of load

Per Roark and Young 5 ed. Table 31 case 9

Maximum stresses circumferential

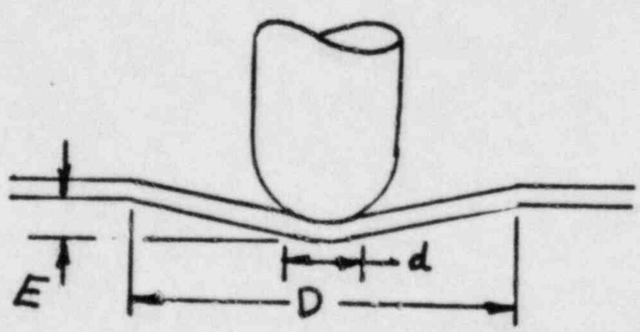
$\sigma_2 = \frac{.4P}{t^2}$; $\sigma_2 = 2.4\frac{P}{t^2}$; $y = \frac{P}{Et}[.48 (\frac{L}{R})^{1/2}(\frac{R}{t})^{1.22}]$

$f_{hoop\text{-}membrane} \quad \frac{.4P}{t^2} = \frac{.4 \times 11.61}{.105^2} = 421 \text{ ksi}$

$f_{hoop\text{-}bending} \quad \frac{2.4P}{t^2} = \frac{2.4 \times 1161}{.105^2} = 2527$

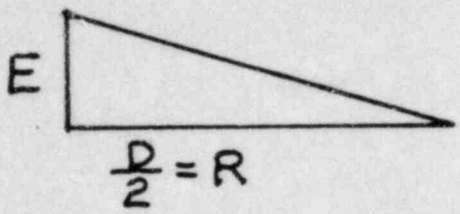
$2527 + 421 = 2948 \text{ ksi} >> \text{yield}$

Energy goes into denting as well as dimpling



To form a dent the material must yield in bending under the missile and around the perimeter. Stretching must also occur for a given E and D. The energy absorbed can be computed for these assumptions. It should also be possible to get an angle on maximum force. The energy imparted by the force can be compared with the energy of the missile and the energy absorbed to adjust E and D.

Assume a circular Dent with uniformly distributed plastic strain.



$$\varepsilon = \frac{\sqrt{[E^2 + R^2]} - R}{R}$$

$$\omega = \sigma_y \varepsilon$$

use σ_y = Dynamic Flow Stress = 36

$$W = \int_A \sigma_y \varepsilon dA = \sigma_y \varepsilon \int_A dA = \sigma_y \varepsilon A_{Dent}$$

Max impact force

use circumference at R/2 and slope of dented material stress = 36 ksi.

1/2 P_{max} x E should equal energy of system

Try solving for ε

$$.520 = 36 \times \varepsilon \times 2\pi \; ; \quad \varepsilon = \frac{.520}{36 \times 2\pi} = .002299$$

$$.002299 = \frac{\sqrt{[E^2 + 2^2]} - 2}{2} \; ; \; 2x\ .02299 + 2 = \sqrt{[E^2 + 2^2]}$$

$$E^2 + 2^2 = 4.0134$$

$$E^2 = .014$$

$$E = .1357"$$

Try E = .136"

$$\varepsilon = \frac{\sqrt{[.136^2 + 2^2]} - 2}{2} = .00231 \text{ in/in}$$ Typical elastic strain system

w = 36x.00231 x 2.π = .522 in-k - close enough to energy of missile

Estimate force required to produce this strain.

circumference = 2π = 6.28" thickness .105

Area --- .660 in^2 x 36 = 23.7 K

Slope .136/2 = .068   .068x23.7 = 1.61 K

1/2x 1.61 x .136 = .109 in-k < .520

Larger dent required to adsorb energy amount

Try D=10" R=5"

$\varepsilon = \frac{520}{36x5\pi} = .000919$ $5x.000919\ x5 = \sqrt{E^2 + 5^2}$

E = .214"

$5\pi \times 105 \times 36 \times \frac{.214}{5} = 2.55^k$ 2.55 x .214 = .545 close

The above analysis indicates that neglecting energies of bending and dimpling and accepting the relatively crude assumptions a maximum impact force of 2.55^k will be generated and a dent of about 10"ø and 1/4" deep will occur. With a maximum strain of .0009 in/in even used as an extremely rough indication of what happens, this analysis indicates extreme safety against penetration by the missile.

