SAFETY ANALYSIS REPORT
FOR THE
14-215 RADWASTE SHIPPING CASK

REVISION 3

Referencing
10CFR71 TYPE "A" Packaging Regulations

STD-R-02-016

Scientific Ecology Group, Inc.
1560 Bear Creek Rd.
P. O. Box 2530
Oak Ridge, TN 37831

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FORM-01(B)

TO THE USER

This document and the referenced drawings have been compiled to facilitate the U.S. Nuclear Regulatory Commission review and certification process by presenting in a consolidated form all of the information pertinent to the certification of this cask. As such, this document is extensively based on excerpts of information and precedent in the public record associated with NRC certificate 71-9176, which describes casks similar in design to the one described herein. However, this document and the referenced drawings have been prepared to embody all of the design detail and commitments sufficient to warrant licensure and be appropriate for reference in a cask certificate.

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1.0 GENERAL INFORMATION

1.1 Purpose

The purpose of the following document is to provide the information and engineering analysis that demonstrates the performance capability and structural integrity of the 14-215 Radwaste Shipping Cask and its compliance with the requirements of 10CFR71.

1.2 Package Description

1.2.1 General Description

The 14-215 Shipping Cask is a top-loading, shielded container designed specifically for the safe transport of low specific activity radioactive waste materials between nuclear facilities and waste disposal sites. The radioactive materials can be packaged in a variety of different type disposable containers.

The 14-215 Shipping Cask is a primary containment vessel for radioactive materials. It consists of a cask body, cask lid, and a shield plug being basically a top-opening right circular cylinder which is on its vertical axis. Its principal dimensions are 83-1/2 inches outside diameter by 92-1/4 inches high with a cavity of 77-1/4 inches diameter by 80-1/4 inches high.

1.2.2 Materials of Construction, Dimensions and Fabricating Methods

The cask certification drawing for the 14-215 Cask, drawing STD-02-077, provides the overall dimensions as well as the materials of construction.

The walls of the cask contain a lead thickness of 1-7/8 inches encased in a 3/8 inch thick inner steel shell and a 7/8 inch thick outer steel shell. The top and bottom ends of the cylindrical cask are constructed of a pair of 2 inch thick stacked steel plates.

The top serves as a removable cask lid and is secured to the cylindrical cask body by eight high strength ratchet binders. A 29 inch secondary cask lid is located in the center of the primary lid and is secured to the primary lid by eight 3/4 inch studs. Lifting lugs and tiedown lugs are a structural part of the package.

1.2.3 Containment Vessel

The inner shell and inner end plates of each cask serve as the containment vessel and its mechanical configuration is described in the foregoing paragraph.

A 50 Durometer neoprene gasket is employed in both the primary and secondary lid interfaces.

Waste products will be contained in 55 gallon drums, in heavy gauge disposable steel liners, in high integrity containers, in crates or other suitable palletized forms.

1.2.4 Neutron Absorber

There are no materials used as neutron absorbers or moderators in the 14-215 package.

1.2.5 Gross Package Weight

The respective gross weights of the cask components and its designated maximum payload are as follows:

Cask Body	31,800
Closure Lid	5,450
Shield Plug	1,150
Total Cask (unloaded)	38,400 lbs
Maximum Payload	20,000 lbs
Gross Package Weight	58,400 lbs

1.2.6 Receptacles

There are no internal or external structures supporting or protecting receptacles.

1.2.7 Containment Penetrations

The cask is provided with a 3/4 inch pipe drain line sealed with a pipe plug. Its use is for removal of entrapped liquids, such as rain or decontamination fluids.

A pressure tap is also included in the primary lid design. It consists of a 1/4 inch diameter hole drilled at a 30° angle through the lid top plate sealed with a pipe plug.

1.2.8 Tiedown Lugs

Tiedown lugs are a structural part of the package. From the cask certification drawing, it can be seen that four reinforced tiedown lug location are provided. Refer to Section 2.4.4 for a detailed analysis of their structural integrity.

1.2.9 Lifting Devices

Lifting devices are a structural part of the package. From the cask certification drawing, it can be seen that three reinforced lifting locations are provided. Refer to Section 2.4.3 for a detailed analysis of their structural integrity.

1.2.10 Pressure Relief System

There are no pressure relief valves.

1.2.11 Heat Dissipation

There are no special devices used for the dissipation of heat. The package maximum structural design capacity is 400 watts. However, decay heat limits based upon the shielding capabilities of the cask are given on page 3-2.

1.2.12 Coolants

There are no coolants involved.

1.2.13 Protrusions

There are no outer or inner protrusions, except for the lifting and tiedown lugs described above.

1.2.14 Shielding

The contents will be limited such that the radiological shielding provided will ensure compliance with DOT and IAEA regulatory requirements. Should lead slump occur, as the result of a flat end drop, the deeply steeped lid will provide full shielding protection.

As an option, the cask contents may include a removable solid steel, close fitting sleeve which provides shoring and additional shielding to the waste disposal container. This open-ended sleeve or insert is not attached to the cask or the disposal container. It serves to augment any shielding inherent in the waste container design and the self-shielding of the waste form. The inserts used vary from 3/4" thick to 1 1/2" thick. They fit the inside diameter of the cask to within 1/2" on a side. Insert heights vary from 1 1/4" to 2 3/4" shorter than the cask cavity height. Each insert is capable of withstanding all conceivable normal conditions of transport without deflection or dislodging. Although one would expect this insert to remain effective in a hypothetical accident, no credit is taken for the shielding by the insert to satisfy the 10CFR71 post-accident cask contact dose rate limit of 1 R/hour.

1.3 Operational Features

Refer to the cask certification drawing of the packaging. There are no complex operational requirements connected with the 14-215 package and none that have any transport significance.

1.4 Contents of Packaging

This application is for transporting the following radioactive materials as defined in the U.S.A. and I.A.E.A. regulations:

a. Type "A" quantities in normal or special form;

b. Fissile quantities are those limited to the amounts as generally licensed under 10CFR71.18 and 71.22;

c. L.S.A. materials greater than Type "A" quantities;

d. The chemical and physical form of the package contents will be in all forms, other than liquids. This will include ion exchange resins in a dewatered or solidified state, typical PWR or BWR solidified radioactive waste and miscellaneous contaminated materials such as pipe, wood, metal scrap, etc. All wastes will be contained within a separate disposable container. These containers will isolate the contents from the cask.

2.0 STRUCTURAL EVALUATION

2.1 Structural Design

2.1.1 Discussion

The principal structural member of the 14-215 package is the containment vessel described in Section 1.2.1. The above components are identified on the cask certification drawing, drawing No. STD-02-077. A detailed discussion of the structural design and performance of these components will be provided below.

2.1.2 Design Criteria

The 14-215 cask has been designed to be a simple, strong package that will provide maximum flexibility for usage as well as minimum potential exposure to operating personnel. Its size and shielding capacity will allow a variety of payloads to be safely transported. The shield top and bottom are constructed of two laminated steel plates. Cylindrical side walls have an external skin of .875 inches and an internal skin of .375 inches thick plate. These two plates encase a 1.88 inch thickness of lead. Pertinent dimensions of the 14-215 package are provided on the cask certification drawing. The package has been designed to provide well defined load paths which lend themselves to simple, highly reliable structural analysis methods. No new state-of- the-art approaches have been used for analytical evaluation. All analytical techniques used throughout the SAR are proven methods that have been used in past submittals. Details of these methods are given where used. Regulatory Guide 7.8, "Load Combinations for the Structural Analysis of Shipping Casks", was used in evaluating the 14-215 package. Materials properties used in the analysis can be found in Section 2.3.

2.2 Weights and Center of Gravity

The weight of the 14-215 cask and payload is summarized in Section 1.2.5. The center of gravity for the assembled package is located at the approximate geometric center of gravity.

2.3 Mechanical Properties of Materials

The 14-215 package is fabricated of ASTM A516 Gr. 70 steel except as noted below. Material properties of the A516 steel are as follows:

$$F_{tu} = 70,000 \text{ psi}$$

$$F_{tu} = 38,000 \text{ psi}$$

$$F_{su} = 42,000 \text{ psi} \quad (.6\ F_{tu})$$

$$F_{sy} = 22,800 \text{ psi} \quad (.6\ F_{ty})$$

The vertical plates of the lifting/tiedown lugs are constructed of ASTM A514 steel. Material properties used for these steels are as follows:

F_{tu} = 110,000 to 135,000 psi

F_{ty} = 100,000 psi

F_{su} = 66,000 to 81,000 psi (.6 F_{tu})

F_{sy} = 60,000 psi (.6 F_{tu})

The lid standoffs are constructed of AISI 1018 or equivalent steel plate. Material properties used are as follows:

F_{tu} = 69,000 psi

F_{ty} = 40,000 psi

F_{su} = 41,400 psi (.6 F_{tu})

F_{sy} = 24,000 psi (.6 F_{tu})

Lead shielding will possess those properties referenced in ORNL-NSIC-68, Table 2.6, page 84. The optional removable shielding inserts occasionally installed as part of the contents are constructed of ASTM A 36 plate.

Lid studs are fabricated of ASTM A320 Grade L-7 or equivalent steel. Properties used for analysis are as follows:

Bar Properties (Per ASTM A320-78)

F_{tu} = 125,000 psi

F_{ty} = 105,000 psi

2.4 General Standards

This section demonstrates that the general standards for the package are met.

2.4.1 Chemical and Galvanic Reactions

The cask is constructed from heavy structural steel plates. All exterior surfaces are primed and painted with high quality epoxy paint. There will be no galvanic, chemical or other reaction in air, nitrogen or water atmosphere.

2.4.2 Positive Closure

As described in Section 1.2.1, the positive closure system consists of a primary lid secured by eight high strength ratchet binders and a secondary lid affixed with eight 3/4 inch diameter studs. In addition, each package will be sealed with an approved tamper indicating seal to prevent inadvertent and undetected opening.

2.4.3 Lifting Devices

There are four lifting lugs for the package, three lifting lugs for the lid assembly (primary and secondary lids) and a single lifting lug for the secondary lid. All lifting lugs are evaluated versus the requirements of 10 CFR 71, Section 71.45.

2.4.3.1 Package Lifting Lugs

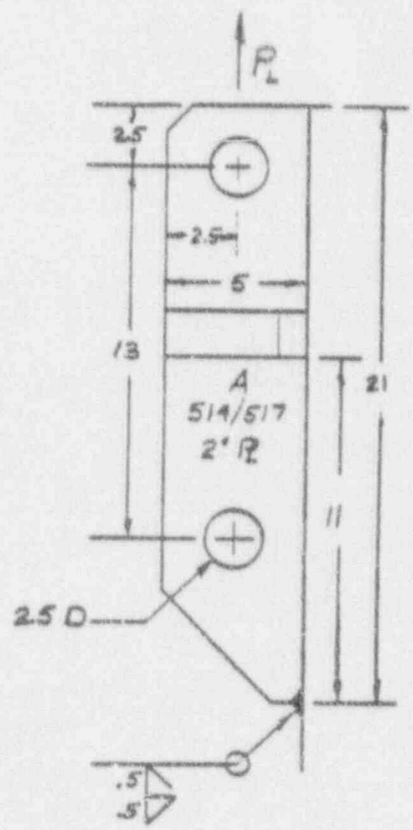
For conservatism, the package is assumed to be lifted by only two of the four identical lifting lugs. The maximum package weight is 58,400 lbs. The lug load is calculated as:

$P_L = Wa_g/N$; where W = Package Weight

a_g = Load Factor, 3 g's

N = Number of lugs

$$P_L = (58,400)(3)/2 = 87,600 \text{ lbs.}$$



Using the conventional 40° shear expression:

$$P_{yld} = 2\ F_{sy}\ t(e_d - \frac{d}{2}\cos 40°)$$

$$= 2(60,000)\ 2(2.5 - \frac{2.5}{2}\cos 40°)$$

$$= 370,200 \text{ lbs.}$$

$$M.S. = \frac{P_{yld}}{P_L} - 1$$

$$= \frac{370,200}{87,600} - 1 = \underline{+3.23}$$

The weld stresses are composed of pure shear and tension/compression due to the moment.

Pure shear on weld: $F_s = \frac{P_L}{A_W}$

Where: F_s = Shear Stress

A_w = Weld Area = Lw x tw

L_w = 2(8" + 11") = 38" (Considering only the vertical welds attaching the ASTM A514 plate to the cask.)

t_w = (.5")(1.00) + (.5")(.707) = .854" (Groove + fillet weld)

A_w = 38" (.854") = 32.3 in.^{2}

Then, $F_s = \frac{87,600}{32.3} = 2,712$ psi

Moment force on Weld:

Maximum Moment = M = 87,600 (2.5") = 219,000 in-lbs.

Calculate weld neutral axis assuming no contribution from the horizontal lug:

$\overline{d}$ = Distance from horizontal lug center line to neutral axis (NA)

Section	A	d	Axd
1	(.854)(8) = 6.83	5.0	34.16
2	(.854)(11) = 9.39	- 6.5	-61.06
	16.22		-26.90

$$\overline{d} = \frac{-26.90}{16.22} = -1.66 \text{ in.}$$

The stress due to the moment is

$$F_M = \frac{M}{z}$$

Where:

M = 219,000 in-lbs

$$z = \frac{I}{C}$$

$$I = 2(I_1 + A_1 d_1^2 + I_2 + A_2 d_2^2)$$

$$I_1 = \frac{1}{12}\ (.854)\ (8)^3 = 36.4 \text{ in}^4$$

$$A_1 = (.854)\ (8) = 6.83 \text{ in}^2$$

$$d_1 = 1.66 + 1.0 + \frac{8.0}{2} = 6.66 \text{ in}$$

$$I_2 = \frac{1}{12}\ (.854)\ (11)^3 = 94.7 \text{ in}^4$$

$$A_2 = (.854)\ (11) = 9.39 \text{ in}^2$$

$$d_2 = 1.0 + 5.5 - 1.66 = 4.84 \text{ in}$$

$$I = 2(36.4 + (6.83)(6.66)^2 + 94.7 + (9.39)(4.84)^2) = 1308 \text{ in}^4$$

$$C = 9.0 + 1.66 = 10.66 \text{ in}$$

$$z = \frac{1308}{10.66} = 122.7 \text{ in}^3$$

Then,

$$F_M = \frac{219,000}{122.7} = 1785 \text{ psi}$$

Combined Stress:

$$F_c = \sqrt{(F_s)^2 + (F_M)^2}$$
$$= \sqrt{(2712)^2 + (1785)^2} = 3247 \text{ psi}$$

The allowable stress for E70 weld rods is 30% of the tensile strength of 70,000 psi, or

$$F_a = (.30)(70,000) = 21,000 \text{ psi}$$

The lug weld Margin of Safety is:

$$\text{M.S.} = \frac{F_a}{F_c} - 1 = \frac{21,000}{3,247} - 1 = \underline{+5.47}$$

Therefore, it can be safely concluded that the lifting lugs will not yield under a load equal to three times the weight of the package. Should a lug experience a load in excess of 370,200 lbs., it will begin to shear out locally through the eye, and will have no adverse effects upon the package's ability to meet other requirements.

2.4.3.2 Primary and Secondary Lid Lifting Lugs

The primary and secondary lid lifting lugs are identical in size and shape. The following analysis conservatively considers the maximum lug load in order to assess both primary and secondary lid lugs.

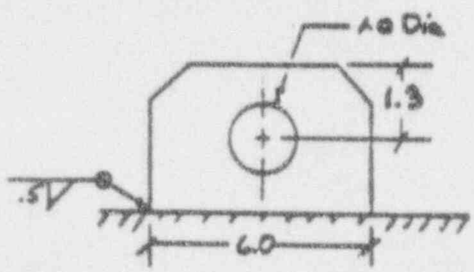
The maximum lid weight is 5,450 lbs.
Using three lugs the load per lug is:

$$P_L = (5,450 \text{ lbs}) \ (3 \text{ g's})/3 \text{ lugs}$$

$$P_L = 5,450 \text{ lbs/lug}$$

This is greater than the secondary lug load of:

$$3(1150 \text{ lbs}) = 3450 \text{ lbs.}$$



Using the conventional 40° shear out equation, the yield capacity is:

$$P_s = F_{sy} 2t \left(e_d - \frac{d}{2} \cos 40°\right)$$

Where: F_{sy} = 22,800 psi (yield)

t = 1.0 in.

d = 1.0 in.

E_d = 1.3 in.

$$P_s = (22{,}800)(2)(1.0)\left(1.3 - \frac{(1.0)}{2} \cos 40°\right)$$

$$P_s = 41{,}810 \text{ lbs.}$$

The yield Margin of Safety, using the maximum lug load, is:

$$M.S. = \frac{P_s}{P_L} - 1 = \frac{41{,}810}{5{,}450} - 1$$

$$= \underline{+6.67}$$

The yield capacity of the lug-to-lid weld may be estimated as:

$$P_a = F_{sy} \cdot A_w$$

Where:

F_{sy} = 21,000 (E70 Weld Rod)

A_w = $L_w \cdot t_w$

L_w = 2(6.0" + 1.0") = 14.0"

t_w = (0.5)(.707) = .354" (Fillet Weld)

A_w = (14.0)(.354) = 4.95 in.^{2}

Then:

P_a = (21,000)(4.95) = 103,929 lbs.

The lug-to-lid weld Margin of Safety is:

$$M.S. = \frac{P_a}{P_L} - 1 = \frac{103{,}929}{5{,}450} - 1 = \underline{+18.07}$$

Therefore, it can be concluded that the primary and secondary lid lifting lugs are more than adequate to resist a load equal to three times their maximum loads. As for the package lifting lugs, the lid lifting lugs fail by local shearout through the eye and therefore, have no adverse effect upon the package's ability to meet other requirements of 10CFR71. Since the lid lifting lugs are not capable of reacting the full package load, they will be covered during transit.

2.4.4 Tiedowns

Four tiedown lugs are provided to resist transportation induced loads. The required load factors are:

A_x = 10g (longitudinal)

A_y = 5g (lateral)

A_z = 2g (vertical)

The four tiedown lugs are located at 90° intervals around the package sidewall at an elevation above the package base. The tiedown arrangement for the 14-215 cask is shown in Figure 2.4.4-1. Tiedown cables are assumed to be fastened to the trailer at the same elevation as the base of the cask as shown (i.e., top of trailer deck).

From the geometry given in the sketch, the cable tension due to horizontal accelerations can be determined by summing moments about the opposite bottom corner of the package. For the longitudinal acceleration case:

$$A_x Wc = 2(P_v d' + P_h h)$$

But,

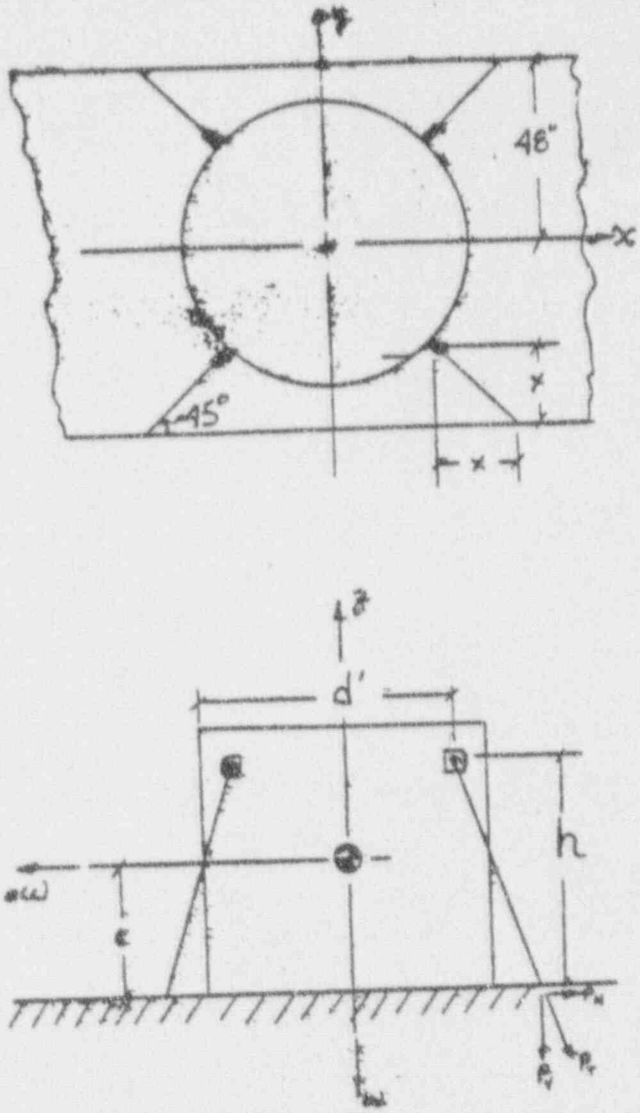
$$A_x Wc = 2P_T(B_z d' + B_x h)$$

Solving for P_T:

$$P_{T_{long}} = \frac{W}{2}\left(\frac{A_x c}{B_z d' + B_x h}\right)$$

Similarly, the cable tension due to the lateral acceleration is:

$$P_{T_{lat}} = \frac{W}{2}\left(\frac{A_y c}{B_z d' + B_y h}\right)$$



B_x, B_y, B_z are cable direction cosines. If ℓ is the cable length:

$B_x = x/\ell$ $\qquad$ $P_h = B_x P_t$ or $B_y P_t$

$B_y = y/\ell$ $\qquad$ $P_v = B_z P_t$

$B_z = h/\ell$

Figure 2.4.4-1

The cable tension due to the vertical acceleration is simply:

$$4P_v = A_z W = 4B_z P_T$$

Solving for P_T:

$$P_{T_{vert}} = \frac{A_z W}{4B_z}$$

For conservatism, these three loads may be assumed to coincide for the most severely loaded cable:

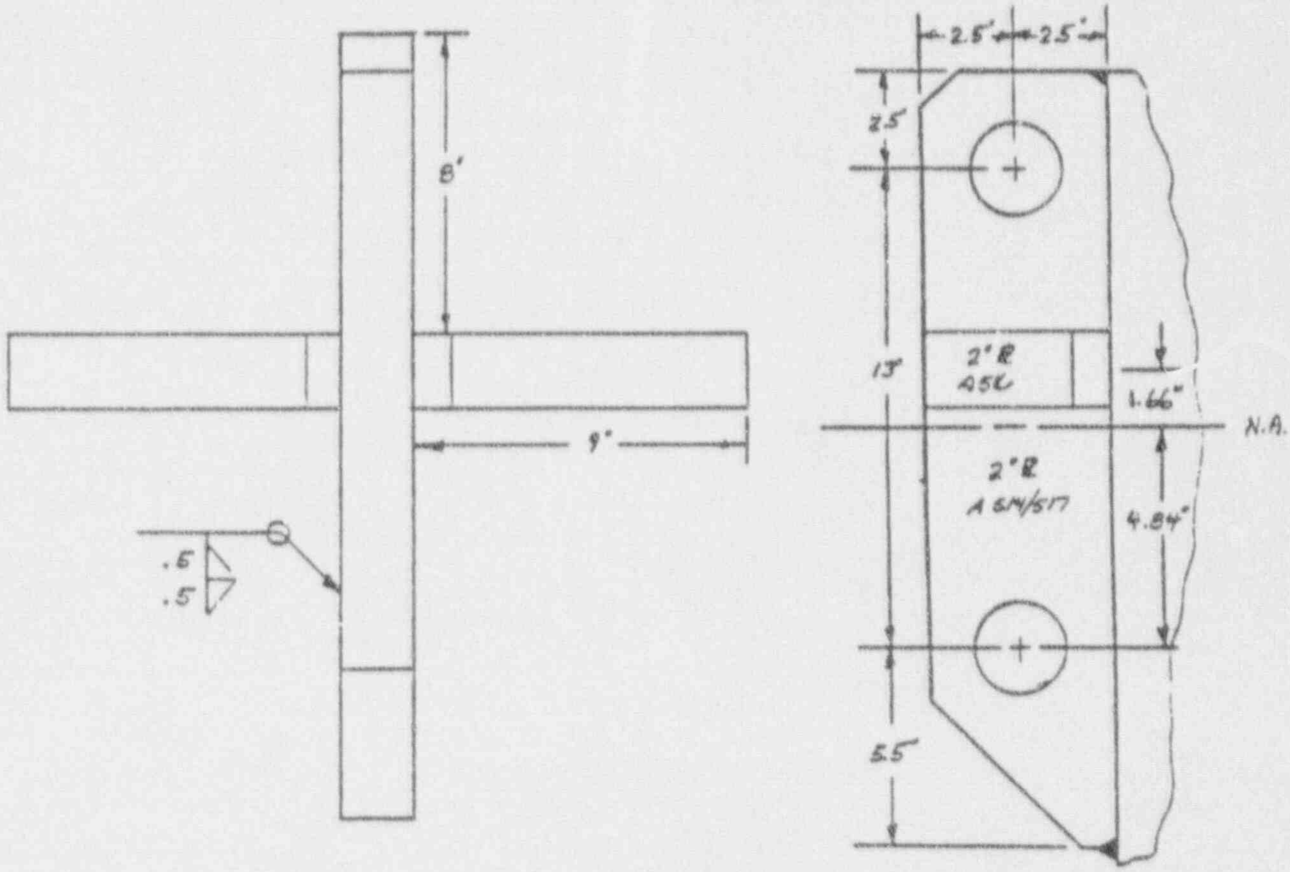
$$P_T = \frac{W}{2}\left(\frac{A_x c}{B_z d' + B_x h} + \frac{A_y c}{B_z d' + B_y h} + \frac{A_z}{2B_z}\right)$$

TABLE 2.4.4-1

CASK TIEDOWN CABLE FORCES

Cask Model	Gross Weight (lb.)	Outside Diameter (in.)	Outside Height (in.)	d' (in.)	h (in.)	Cable Length (in.)	Bx, By	Bz	Cable Tension (lb.)
14-215	58,400	83.5	88.25	73.0	70.6	74.5	.224	.948	257,900

The cable force calculated for the 14-215 cask is 257,900 lbs utilizing the above equations. The tiedown lug is made of three plates welded together as shown in the sketch below. The tiedown cable is attached to the lower hole. The cable lies in a vertical plane which also is the lug plane of symmetry. Therefore, no twisting moments are induced in the lug.



The tiedown lug capacity is calculated using the 40° shearout expression at the tiedown eyes.

$$P_L = 2F_{sy}t\,(e_d - \frac{d}{2}\cos 40°)$$

From the figure above:

$$t = 2''$$

$$e_d = 2.5''$$

$$d = 2.5''$$

Then:

$$P_L = 2(60{,}000)(2'')(2.5 - \frac{2.5}{2} \cos 40°)$$

$$= 370{,}200 \text{ LBS.}$$

Using the maximum cable tension of 257,900 lb. the yield Margin of Safety is:

$$M.S. = \frac{370{,}200}{257{,}900} - 1 = \underline{+0.44}$$

The cable load consists of both horizontal and vertical components. The cask produces a cable load which introduces both a bending moment and a shear load into the outer shell through the lug to shell weld.

The weld stresses in the lug-to-shell weld are composed of pure shear and tension/compression due to the moments.

Pure shear on weld due to vertical component of the lug load, P_v:

$$F_s = \frac{P_v}{A_w}$$

The vertical component of force is:

$$P_v = (.948)(257{,}900) = 244{,}489 \text{ lbs.}$$

From Section 2.4.3.1, Package Lifting Lugs:

$$A_w = 32.3 \text{ in.}^2$$

Then,

$$F_s = \frac{244{,}489}{32.3} = 7{,}569 \text{ psi}$$

The moment force on the weld is the summation of the moments due to the horizontal and vertical components of the force, or:

$$M = F_v e_v + F_H e_H$$

Where:

F_V = 244,489 lbs.

e_V = 2.5"

F_H = (.224)(244,489) = 54,766 lbs.

e_H = 4.84"

Then, assuming a CCW moment is positive:

$$M = (244,489)(2.5) - (54,766)(4.84) = 346,155 \text{ in-lbs}$$

Again, from Section 2.4.3.1, Package Lifting Lugs:

$$z = 122.7 \text{ in}^3$$

$$F_M = \frac{346,155}{122.7} = 2821 \text{ psi}$$

Combined Stress:

$$F_c = \sqrt{(7569)^2 + (2821)^2} = 8078 \text{ psi}$$

The lug-to-shell weld Margin of Safety is:

$$M.S. = \frac{F_a}{F_c} - 1 = \frac{21,000}{8,078} - 1 = \underline{1.60}$$

The stresses induced into the outer shell by the tiedown lugs were determined using the finite element analysis program ANSYS, Revision 3, Update 67L, available on the Boeing Computer Services (BCS) National Network, MAINSTREAM - EKS. The capabilities are outlined in Appendix 2.10.5.

The Finite Element model consisted of a 45° section of the cask outer shell, cask wall top plate, and one-half the lug. The length of the cask model below the tiedown lug was sufficient to eliminate any end (boundary condition) effects from affecting the final results. To react to the lug loads, the nodes along the bottom of the inside and outside shells were constrained from displacing vertically. For symmetry, the nodes along the sectional cuts were constrained from displacing circumferentially and rotating about the X (radial) and Z (vertical) axes.

Springs were introduced between the inner and outer shells at locations where the shells displaced radially towards each other (compression only) to account for the presence of the lead. The corresponding spring stiffness was estimated for a column of lead as k = AE/L. Since the purpose of the springs was to prevent fictitious localized bending stresses, placement of the lead spring was conservatively chosen as one every four inches.

The model, with exception of the spring elements, was defined entirely of quadrilateral shell elements. The geometry plots are illustrated in Figures 2.4.4-2 to 2.4.4-5. Figures 2.4.4-2 and -3 have omitted the side lug plate for clarity. The quadrilateral shell element has both bending and membrane stress capabilities with six degrees of freedom at each node: translations in the nodal x, y, and z directions and rotations about the nodal x, y, and z axis. Each element, either triangular or quadrilateral in shape, was defined by four nodes that lie in a plane. The thickness at each node in an element was defined in a real constant table for each element type.

The element size was decreased in the area of the lug for greater accuracy. Furthermore, to enhance to model definition, the node directly adjacent to each of the lug attachment nodes was linerly constrained to move with that node (e.g., Node 2 was linearly constrained to move with Node 1, Node 14 with Node 13, Nodes 99 and 123 to move with Node 111, etc.) to simulate the presence of the two-inch wide lug plates.

A 281,000 lb. load was introduced as a 89,000 lb. outward radial component combined with a 267,000 lb. downward vertical component at Node 622. This is conservatively higher than the cable tension for the 14-215 cask. The lug hole was omitted to decrease the complexity of the model as any local effects of the hole would not directly affect the reaction of the outer shell.

Other than the springs between the inner and outer shells, the contribution of the lead strength was neglected. Also, for conservatism, the cask wall top plate was defined as being one-half inch thick.

The maximum combined stress occurred at Element 232, directly below the lug, on the outside of the outer shell. The 20,749 psi combined stress was comprised of a 22,792 psi compressive longitudinal stress, a 5004 psi compressive circumferential stress, and a 164 psi shear stress as shown on page 2-19a. A description of how to interpret element stress output is provided in Appendix 2.10.5. The second highest stress area in the outer shell occurred around the end of the horizontal lug. In this area, the element with the highest stresses, Element 88, contained a combined stress of 18,203 psi.

The largest outward radial displacement of the outer shell, 0.0417 inches, occurred at Node 1. The largest inward radial displacement on the outer shell, 0.0331 inches, occurred at Node 386.

The Margin of Safety of the outer shell is:

$$M.S. = \frac{38,000}{20,749} - 1 = \underline{+0.83}$$

In order to preclude damage to the cask under extreme loads, the tiedown lug is designed to fail prior to the weld or cask shell. The ultimate shearout capacity of the lug, using roughly the highest strength A517 steel (F_u = 135,000 psi), which occurs:

$$F_{su} = .6\ (135,000) = 81,000\ \text{psi}$$

The minimum ultimate capacity of the weld or shell (using a minimum value of F_{su} for A516 plate):

$$P_{weld} = \frac{281,000\ (.6)(70,000)}{9922} = 1,186,000\ \text{lbs.}$$

$$P_{shell} = \frac{281,000\ (.6)(70,000)}{20,749} = 567,179\ \text{lbs.}$$

Thus, failure of the lug will not damage the cask.