2.6.9 Compression

Greatest load is 5 x gross weight

$\sigma = \frac{5W}{.12\pi D}$

$= 13.26 \frac{W}{D}$

σ_{14-195} = 4135 psi
σ_{14-170} = 3694 psi
σ_{14-125} = 2635 psi
σ_{6-80} = 2286 psi
σ_{7-100} = 1922 psi
σ_{8-120} = 3152 psi
σ_{21-235} = 4450 psi
σ_{4-85} = 3073 psi
σ_{21-300} = 5175 psi
σ_{21-450} = 5081 psi

All liners will thus support compression loading.

2.7 Hypothetical Accident Conditions

Not Required for Type A package

2.8 Special Form

Not applicable

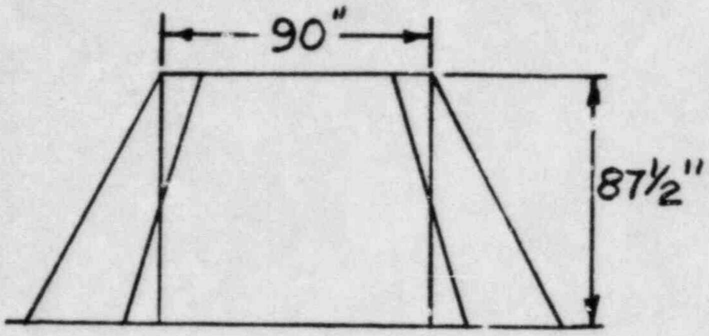
2.9 Fuel Rods

Not applicable

2.10 Appendix

2.10.1 Vibration Calculations

-4 Container



w = 25.4 K

$\frac{25400}{87.5}$ = 290 lbs/in

Hinged at bottom

Consider as hinged-hinged beam.

Roark and Young - STR
Table 36 Case 1b

$$f_n = \frac{K_n}{2\pi} \frac{EI_g}{wl^4}$$

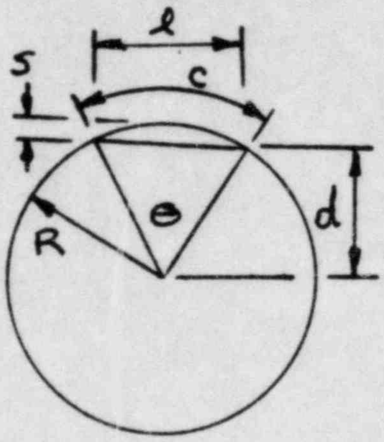
$$I = .049087\ (d^4 - d_1^{\ 4}) = .049087\ (90^4 - 89.79^4) = 29{,}953.9\ in^4$$

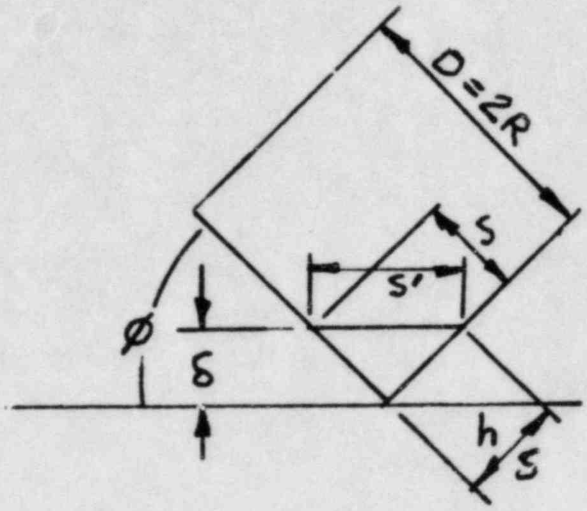
$$f_n = \frac{9.87}{2\pi} \times \frac{29953.9 \times 29 \times 10^6 \times 386.4}{290 \times 87.5^4} = 221\ CPS$$

Relative fixity of base will tend to cancel effects of looseness of top restraint (rel to pinned-pinned) keeping fundamental mode comparable to 220 cps. This is well above the 1-20 cps range of truck suspension systems. O.k. since resonance avoided.