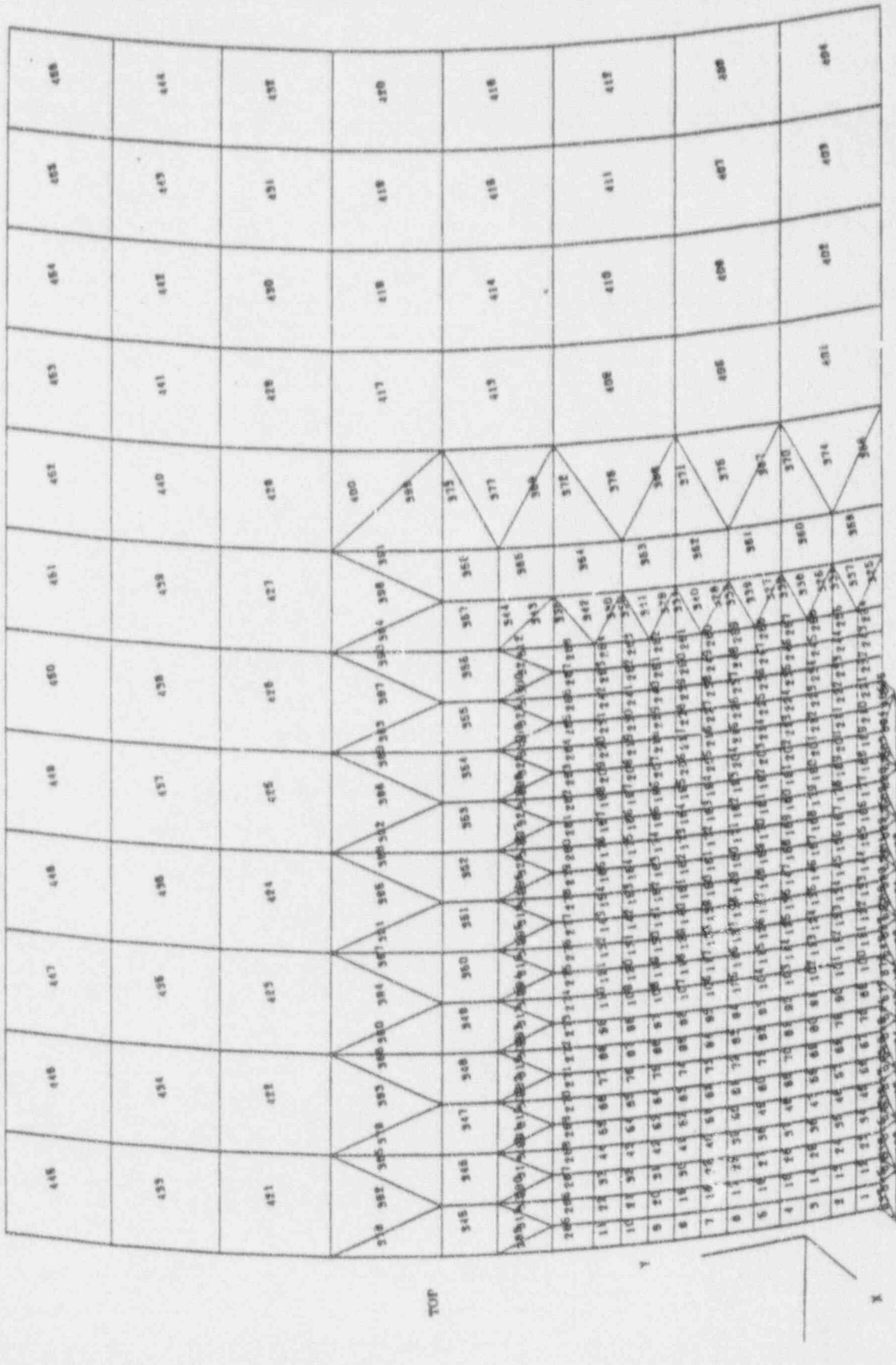


FIGURE 2.4.4-2
CASK OUTSIDE WALL, ELEMENT GEOMETRY

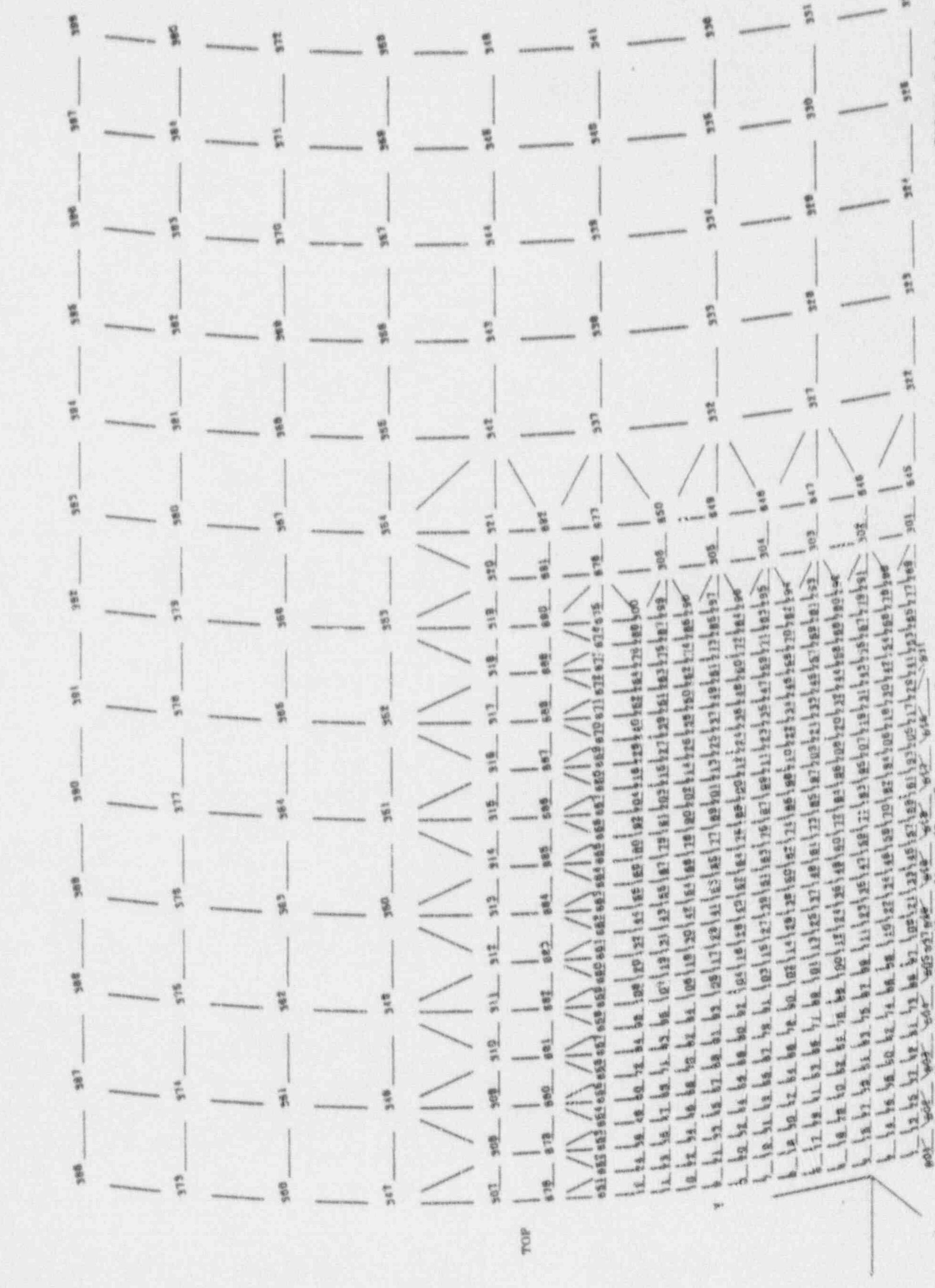


FIGURE 2.4.6-3
CASK OUTSIDE WALL, NODE GEOMETRY

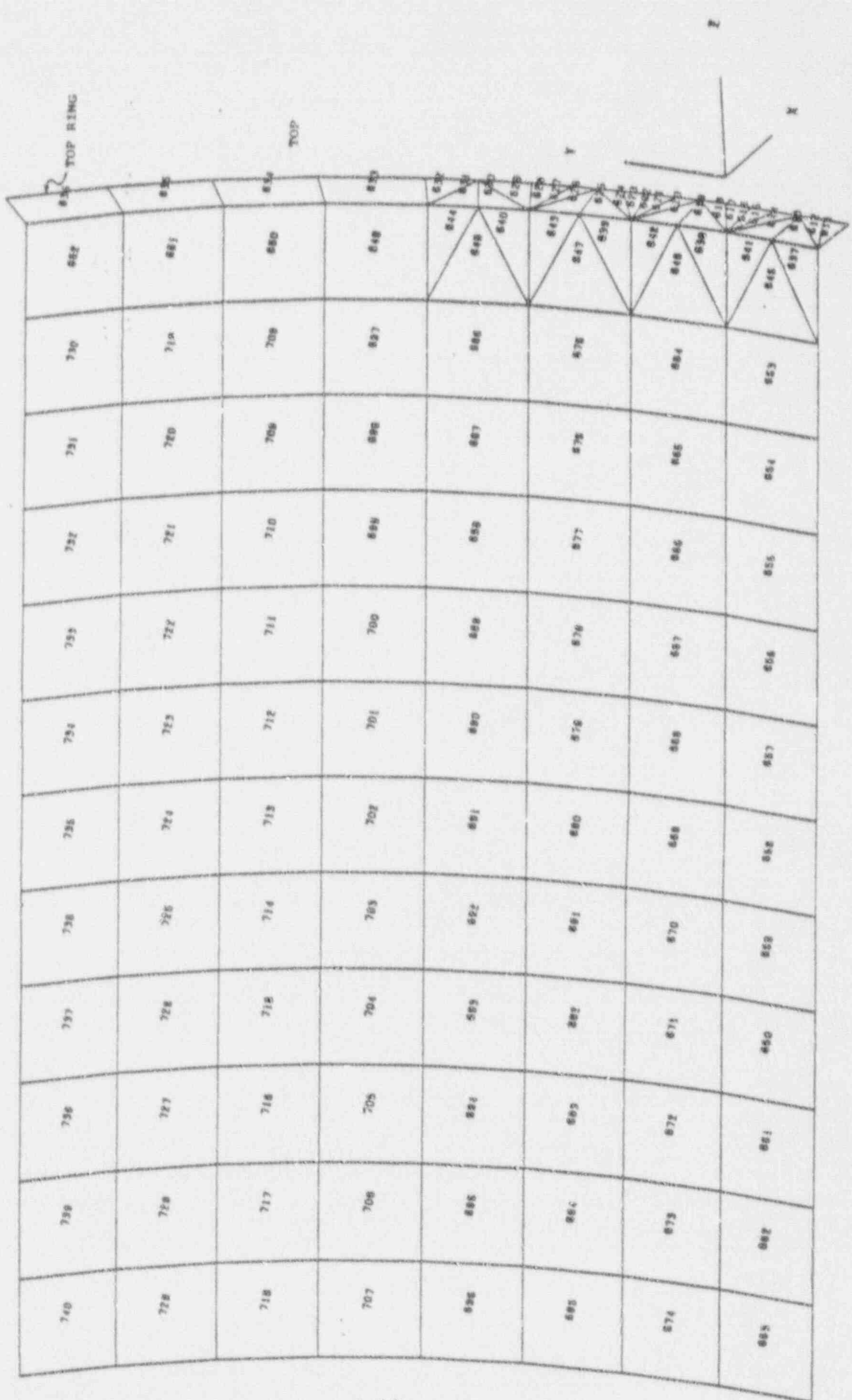


FIGURE 2.4.4-8
CASE INSIDE WALL, ELEMENT GEOMETRY

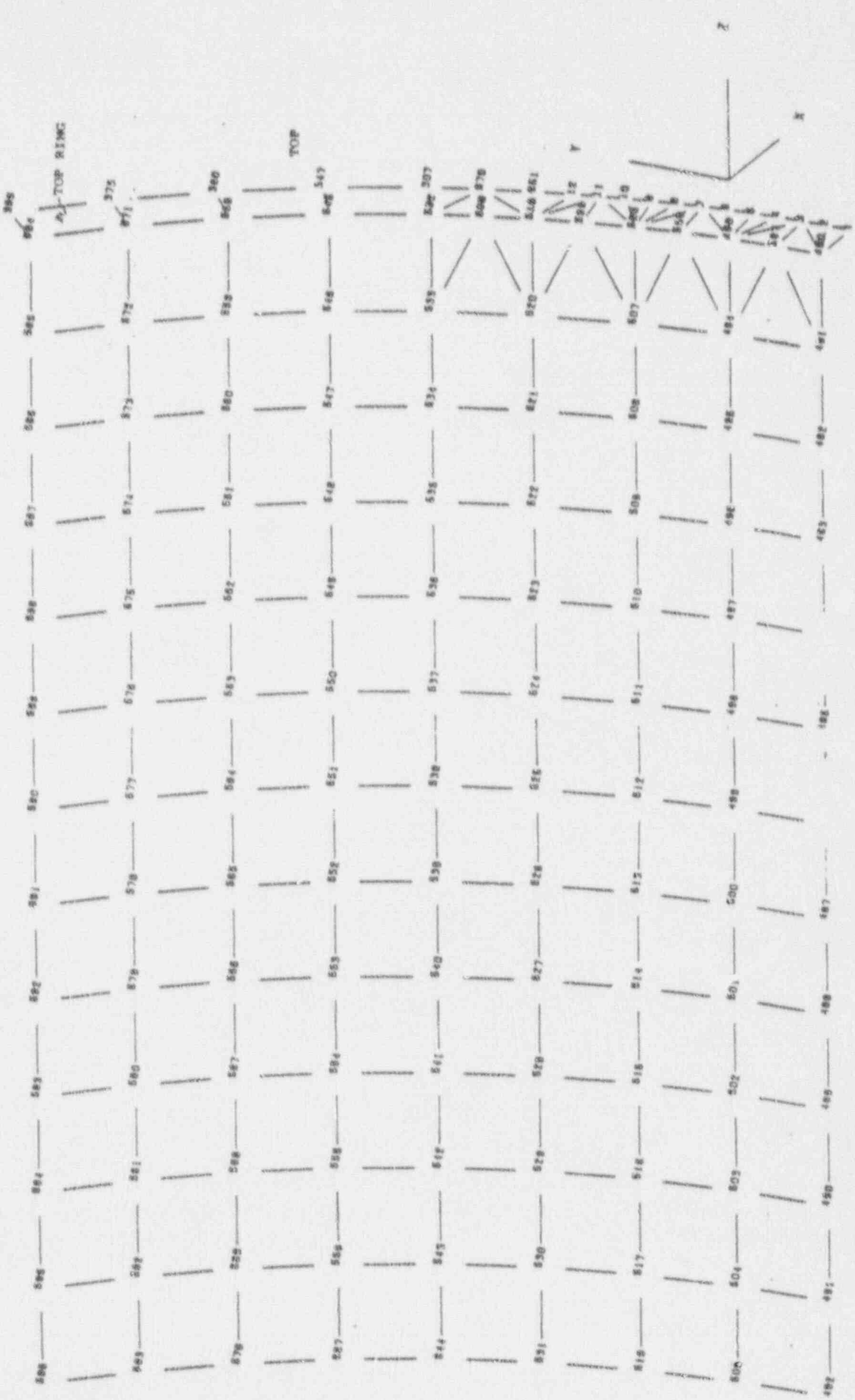


FIGURE 2.4.4-5
CASK INSIDE WALL, HOOP GEOMETRY

```
EL=  220  NODES=  251  252  240  239        MAT=  1  AREA=  1.00        TTOP,TBOT=   70.0   70.0  PRESS= 0.           QUAD SHELL  63
MX,MY,MXY=   257.14          25.650          198.54      NX,NY=  -36.207         -11.373        XC,YC,ZC=  40.0       18.4        -19.5
TOP SX,SY,TXY=  2072.3         -3577.4          2594.4      SMX,SMN,TMX=  3082.9        -4588.0         3835.4      A=  68.7 SIGE=  6685.7
MID SX,SY,TXY=  57.139         -3778.5          1032.5      SMX,SMN,TMX=  320.27        -4041.6         2180.9      A=  75.8 SIGE=  4210.9
BOT SX,SY,TXY= -1958.0         -3979.5          -517.38     SMX,SMN,TMX= -1833.3        -4104.2         1135.4      A= -76.4 SIGE=  3561.1

EL=  221  NODES=  253  254  242  241        MAT=  1  AREA=  1.00        TTOP,TBOT=   70.0   70.0  PRESS= 0.           QUAD SHELL  63
MX,MY,MXY=  -171.38         -571.28          .12176E-09  NX,NY=  -.30650E-09   1677.8        XC,YC,ZC=  41.3       .500        -20.5
TOP SX,SY,TXY= -4910.5         -16368.          -8.7198     SMX,SMN,TMX= -4910.5        -16368.         5729.0      A= -90.0 SIGE=  14549.
MID SX,SY,TXY= -3567.4         -11891.          -8.7198     SMX,SMN,TMX= -3567.5        -11892.         4162.0      A= -89.9 SIGE=  10569.
BOT SX,SY,TXY= -2224.4         -7414.5          -8.7198     SMX,SMN,TMX= -2224.3        -7414.6         2595.1      A= -89.9 SIGE=  6590.2

EL=  232  NODES=  254  253  265  266        MAT=  1  AREA=  1.00        TTOP,TBOT=   70.0   70.0  PRESS= 0.           QUAD SHELL  63
MX,MY,MXY=  -494.06         -1235.7          74.940      NX,NY=   196.20         -223.10        XC,YC,ZC=  41.3       .500        -21.5
TOP SX,SY,TXY= -5004.5         -22792.          163.98      SMX,SMN,TMX= -5002.8        -22796.         8895.4      A=  89.5 SIGE=  20749.
MID SX,SY,TXY= -2039.9         -15378.          -285.66     SMX,SMN,TMX= -2033.8        -15384.         6675.1      A= -88.8 SIGE=  14475.
BOT SX,SY,TXY=  924.42         -7964.0          -735.29     SMX,SMN,TMX=  984.84        -8024.4         4504.6      A= -85.3 SIGE=  8559.4

EL=  222  NODES=  242  254  255  243        MAT=  1  AREA=  1.00        TTOP,TBOT=   70.0   70.0  PRESS= 0.           QUAD SHELL  63
MX,MY,MXY=  -827.94         -351.89          -234.19     NX,NY=  -2000.4          638.06        XC,YC,ZC=  41.3       1.50        -20.5
TOP SX,SY,TXY= -15417.          329.54          -5883.5     SMX,SMN,TMX=  2285.0        -17373.         9828.8      A= -18.4 SIGE=  18621.
MID SX,SY,TXY= -10450.          2446.9          -4470.4     SMX,SMN,TMX=  3844.0        -11853.         7848.4      A= -17.4 SIGE=  14171.
BOT SX,SY,TXY= -5482.0          4552.2          -3073.3     SMX,SMN,TMX=  5418.6        -6348.4         5883.5      A= -15.7 SIGE=  10201.

EL=  233  NODES=  254  256  267  255        MAT=  1  AREA=  1.00        TTOP,TBOT=   70.0   70.0  PRESS= 0.           QUAD SHELL  63
MX,MY,MXY=  -1062.9         -563.19          -95.530     NX,NY=   431.03          805.63        XC,YC,ZC=  41.3       1.50        -21.5
TOP SX,SY,TXY= -20893.         -2999.7          -3346.2     SMX,SMN,TMX= -2394.6        -21502.         9553.5      A= -10.3 SIGE=  20410.
MID SX,SY,TXY= -13641.          844.95          -2694.0     SMX,SMN,TMX=  1329.8        -14125.         7727.6      A= -10.2 SIGE=  14835.
BOT SX,SY,TXY= -6384.8          4689.6          -2041.9     SMX,SMN,TMX=  5054.1        -6749.3         5901.7      A= -10.1 SIGE=  10257.

EL=  243  NODES=  277  278  266  265        MAT=  1  AREA=  1.00        TTOP,TBOT=   70.0   70.0  PRESS= 0.           QUAD SHELL  63
MX,MY,MXY=  -397.40         -731.08          20.165      NX,NY=  -70.656         -483.33        XC,YC,ZC=  41.3       .500        -22.5
TOP SX,SY,TXY= -2737.1         -21445.          1310.2      SMX,SMN,TMX= -2645.8        -21537.         9445.4      A=  86.0 SIGE=  20343.
MID SX,SY,TXY=  377.19         -15716.          1152.2      SMX,SMN,TMX=  459.27        -15798.         8128.6      A=  85.9 SIGE=  16033.
BOT SX,SY,TXY=  3491.5         -9986.7          994.15      SMX,SMN,TMX=  3564.4        -10060.         6812.0      A=  85.8 SIGE=  12238.

EL=  244  NODES=  278  279  267  266        MAT=  1  AREA=  1.00        TTOP,TBOT=   70.0   70.0  PRESS= 0.           QUAD SHELL  63
MX,MY,MXY=  -347.97         -637.75          7.3221      NX,NY=   294.61         -378.86        XC,YC,ZC=  41.3       1.50        -22.5
TOP SX,SY,TXY= -2930.9         -18467.          2629.4      SMX,SMN,TMX= -2497.9        -18900.         8201.2      A=  80.7 SIGE=  17784.
MID SX,SY,TXY= -203.89         -13470.          2572.0      SMX,SMN,TMX=  277.34        -13951.         7114.1      A=  79.4 SIGE=  14092.
BOT SX,SY,TXY=  2523.1         -8471.6          2514.7      SMX,SMN,TMX=  3070.9        -9019.5         6045.2      A=  77.7 SIGE=  10885.

EL=  223  NODES=  255  256  244  243        MAT=  1  AREA=  1.00        TTOP,TBOT=   70.0   70.0  PRESS= 0.           QUAD SHELL  63
MX,MY,MXY=   36.279         -406.89          255.21      NX,NY=   309.96          597.98        XC,YC,ZC=  41.2       2.50        -20.5
TOP SX,SY,TXY=  1754.6         -13342.          5276.2      SMX,SMN,TMX=  3415.8        -15004.         9209.7      A=  72.5 SIGE=  16971.
MID SX,SY,TXY=  1470.3         -10154.          3276.2      SMX,SMN,TMX=  2330.1        -11014.         6671.8      A=  75.3 SIGE=  12345.
BOT SX,SY,TXY=  1186.0         -6965.1          1276.2      SMX,SMN,TMX=  1381.2        -7160.2         4270.7      A=  81.3 SIGE=  7941.4

EL=  234  NODES=  267  268  256  255        MAT=  1  AREA=  1.00        TTOP,TBOT=   70.0   70.0  PRESS= 0.           QUAD SHELL  63
MX,MY,MXY=  -80.983         -608.52          114.54      NX,NY=   439.32         -36.808        XC,YC,ZC=  41.2       2.50        -21.5
TOP SX,SY,TXY= -339.27         -15185.          3576.1      SMX,SMN,TMX=  477.23        -16002.         8239.6      A=  77.1 SIGE=  16246.
MID SX,SY,TXY=  295.37         -10417.          2678.5      SMX,SMN,TMX=  927.80        -11049.         5988.4      A=  76.7 SIGE=  11541.
BOT SX,SY,TXY=  930.01         -5647.7          1780.9      SMX,SMN,TMX=  1381.2        -6099.0         3740.1      A=  75.8 SIGE=  6894.2

EL=  245  NODES=  279  280  268  267        MAT=  1  AREA=  1.00        TTOP,TBOT=   70.0   70.0  PRESS= 0.           QUAD SHELL  63
MX,MY,MXY=  -123.10         -490.04          26.081      NX,NY=   373.54         -159.48        XC,YC,ZC=  41.2       2.50        -22.5
TOP SX,SY,TXY= -1409.2         -14712.          2876.6      SMX,SMN,TMX= -813.75        -15307.         7246.7      A=  78.3 SIGE=  14917.
MID SX,SY,TXY= -444.45         -10871.          2672.2      SMX,SMN,TMX=  200.49        -11516.         5858.4      A=  76.4 SIGE=  11618.
BOT SX,SY,TXY=  520.23         -7031.1          2467.8      SMX,SMN,TMX=  1255.2        -7766.1         4510.7      A=  73.4 SIGE=  8463.8
```

2-19a

STD-R-02-016

2.5 Standards for Type "B" & Large Quantity Packaging

This section demonstrates that the standards of Section 71.13 and 71.51, 10CFR71, for Type "B" and large quantity packagings are met.

2.5.1 Load Resistance

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

$$S_f = \frac{MC}{I}$$

$$M = \frac{5WL}{8} = (5)(1/8)\ (58{,}400)(88.25) = 3.221 \times 10^6 \text{ in-lb}$$

$$C = D = \frac{83.5}{2} = 41.75 \text{ in.}$$

$$I = \frac{\pi\, d_o^4 - d_i^4}{64} = \frac{\pi}{64}(83.50^4 - 81.75^4)$$

$$= 193{,}843 \text{ in}^4$$

and the corresponding stress is:

$$S_f = \frac{MC}{I} = \frac{(3.221 \times 10^6)(41.75)}{193{,}843} = 694 \text{ psi}$$

which results in a Margin of Safety of:

$$MS = \frac{F_{ty}}{S_f} - 1 = \frac{38{,}000}{694} - 1 = \underline{+53.75}$$

Therefore, the package can safely react the "Load Resistance" condition.

2.5.2 External Pressure

An external pressure of 25 psig is reacted by the external shell in hoop compression. The stress can be calculated as follows:

$$F = Pr/t$$

Where:

P = 25 psig

r = (83.5 - .875)/2 = 41.31 inches

t = .875 in. (outside shell only)

F = (25)(41.31)/.875 = 1180 psi

Margin of Safety:

$$M.S. = (F_{ty}/F)-1$$

$$= (38,000/1180) - 1$$

$$= \underline{+ 31.2}$$

The analysis is conservative due to the presence of the lead and internal shell. The lead assures buckling stability of the shell. Pressure across the end is carried in plate bending by a minimum of two inch thick steel plates top and bottom. Assuming a circular plate, uniformly loaded and with edges simply supported, the stress can be calculated as follows:

$$f_r = 3W(3M+1)/8\pi Mt^2$$ (Per "Formulas for Stress and Strain" by Roark)

Where:

W = (25) $\pi(83.50)^2/4$ = 136,900

t = 2"

M = 1/.33 = 3

$$f_r = [\ (3)(136,900\text{x}10)]/[8\pi\ (3)(2)^2]$$

$$f_r = 13,618 \text{ psi}$$

Margin of Safety:

$$M.S. = 38,000/13,618 - 1$$

$$M.S. = \underline{+1.79}$$

It is therefore safe to conclude that the containment vessel can react a 25 psig external pressure without loss of contents.

2.6 Normal Conditions of Transport

The 14-215 cask has been designed and constructed, and the contents are limited (as described in Section 1.2.3 above), such that the performance requirements specified in 10CFR71 will be met when the package is subjected to the normal conditions of transport specified in Subpart F of 10CFR71. The ability of the 14-215 package to satisfactorily withstand the normal conditions of transport has been assessed as described on the following pages.

2.6.1 Heat

A detailed thermal analysis can be found in Section 3.4 wherein the package was exposed to three combinations of solar heating, internal decay heat and 130°F ambient air. The steady state analysis conservatively assumed a 24-hour day as maximum solar heat load. The maximum steady state temperature was found to be 192°F. These temperatures will have no detrimental effects on the package.

2.6.2 Cold

The 14-215 cask containment components are constructed of A516 Grade 70 ferritic steel. This material provides appropriate resistance to brittle fracture failures in accordance with the recommendations for Category III payloads as setforth in NUREG CR-1815. Specifically, package materials selections comply with criteria established in Section 5.3 of NUREG CR-1815.

2.6.3 Pressure

A differential pressure of 0.5 atmospheres will be reacted by the lid and its associated closures comprised of ratchet binders for the primary lid and studs for the second y lid. Loads on th primary lid ratchet binders are calculated as:

$$P_s = AP/N; \text{ where: } A = \frac{\pi D^2}{4}$$

$$P = 14.7/2 \text{ psi}$$

$$N = 8$$

For the worst case loading:

$$P_s = \frac{\pi(81.82)^2}{4} \times \frac{14.7}{2} \times \frac{1}{8} = 4{,}831 \text{ lbs.}$$

The rated load of the ratchet binder is 100,000 lbs. (see Appendix 2.10.3). Thus, the Margin of Safety is:

$$M.S. = \frac{100{,}000}{4{,}831} - 1 = \underline{19.69}$$

For the secondary lid studs, the load is:

$$P_s = \frac{\pi(33.87)^2}{4} \times \frac{(14.7)}{2} \times \frac{1}{8} = 828 \text{ lbs}$$

The tensile strength of the 3/4-10 UNC, ASTM A320 Grade L-7 studs (minor thread dia. = 0.309) is:

$$P_A = (105{,}000)(.309) = 32{,}450 \text{ lbs.}$$

Thus, the margin of safety is:

$$M.S. = 32{,}450/838 - 1 = \underline{37.72}$$

Stresses induced in the cylinder portion of the cask are conservatively estimated by assuming the pressure differential is totally borne by 3/8 inch thick inner shell. The hoop and longitudinal stresses are:

$$f_h = PR/t = \left(\frac{14.7}{2}\right)\left(\frac{38.63}{.375}\right) = 757 \text{ psi}$$

$$f_\ell = PR/2t = \left(\frac{14.7}{2}\right)\left(\frac{38.63}{.375}\right)\left(\frac{1}{2}\right) = 379 \text{ psi}$$

Assuming these biaxial stresses are additive,

$$f_{max} = f_h + f_\ell = 757 + 379 = \underline{1136 \text{ psi}}$$

The margin of safety is:

$$M.S. = 38,000/1,136 - 1 = \underline{32.45}$$

Pressure across the end is carried in plate bending by the 2 inch (minimum) thick steel plates top and bottom. Assuming a circular plate, uniformly loaded and with edges simply supported, the stress can be calculated as follows:

$$f_r = 3W(3M+1)/8\pi Mt^2$$ (Per "Formulas for Stress and Strain" by Roark)

Where: $W = (7.35) \; (\pi) \; (83.50)^2/4 = 40,250$ lbs.

$t = 2''$

$M = 1/.33 = 3$

$$f_r = (3)(40250)(10)/8\pi \; (3)(2)^2$$

$$f_r = 4,006 \text{ psi}$$

Margin of Safety:

$$M.S. = 38,000/4006 - 1 = \underline{+ 8.48}$$

It can therefore be concluded that the packaging can safely react an atmospheric pressure of 0.5 times standard atmospheric pressure.

2.6.4 Vibration

Shock and vibration normally incident to transport are considered to have negligible effects on the package.

2.6.5 Water Spray

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

2.6.6 Free Drop

The free drop height specified by Subpart F of 10CFR71 for the 14-215 package is 12 inches, since the package is greater than 30,000 lbs. gross weight.

Three drop orientations are possible: flat end drop, side drop and corner drop. For the flat end drop, the most critical condition will be settlement of the unbonded lead shield at the end opposite the point of impact. For the side drop, local flattening and impact onto a lifting lug will be evaluated. For the corner drop, the most critical conditions will be impact on the lid edge and its effect on the closure.

2.6.6.1 Flat End Drop

The evaluation of flat end impact upon settlement of lead shielding closely follows Shappert's approach for a cylindrical lead shield, outlined in Section 2.7.3 of his Cask Designer's Guide, ORNL-NSIC-68, February 1970. The lead settlement distance is given by:

$$\Delta H = \frac{RWH}{\pi(R^2 - r^2)\ (t_s\sigma_s + R\sigma_{pb})}$$

Where:

ΔH = Settlement depth (in.)

H = Drop Height (in.) = 12"

R = Outer lead radius (in.) = 40.88 in.

W = Weight of Lead (lbs.) = 16,290 lbs.

r = Inner lead radius (in.) = 39.00 in.

t_s = Thickness of external steel shell (in.) = .875 in

σ_s = Steel dynamic flow stress, 50,000 psi

σ_{pb} = Lead dynamic flow stress, 5,000 psi

Therefore the settlement depth, ΔH, equals 0.068 inches.

This modest settlement "void" in the lead shield, .068 inches, cannot transmit radiation because of the stepped design of the package ends. The innermost solid steel end plates completely back (shield) lead settlement regions at both ends of the package. Thus, lead settlement due to a flat end drop does not compromise, nor alter, the integrity of radiation shielding in any fashion.

2.6.6.2 <u>Side Drop</u>

The effect of a side drop on the cask shielding capabilities is evaluated using the methods outlined in Section 2.7.2 of Shappert's Cask Designer's Guide, ORNL-NSIC-68. The governing equation (2.13) is:

$$\overbrace{\frac{WH}{t_s R L \sigma_s}}^{\alpha} = \overbrace{F_1(\theta) \frac{R}{t_s} (\sigma_{pb}/\sigma_s) + 2 (R/L)(t_e/t_s) + F_2(\theta)}^{\beta}$$

Where:

W = cask weight (lbs.) = 58,400 lbs.

H = 12 in.

$F_1(\theta)$ = $\theta - 1/2 \sin 2\theta$

$F_2(\theta)$ = $\sin\theta(2-\cos\theta) - \theta$

σ_s = 50,000 psi

σ_{pb} = 5,000 psi

θ = 6.35°

t_s = outer shell thickness = 0.875 in.

t_e = end plate thickness = 4.00 in.

The flattening of the cask is equal to:

$$d = R(1-\cos\theta)$$

Therefore:

$$d = 0.256 \text{ inches}$$

Shielding is reduced by side impact as follows:

$$\% \text{ Shield Reduction} = \frac{d}{T_s}\left(\frac{2\theta}{360}\right)(100)$$

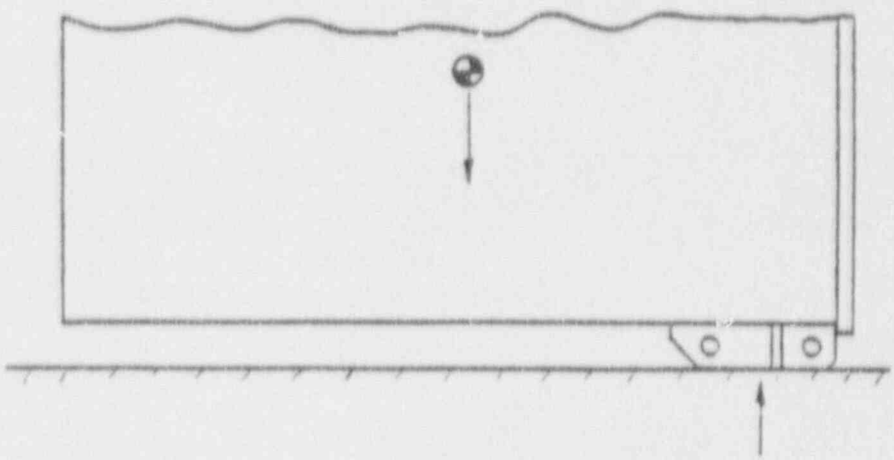
Where: T_s = Normal Shield Thickness = 0.875 inches

Therefore:

% Shield Reduction = 0.33

This insignificant reduction of shielding demonstrates that side impact does not compromise the integrity of the package's shielding in any measurable fashion.

The potential for damage to the cask seal resulting from a side drop onto a tiedown lug is also evaluated. Because the lug is located at the upper end of the cask, the impact force will be shared by both upper and lower ends. If we conservatively assume, that the lug carries the entire load, then an estimation of the deceleration load can be calculated.



Assuming that the lug plate of 514/517 steel deforms the softer 516 steel cylinder wall, a crush depth can be found using a dynamic flow stress of (σ_s) 50,000 psi:

$U = V\sigma_s$

Where:

U = Total energy = 58,400 (12) = 700,800 in-lbs.

V = Crush volume

$= \ell_{lug}\, t_{lug}\, \delta$

$= (21)(2)\delta = 42\delta$

Substituting and transposing:

$$\delta = \frac{700,800}{42(50,000)} = .334 \text{ in.}$$

Note that this is less than half of the .88 wall thickness.

Impact velocity is:

$$v = \sqrt{2gh}$$

$$= \sqrt{2(386.4)12}$$

$$= 96.3 \text{ in/sec.}$$

Deceleration in g's is then,

$$a = \frac{v^2}{2g\delta} = \frac{96.3^2}{2(386.4)(.334)} = 35.9 \text{ g's}$$

Note that this is within the range of the values found for the corner drop in Section 2.6.6.3 below.

The tiedown lug extends to the top of the cylinder wall so the wall is backed by the cylinder top ring as well as the lead shielding below it, thus resisting gross radial deflection of the outside cylinder wall. The circularity of the cylinder in this area is insured by the stepped lid. Thus, the sealing surfaces in this area are expected to remain relatively undeformed assuring the preservation of the seal.

2.6.6.3 Corner Drop

The impact energy associated with a corner drop will be absorbed by inelastic deformation of the corner. Using the "dynamic flow pressure" concept, total deformation of the corner is estimated and used to compute package deceleration. This deceleration is then used to check the integrity of the lid closure.

Both steel and lead components of the cask are distorted upon corner impacts. The assessment of deformation and resultant decelerations is based upon a careful consideration of detail corner geometry for a range of assumed deformations. It is assumed that the steel end plates of the cask undergo plastic flexural deformation and do not crush. This flexural deformation of the ends enforces a crushing of the contiguous lead side walls and the thin cylindrical external steel shell. The predictions of peak rigid body impact decelerations are based upon the crush geometry of the lead side walls and the associated external steel shell. Resultant deformation prediction estimates are based upon two energy balance techniques:

- o The plastic flow pressure concept

- o An integration of force - deflection relations based upon crush stress approaches.

For the plastic flow stress approach, properties of steel and lead are based upon recommended deformation basis values used by Shappert in the Cask Designer's Guide, ORNL NSIC-68, Section 2.7.1:

σ_{pb} = 5,000 psi

σ_{s} = 50,000 psi

For the crush stress approach, steel crush properties are assumed to be equal to approximately 1.5 times the yield stress, approximately the midpoint between yield and ultimate stress. This conservative approach is intended to account for both strain rate effects and strain hardening. This provides a crush stress equivalent for steel of 55,000 psi. For lead, the crush stress equivalent is taken as twice yield, or 1380 x 2 = 2760 psi, reference Table 2.6, Shappert, Cask Designer's Guide, ORNL-NSIC-68.

Analytics used for this estimate are outlined in Appendix 2.10.2. The results are summarized in Table 2.6.6.3-1; detailed computer analysis results for the cask configuration follow the table.

The deceleration resulting from impact onto the bottom corner of the cask is conservatively used in evaluating the drop onto the top corner of the cask. The actual deceleration for the top corner drop would be significantly less due to the bending of the lid top plate during impact.

TABLE 2.6.6.3-1

CORNER IMPACT DEFORMATION & DECELERATION ESTIMATES

Cask	Drop Height (in)	Weight (lbs)	Radius (in)	Crush Zone Geometry Volume (in^3)	Area (in^2)	Depth (in)	(1) Load Factor (g's)
14-215	12	58,400	41.785	15.4	34.5	1.12	32.6

(1) Intepolated for greatest crush depth prediction corresponding to a strain energy/kinetic energy ratio of unity.

2.75 EQ SHIELDING

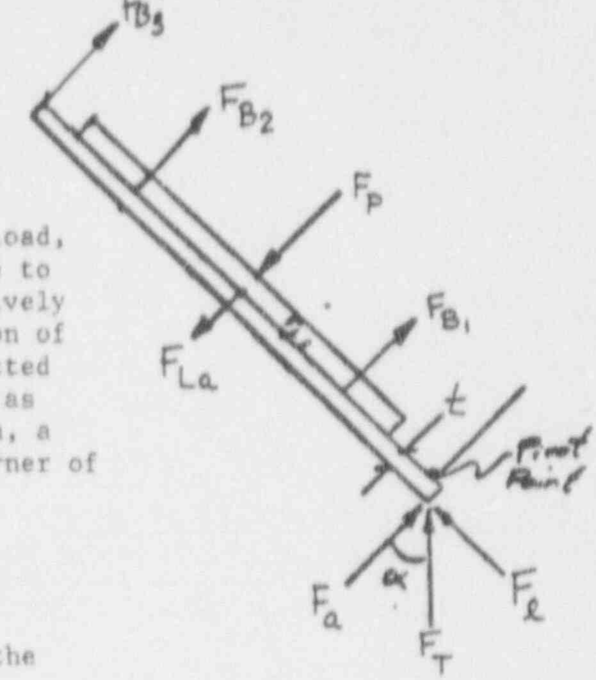
```
PACKAGE WEIGHT              = 58400.00 (LBS)
DROP HEIGHT                 =    12.000 (IN)
PACKAGE RADIUS              =    41.785 (IN)

STEEL DYNAMIC FLOW STRESS = 50000.00 (PSI)
STEEL CRUSH STRESS          = 55000.00 (PSI)
LEAD DYNAMIC FLOW STRESS    =  5000.00 (PSI)
LEAD CRUSH STRESS           =  2760.00 (PSI)

STEEL SHELL THICKNESS       =      .875 (IN)
STEEL BOTTOM THICKNESS      =     4.250 (IN)

ORIENTATION ANGLE           =     43.28 (DEG)
```

0024k

2.75 EQ SHIELDING

CRUSH DEPTH (IN)	KINETIC ENERGY (IN-LB)	++CRUSH VOLUME++ TOTAL (IN3)	STEEL (IN3)	LEAD (IN3)	+FLOW STRESS BASIS+ STRAIN ENERGY ENERGY (IN-LB)	RATIO (SE/KE)	+++ CRUSH AREA +++ TOTAL (IN2)	STEEL (IN2)	LEAD (IN2)	++ IMPACT ++ FORCE (LBS)	ACCEL. (G)	++CRUSH STRESS BASIS STRAIN ENERGY ENERGY (IN-LB)	RATIO (SE/KE)
.05	703720.	.0	.0	0.0	330.	.00	.3	.3	0.0	18132.	.3	453.	.00
.10	706640.	.0	.0	0.0	1865.	.00	.9	.9	0.0	51273.	.9	2188.	.00
.15	709560.	.1	.1	0.0	5138.	.01	1.7	1.7	0.0	94170.	1.6	5825.	.01
.20	712480.	.2	.2	0.0	10545.	.01	2.6	2.6	0.0	144946.	2.5	11802.	.02
.25	715400.	.4	.4	0.0	18417.	.03	3.7	3.7	0.0	202515.	3.5	20489.	.03
.30	718320.	.6	.6	0.0	29047.	.04	4.8	4.8	0.0	266143.	4.6	32205.	.04
.35	721240.	.9	.9	0.0	42696.	.06	6.1	6.1	0.0	335290.	5.7	47241.	.07
.40	724160.	1.2	1.2	0.0	59605.	.08	7.4	7.4	0.0	409538.	7.0	65862.	.09
.45	727080.	1.6	1.6	0.0	79999.	.11	8.9	8.9	0.0	488549.	8.4	88314.	.12
.50	730000.	2.1	2.1	0.0	104086.	.14	10.4	10.4	0.0	572045.	9.8	114829.	.16
.55	732920.	2.6	2.6	0.0	132067.	.18	12.0	12.0	0.0	659789.	11.3	145625.	.20
.60	735840.	3.3	3.3	0.0	164129.	.22	13.7	13.7	0.0	751577.	12.9	180909.	.25
.65	738760.	4.0	4.0	0.0	200451.	.27	15.4	15.4	0.0	847232.	14.5	220879.	.30
.70	741680.	4.8	4.8	0.0	241206.	.33	17.2	17.2	0.0	946596.	16.2	265725.	.36
.75	744600.	5.7	5.7	0.0	286559.	.38	19.1	19.1	0.0	1049530.	18.0	315628.	.42
.80	747520.	6.7	6.7	0.0	336670.	.45	21.0	21.0	0.0	1155907.	19.8	370764.	.50
.85	750440.	7.8	7.8	0.0	391692.	.52	23.0	23.0	0.0	1265615.	21.7	431302.	.57
.90	753360.	9.0	9.0	0.0	451775.	.60	25.1	25.1	0.0	1378549.	23.6	497406.	.66
.95	756280.	10.3	10.3	0.0	517062.	.68	27.2	27.2	0.0	1494614.	25.6	569235.	.75
1.00	759200.	11.8	11.8	0.0	587695.	.77	29.3	29.3	0.0	1613721.	27.6	646943.	.85
1.05	762120.	13.3	13.3	0.0	663809.	.87	31.6	31.6	0.0	1735791.	29.7	730681.	.96
1.10	765040.	14.9	14.9	0.0	745538.	.97	33.8	33.8	0.0	1860747.	31.9	820595.	1.07
1.15	767960.	16.7	16.7	0.0	833010.	1.08	36.2	36.2	0.0	1988520.	34.0	916826.	1.19
1.20	770880.	18.5	18.5	0.0	926354.	1.20	38.5	38.5	0.0	2119043.	36.3	1019515.	1.32
1.25	773800.	20.5	20.5	0.0	1025691.	1.33	41.0	41.0	0.0	2252255.	38.6	1128798.	1.46
1.30	776720.	22.6	22.6	0.0	1131144.	1.46	43.4	43.4	0.0	238[illegible]98.	40.9	1244807.	1.60
1.35	779640.	24.9	24.9	0.0	1242830.	1.59	45.9	45.9	0.0	2526518.	43.3	1367672.	1.75
1.40	782560.	27.2	27.2	0.0	1360866.	1.74	48.5	48.5	0.0	2667462.	45.7	1497522.	1.91
1.45	785480.	29.7	29.7	0.0	1485364.	1.89	51.1	51.1	0.0	2810882.	48.1	1634480.	2.08
1.50	788400.	32.3	32.3	0.0	1616437.	2.05	53.8	53.8	0.0	2956731.	50.6	1778671.	2.26
1.55	791320.	35.1	35.1	0.0	1754194.	2.22	56.5	56.5	0.0	3104965.	53.2	1930213.	2.44
1.60	794240.	38.0	38.0	0.0	1898742.	2.39	59.2	59.2	0.0	3255542.	55.7	2089226.	2.63
1.65	797160.	41.0	41.0	0.0	2050187.	2.57	62.0	62.0	0.0	3408423.	58.4	2255825.	2.83
1.70	800080.	44.2	44.2	0.0	2208633.	2.76	64.8	64.8	0.0	3563567.	61.0	2430125.	3.04
1.75	803000.	47.5	47.5	0.0	2374182.	2.96	67.7	67.7	0.0	3720940.	63.7	2612237.	3.25
1.80	805920.	50.9	50.9	0.0	2546934.	3.16	70.6	70.6	0.0	3880505.	66.4	2802273.	3.48
1.85	808840.	54.5	54.5	0.0	2726988.	3.37	73.5	73.5	0.0	4042230.	69.2	3000342.	3.71
1.90	811760.	58.3	58.3	0.0	2914441.	3.59	76.5	76.5	0.0	4206080.	72.0	3206549.	3.95
1.95	814680.	62.2	62.2	0.0	3109390.	3.82	79.5	79.5	0.0	4372027.	74.9	3421002.	4.20
2.00	817600.	66.2	66.2	0.0	3311930.	4.05	82.5	82.5	0.0	4540039.	77.7	3643804.	4.46

Loads due to impact on top corner



Binders react the forces due to payload, weight of the lid and the moment due to the impact point offset. Conservatively ignoring the effect of the deflection of the lid and deformation of the impacted corner, the impact point is located as shown. Binders are located as shown, a distance of 1.9" inward from the corner of the octagon.

$$r_B = \frac{\ell_F}{2\cos 22.5°} - 1.9"$$

ℓ_D is equal to the outer radius of the cask body.

d_i is the impact moment arm.

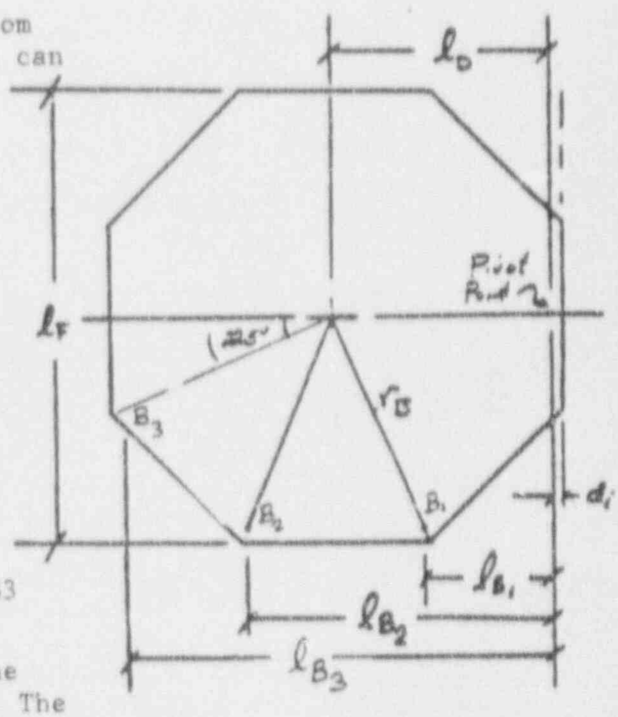
$$d_i = 0.5\ \ell_F - \ell_D$$

With these dimensions, the distance from the pivot point to the ratchet binders can be calculated:

$$\ell_{B1} = \ell_D - r_B \sin 22.5$$

$$\ell_{B2} = \ell_D + r_B \sin 22.5$$

$$\ell_{B3} = \ell_D + r_B \cos 22.5$$



Binder loads are assumed to increase linearly with distance from the pivot point.

Therefore:

$$F_{B2} = \frac{\ell_{B2}}{\ell_{B3}} F_{B3}, \qquad F_{B1} = \frac{\ell_{B1}}{\ell_{B3}} F_{B3}$$

The pivot point is assumed to be at the outer edge of the lid/cask interface. The axial and lateral forces imposed by the cask body on the lid are assumed to pass through this point, therefore causing no moment. Summing moments due to the other forces:

$$F_{La}\ (\ell_D) + F_p(\ell_D) + F_a\ (d_i) =$$

$$2F_{b3}\ (\ell_{B3}) + 2F_{b2}\ (\ell_{B2}) + 2F_{b1}\ (\ell_{B1}) + F_e(t)$$

The forces are the axial or lateral component of the impact force.

$$F_{La} = W_{lid}\ (A_g)\ (\cos\alpha)$$

$$F_p = W_p\ (A_g)\ (\cos\alpha)$$

$$F_s = W_t\ (A_g)\ (\cos\alpha)$$

$$F_e = W_t A_g\ (\sin\alpha)$$

Substituting the above and the expressions for binder force:

$$W_{lid}\ (A_g)\cos\alpha(\ell_D) + W_p(A_g)\cos\alpha(\ell_D) + W_t(A_g)\cos\alpha(d_1) = 2\ell_{B3}\ F_{b3} + 2\ \frac{\ell^2_{B2}}{\ell_{B3}}\ F_{b3} + 2\ \frac{\ell^2_{B1}}{\ell_{B3}}\ F_{b3} + W_t\ (A_g)\ \sin\alpha(t)$$

Collecting terms:

$$A_g\ ((W_{lid} + W_p)\ \ell_D\cos\alpha + W_t(d_1\ \cos\alpha - t\sin\alpha)) = \frac{2F_{b3}}{\ell_{B3}}\ (\ell^2_{B3} + \ell^2_{B2} + \ell^2_{B1})$$

Solving for F_{B3}, the maximum binder force,

$$F_{B3} = \frac{A_g \ell_{B3}((W_{lid} + W_p)\ell_D\ \cos\alpha + W_t(d_1\cos\alpha - t\sin\alpha))}{2(\ell^2_{B3} + \ell^2_{B2} + \ell^2_{B1})}$$

The interface forces between the lid and body are calculated as follows:

$$F_{axial} = A_g\ \cos\alpha\ (W_t - W_p - W_{lid})\ + 2(F_{b1} + F_{b2} + F_{b3})$$

$$F_{lateral} = A_g \sin\alpha\ (W_t - W_{lid})$$

TABLE 2.6.6.3-2

LID INTERFACE FORCES

Cask	Gross Weight (lbs.)	Payload Weight (lbs.)	Lid Weight (lbs.)	Body Dia. (in.)	Lid Dim. (in.)	Impact Angle (deg.)	Impact Accel. (g's)	Maximum Binder Force (lbs.)	Interface Axial Force (lbs.)	Interface Lateral Force (lbs.)
14-215	58,400	20,000	6,600	83.50	84.93	43.90	32.6	92,800	1,121,000	1,171,000

Thus, in this instance, the maximum binder force is 92,800 lbs.

The allowable load of the binder is rated at 100,000 lbs. (see Appendix 2.10.3). Thus, the Margin of Safety is:

$$M.S. = 100,000/92,800 - 1 = \underline{+0.08}$$

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

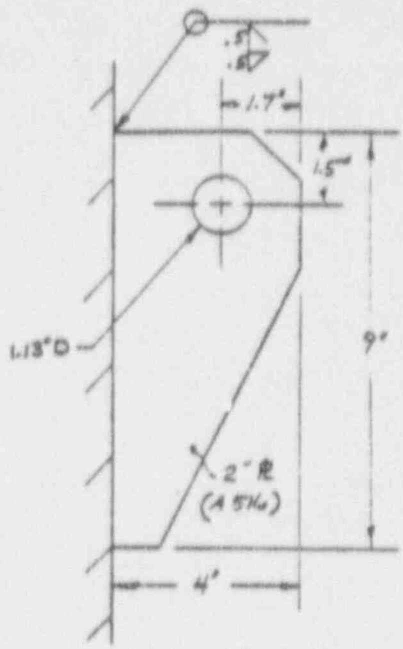
Therefore, it can be concluded that the binders static allowable capabilities will not be lower under shock or dynamic loading.

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

In the case of a top corner impact directly above a binder lug, some bending of the ocatgonal lid corner may occur. This will decrease the distance between the cask binder attachment lugs and would normally induce a damaging compressive load in the binder. This, in turn, could result in damage to the cask outer shell due to the moment induced in the binder lug. The binder design precludes this since it will allow a significant amount of axial deflection before it will take a compressive load (see Appendix 2.10.3).

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

Body Lugs



Shear out:

Using the standard 40° shear out relation:

$$P_s = F_{sy} 2t \left(e_d - \frac{d}{2} \cos 40°\right)$$

Where:

F_{sy} = 22,800 psi

t = 2.0 in.

e_d = 1.5 in.

d = 1.125 in.

$$P_s = (22,800)(2)(2.0)\left(1.5 - \frac{1.125}{2} \cos 40°\right)$$

$$= 97,500 \text{ lbs. shear out}$$

Weld Area:

The weld stresses are composed of pure shear and tension/compression due to the moment.

Pure shear on the weld:

F_s = P.

Where:

F_s = Weld shear stress

A_w = Weld Area = L_w ' t_w

L_w = 2(9" + 2") = 22"

t_w = (.5) + (.5) (.707) = 0.854" (Groove + fillet weld)

A_w = (22) (.854) = 18.78 in.^{2}

Then,

$$F_s = \frac{P}{18.78}$$

The stress due to the bending moment is

$$F_B = \frac{M}{Z}$$

Where:

$M = P(2.3)$

$Z = \frac{I}{C}$

$I = I_H + A_H d_H^2 + 2I_V$

$I_H = \frac{1}{12} (2) (.854)^3 = 0.1 \text{ in}^4$

$A_H = (.854)(2) = 1.71 \text{ in}^2$

$d_H = 4.5$ in.

$I_V = \frac{1}{12} (.854)(9)^3 = 51.9 \text{ in}^4$

$I = .1 + (1.71)(4.5)^2 + 2(51.9) = 138.5 \text{ in}^4$

$C = 4.5$ in

$Z = \frac{138.5}{4.5} = 30.78 \text{ in}^3$

Then,

$$F_B = \frac{P(2.3)}{30.78} = \frac{P}{13.38}$$

Combined stress cannot exceed the weld allowable shear stress, F_a = 21,000 (E70 Weld Rods)

$$F_a = \sqrt{(F_s)^2 + (F_B)^2} = \sqrt{\left[\frac{P}{18.78}\right]^2 + \left[\frac{P}{13.38}\right]^2} = 21,000$$

Solving for P:

P = 228,840 lbs.

Plate Area:

Utilizing the same approach as above, the plate yield shear capacity is:

Pure shear on plate:

$$F_s = \frac{P}{A_p}$$

Where:

F_s = Plate Shear Stress

A_p = (9)(2) = 18 in.^{2}

Then,

$$F_s = \frac{P}{18}$$

Moment force on plate:

$$M = 2F_B A_p d = P(2.3)$$

Where:

F_B = Plate bending stress

A_p = 18 in.^{2}

d = 2/3(4.5) = 3.0 in.

Then,

$$2F_B(18)(3.0) = P(2.3)$$

$$F_B = \frac{P}{46.96}$$

Combined stress cannot exceed the plate allowable shear stress, F_a = 21,800 psi

$$F_a = \sqrt{(F_s)^2 + (F_B)^2} = \sqrt{\left(\frac{P}{18}\right)^2 + \left(\frac{P}{46.96}\right)^2} = 21{,}800 \text{ psi}$$

P = 366,405 lbs.

Outer Shell:

The body lugs introduce a bending moment into the outer shell similar to the tiedown lugs in Section 2.4.4.

Assuming bending about the body lug center, the moment induced in the outer shell is:

$$M_B = P(4.0 - 1.7) = P(2.3)$$

Again, assuming bending about the tiedown lug center, the moment induced in the outer shell by a 89,000 lb. outward radial load and a 267,000 lb. downward load (from the finite element analysis) is:

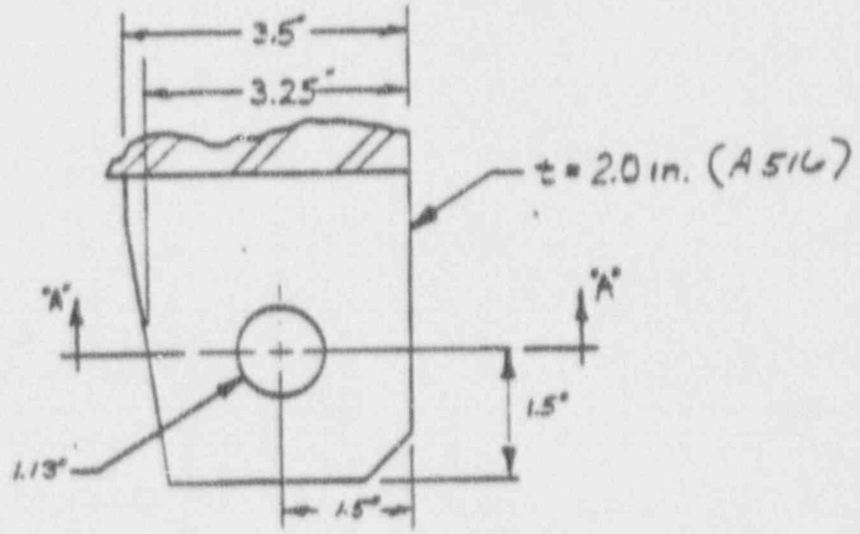
$$M_T = 267{,}000(2.5) - 89{,}000(4.84) = 236{,}740 \text{ in-lbs.}$$

The maximum outer shell combined stress from Section 2.4.4, Tiedowns, is 20,749 psi. The outer shell yield capacity at the body lugs is:

$$\frac{M_B}{M_T} = \frac{P(2.3)}{236{,}740} = \frac{38{,}000}{20{,}749}$$

or P = 188,508 lbs.

Lid Lugs:



The lug yield strength capab' .ty across net area (A-A) is:

$$P_t = F_{ty}A$$

Where:

$$F_{ty} = 38{,}000 \text{ psi}$$

$$A = (3.25 - 1.125)(2.0)$$

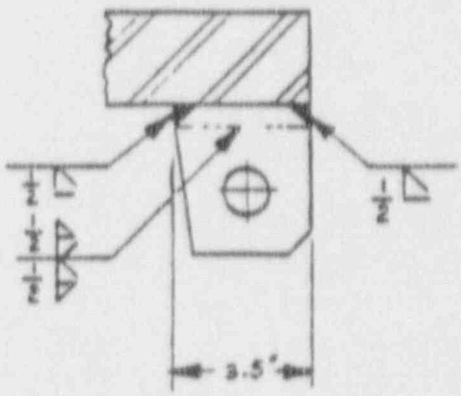
$$= 4.25$$

$$P_t = (38{,}000 \text{ psi})(4.25 \text{ in}^2)$$

$$P_t = 161{,}500 \text{ lbs. (Net Area)}$$

Lug shear out capability is identical to that of the lower lug evaluated above (i.e., P_s = 97,500 lbs.).

Lug to lid attachment:



Weld Shearing:

$$P_s = F_s A_w$$

Where:

$$F_s = 21{,}000 \text{ psi (E70 Weld Rods)}$$

$$A_w = (2)(2)(0.5)+(2)(3.5)(.854)$$

$$= 7.98 \text{ in.}^2$$

$$P_s = (21{,}000 \text{ psi})(7.98 \text{ in.}^2)$$

$$P_s = 167{,}580 \text{ lbs./lug}$$

The weakest link in the binder lugs is the shearout failure.

At this location, the minimum Margin of Safety is:

$$M.S. = \frac{97,500}{92,800} - 1 = \underline{+\ 0.05}$$

The ratchet binders load the lid top plate with a series of edge moments. The two inch plate of the casks will be evaluated for these loads. Both local and gross effects on this lid top plate are evaluated.

For a maximum ratchet binder load of 92,800 lbs., the associated moment introduced into the top plate of the lid is estimated as:

$$M = (92,800)(.375 + 3.5 - 1.50) = 220,400 \text{ in-lb.}$$

The local moment capability of an octagonal lid cover is estimated as follows:

$$M_{\ell} = \frac{\sigma I}{c}$$

Where:

σ = 38,000 psi

c = 1.0 inch

$$I = \frac{bh^3}{12} = \frac{(18.35)(2)^3}{12} = 12.23 \text{ in.}^4$$

$$b = (2)(3.8) \tan 67.5° = 18.35$$

Local moment capability is then:

$$M = \frac{(38,000)(12.23)}{1} = 464,800 \text{ in-lb.}$$

Thus, local moment yield Margin of Safety of the lid is:

$$M.S. = \frac{464,800}{220,400} - 1 = \underline{+\ 1.11}$$

Gross moment capability is assessed using both the exterior and interior lid plates. For a uniform edge moment the expression relating stress to moment in a circular plate is given by Roark as:

$$\sigma = \frac{6M}{t^2} \; ; \; M = \frac{\sigma t^2}{6}$$

For the 2" exterior plate:

$$M = \frac{38{,}000(2)^2}{6} = 25{,}330 \text{ in-lb/in.}$$

For the 2" interior plate:

$$M = \frac{38{,}000\ (2.0)^2}{6} = 25{,}330 \text{ in-lb/in.}$$

The total edge moment capability is: 50,660 in-lb/in.

For the circular lid of 83.50" diameter, the corresponding concentrated moment acting on 1/8th of the edge is:

$$M_g = \frac{(50{,}660)\ (83.50)\ (\Pi)}{8} = 1{,}661{,}160 \text{ in-lb.}$$

Thus, the gross moment yield Margin of Safety of the lid is:

$$M.S. = \frac{1{,}661{,}160}{220{,}400} - 1 = \underline{+6.54}$$

The maximum bending stress in the lid can be approximated by applying a pressure load against the lower lid plate which is made up both the lid weight and the weight of the payload.

Total force is then

$$F_p = (W_{lid} + W_p)(A_g) \cos\alpha$$

$$= (6600 + 20{,}000)\ (32.6)\ \cos\ (43.9°)$$

$$= 624{,}833$$

Distributing this force over the face of the lower plate the pressure, p, becomes

$$P = F_p/A$$

$$A = \Pi(38.63)^2 = 4688 \text{ in}^2$$

$$p = 624{,}833/4688 = 133.3 \text{ psi}$$

The pressure on the secondary lid is applied to the primary lid as a ring load, W, with diameter equal to the bolt circle. Using a 32" bolt circle and a 29" diameter secondary lid plate, the ring load is

$$W = \frac{133.3 \ \frac{\pi}{4} \ (29)^2}{\pi(32)} = 876 \text{ lb/in}$$

or 14,026 lb/radian

A finite element model of the lid was used to calculate the stresses resulting from this loading and to evaluate the ability of the lid to act as a composite plate. (See Appendix 2.10.6). The maximum plate stress intensity calculated for the above loading was 33,830 psi and occurred at the lower surface of the lid at the edge of the access hole. The resulting Margin of Safety is

$$M.S. = \frac{38,000}{33,830} - 1 = \underline{+0.12}$$

If a "loose" payload is assumed, an equivalent pressure load against the inside of the secondary lid can be calculated using the payload density, payload depth and impact acceleration. Payload weight reacted by the lid is:

$$W_p = 80.25" \ (29")^2 \frac{\pi}{4} \ \left(\frac{20,000 \text{ lb.}}{217 \text{ ft.}^3}\right) \frac{1}{1728 \text{ in}^3/\text{ft}^3} = 2827 \text{ lb.}$$

Secondary lid weight:

$$W_L = 1150 \text{ lbs.}$$

Total force reacted by the secondary lid lugs is then:

$$F_T = (W_p + W_L) \ a_g \ \cos\sigma$$

Where a_g is the impact acceleration and σ is the impact angle ($\approx$ 45°).

$$F_T = (2827 + 1150)(33.9)(.707) = 95,320 \text{ lbs.}$$

Maximum bending stress in the lid can be found assuming a line load on the 1" plate at the outer diameter of the 2" plate directly below (diameter = 30.75 in.). Assume the outer edge of the 1" plate is simply supported (diameter = 35.8"). The maximum moment in the plate is given in Roark (5th Edition), Table 24, Case 9a, as:

$M_c = wa\ L_9$

Where $L_9 = \frac{r_o}{a}\left[\frac{1+\nu}{2}\ \ln\frac{a}{r_o} + \frac{1-\nu}{4}\left[1-\left(\frac{r_o}{a}\right)^2\right]\right]$

giving:

$$M_c = \frac{95,320 \quad (35.8)\ (.1235)}{\pi\ (30.75)}$$

$$= 4,362 \text{ in-lb/in.}$$

Plate bending stress is given by:

$$f_b = \frac{6M_c}{t^2}$$

$$= 6(4362)/1^2 = 26,175 \text{ psi}$$

Thus, even with this conservative assumption, the Margin of Safety is positive:

$$M.S. = \frac{38,000}{26,175} - 1 = +\underline{0.45}$$

The stress in the stud consists of two parts, that due to preload and the impact loading. The preload force can be estimated using Equation 6-16 from Shigley, Mechanical Engineering Design, 3rd Edition:

$$T = 0.20\ F_{bp}d$$

Where T is the bolt torque (100 ft-lbs.), F_i is the bolt preload and d is the bolt diameter (.75 in.)

$$F_{bp} = \frac{100 \text{ ft-lb } (12\text{in/ft})}{.20(.75 \text{ in.})} = 8,000 \text{ lb.}$$

Impact force reacted by the bolt is:

$$F_{bi} = \frac{95,320}{8} = 11,915 \text{ lbs.}$$

These forces are added because the gasket "spring" is much softer than the stud "spring", thus preventing unloading of the gasket when an additional tension is applied to the bolt.