2.10.2 Free Drop Test Calculations

Container Crush Volume Corner Drop





$\delta = h\cos\phi \qquad h = \dfrac{\delta}{\cos\phi}$

$s = s'\cos\phi$

$h = s\tan\phi \qquad s = \dfrac{h}{\tan\phi}$

$d = \dfrac{1}{2} R\cos\theta \qquad \theta = 2\cos^{-1}\dfrac{d}{R}$

$c = R\theta \qquad \theta = \dfrac{C}{R} \qquad d = R-s$

From the above equations:

$$\theta = 2\cos^{-1}\frac{d}{R} = \frac{C}{R}, \quad d = R-s = R-\frac{h}{\tan\phi} \qquad \frac{d}{R} = \frac{R-\frac{h}{\tan\phi}}{R}$$

$$\text{so, } C = 2R\cos^{-1}\frac{d}{R} = 2R\cos^{-1}\frac{R-\frac{h}{\tan\phi}}{R}$$

$$= 2R\cos^{-1}\left(1-\frac{h}{R\tan\phi}\right)$$

$$\left(\text{since } h = \frac{\delta}{\cos\phi}\right) = 2R\cos^{-1}\left(1-\frac{\delta}{R\cos\phi\tan\phi}\right)$$

$$C = 2R\cos^{-1}\left(1-\frac{\delta}{R\sin\phi}\right)$$

$$\text{Area} = \frac{2}{3}hC = \frac{2}{3}\left(\frac{\delta}{\cos\phi}\right)\left[2R\cos^{-1}\left(1-\frac{\delta}{R\sin\phi}\right)\right]$$

$$= \frac{4R\delta}{3\cos\phi}\cos^{-1}\left(1-\frac{\delta}{R\sin\phi}\right)$$

3. THERMAL EVALUATION

The 1-184-109 containers are designed for the transportation of process solids either dewatered, solid or solidified which meet the requirements for LSA materials. Since there is no significant external heat load for normal conditions of transport or generated internally, thermal design has not been considered as part of this application.

4. CONTAINMENT

4.1 Containment Boundary

The 1-184-109 containers are of welded steel construction (see CNSI drawing - C-901-E-0025 section 1.3). The containment boundary is the steel vessel the only penetration is the barrel top which is sealed with a gasket and 17H drum lid and/or a 150 pound flange sealed with mating flange or pipe plug.

4.2 Requirements for Normal Conditions of Transport

As shown in section 1 and 2 of this report, the 1-184-109 liner are designed to transport process solids either dewatered, solid or solidified which meet requirements for LSA material. These liners, being all welded construction using one material, will maintain integrity during normal conditions of transport resulting from heat, cold, pressure or vibration as specified in 10 CFR part 71 Appendix A. The requirements for free drop, penetration and compression are reviewed in sections 2.6.6 through 2.6.9. These calculations show that the container will deform in the plastic region, but there will be no release of radioactive material from the containment vessel.

4.3 Containment Requirements for Hypothetical Accident Conditions

These containers are intended for use with LSA materials and thus analysis for hypothetical accident conditions is not required.

5. SHIELDING EVALUATION

These liners are designed for the transport of LSA materials and are not considered to provide any shielding for materials contained.

6. CRITICALITY EVALUATION

These liners are designed for the transport of LSA material. Criticality is therefore not considered.

7. OPERATING PROCEDURES

CNSI has in place a quality assurance program satisfying each applicable criteria specified in 10 CFR 71 Subpart D and Appendix E (see reference a). All procedures for the operation of CNSI equipment including the use of these liners are written in accordance with this program.

8. ACCEPTANCE TESTS AND MAINTENANCE PROGRAM

The 1-184-109 liners are accepted in accordance with the CNSI quality assurance program (see reference a) and are designed as single use containers which do not require a separate maintenance program.