Total force in the bolt is then:

$$F_{bx} = F_{bp} + F_{bi}$$

$$= 19,915 \text{ lbs.}$$

Stud capacity is (for a 3/4-10 UNC ASTM A320 Grade L-7):

$$P = F_t A = 105{,}000\ (.309) = 32{,}450 \text{ lbs.}$$

The Margin of Safety for the studs is then:

$$M.S. = \frac{32{,}450}{19{,}915} - 1 = + .63$$

When impacts occur on the lid end, a normal compressive load of 1,121,000 lbs (Table 2.6.6.3-2) is then transferred from the lid to the lid closure ring. The loaded length is conservatively estimated by considering only the length of the section which would be deformed during the impact. This load is then transferred to the cask via direct compression of the lead shielding and the steel walls.

$$\ell = 2R\Theta$$

Where:

$$R = 41.75 \text{ in.}$$

$$\Theta = \cos^{-1}\left(\frac{r}{R}\right)$$ See Appendix 2.10.2

$$r = R - \frac{\delta}{\sin\alpha}$$

$$\delta = 1.15$$

$$\alpha = 43.28°$$

$$r = 41.75 - \frac{1.15}{\sin 43.28} = 40.07 \text{ in.}$$

$$\Theta = \cos^{-1}\left(\frac{40.07}{41.75}\right) = 0.2844 \text{ rad.}$$

$$\ell = (2)(41.75)(.2844) = 23.75 \text{ in.}$$

The minimum yield bearing capacity of the .19 x 1.50" bearing ring (AISI 1018 or A-36) is:

$$F_B = (23.75)(1.50)\ (36{,}000) = 1{,}282{,}500 \text{ lbs.}$$

The associated Margin of Safety is:

$$M.S. = \frac{1{,}282{,}500}{1{,}121{,}000} - 1 = \underline{+ 0.03}$$

The lateral load transferred between the lid and the cask is estimated as 1,171,000 lbs. The load is initially transferred from the exterior lid plate to the interior lid plate via a 1/2" circumferential bevel weld. The interior lid plate transfers this load to the cask body by direct compression. This compressive load is transferred across a deeply stepped recess of the interior lid plate within the cask inner cavity. The load yield capability of the circumferential lid weld is:

$$F_w = F_s A_s = F_s \cdot \pi D \cdot t_w$$

$$= (21,000)(\pi)(77.25)\ (.5) = 2,548,224 \text{ lbs.}$$

The associated Margin of Safety is:

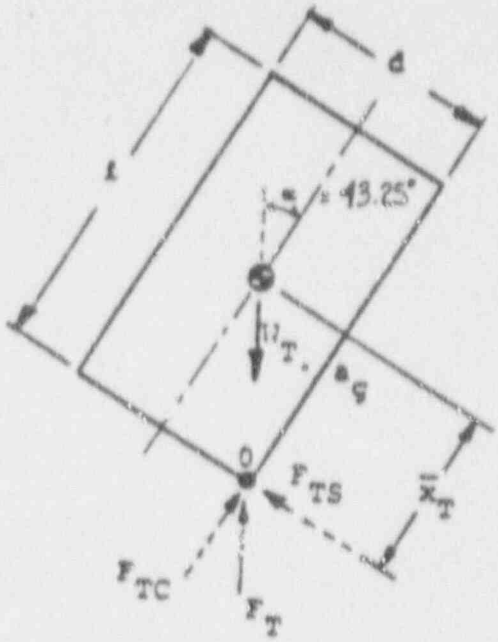
$$M.S. = \frac{2,548,224}{1,171,000} - 1 = +1.18$$

Therefore, it can be concluded that the package can survive a normal corner drop on the top corner.

The damage to the area immediately adjacent to the impact crush zone for the bottom corner drop is minimal. The base plate-to-outer shell weld is partially crushed but this does not affect the cask integrity. The drain plug is located well outside the crush area and therefore, will not be damaged.

The integrity of the cask base can be demonstrated for the bottom corner drop using the base interface forces given in Table 2.6.6.3-3.

The interface forces result from body force loads imposed upon the cask, payload and lid as indicated in the following free body diagrams:



Where:

$\alpha = \tan^{-1}(d/\ell)$

W_T = total weight

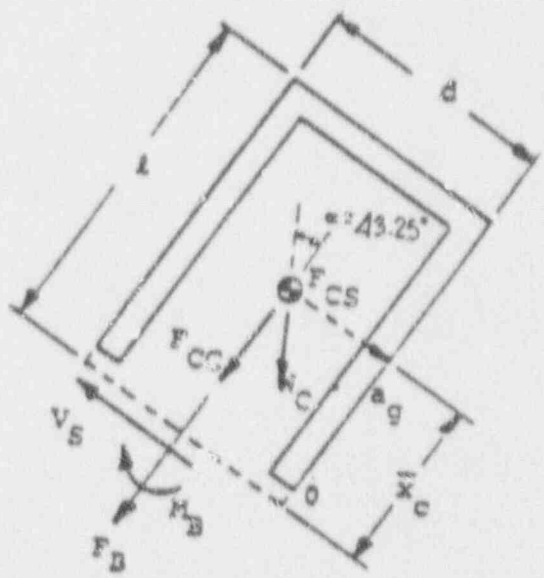
a_g = load factor

$F_T = W_T a_g$, total impact force

$F_{TC} = F_T \cos\alpha$, longitudinal impact force

$F_{TS} = F_T \sin\alpha$, lateral impact force

The cask body (sides and bottom) internal forces are:



Where:

W_c = weight of cask

$F_{cc} = W_c\ a_g \cos\alpha$

$F_{cs} = W_c\ a_g \sin\alpha$

F_B, V_S & M_B are unknown lid interface forces and moments, respectively.

Similarly, the payload forces are:

$F_{pc} = W_p a_g \cos\alpha$ at $\bar{x}_p$

$F_{ps} = W_p a_g \sin\alpha$

Where:

W_p = payload weight

TABLE 2.6.6.3-3

CASK BASE LOADS DUE TO BOTTOM IMPACT

CASK MODEL	WEIGHT (lbs)	INSIDE DIAMETER (in.)	OUTSIDE DIAMETER (in.)	OUTSIDE HEIGHT (in.)	LOAD FACTOR (g's)	INTERFACE FORCES AXIAL (lb.) x10^{+6}	SHEAR (lb.) x10^{+6}	MOMENT (in-lb) x10^{+6}
14-215	58,400	77.25	83.5	88.75	32.6	1.237	1.191	52.75

Now, based upon the payload and cask body forces, the lid interface forces F_B, V_S and M_B can be estimated:

Axial: $F_B + F_{cc} + F_{pc} = 0$

$F_B = -a_g (W_c + W_p) \cos \alpha$

Shear: $V_S - F_{cs} - F_{ps} = 0$

$V_S = a_g (W_c + W_p) \sin \alpha$

Moment: $M_V + F_{cs} \ddot{x}_c + F_{ps} \ddot{x}_p = 0$

$M_B = -a_g (W_c \bar{x}_c + W_p \bar{x}_p) \sin \alpha$

Assuming that the stress due to the moment varies linearly with distance from the cask center, the stress due to the moment can be calculated using simple beam theory. Assuming that the base plate-to -outer shell weld carries the entire load:

$$f_t = \frac{F_B}{\pi D t}$$

Where:

$F_B = 1,237,000$ lb.

$D = 83.5 - 2(0.875) = 81.75$ in.

$t = .5 + .707(.75) = 1.03$ in.

$$f_t = \frac{1,237}{\pi (81.75)(1.03)} = 4,676 \text{ psi}$$

$$f_b = \frac{M_B c}{I}$$

Where:

$M_B = 50,750,000$ in-lbs.

$C = 81.75/2 = 40.88$

$I = \pi(r)^3 t = \pi(40.88)^3(.88) = 188,802 \text{ in.}^4$

$$f_b = \frac{50,750,000 \ (40.88)}{188,802} = 10,989 \text{ psi}$$

Summing the forces:

$f_T = 10,989 + 4676 = 15,655$ psi

The Margin of Safety is:

$$M.S. = \frac{21,000}{15,655} - 1 = \underline{+.34}$$

Assume that the shear component V_s is carried entirely by the .5 inch fillet weld joining the two base plates.

$$f\nu = \frac{V_s}{A_w}$$

Where:

V_s = 1,191,000 lbs.

$A_w = \pi(81.75 - 2(1.5))\ (.707)(.5) = 87.46\ \text{in.}^2$

$$f\nu = \frac{1,191,000}{87.46} = 13,618\ \text{psi}$$

Margin of Safety is:

$$M.S. = \frac{21,000}{13,618} - 1 = \underline{+.54}$$

The maximum bending stress in the base can be evaluated by applying a pressure loading which reflects the payload weight and the weight of the base plates. Conservatively use the loadings from the lid analysis and consider the base to be simply supported plate with a diameter of 83.5". Applying the 138.6 psi load over the entire plate the moment becomes (using Table 24 Case 10 from Roark):

K_{Mc} = .20625

$$M = K_{Mc} q a^2$$

$$= .20625\ (138.6) \left[\frac{83.5}{2}\right]^2 = 49830\ \text{in-lb/in}$$

Bending stress is then

$$f_b = \frac{6Mc}{t^2} = \frac{6(49830)}{16} = 18690\ \text{psi}$$

$$M.S. = \frac{38,000}{18,690} - 1 = \underline{+1.03}$$

The ability of the plates to act as a composite can be inferred from the results of the finite element analysis used for the lid evaluation where a much higher bending stress resulted in a relatively small weld stress. (See Appendix 2.10.6).

Thus, the cask base is seen to be capable of withstanding the corner drop impact and maintaining the cask integrity.

2.6.7 Corner Drop

This requirement is not applicable since the 14-215 cask is fabricated of steel.

2.6.8 Penetration

From previous container tests, as well as engineering judgment, it can be concluded that the 13 pound rod would have a negligible effect on the heavy gauge steel shell of the cask.

2.7 HYPOTHETICAL ACCIDENT CONDITIONS

Not applicable for Type "A" packages.

2.8 SPECIAL FORM

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

2.9 FUEL RODS

Not applicable.

2.10 APPENDIX

2.10.1 Intentionally Blank

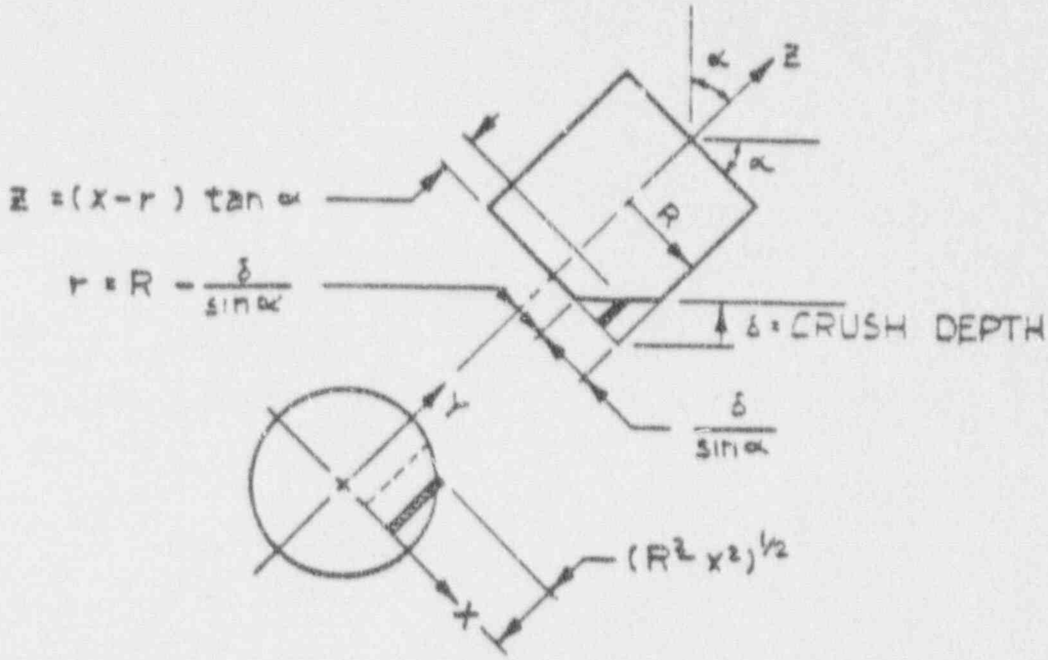
APPENDIX 2.10.2

VOLUME AND AREA ESTIMATES CORNER IMPACT ON A CYLINDER

1.0 Volume Estimates

1.1 Total Volume

The geometry and nomenclature of this model is:



The volume of the shaded differential slice shown is:

$$dV = (R^2-x^2)^{\frac{1}{2}} Z \, dx$$

$$= (R^2-x^2)^{\frac{1}{2}} \cdot (x-r) \sin \alpha \, dx$$

The total volume is:

$$V_t = 2 \tan\alpha \int_r^R (R^2-x^2)^{\frac{1}{2}} (x-r) \, dx$$

Evaluation gives:

$$V_t = 2 \tan\alpha \left\{ \frac{(R^2-r^2)^{3/2}}{3} + \frac{r^2}{2} (R^2-r^2)^{\frac{1}{2}} - \frac{rR^2}{2} \left[\frac{\pi}{2} - \sin^{-1}\left(\frac{r}{R}\right)\right]\right\}$$

Or:

$$V_t = 2 \tan \alpha \left\{ \frac{t^3}{3} + \frac{r^2 t}{2} - \frac{rR^2}{2} \left[\frac{\pi}{2} - \sin^{-1} \left(\frac{r}{R}\right)\right]\right\}$$

Where:

$$t = (R^2-r^2)^{\frac{1}{2}}; \quad r = R - \frac{\delta}{\sin\alpha}$$

1.2 Component Volumes

The steel volume is composed of side and bottom portions:

$$V_s = V_{side} + V_{bot}$$

$$V_{side} = R\Theta\ (R-r)t_s\ \tan\alpha$$

$$V_{bot} = t_b\ [\Theta R^2 - rR\ \sin\Theta]$$

Where:

$$\Theta = \cos^{-1}\left(\frac{r}{R}\right)$$

t_s = external steel side thickness (in)

t_b = steel end thickness (in)

The lead area represents the residual

$$V_\ell = V_t - V_s;\ (V_t - V_s) > 0$$

$$= 0 \qquad ;\ (V_t - V_s) < 0$$

2.0 Area Estimates

2.1 Total Area

The differential contact area is:

$$dA = \left(\frac{R^2 - x^2}{\cos\alpha}\right)^{1/2} \cdot dx$$

The total area is:

$$A_t = \frac{2}{\cos\alpha} \int_r^R (R^2 - x^2)^{1/2}\ dx$$

2.2 Component Areas

The steel area (of the side walls) is:

$$A_s = 2t_s R\Theta \cdot \left[1 + \frac{\sin\Theta}{\Theta} \cdot \left(\frac{1}{\cos\alpha} - 1\right)\right]$$

The lead area is the residual:

$$A_\ell = A_t - A_s;\ (A_t - A_s) > 0$$

$$= 0 \qquad ;\ (A_t - A_s) < 0$$

3.0 Strain Energy Estimates

3.1 Flow Stress Approach

$$S.E. = V_s \cdot \sigma_{sp} + V_\ell \cdot \sigma_{\ell p}$$

Where:

σ_{sp} = steel flow stress

$\sigma_{\ell p}$ = lead flow stress

3.2 Crush Stress Approach

$$S.E. = \frac{1}{2} \sum_i \left[(F_i + F_{i-1}) (\delta_i - \delta_{i-1}) \right]$$

Where:

$F_i = A_{s_i} \sigma_{sc} + A_{\ell_i} \sigma_{\ell c}$

σ_{sc} = steel crush stress

$\sigma_{\ell c}$ = lead crush stress

δ_i = assumed crush depth at the i^{th} step

APPENDIX 2.10.3

CASK BINDER SPECIFICATION

1.0 Binder

Reference Drawing STD-02-077 for design details.

1.1 Bolt Strength

Bolt yield capacity is (for a 1-1/4-12UNF, ASTM A320, Grade L-7)

$$P_y = F_{ty}A = (105,000)\ (1.073) = 112,665 \text{ lbs.}$$

1.2 Lug Strength

(Ref. Hughes Structures Methods Manual, Section 4.4, Lugs, on following pages)

Lug Yield Capacity is:

$$P_y = 2KDty\ F_{ty}$$

Where:

K = Efficiency Factor (Use W/D Ratio in Figure 4.4.1-1)

$\frac{W}{D} = \frac{3.00}{1.13} = 2.65$

K = 1.51

D = 1.13

t = .94

y = Yield Factor (Use K Factor in Figure 4.4.1-2)

= 1.05

F_{ty} = 38,000 (ASTM A-516, Grade 70)

P_y = 2(1.51) (1.13) (.94) (1.05) (38,000) = 127,993 lbs.

1.3 Pin Strength: (Ref. Drawing STD-07-077, Note 13)

Upper Pin: Double shear yield capacity = 117,000 lbs.

Lower Pin: 1" Dia, Grade 8 bolt

$$P_y = 2F_{sy}A$$

Where:

$$F_{sy} = (.6)\ (130{,}000) = 78{,}000 \text{ psi}$$

$$A \quad = \frac{\pi}{4} (1)^2 = .785 \text{ in.}^2$$

$$P_y \quad = 2(78{,}000)\ (.785) = 122{,}460 \text{ lbs.}$$

Rated binder capacity is 100,000 lbs. Bolt yield capacity is the minimum at 112,665 lbs. The resulting Margin of Safety is:

$$\text{M.S.} = \frac{P_y}{P} - 1 = \frac{112{,}665}{100{,}000} - 1 = \underline{+\ 0.13}$$

STRUCTURES METHODS MANUAL

Hughes Aircraft Company
Space Systems Division
El Segundo, California

February 1966

SSD 60048R

4.4 LUGS

The following analytical procedure should be used for the design of lugs and shear pins. This analysis is based on static loading and does not consider the effects of multiple applications of near-limit loads.

The design charts encompass the following types of failure for a lug-pin combination (see Figure 4.4-1):

1) Tension across net section

2) Shear tearout or bearing

3) Hoop tension at tip of lug

4) Pin shear

5) Pin bending

These charts represent envelopes of structural failure and are not identifible to a specific failure mode.

Lugs should be conservatively designed, as their weight is usually small in relation to their importance, and inaccuracies in manufacturing are difficult to control. Applicable fitting and casting factors shall always be used in the analysis. Margins of safety for presentation in the stress analysis report shall be based upon the pin size and lug hole diameter shown on the engineering drawing.

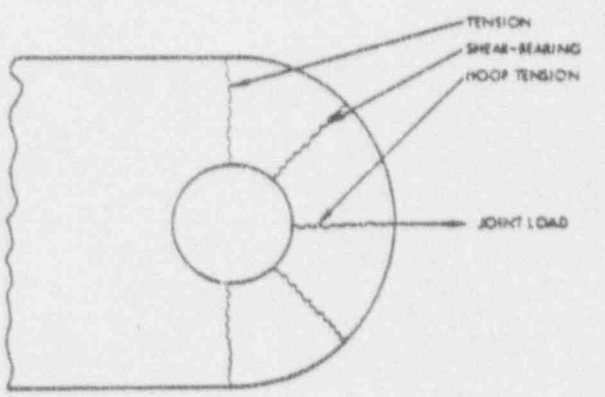


Figure 4.4-1. Failure Modes

4.4.1 Symmetrically Loaded Lugs

Axial Load

1) Allowable ultimate axial load

   a) Enter Figure 4.4.1-1 with R/D and W/D to obtain the minimum K. Use the appropriate W/D curves indicated by the material classification in Table 4.4.1-1.

   b) Compute allowable load by $P_u = KDtF_{tu}$.

   c) Compute the margin of safety in the normal manner.

2) Allowable yield axial load

   a) Enter Figure 4.4.1-2 with the minimum K determined in 1 above to obtain y.

   b) Compute the allowable load by $P_y = y\ (F_{ty}/F_{tu})\ P_u$ (Lug yielding is based on a permanent set of 0.02 times the pin diameter).

   c) Compute the margin of safety in the normal manner.

Lateral Load

1) Allowable ultimate lateral load

   a) Compute the allowable ultimate axial load per above mentioned procedure.

   b) Enter Figure 4.4.1-3 with θ, angle of load application, to obtain (P_θ/P). Use the appropriate curve indicated by the material classification in Table 4.4.1-1.

   c) Compute allowable load by $P_\theta = (P_\theta/P)P_u$.

   d) Compute the margin of safety in the normal manner.

2) Allowable yield lateral load

   a) Compute the allowable yield axial load as previously mentioned in the axial load procedure.

   b) Enter Figure 4.4.1-3 with θ, angle of load application, to obtain (P_θ/P). Use curve 2 only.

   c) Compute allowable load by $P_\theta = (P_\theta/P)P_y$.

   d) Compute the margin of safety in the normal manner.

TABLE 4. 1. 1-1. MATERIAL CLASSIFICATION

Material	Applicable W/D Curves for Critical Grain Direction - Fig. 4. 4. 1-1[2, 3]			Laterally Loaded Lugs[1] Fig. 4. 4. 1-3
	Longi-tudinal	Long Trans-verse	Short Trans-verse	
Carbon and alloy steels - AISI grades	1	1	1	1
18-8 stainless steels	4	4	4	4
2014-T6 plate	1	1	5	4
2014-T6 die forging	1	1	5	4
2014-T6 hand forged billet				
Area ≤ 36 square inches	1	1	5	4
Area > 36 square inches	1	3	5	4
2024-T4 extrusion	2	2	2	4
2024-T4 bar	2	2	5	4
2024-T3 plate	2	2	5	3
2024-T4 plate ≤ 0. 5	2	2	5	3
> 0. 5				4
7075-T6 extrusion	1	1	1	4
7075-T6 plate t ≤ 1 inch	1	1	5	4
t > 1 inch	2	2	5	4
7075-T6 rolled bar	1	5	5	4
7075-T6 die forging	1	1	5	4
7075-T6 hand forged billet				
Area ≤ 16 square inches	1	2	5	4
16 square inches < area ≤ 36 square inches	1	3	5	4
Area > 36 square inches	2	3	5	4
195-T6 casting	3	3	3	4
220-T4 casting	3	3	3	3
356-T6 SC casting	3	3	3	4
356-T6 P. M. casting	3	3	3	4
Ti-6A1-4V forging	1	1	3	4
Mag. ZK60A die forging	1	1	3	4

* Use the curves designated herein for Figures 4. 4. 1-1 and 4. 4. 1-3

1 Use curve 2 for all yield computations

2 Curve A is to be used for all aluminum alloy, hand forged billet when the long transverse grain direction is the same as that critical for R/D shown in Figure 4. 4. 1-1

3 Curve B is to be used for all aluminum alloy plate, bar and hand forged billet when the short transverse grain direction is the same as that critical for R/D shown in Figure 4. 4. 1-1, and for die forgings when the lug contains the parting plane in a normal direction

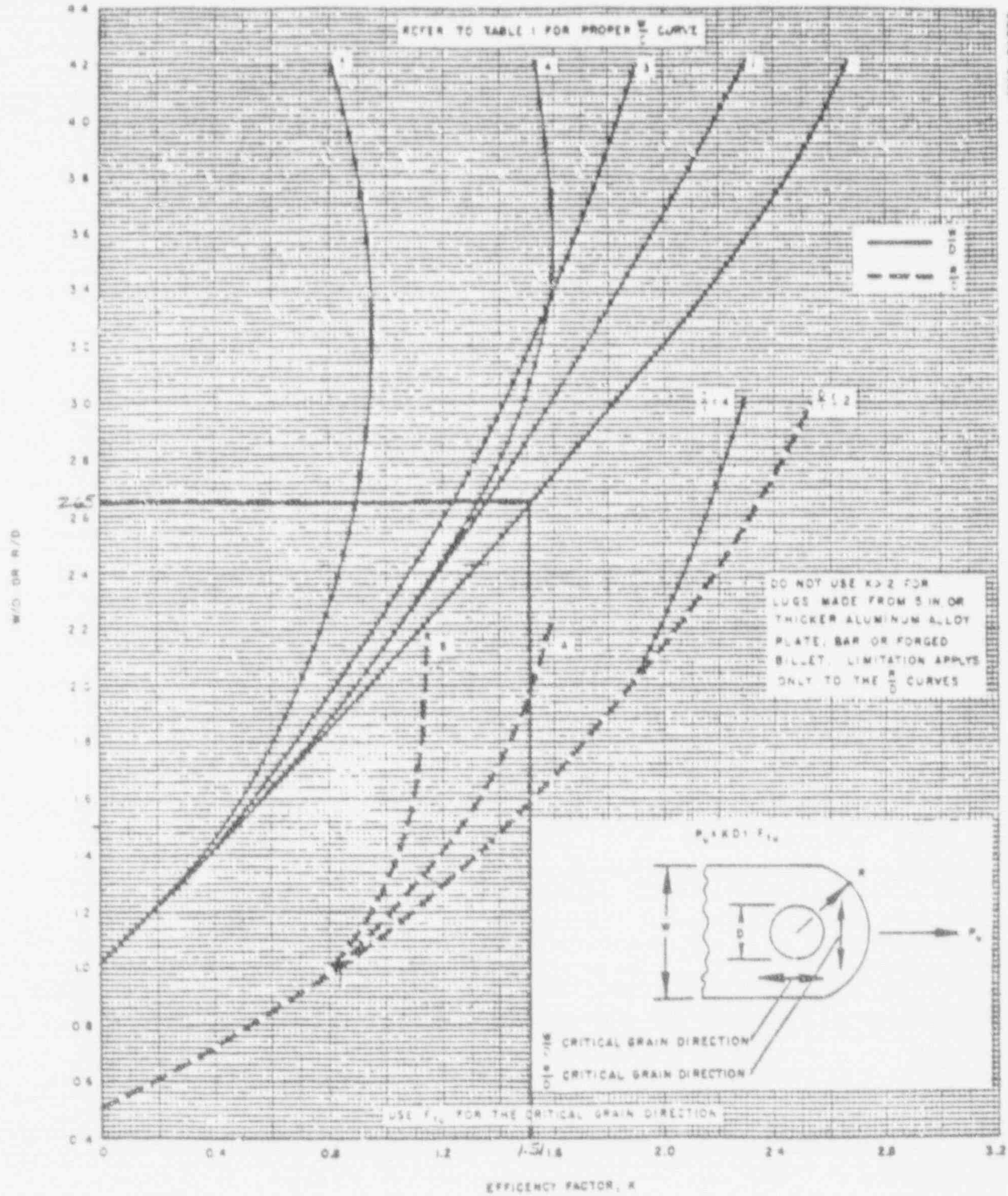


Figure 4.4.1-1. Axially Loaded Lug Design Chart

4.4.1-3

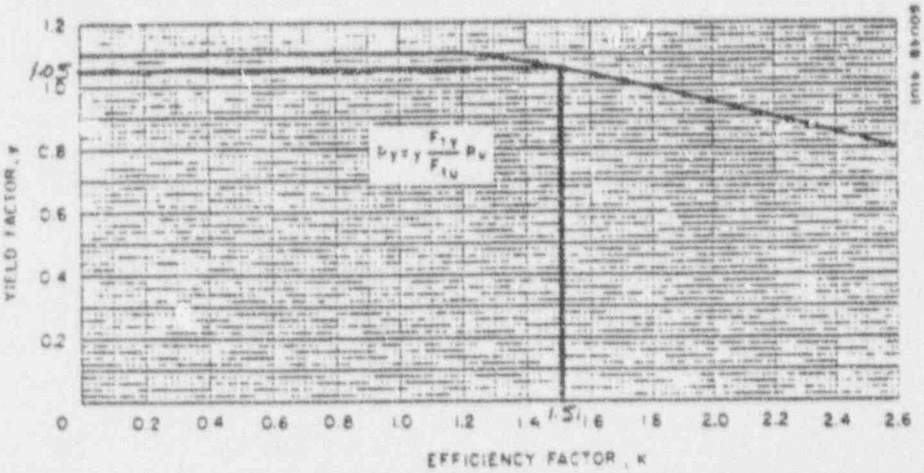


Figure 4.4.1-2. Yield Correction Factor for Axially Loaded Lugs

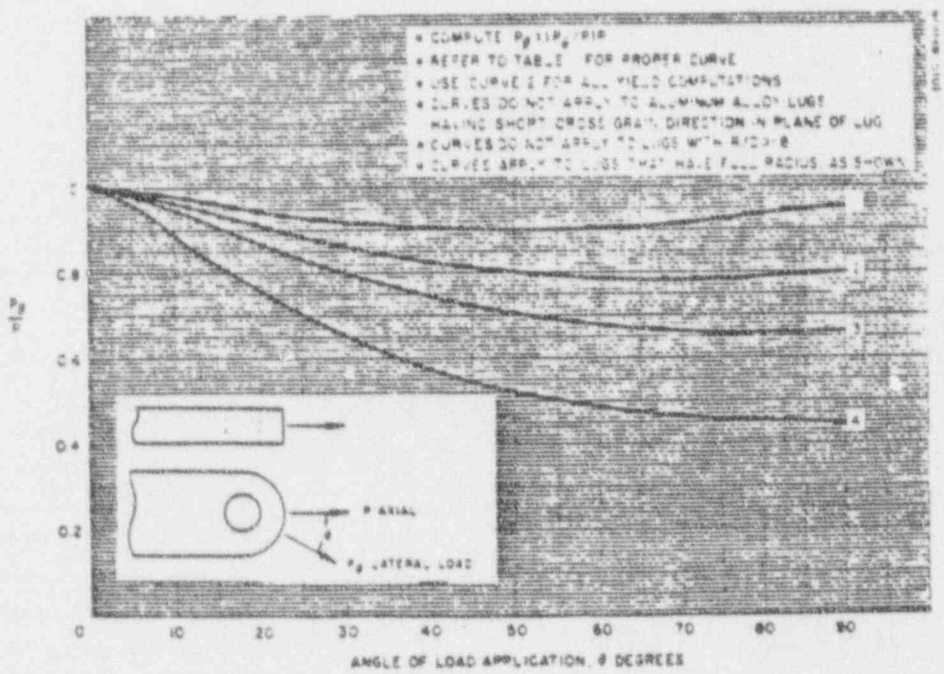


Figure 4.4.1-3. Allowable Laterial-Lug Loads

APPENDIX 2.10.4

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APPENDIX 2.10.5

ANSYS CAPABILITIES

ANSYS USER'S MANUAL

ABSTRACT

The ANSYS computer program is a large-scale general purpose computer program for the solution of several classes of engineering analysis problems. Analysis capabilities include static and dynamic; elastic, plastic, creep and swelling; buckling; small and large deflections; steady state and transient heat transfer and fluid flow.

The matrix displacement method of analysis based upon finite element idealization is employed throughout the program. The library of finite elements available numbers more than forty for static and dynamic analyses, and twenty for heat transfer analyses. This variety of elements gives the ANSYS program the capability of analyzing two- and three-dimensional frame structures, piping systems, two-dimensional plane and axisymmetric solids, three-dimensional solids, flat plates, axisymmetric and three-dimensional shells and nonlinear problems including interfaces and cables.

Loading on the structure may be forces, displacements, pressures, temperatures or response spectra. Loadings may be arbitrary time functions for linear and nonlinear dynamic analyses. Loadings for heat transfer analyses include internal heat generation, convection and radiation boundaries, and specified temperatures or heat flows.

The ANSYS program uses the wave front (or "frontal") direct solution method for the system of simultaneous linear equations developed by the matrix displacement method, and gives results of high accuracy in a minimum of computer time. The program has the capability of solving large structures. There is no limit on the number of elements used in a problem. There is no "band width" limitation in the problem definition; however, there is a "wave front" restriction. The "wave front" restriction depends on the amount of core storage available for a given problem. Up to 576* degrees of freedom on the wave front can be handled in a large core. The wave front limitation tends to be restrictive only for analysis of arbitrary three-dimensional structures.

ANSYS has the capability of generating substructures (or superelements). These substructures may be stored in a library file for use in other analyses. Substructuring portions of a model can result in considerable computer time savings for nonlinear analyses.

Geometry plotting is available for all elements in the ANSYS library, including isometric, perspective, section views, and hidden line plots of three-dimensional structures. Plotting routines are also available for the plotting of stresses and displacements from two- and three-dimensional solid or shell analyses, mode shapes from dynamic analyses, distorted geometries from static analyses, transient forces and displacements vs. time curves from transient dynamic analyses, and stress-strain plots from plastic and creep analyses.

Postprocessing routines are available for algebraic modification, differentiation, and integration of calculated results. Root-sum-square operations may be performed on seismic modal results. Response spectra may be generated from dynamic analysis results. Results from various loading modes may be combined for harmonically loaded axisymmetric structures.

---
*An optional 1152 wave front is available on some very large computers.

The input data for the ANSYS program has been designed to make it as easy as possible to define the problem to the computer. Options for multiple coordinate systems in cartesian, cylindrical, or spherical coordinates are available, as well as multiple region generation capabilities to minimize the input data for repeating regions.

Sophisticated geometry generation capabilities are included for two-dimensional plane and axisymmetric structures and for intersecting three-dimensional shell and solid structures.

The ANSYS program capabilities are continually being enhanced by the addition of new or improved elements, new analysis capabilities, and new input, output and graphic techniques. The ANSYS USER'S MANUAL is modified periodically to reflect the latest additions.

4.63 QUADRILATERAL SHELL

This element has both bending and membrane capabilities. Both in-plane and normal loads are permitted. The element has six degrees of freedom at each node: translations in the nodal x, y, and z directions and rotations about the nodal x, y, and z axes. Another four-node shell element (STIF43), restricted to a rectangular or parallelogram shape, has rotated material axes and in-plane pressure capabilities available.

The quadrilateral shell has options for variable thicknesses, elastic foundation supports, suppressing extra shapes, and for concentrating pressure loadings. Stress stiffening and large rotation capabilities are included.

4.63.1 Input Data

The geometry, nodal point locations, loading, and the coordinate system for this element are shown in Figure 4.63.1. The element is defined by four nodal points, four thicknesses, an elastic foundation stiffness, and the orthotropic material properties. The material X-direction corresponds to the element x-direction. The shear modulus term is optional and if it is not included it is computed from the other input material properties.

The thickness is assumed to vary smoothly over the area of the element, with the thickness input at the four nodal points. If the element has a constant thickness, only TK(I) need be input. If the thickness is not constant, all four thicknesses must be input.

The elastic foundation stiffness (EFS) is defined as the pressure required to produce a unit normal deflection of the foundation. The elastic foundation capability is bypassed if EFS is less than, or equal to, zero.

The element loading can be either surface temperatures or pressure, or a combination of both. The positive direction of pressure is along the positive element z-axis. The pressure loading may be uniformly distributed over the face of the element (KEYSUB(2)=0), or a curved shell loading (KEYSUB(2)=1) consisting of an equivalent element load applied at the nodal points may be used. The latter loading produces more accurate stress results in curved shells because certain fictitious element bending stresses are eliminated.

The KEYSUB(1) option is used to suppress the extra displacement shapes as described in Section 4.0.6. The KEYSUB(1A) option allows deleting the nominal in-plane rotational stiffness as described in Section 4.0.7. A summary of the shell element parameters is given in Table 4.63.1. A general description of element input, including the special features, is given in Section 4.0.2.

4.63.2 Output Data

a) Printout - The printout associated with the shell element is summarized in Table 4.63.2. Several items are illustrated in Figure 4.63.2. A general description of element printout is given in Section 4.0.3. Line 2 includes the shear forces NX and NY in the element x and y faces, respectively (positive in the positive element z direction). The moments about the x face (MX), the moments about the y face (MY), and the twisting moment (MXY) are also printed in line 2. The forces and moments are calculated per unit length in the element coordinate system. The optional edge printout is valid only along free edges of the element.

The next three lines include the stresses for top, middle, and bottom element surfaces, respectively. The combined stresses SX and SY and the twisting stress TXY are the combination of the membrane stresses and the stresses corresponding to the caculated bending moments, respectively. The positive bending stresses occur on the top face of the element for the positive bending moments shown in Figure 4.63.3. Nodal stresses may be obtained from the POST25 printout, see Section 6.25.

b) Post Data - The post data associated with the shell element is shown below. The data are written on file TAPE12, if requested, as described in Section 4.0.4.

1. SX(MID)*TK	9-11. SX,SY,TXY[TOP]	33-35. XC,YC,ZC
2. SY(MID)*TK	2- 12-17. 9-11 @ [MID,BOT]	36-37. AREA,TTOP
3. TXY(MID)*TK	18-20. SMX,SMN,TMX[TOP]	3- 38-39. TBOT,PRESS
4-5. NX,NY	21-22. SIGE,A[TOP]	
1- 6-8. MX,MY,MXY	23-32. 18-22 @ [MID,BOT]	

4.63.3 Theory

The membrane stiffness is the same as for the membrane shell element (STIF41), including the extra shapes. The bending stiffness is formed from the bending stiffness of four triangular shell elements (STIF53). Two triangles have one diagonal of the element as a common side and two triangles have the other diagonal of the element as a common side. The stiffness is obtained from the sum of the four stiffnesses divided by two.

4.63.4 Assumptions and Restrictions

Zero area elements are not allowed. This occurs most often whenever the elements are not numbered properly. Zero thickness elements or elements tapering down to a zero thickness at any corner are not allowed. The applied transverse thermal gradient is assumed to be linear through the thickness and uniform over the shell surface.

An assemblage of flat shell elements can produce a good approximation to a curved shell surface provided that each flat element does not extend over more than a 15° arc. If an elastic foundation stiffness in input, one-fourth of the total is applied at each node. Shear deflection is not included in this thin-shell element.

A triangular element may be formed by defining duplicate K and L node numbers as described in Section 4.0.9. The extra shapes are automatically deleted for triangular elements so that the membrane stiffness reduces to a constant strain formulation.

The four nodal points defining the element should lie in an exact flat plane; however, a small out-of-plane tolerance is permitted so that the element may have a slightly warped shape. A slightly warped element will produce a warning message in the printout. If the warpage is too severe, a fatal message results and a triangular element should be used, see Section 4.0.9. The triangular shape is recommended for large deflection analyses since a four-node element may warp during deflection. The out-of-plane (normal) stress for this element is assumed to be zero.

TABLE 4.63.1

QUADRILATERAL SHELL

ELEMENT NAME	STIF63	
NO. OF NODES	4	I,J,K,L
DEGREES OF FREEDOM PER NODE	6	UX,UY,UZ,ROTX,ROTY,ROTZ
REAL CONSTANTS	5	TK(I),TK(J),TK(K),TK(L),EFS (TK(J),TK(K),TK(L) DEFAULT TO TK(I))
MATERIAL PROPERTIES	6	EX,EY,ALPX,ALPY,NUXY,DENS GXY (OPTIONAL) (DIRECTION I-J IS X)
PRESSURES	1	NORMAL PRESSURE ACTING ON FACE 1 (USE NEGATIVE PRESSURE FOR OPPOSITE LOADING)
TEMPERATURES	2	TTOP,TBOTTOM
SPECIAL FEATURES	STRESS STIFFENING, LARGE ROTATION	
KEYSUB(1)	0 - INCLUDE EXTRA DISPLACEMENT SHAPES 1 - SUPPRESS EXTRA DISPLACEMENT SHAPES	
KEYSUB(1A)	0 - ZIENKIEWICZ IN-PLANE ROTATIONAL STIFFNESS 1 - NO IN-PLANE ROTATIONAL STIFFNESS	
KEYSUB(2)	0 - FLAT SHELL PRESSURE LOADING 1 - CURVED SHELL PRESSURE LOADING	
KEYSUB(2B)	0 - NO EDGE PRINTOUT N - EDGE PRINTOUT AT EDGE N (N= 1,2,3 OR 4)	

****

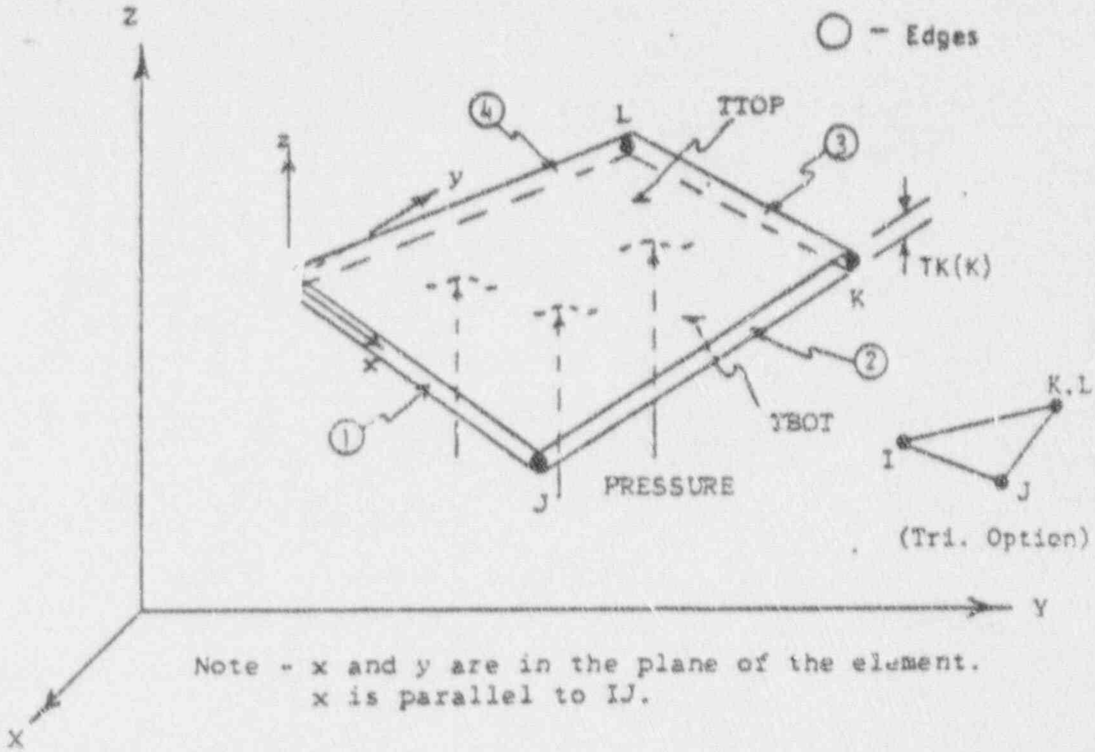


Figure 4.63.1 Quadrilateral Shell

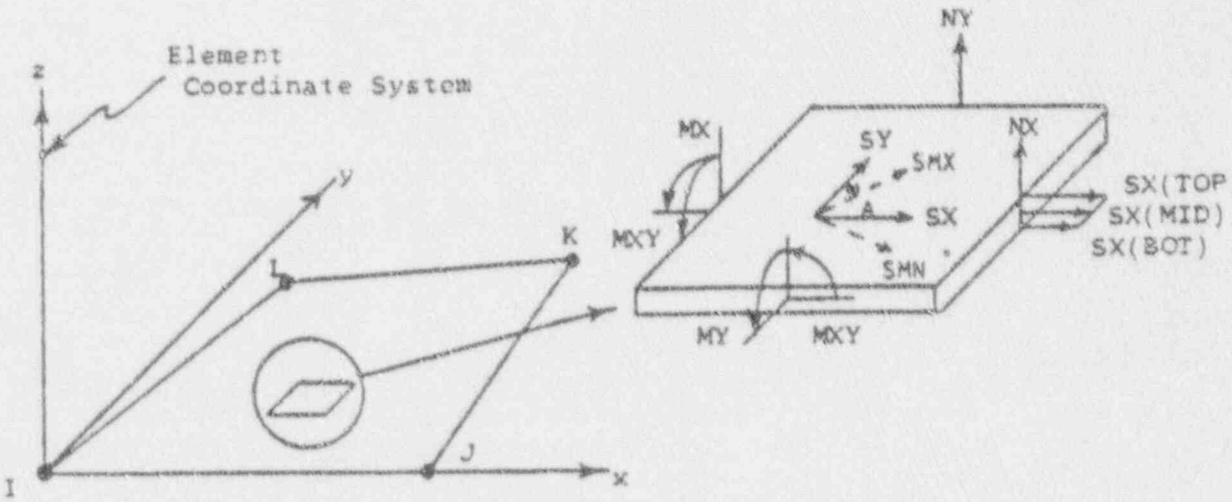


Figure 4.63.2 Quadrilateral Shell Output

TABLE 4.63.2

QUADRILATERAL SHELL

ELEMENT PRINTOUT EXPLANATIONS

LABEL	NUMBER OF CONSTANTS	FORMAT	EXPLANATION
LINE 1			
EL	1	I5	ELEMENT NUMBER
NODES	4	4I5	NODES - I,J,K,L
MAT	1	I3	MATERIAL NUMBER
AREA	1	G10.3	AREA
TTOP,TBOT	2	2F7.1	SURFACE TEMPERATURES - TOP,BOTTOM
PRESS	1	G11.4	SURFACE PRESSURE
LINE 2			
MX,MY,MXY	3	3G13.5	MOMENTS IN ELEMENT X AND Y DIRECTIONS
NX,NY	2	2G13.5	SHEAR FORCES
XC,YC,ZC	3	3G10.4	GLOBAL X,Y,Z LOCATION OF CENTROID
LINES 3 - 5			
LOC			TOP, MIDDLE, OR BOTTOM
SX,SY,TXY	3	3G12.5	COMBINED MEMBRANE AND BENDING STRESSES (ELEMENT COORDINATES)
SMX,SMN,TMX	3	3G12.5	PRINCIPAL STRESSES - SIGMAX,SIGMIN,TAUMAX
A	1	F6.1	ANGLE OF PRINCIPAL STRESSES RELATIVE TO ELEMENT X-Y AXES
SIGE	1	G12.5	EQUIVALENT STRESS
LINES 6-9	EDGE PRINTOUT (PRINTED ONLY IF KEYSUR(2B) = 1,2,3, OR 4)		
LOC	2	2I6	EDGE NODES
FORCE/LENGTH	8	8G13.5	(SX,SY,TXY AT EDGE) * (THICKNESS), MX,MY,MXY AT EDGE, NX,NY AT EDGE
STRESSES	8	8G13.5	SX,SY,TXY AT EDGE, (MX,MY,MXY AT EDGE) * (6/(THICKNESS**2)), (NX,NY AT EDGE) * (1.5/THICKNESS)

****

STIF63

APPENDIX 2.10.6

CASK LID ANALYSIS

The 14-215 cask lid was analyzed for a pressure load plus a ring load which simulated the axial impact force imposed on the lid due to its own weight and the weight of the payload. The lid was modelled and analyzed using ANSYS (See Appendix 2.10.5).

The lid was considered to be two circular plates connected by two continuous welds as shown in figures 2.10.6-1&2. The remaining interface between the plates was represented with gap elements which allowed compressive load transfer but no tensile loads. A coefficient of friction of .5 was used to model the contact friction between plates. A 10 psi pressure was applied to the entire lower surface of the lower plate. A corresponding ring load was applied to the upper surface of the upper plate at a radius of 16" to represent the secondary lid loading. The upper plate was simply supported at its outer edge.

The stresses resulting from the analysis are given on the following pages. The maximum stress is found in Element 1 with a stress intensity of 2450.5 psi. As expected, the stresses decrease with increasing radius. Note also that stresses Elements 8 & 9 and 150 & 151 are relatively low indicating the welds allow the 2" plates to act together as a 4" composite plate.

Figure 2.10.6-1

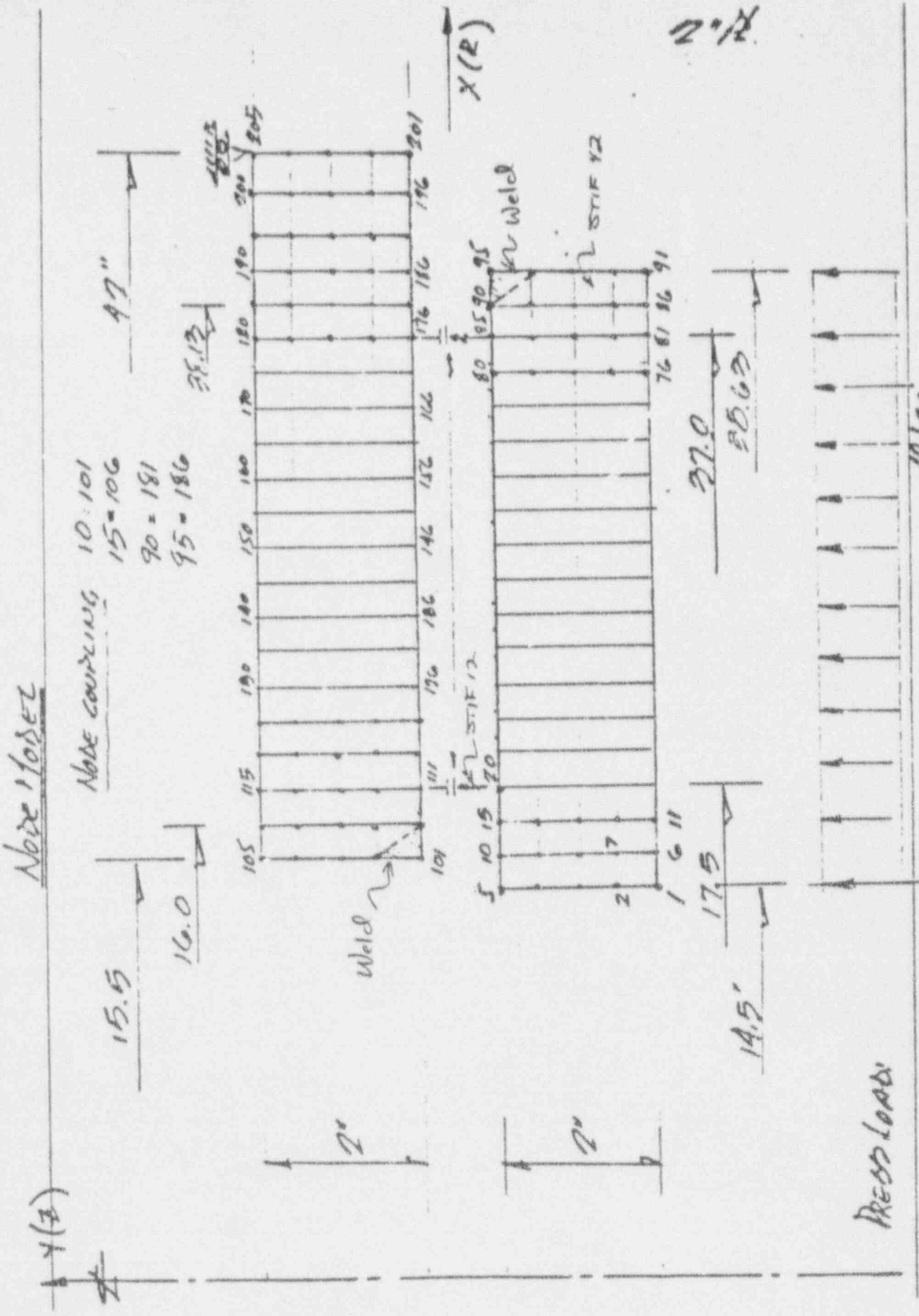
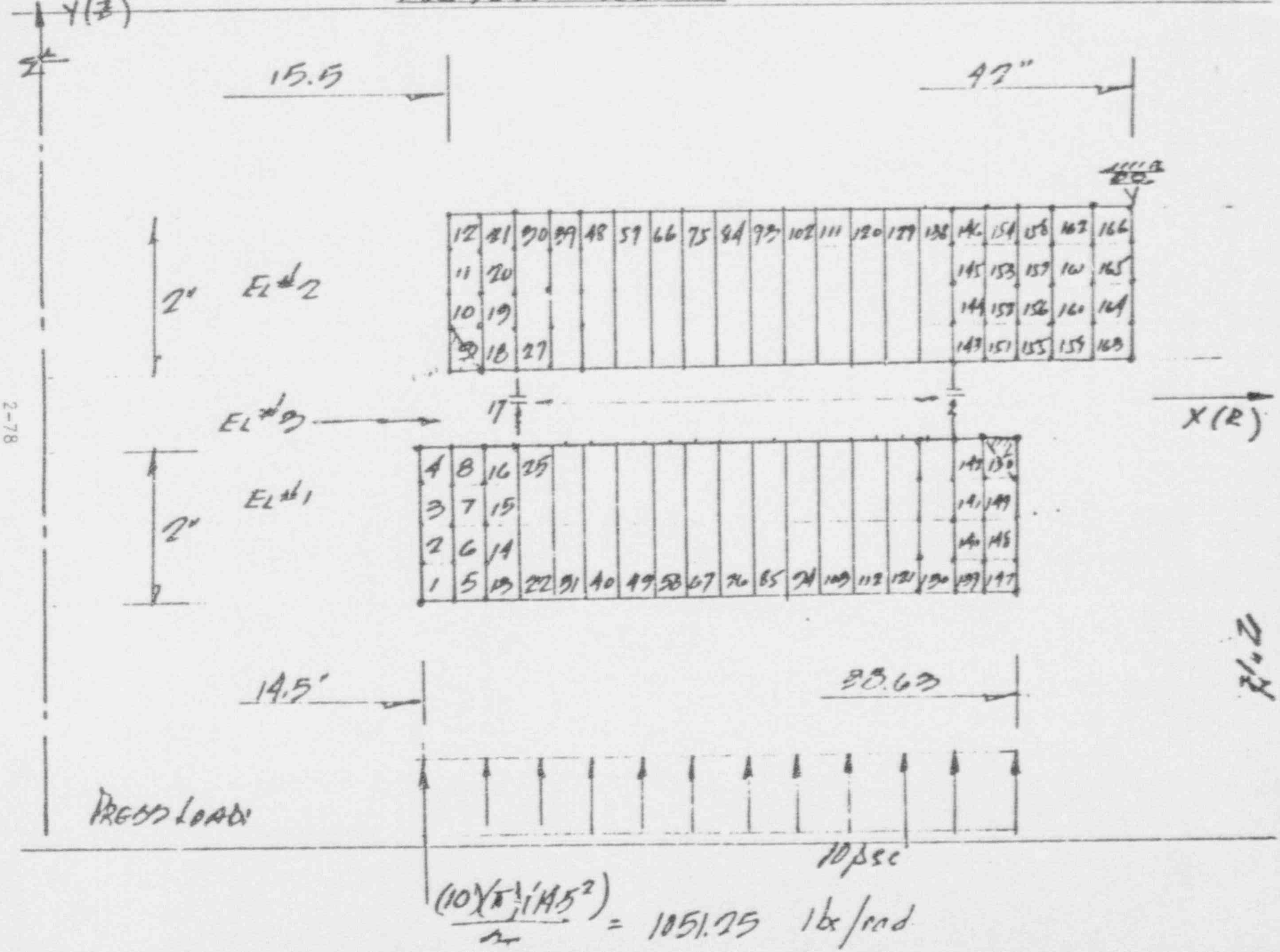


Figure 2.10.6-2

ELEMENT MODEL



STEEL PROPS — MAT'L #1 (ASTM-516-GR70)

$E = 27.9 \times 10^6$

$\mu = .3$ $\rho = 0$

$\alpha = 6.5 \times 10^{-6}$

ELEMENTS #1 & #2 (STEEL) [STIF 42]

• MAT'L #1

• KEYOPT (1) = 1 N. REAL CONSTS

(14) = 0

(15) = 0

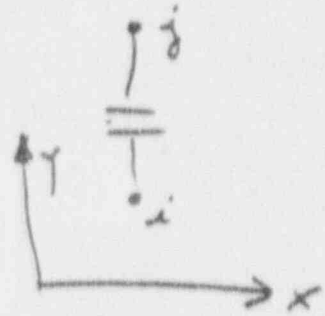
(9) = 0

(24) = 0

ELEM #3 (GAP) [STIF 12]

KEYOPT (1) = 1

(2) = 0



REAL CONSTANTS

(1) $\theta = 0$

(2) $K = \frac{AE}{l} = \frac{(1.5\pi)(1.5)(29 \times 10^6)}{.1} = 20.5 \times 10^9$

(3) INTERF $= \frac{F}{K} = \frac{10(1.5\pi)(15)}{K} = 34 \times 10^{-9}$

(4) START = 1 $= 3. \times 10^{-8}$

MU = .3

0024k

```
              ANSYS - ENGINEERING ANALYSIS SYSTEM   REVISION 3   UPDATE 67L  BCS NOS  JUNE 1,1979
       SWANSON ANALYSIS SYSTEMS, INC.        HOUSTON, PENNSYLVANIA 15342   PHONE (412) 746-3304

ANALYSIS - 14-215 PACKAGE, NOMINAL 10 PSIG PRESSURE                          16.7356   2/ 3/83 CP=   30.537

*** ELEMENT STRESSES *****  TIME =  0.              LOAD STEP=   3   ITERATION= 10   CUM. ITER.=  20                      SR

   1  NODES-     1    6     7    2         MAT=  1   VOL=  7.500                                                2-D SOLID  42
C=  15.00     -1.750      TEMP=  70.0  A=  85.4  S.I.=  2450.5          SIGE=  2441.2
SY,TXY,SZ=  -90.843       -108.52        1.4824      -2540.4     SMX,SMN,TMX=  -89.924        -108.64        9.3588

   2  NODES=     2    7     8    3         MAT=  1   VOL=  7.500                                                2-D SOLID  42
C=  15.00     -1.250      TEMP=  70.0  A=  89.2  S.I.=  1771.2          SIGE=  1723.8
SY,TXY,SZ=  -32.313       -131.27        1.4041      -1803.5     SMX,SMN,TMX=  -32.293        -131.29       49.500

   3  NODES=     3    8     9    4         MAT=  1   VOL=  7.500                                                2-D SOLID  42
C=  15.00     -.7500      TEMP=  70.0  A= -74.5  S.I.=  1131.2          SIGE=  1033.5
SY,TXY,SZ=   50.244       -152.31       -41.047 -    -1064.0     SMX,SMN,TMX=   67.222        -169.29       118.25

   4  NODES=     4    9    10    5         MAT=  1   VOL=  7.500                                                2-D SOLID  42
C=  15.00     -.2500      TEMP=  70.0  A= -40.1  S.I.=  366.29          SIGE=  317.23
SY,TXY,SZ=  -118.19       -86.114       -91.951      -375.10     SMX,SMN,TMX=  -8.8138        -195.49       93.339

   5  NODES=     6   11    12    7         MAT=  1   VOL=  3.938                                                2-D SOLID  42
C=  15.75     -1.750      TEMP=  70.0  A=  11.9  S.I.=  2441.9          SIGE=  2385.5
SY,TXY,SZ=  -251.74        25.164        61.247      -2403.8     SMX,SMN,TMX=   38.186        -264.68       151.39

   6  NODES=     7   12    13    8         MAT=  1   VOL=  3.933                                                2-D SOLID  42
C=  15.75     -1.250      TEMP=  70.0  A=  31.8  S.I.=  1716.8          SIGE=  1631.9
SY,TXY,SZ=  -101.87       -26.244        82.393      -1685.2     SMX,SMN,TMX=   30.891        -153.00       91.947

   7  NODES=     8   13    14    9         MAT=  1   VOL=  3.938                                                2-D SOLID  42
C=  15.75     -.7500      TEMP=  70.0  A=  73.7  S.I.=  1109.3          SIGE=  1007.2
SY,TXY,SZ=   157.92       -54.686        67.860      -933.56     SMX,SMN,TMX=   177.74        -74.426       126.08

   8  NODES=     9   14    15   10         MAT=  1   VOL=  3.938                                                2-D SOLID  42
C=  15.75     -.2500      TEMP=  70.0  A= -55.9  S.I.=  513.53          SIGE=  511.37
SY,TXY,SZ=   4.1204       -184.42       -236.50      -349.09     SMX,SMN,TMX=   164.44        -344.74       254.59

   9  NODES=   101  106   107  102         MAT=  1   VOL=  3.938                                                2-D SOLID  42
C=  15.75      .2500      TEMP=  70.0  A= [illegible]  S.I.=  742.96          SIGE=  737.36
SY,TXY,SZ=  -214.04        113.66       -327.07       326.95     SMX,SMN,TMX=   315.63        -416.01       365.82

  10  NODES=   102  [illegible]   108  103         MAT=  1   VOL=  3.938                                                2-D SOLID  42
C=  15.75      .7500      TEMP=  70.0  A=  10.8  S.I.=  1157.9          SIGE=  1028.8
SY,TXY,SZ=  -82.188        242.16        64.244       1063.4     SMX,SMK,TMX=   254.42        -94.449       176.43

  11  NODES=   103  108   109  104         MAT=  1   VOL=  3.938                                                2-D SOLID  42
C=  15.75      1.250      TEMP=  70.0  A=  34.2  S.I.=  1770.3          SIGE=  1676.4
SY,TXY,SZ=   56.449        132.85        96.290       1761.4     SMX,SMN,TMX=   198.24        -8.9415       103.59

  12  NODES=   104  109   110  105         MAT=  1   VOL=  3.938                                                2-D SOLID  42
C=  15.75      1.750      TEMP=  70.0  A=  60.9  S.I.=  2421.7          SIGE=  2382.7
SY,TXY,SZ=   66.955        24.960        34.013       2427.7     SMX,SMN,TMX=   85.925         5.9700       39.978

  13  NODES=    11   16    17   12         MAT=  1   VOL=  12.56                                                2-D SOLID  42
C=  16.75     -1.750      TEMP=  70.0  A=   3.2  S.I.=  2323.4          SIGE=  2121.9
SY,TXY,SZ=  -488.80       -3.9776        27.597      -2325.8     SMX,SMN,TMX=  -2.4117        -490.36       243.98

  14  NODES=    12   17    18   13         MAT=  1   VOL=  12.56                                                2-D SOLID  42
```


STD-R-02-016

MAR 2 0 [illegible]

```
 XC,YC=  16.75     -1.250      TEMP=  70.0  A=  12.5  S.I.=  1597.1          SIGE=  1513.5
  SX,SY,TXY,SZ=  -141.69       25.228       38.870      -1563.3      SMX,SMN,TMX=   33.811      -150.27       92.041

 EL=   15  NODES=   13   18   19   14       MAT=  1   VOL=  12.56                                                   2-D SOLID  42
 XC,YC=  16.75     -.7500      TEMP=  70.0  A= -85.4  S.I.=  992.64          SIGE=  934.28
  SX,SY,TXY,SZ=   182.01       53.236      -10.347      -889.81      SMX,SMN,TMX=   182.83       52.410       65.212

 EL=   16  NODES=   14   19   20   15       MAT=  1   VOL=  12.56                                                   2-D SOLID  42
 XC,YC=  16.75     -.2500      TEMP=  70.0  A= -79.8  S.I.=  827.88          SIGE=  813.68
  SX,SY,TXY,SZ=   849.77      101.64      -139.82       47.169      SMX,SMN,TMX=   875.05       76.360      399.34

 EL=   17  NODES=   20  111  USEP= -.000000  USLIDE= -.000133  FN= -34.510       FS= -17.255      STAT= -2  OLDST= -2   2-D GAP  12

 EL=   18  NODES=  106  111  112  107       MAT=  1   VOL=  12.56                                                   2-D SOLID  42
 XC,YC=  16.75      .2500      TEMP=  70.0  A= -10.3  S.I.=  954.26          SIGE=  940.62
  SX,SY,TXY,SZ=  -943.52      -76.400      -162.98      -18.875      SMX,SMN,TMX=  -46.778      -973.14      463.18

 EL=   19  NODES=  107  112  113  108       MAT=  1   VOL=  12.56                                                   2-D SOLID  42
 XC,YC=  16.75      .7500      TEMP=  70.0  A= -10.2  S.I.=  1076.6          SIGE=  1001.8
  SX,SY,TXY,SZ=  -234.77      -73.625      -29.815       856.49      SMX,SMN,TMX=  -68.284      -240.11       85.914

 EL=   20  NODES=  108  113  114  109       MAT=  1   VOL=  12.56                                                   2-D SOLID  42
 XC,YC=  16.75      1.250      TEMP=  70.0  A=  67.7  S.I.=  1650.8          SIGE=  1573.7
  SX,SY,TXY,SZ=   86.124      -33.230       58.918       1593.4      SMX,SMN,TMX=   110.31      -57.414       83.861

 EL=   21  NODES=  109  114  115  110       MAT=  1   VOL=  12.56                                                   2-D SOLID  42
 XC,YC=  16.75      1.750      TEMP=  70.0  A=  82.3  S.I.=  2348.7          SIGE=  2184.7
  SX,SY,TXY,SZ=   355.62      -8.1411       49.914       2333.9      SMX,SMN,TMX=   362.34      -14.866      188.60

 EL=   22  NODES=   16   21   22   17       MAT=  1   VOL=  13.69                                                   2-D SOLID  42
 XC,YC=  18.25     -1.750      TEMP=  70.0  A=  -1.9  S.I.=  2175.9          SIGE=  1939.2
  SX,SY,TXY,SZ=  -638.79      -9.8389      -20.642      -2185.1      SMX,SMN,TMX=  -9.1622      -639.46      315.15

 EL=   23  NODES=   17   22   23   18       MAT=  1   VOL=  13.69                                                   2-D SOLID  42
 XC,YC=  18.25     -1.250      TEMP=  70.0  A= -11.2  S.I.=  1456.7          SIGE=  1355.2
  SX,SY,TXY,SZ=  -210.95       4.7934      -44.374      -1443.2      SMX,SMN,TMX=   13.564      -219.72      116.64

 EL=   24  NODES=   18   23   24   19       MAT=  1   VOL=  13.69                                                   2-D SOLID  42
 XC,YC=  18.25     -.7500      TEMP=  70.0  A= -76.8  S.I.=  958.96          SIGE=  859.38
  SX,SY,TXY,SZ=   257.94       26.318      -57.377      -687.59      SMX,SMN,TMX=   271.37       12.883      129.24

 EL=   25  NODES=   19   24   25   20       MAT=  1   VOL=  13.69                                                   2-D SOLID  42
 XC,YC=  18.25     -.2500      TEMP=  70.0  A=  88.1  S.I.=  618.32          SIGE=  601.63
  SX,SY,TXY,SZ=   592.52      -24.439       20.526       9.7793      SMX,SMN,TMX=   593.28      -25.121      309.16

 EL=   26  NODES=   25  116  USEP= -.000000  USLIDE= -.000199  FN= -232.73       FS= -103.87      STAT=  1  OLDST=  1   2-D GAP  12

 EL=   27  NODES=  111  116  117  112       MAT=  1   VOL=  13.69                                                   2-D SOLID  42
 XC,YC=  18.25      .2500      TEMP=  70.0  A=   2.5  S.I.=  662.73          SIGE=  661.30
  SX,SY,TXY,SZ=  -653.23       6.9998       28.784       5.3743      SMX,SMN,TMX=   8.2524      -654.48      331.37

 EL=   28  NODES=  112  117  118  113       MAT=  1   VOL=  13.69                                                   2-D SOLID  42
 XC,YC=  18.25      .7500      TEMP=  70.0  A=  -9.0  S.I.=  1042.6          SIGE=  927.54
  SX,SY,TXY,SZ=  -337.20      -43.371      -47.659       697.85      SMX,SMN,TMX=  -35.834      -344.73      154.45

 EL=   29  NODES=  113  118  119  114       MAT=  1   VOL=  13.69                                                   2-D SOLID  42
 XC,YC=  18.25      1.250      TEMP=  70.0  A= -75.7  S.I.=  1487.2          SIGE=  1409.2
  SX,SY,TXY,SZ=   124.31      -26.558      -41.220       1450.2      SMX,SMN,TMX=   134.84      -37.085       85.963

 EL=   30  NODES=  114  119  120  115       MAT=  1   VOL=  13.69                                                   2-D SOLID  42
```

0024k

```
XC,YC=  18.25       1.750       TEMP=  70.0  A= -87.9  S.I.=  2199.2          SIGE=  1978.3
 SX,SY,TXY,SZ=   563.30         .13699       -20.744         2198.6       SMX,SMN,TMX=   564.07        -.62600        282.35

EL=   31  NODES=   21   26    27   22         MAT=  1   VOL=  14.81                                                          2-D SOLID  42
XC,YC=  19.75      -1.750       TEMP=  70.0  A=  -1.4  S.I.=  2032.0          SIGE=  1797.5
 SX,SY,TXY,SZ=  -657.19        -8.7012       -16.296        -2040.3       SMX,SMN,TMX=  -8.2919        -657.60        324.65

EL=   32  NODES=   22   27    28   23         MAT=  1   VOL=  14.81                                                          2-D SOLID  42
XC,YC=  19.75      -1.250       TEMP=  70.0  A=  -8.1  S.I.=  1336.9          SIGE=  1220.2
 SX,SY,TXY,SZ=  -260.85        -12.681       -36.104        -1344.4       SMX,SMN,TMX=  -7 5352        -266.03        129.23

EL=   33  NODES=   23   28    29   24         MAT=  1   VOL=  14.81                                                          2-D SOLID  42
XC,YC=  19.75      -.7500       TEMP=  70.0  A= -81.6  S.I.=  768.35          SIGE=  709.62
 SX,SY,TXY,SZ=   103.78        -28.022       -19.796        -661.66       SMX,SMN,TMX=   106.69        -30.931        68.811

EL=   34  NODES=   24   29    30   25         MAT=  1   VOL=  14.81                                                          2-D SOLID  42
XC,YC=  19.75      -.2500       TEMP=  70.0  A= -87.0  S.I.=  516.53          SIGE=  493.21
 SX,SY,TXY,SZ=   508.66        -4.9931       -27.222         44.107       SMX,SMN,TMX=   510.10        -6.4317        258.27

EL=   35  NODES=   30  121  USEP= -.000000  USLIDE= -.000270  FN= -163.75      FS= -81.874      STAT= -2  OLDST= -2   2-D GAP  12

EL=   36  NODES=  116  121   122  117         MAT=  1   VOL=  14.81                                                          2-D SOLID  42
XC,YC=  19.75       .2500       TEMP=  70.0  A=  -2.8  S.I.=  574.5E          SIGE=  559.33
 SX,SY,TXY,SZ=  -580.15        -8.2895       -27.941        -38.788       SMX,SMN,TMX=  -6.9275        -581.51        287.29

EL=   37  NODES=  117  122   123  118         MAT=  1   VOL=  14.81                                                          2-D SOLID  42
XC,YC=  19.75       .7500       TEMP=  70.0  A=  -5.[illegible]  S.I.=  842.78          SIGE=  764.44
 SX,SY,TXY,SZ=  -171.96         10.487       -18.819         668.99       SMX,SMN,TMX=   20.329        -173.80        97.063

EL=   38  NODES=  118  123   124  119         MAT=  1   VOL=  14.81                                                          2-D SOLID  42
XC,YC=  19.75       1.250       TEMP=  70.0  A= -79.7  S.I.=  1352.9          SIGE=  1265.0
 SX,SY,TXY,SZ=   192.84         6.1672       -35.120         1352.7       SMX,SMN,TMX=   199.23        -.22167        99.724

EL=   39  NODES=  119  124   125  120         MAT=  1   VOL=  14.81                                                          2-D SOLID  42
XC,YC=  19.75       1.750       TEMP=  70.0  A= -88.4  S.I.=  2049.2          SIGE=  1826.9
 SX,SY,TXY,SZ=   588.66        -1.4478       -16.392         2047.3       SMX,SMN,TMX=   589.12        -1.9020        295.51

EL=   40  NODES=   26   31    32   27         MAT=  1   VOL=  15.94                                                          2-D SOLID  42
XC,YC=  21.25      -1.750       TEMP=  70.0  A=  -1.3  S.I.=  1989.5          SIGE=  1680.0
 SX,SY,TXY,SZ=  -666.83        -8.9886       -15.505        -1918.2       SMX,SMN,TMX=  -8.6233        -667.19        329.29

EL=   41  NODES=   27   32    33   28         MAT=  1   VOL=  15.94                                                          2-D SOLID  42
XC,YC=  21.25      -1.250       TEMP=  70.0  A=  -5.9  S.I.=  1259.1          SIGE=  1134.2
 SX,SY,TXY,SZ=  -319.92        -9.1940       -32.540        -1264.9       SMX,SMN,TMX=  -5.8230        -323.[illegible]        158.74

EL=   42  NODES=   28   33    34   29         MAT=  1   VOL=  15.94                                                          2-D SOLID  42
XC,YC=  21.25      -.7500       TEMP=  70.0  A= -57.9  S.I.=  673.93          SIGE=  631.70
 SX,SY,TXY,SZ=   42.005         .41117       -42.873        -605.07       SMX,SMN,TMX=   68.859        -26.442        47.651

EL=   43  NODES=   29   34    35   30         MAT=  1   VOL=  15.94                                                          2-D SOLID  42
XC,YC=  21.25      -.2500       TEMP=  70.0  A= -87.9  S.I.=  400.47          SIGE=  376.54
 SX,SY,TXY,SZ=   394.64        -4.7023       -15.012         48.340       SMX,SMN,TMX=   395.20        -5.2658        200.2[illegible]

EL=   44  NODES=   35  126  USEP= -.000000  USLIDE= -.000321  FN= -228.43      FS= -114.22      STAT= -2  OLDST= -2   2-D GAP  12

EL=   45  NODES=  121  126   127  122         MAT=  1   VOL=  15.94                                                          2-D SOLID  42
XC,YC=  21.25       .2500       TEMP=  70.0  A=  -1.9  S.I.=  454.65          SIGE=  435.32
 SX,SY,TXY,SZ=  -459.64        -5.9944       -15.107        -47.150       SMX,SMN,TMX=  -5.4918        -460.14        227.33

EL=   46  NODES=  122  127   128  123         MAT=  1   VOL=  15.94                                                          2-D SOLID  42
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XC,YC=  21.25      .7500      TEMP=  70.0  A= -21.3  S.I.=  730.04           SIGE=  674.86
 SX,SY,TXY,SZ=  -107.61      -12.114       -43.684       605.95     SMX,SMN,TMX=   4.9334       -124.05       64.494

EL=   47  NODES=  123  128  129  124       MAT=  1   VOL=  15.94                                                      2-D SOLID  42
XC,YC=  21.25     1.250       TEMP=  70.0  A= -82.9  S.I.=  1272.8           SIGE=  1162.5
 SX,SY,TXY,SZ=   256.72      -2.2523       -32.767      1266.5      SMX,SMN,TMX=   260.80       -6.3340       133.57

EL=   48  NODES=  124  129  130  125       MAT=  1   VOL=  15.94                                                      2-D SOLID  42
XC,YC=  21.25     1.750       TEMP=  70.0  A= -88.6  S.I.=  1921.8           SIGE=  1781.7
 SX,SY,TXY,SZ=   604.59      -.92455       -15.189      1920.5      SMX,SMN,TMX=   604.97       -1.3053       303.14

EL=   49  NODES=   31   36   37   32       MAT=  1   VOL=  17.06                                                      2-D SOLID  42
XC,YC=  22.75    -1.750       TEMP=  70.0  A=  -1.4  S.I.=  1882.8           SIGE=  1580.3
 SX,SY,TXY,SZ=  -665.60      -9.4785       -15.671     -1811.9      SMX,SMN,TMX=  -9.1045       -665.98       328.44

EL=   50  NODES=   32   37   38   33       MAT=  1   VOL=  17.06                                                      2-D SOLID  42
XC,YC=  22.75    -1.250       TEMP=  70.0  A=  -6.2  S.I.=  1188.4           SIGE=  1059.3
 SX,SY,TXY,SZ=  -343.13      -7.8498       -37.089     -1192.2      SMX,SMN,TMX=  -3.7960       -347.19       171.69

EL=   51  NODES=   33   38   39   34       MAT=  1   VOL=  17.06                                                      2-D SOLID  42
XC,YC=  22.75    -.7500       TEMP=  70.0  A= -38.7  S.I.=  592.20           SIGE=  560.50
 SX,SY,TXY,SZ=  -26.433      -11.256       -34.148      -576.06     SMX,SMN,TMX=   16.136       -53.825       34.981

EL=   52  NODES=   34   39   40   35       MAT=  1   VOL=  17.06                                                      2-D SOLID  42
XC,YC=  22.75    -.2500       TEMP=  70.0  A= -86.0  S.I.=  303.99           SIGE=  281.09
 SX,SY,TXY,SZ=   290.99      -10.101       -20.965       41.947     SMX,SMN,TMX=   292.44       -11.553       152.00

EL=   53  NODES=   40  131  USEP= -.000000  USLIDE= -.069362  FN= -331.88      FS= -165.94      STAT= -2  OLDST= -2  2-D GAP  12

EL=   54  NODES=  126  131  132  127       MAT=  1   VOL=  17.06                                                      2-D SOLID  42
XC,YC=  22.75      .2500      TEMP=  70.0  A=  -3.7  S.I.=  342.28           SIGE=  324.46
 SX,SY,TXY,SZ=  -347.17      -7.8017       -22.287      -45.559     SMX,SMN,TMX=  -6.3444       -348.63       171.14

EL=   55  NODES=  127  132  133  128       MAT=  1   VOL=  17.06                                                      2-D SOLID  42
XC,YC=  22.75      .7500      TEMP=  70.0  A= -55.2  S.I.=  630.67           SIGE=  594.45
 SX,SY,TXY,SZ=  -31.013      -3.5056       -37.993       572.87     SMX,SMN,TMX=   22.879       -57.797       40.338

EL=   56  NODES=  128  133  134  129       MAT=  1   VOL=  17.06                                                      2-D SOLID  42
XC,YC=  22.75     1.250       TEMP=  70.0  A= -81.9  S.I.=  1198.9           SIGE=  1081.2
 SX,SY,TXY,SZ=   281.61      -4.3701       -41.477      1188.6      SMX,SMN,TMX=   287.56       -10.320       148.94

EL=   57  NODES=  129  134  135  130       MAT=  1   VOL=  17.06                                                      2-D SOLID  42
XC,YC=  22.75     1.750       TEMP=  70.0  A= -88.3  S.I.=  1809.4           SIGE=  1595.6
 SX,SY,TXY,SZ=   601.94      -.53326       -17.836      1808.3      SMX,SMN,TMX=   602.47       -1.0608       301.76

EL=   58  NODES=   36   41   42   37       MAT=  1   VOL=  18.19                                                      2-D SOLID  42
XC,YC=  24.25    -1.750       TEMP=  70.0  A=  -1.4  S.I.=  1706.6           SIGE=  1493.1
 SX,SY,TXY,SZ=  -649.96      -9.2297       -15.812     -1715.5      SMX,SMN,TMX=  -8.8398       -650.35       320.76

EL=   59  NODES=   37   42   43   38       MAT=  1   VOL=  18.19                                                      2-D SOLID  42
XC,YC=  24.25    -1.250       TEMP=  70.0  A=  -5.3  S.I.=  1126.6           SIGE=  995.82
 SX,SY,TXY,SZ=  -367.22      -9.4634       -33.563     -1132.9      SMX,SMN,TMX=  -6.3420       -370.34       182.00

EL=   60  NODES=   38   43   44   39       MAT=  1   VOL=  18.19                                                      2-D SOLID  42
XC,YC=  24.25    -.7500       TEMP=  70.0  A= -21.8  S.I.=  556.86           SIGE=  512.70
 SX,SY,TXY,SZ=  -82.732      -7.2512       -36.048      -549.66     SMX,SMN,TMX=   7.1986       -97.182       52.190

EL=   61  NODES=   39   44   45   40       MAT=  1   VOL=  18.19                                                      2-D SOLID  42
XC,YC=  24.25    -.2500       TEMP=  70.0  A= -85.2  S.I.=  211.66           SIGE=  194.14
 SX,SY,TXY,SZ=   201.66      -7.1006       -17.473       33.321     SMX,SMN,TMX=   203.11       -8.5531       105.83
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EL=   62  NODES=   45  136  USEP= -.000000  USLIDE= -.000390  FN= -176.35      FS= -84.910       STAT=  1  OLDST=  1   2-D GAP  12

EL=   63  NODES=  131  136  137  132        MAT=  1   VOL=  18.19                                                     2-D SOLID  42
XC,YC=  24.25        .2500       TEMP=  70.0  A=  -5.9  S.I.=  238.46             SIGE=  218.45
 SX,SY,TXY,SZ=  -234.38       -8.8344       -23.685       -32.798       SMX,SMN,TMX=  -6.3741       -236.84        115.23

EL=   64  NODES=  132  137  138  133        MAT=  1   VOL=  18.19                                                     2-D SOLID  42
XC,YC=  24.25        .7500       TEMP=  70.0  A= -56.6  S.I.=  584.60             SIGE=  539.40
 SX,SY,TXY,SZ=   35.398       -6.5704       -48.785        545.91       SMX,SMN,TMX=   67.524       -38.697        53.111

EL=   65  NODES=  133  138  139  134        MAT=  1   VOL=  18.19                                                     2-D SOLID  42
XC,YC=  24.25       1.250        TEMP=  70.0  A= -81.6  S.I.=  1132.9             SIGE=  1012.0
 SX,SY,TXY,SZ=   302.83       -2.1682       -45.798        1124.0       SMX,SMN,TMX=   309.56       -8.8965        159.23

EL=   66  NODES=  134  139  140  135        MAT=  1   VOL=  18.19                                                     2-D SOLID  42
XC,YC=  24.25       1.750        TEMP=  70.0  A= -87.8  S.I.=  1703.1             SIGE=  1501.3
 SX,SY,TXY,SZ=   569.11       -.77762       -21.487 .      1701.5       SMX,SMN,TMX=   569.92       -1.5866        285.75

EL=   67  NODES=   41   46   47   42        MAT=  1   VOL=  19.31                                                     2-D SOLID  42
XC,YC=  25.75      -1.750        TEMP=  70.0  A=  -1.6  S.I.=  1618.0             SIGE=  1414.6
 SX,SY,TXY,SZ=  -623.67       -9.6238       -17.040       -1627.1       SMX,SMN,TMX=  -9.1509       -624.14        307.50

EL=   68  NODES=   42   47   48   43        MAT=  1   VOL=  19.31                                                     2-D SOLID  42
XC,YC=  25.75      -1.250      . TEMP=  70.0  A=  -5.9  S.I.=  1076.1             SIGE=  945.07
 SX,SY,TXY,SZ=  -379.55       -6.7370       -30.888       -1078.8       SMX,SMN,TMX=  -2.7239       -383.56        190.42

EL=   69  NODES=   43   48   49   44        MAT=  1   VOL=  19.31                                                     2-D SOLID  42
XC,YC=  25.75      -.7500        TEMP=  70.0  A= -14.9  S.I.=  537.68             SIGE=  479.73
 SX,SY,TXY,SZ=  -136.93       -3.8886       -38.222       -531.37       SMX,SMN,TMX=   6.3106       -147.12        76.718

EL=   70  NODES=   44             50   45        MAT=  1   VOL=  19.31                                                     2-D SOLID  42
XC,YC=  25.75      -.2500        TEMP=  70.0  A= -80.9  S.I.=  116.02             SIGE=  106.86
 SX,SY,TXY,SZ=   108.75       -1.4272       -18.176        17.269       SMX,SMN,TMX=   111.67       -4.3481        58.009

EL=   71  NODES=   50  141  USEP=  .000004  USLIDE= -.000405  FN= 0.             FS= 0.           STAT=  3  OLDST=  3   2-D GAP  12

EL=   72  NODES=  136  141  142  137        MAT=  1   VOL=  19.31                                                     2-D SOLID  42
XC,YC=  25.75        .2500       TEMP=  70.0  A= -11.9  S.I.=  117.52             SIGE=  113.62
 SX,SY,TXY,SZ=  -109.46       -1.8842       -23.647       -5.1446       SMX,SMN,TMX=   3.0842       -114.43        58.758

EL=   73  NODES=  137  142  143  138        MAT=  1   VOL=  19.31                                                     2-D SOLID  42
XC,YC=  25.75        .7500       TEMP=  70.0  A= -67.9  S.I.=  551.98             SIGE=  496.48
 SX,SY,TXY,SZ=   99.900       -1.8855       -49.439        530.03       SMX,SMN,TMX=   119.96       -21.945        70.953

EL=   74  NODES=  138  143  144  139        MAT=  1   VOL=  19.31                                                     2-D SOLID  42
XC,YC=  25.75       1.250        TEMP=  70.0  A= -81.1  S.I.=  1074.0             SIGE=  953.72
 SX,SY,TXY,SZ=   308.95       -1.5188       -50.064        1064.6       SMX,SMN,TMX=   316.82       -9.3923        163.11

EL=   75  NODES=  139  144  145  140        MAT=  1   VOL=  19.31                                                     2-D SOLID  42
XC,YC=  25.75       1.750        TEMP=  70.0  A= -87.6  S.I.=  1601.6             SIGE=  1415.0
 SX,SY,TXY,SZ=   518.21       -.56811       -22.163        1600.0       SMX,SMN,TMX=   519.16       -1.5132        260.34

EL=   76  NODES=   46   51   52   47        MAT=  1   VOL=  20.44                                                     2-D SOLID  42
XC,YC=  27.25      -1.750        TEMP=  70.0  A=  -2.2  S.I.=  1531.4             SIGE=  1341.1
 SX,SY,TXY,SZ=  -575.09       -9.5724       -21.384       -1540.2       SMX,SMN,TMX=  -8.7650       -575.90        283.57

EL=   77  NODES=   47   52   53   48        MAT=  1   VOL=  20.44                                                     2-D SOLID  42
XC,YC=  27.25      -1.250        TEMP=  70.0  A=  -6.9  S.I.=  1029.2             SIGE=  900.37
 SX,SY,TXY,SZ=  -382.60       -6.5620       -46.134       -1030.2       SMX,SMN,TMX=  -.98598       -388.25        193.63
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EL=  78  NODES=   48   53   54   49        MAT=  1   VOL=  20.44                                                        2-D SOLID  42
XC,YC=  27.25      -.7500       TEMP=  70.0  A= -13.2  S.I.=  529.24         SIGE=  461.46
 SX,SY,TXY,SZ=  -191.67       -2.5822       -46.881      -520.84      SMX,SMN,TMX=    8.4029       -202.64        105.53

EL=  79  NODES=   49   54   55   50        MAT=  1   VOL=  20.44                                                        2-D SOLID  42
XC,YC=  27.25      -.2500       TEMP=  70.0  A= -45.3  S.I.=  41.862         SIGE=  37.992
 SX,SY,TXY,SZ=   .69144        .25560       -20.930      -10.890      SMX,SMN,TMX=   21.404       -20.457        20.931

EL=  80  NODES=   55  146   USEP=  .000015  USLIDE= -.000486  FN= 0.          FS= 0.              STAT=  3  OLDST=  3   2-D GAP  12

EL=  81  NODES=  141  146  147  142        MAT=  1   VOL=  20.44                                                        2-D SOLID  42
XC,YC=  27.25       .2500       TEMP=  70.0  A= -53.4  S.I.=  43.495         SIGE=  43.168
 SX,SY,TXY,SZ=   13.331        .79755       -20.825       20.150      SMX,SMN,TMX=   28.812       -14.683        21.748

EL=  82  NODES=  142  147  148  143        MAT=  1   VOL=  20.44                                                        2-D SOLID  42
XC,YC=  27.25       .7500       TEMP=  70.0  A= -74.7  S.I.=  532.91         SIGE=  468.27
 SX,SY,TXY,SZ=   161.40        .28530       -47.662       520.15      SMX,SMN,TMX=   174.44       -12.758        93.601

EL=  83  NODES=  143  148  149  144        MAT=  1   VOL=  20.44                                                        2-D SOLID  42
XC,YC=  27.25      1.250        TEMP=  70.0  A= -81.6  S.I.=  1019.1         SIGE=  901.73
 SX,SY,TXY,SZ=   310.43       -.22000       -46.917       1012.0      SMX,SMN,TMX=   317.56       -7.1469        162.35

EL=  84  NODES=  144  149  150  145        MAT=  1   VOL=  20.44                                                        2-D SOLID  42
XC,YC=  27.25      1.750        TEMP=  70.0  A= -87.3  S.I.=  1505.3         SIGE=  1336.1
 SX,SY,TXY,SZ=   459.52       -.53064       -21.986       1504.3      SMX,SMN,TMX=   460.56       -1.5713        231.07

EL=  85  NODES=   51   56   57   52        MAT=  1   VOL=  21.56                                                        2-D SOLID  42
XC,YC=  28.75     -1.750        TEMP=  70.0  A=  -2.8  S.I.=  1443.5         SIGE=  1270.5
 SX,SY,TXY,SZ=  -502.66       -9.5294       -24.319      -1451.9      SMX,SMN,TMX=   -8.2230       -503.85        247.76

EL=  86  NODES=   52   57   58   53        MAT=  1   VOL=  21.56                                                        2-D SOLID  42
XC,YC=  28.75     -1.250        TEMP=  70.0  A=  -8.3  S.I.=  985.26         SIGE=  860.15
 SX,SY,TXY,SZ=  -375.19       -7.0440       -54.540      -984.39      SMX,SMN,TMX=    .86601       -383.10        191.98

EL=  87  NODES=   53   58   59   54        MAT=  1   VOL=  21.56                                                        2-D SOLID  42
XC,YC=  28.75      -.7500       TEMP=  70.0  A= -11.8  S.I.=  525.59         SIGE=  455.21
 SX,SY,TXY,SZ=  -248.90       -2.9671       -53.726      -517.33      SMX,SMN,TMX=    8.2576       -260.12        134.19

EL=  88  NODES=   54   59   60   55        MAT=  1   VOL=  21.56                                                        2-D SOLID  42
XC,YC=  28.75      -.2500       TEMP=  70.0  A= -11.2  S.I.=  131.26         SIGE=  114.16
 SX,SY,TXY,SZ=  -121.45       -.64620E-01  -24.985       -49.719      SMX,SMN,TMX=    4.8468       -126.36        65.602

EL=  89  NODES=   60  151   USEP=  .000031  USLIDE= -.000393  FN= 0.          FS= 0.              STAT=  3  OLDST=  3   2-D GAP  12

EL=  90  NODES=  146  151  152  147        MAT=  1   VOL=  21.56                                                        2-D SOLID  42
XC,YC=  28.75       .2500       TEMP=  70.0  A= -80.7  S.I.=  131.42         SIGE=  113.81
 SX,SY,TXY,SZ=   124.43       -.12333       -20.956       62.869      SMX,SMN,TMX=   127.86       -3.5545        65.709

EL=  91  NODES=  147  152  153  148        MAT=  1   VOL=  21.56                                                        2-D SOLID  42
XC,YC=  28.75       .7500       TEMP=  70.0  A= -79.8  S.I.=  522.67         SIGE=  453.45
 SX,SY,TXY,SZ=   216.90       -.22979       -44.017       513.85      SMX,SMN,TMX=   225.49       -8.8136        117.15

EL=  92  NODES=  148  153  154  149        MAT=  1   VOL=  21.56                                                        2-D SOLID  42
XC,YC=  28.75      1.250        TEMP=  70.0  A= -81.8  S.I.=  971.00         SIGE=  856.54
 SX,SY,TXY,SZ=   309.76        .13832       -45.321       964.64      SMX,SMN,TMX=   316.26       -6.3592        161.31

EL=  93  NODES=  149  154  155  150        MAT=  1   VOL=  21.56                                                        2-D SOLID  42
XC,YC=  28.75      1.750        TEMP=  70.0  A= -87.2  S.I.=  1416.9         SIGE=  1264.2
 SX,SY,TXY,SZ=   401.67       -.66320       -19.846       1415.2      SMX,SMN,TMX=   402.65       -1.6390        202.15
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EL=  94  NODES=  56  61   62  57       MAT= 1   VOL= 22.69                                                         2-D SOLID  42
XC,YC=  30.25     -1.750     TEMP=  70.0  A=  -4.0  S.I.= 1353.4          SIGE=  1203.5
 SX,SY,TXY,SZ=  -409.23      -9.7449      -28.319      -1361.1     SMX,SMN,TMX=  -7.7474      -411.22       201.74

EL=  95  NODES=  57  62   63  58       MAT= 1   VOL= 22.69                                                         2-D SOLID  42
XC,YC=  30.25     -1.250     TEMP=  70.0  A=  -9.4  S.I.=  943.72         SIGE=  823.36
 SX,SY,TXY,SZ=  -357.50      -5.9410      -60.879      -939.42     SMX,SMN,TMX=   4.3020      -367.75       186.03

EL=  96  NODES=  58  63   64  59       MAT= 1   VOL= 22.69                                                         2-D SOLID  42
XC,YC=  30.25     -.7500     TEMP=  70.0  A= -11.1  S.I.=  528.52         SIGE=  462.39
 SX,SY,TXY,SZ=  -308.66      -3.2229      -62.292      -519.53     SMX,SMN,TMX=   8.9928      -320.87       164.93

EL=  97  NODES=  59  64   65  60       MAT= 1   VOL= 22.69                                                         2-D SOLID  42
XC,YC=  30.25     -.2500     TEMP=  70.0  A=  -6.0  S.I.=  263.02         SIGE=  229.85
 SX,SY,TXY,SZ=  -257.79      -.56724      -27.454      -98.428     SMX,SMN,TMX=   2.3303      -260.69       131.51

EL=  98  NODES=  65  156  USEP=  .000052  USLIDE= -.000366  FN= 0.          FS= 0.          STAT=  3  OLDST=  3  2-D GAP  12

EL=  99  NODES= 151  156  157  152     MAT= 1   VOL= 22.69                                                         2-D SOLID  42
XC,YC=  30.25      .2500     TEMP=  70.0  A= -85.4  S.I.=  229.20         SIGE=  198.96
 SX,SY,TXY,SZ=   226.88       .63674      -18.356       100.10     SMX,SMN,TMX=   228.36      -.84289       114.60

EL= 100  NODES= 152  157  158  153     MAT= 1   VOL= 22.69                                                         2-D SOLID  42
XC,YC=  30.25      .7500     TEMP=  70.0  A= -80.9  S.I.=  517.59         SIGE=  448.75
 SX,SY,TXY,SZ=   266.51       .62437      -43.966       511.14     SMX,SMN,TMX=   273.59      -6.4501       140.02

EL= 101  NODES= 153  158  159  154     MAT= 1   VOL= 22.69                                                         2-D SOLID  42
XC,YC=  30.25      1.250     TEMP=  70.0  A= -82.4  S.I.=  927.77         SIGE=  816.66
 SX,SY,TXY,SZ=   305.34      -1.3788      -41.415       920.89     SMX,SMN,TMX=   310.83      -6.8726       158.85

EL= 102  NODES= 154  159  160  155     MAT= 1   VOL= 22.69                                                         2-D SOLID  42
XC,YC=  30.25      1.750     TEMP=  70.0  A= -86.7  S.I.= 1334.0          SIGE=  1190.3
 SX,SY,TXY,SZ=   346.23      -.15298      -19.964       1332.7     SMX,SMN,TMX=   347.38      -1.2999       174.24

EL= 103  NODES=  61  66   67  62       MAT= 1   VOL= 23.81                                                         2-D SOLID  42
XC,YC=  31.75     -1.750     TEMP=  70.0  A=  -6.2  S.I.= 1260.0          SIGE=  1142.5
 SX,SY,TXY,SZ=  -294.31      -9.4320      -31.127      -1266.1     SMX,SMN,TMX=  -6.0706      -297.67       145.80

EL= 104  NODES=  62  67   68  63       MAT= 1   VOL= 23.81                                                         2-D SOLID  42
XC,YC=  31.75     -1.250     TEMP=  70.0  A= -11.6  S.I.=  903.27         SIGE=  788.22
 SX,SY,TXY,SZ=  -334.47      -8.4319      -70.000      -897.31     SMX,SMN,TMX=   5.9613      -348.87       177.41

EL= 105  NODES=  63  68   69  64       MAT= 1   VOL= 23.81                                                         2-D SOLID  42
XC,YC=  31.75     -.7500     TEMP=  70.0  A=  -9.9  S.I.=  535.97         SIGE=  480.48
 SX,SY,TXY,SZ=  -370.70      -1.9274      -66.629      -526.23     SMX,SMN,TMX=   9.7417      -382.37       196.06

EL= 106  NODES=  64  69   70  65       MAT= 1   VOL= 23.81                                                         2-D SOLID  42
XC,YC=  31.75     -.2500     TEMP=  70.0  A=  -4.5  S.I.=  412.77         SIGE=  360.60
 SX,SY,TXY,SZ=  -406.92       .85230      -32.035      -155.64     SMX,SMN,TMX=   3.3537      -409.42       206.39

EL= 107  NODES=  70  161  USEP=  .000072  USLIDE= -.000324  FN= 0.          FS= 0.          STAT=  3  OLDST=  3  2-D GAP  12

EL= 108  NODES= 156  161  162  157     MAT= 1   VOL= 23.81                                                         2-D SOLID  42
XC,YC=  31.75      .2500     TEMP=  70.0  A= -86.4  S.I.=  323.25         SIGE=  280.84
 SX,SY,TXY,SZ=   320.36      -.35503      -20.218       137.58     SMX,SMN,TMX=   321.63      -1.6246       161.63

EL= 109  NODES= 157  162  163  158     MAT= 1   VOL= 23.81                                                         2-D SOLID  42
XC,YC=  31.75      .7500     TEMP=  70.0  A= -83.3  S.I.=  516.01         SIGE=  451.32
 SX,SY,TXY,SZ=   310.27      -2.2137      -37.104       509.45     SMX,SMN,TMX=   314.61      -6.5590       160.39
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EL=  110  NODES=  158  163  164  159          MAT=  1   VOL=  23.81
XC,YC=  31.75       1.250          TEMP=  70.0  A= -82.1  S.I.=  877.77              SIGE=  779.77                                        2-D SOLID  42
 SX,SY,TXY,SZ=   304.09           2.1786        -42.630           884.04    SMX,SMN,TMX=    310.00        -3.7252        156.86

EL=  111  NODES=  159  164  165  160          MAT=  1   VOL=  23.81
XC,YC=  31.75       1.750          TEMP=  70.0  A= -86.5  S.I.=  1256.1              SIGE=  1138.4                                        2-D SOLID  42
 SX,SY,TXY,SZ=   289.68          -.81266        -17.875           1254.2    SMX,SMN,TMX=    290.77        -1.9084        146.34

EL=  112  NODES=   66   71   72   67          MAT=  1   VOL=  24.94
XC,YC=  33.25      -1.750          TEMP=  70.0  A= -11.4  S.I.=  1165.8              SIGE=  1090.5                                        2-D SOLID  42
 SX,SY,TXY,SZ=  -167.06          -9.7735        -33.051          -1168.9    SMX,SMN,TMX=   -3.1100        -173.72        85.307

EL=  113  NODES=   67   72   73   68          MAT=  1   VOL=  24.94
XC,YC=  33.25      -1.250          TEMP=  70.0  A= -13.4  S.I.=  861.98              SIGE=  754.39                                        2-D SOLID  42
 SX,SY,TXY,SZ=  -293.63          -6.1259        -72.718          -858.76    SMX,SMN,TMX=    11.220        -310.97        161.10

EL=  114  NODES=   68   73   74   69          MAT=  1   VOL=  24.94
XC,YC=  33.25      -.7500          TEMP=  70.0  A= -10.4  S.I.=  546.48              SIGE=  587.85                                        2-D SOLID  42
 SX,SY,TXY,SZ=  -436.28          -8.6117        -81.176          -540.20    SMX,SMN,TMX=    6.2782        -451.17        228.72

EL=  115  NODES=   69   74   75   70          MAT=  1   VOL=  24.94
XC,YC=  33.25      -.2500          TEMP=  70.0  A=  -3.3  S.I.=  573.98              SIGE=  501.10                                        2-D SOLID  42
 SX,SY,TXY,SZ=  -572.99          -2.8500        -33.167          -224.60    SMX,SMN,TMX=   -.92710        -574.91        286.99

EL=  116  NODES=   75  166  USEP=  .000085  USLIDE= -.000268. FN= 0.              FS= 0.              STAT=  3  OLDST=  3   2-D GAP  12

EL=  117  NODES=  161  166  167  162          MAT=  1   VOL=  24.94
XC,YC=  33.25       .2500          TEMP=  70.0  A= -88.0  S.I.=  410.61              SIGE=  356.69                                        2-D SOLID  42
 SX,SY,TXY,SZ=   469.74         .90784E-01  -14.006           177.03    SMX,SMN,TMX=    410.22        -.38751        205.31

EL=  118  NODES=  162  167  168  163          MAT=  1   VOL=  24.94
XC,YC=  33.25       .7500          TEMP=  70.0  A= -82.4  S.I.=  513.26              SIGE=  456.07                                        2-D SOLID  42
 SX,SY,TXY,SZ=   354.21           8.0279        -47.022           515.02    SMX,SMN,TMX=    360.48         1.7543        179.36

EL=  119  NODES=  163  168  169  164          MAT=  1   VOL=  24.94
XC,YC=  33.25       1.250          TEMP=  70.0  A= -83.3  S.I.=  850.17              SIGE=  747.13                                        2-D SOLID  42
 SX,SY,TXY,SZ=   287.44          -2.5813        -34.587           843.52    SMX,SMN,TMX=    291.51        -6.6491        149.08

EL=  120  NODES=  164  169  170  165          MAT=  1   VOL=  24.94
XC,YC=  33.25       1.750          TEMP=  70.0  A= -86.0  S.I.=  1184.1              SIGE=  1082.8                                        2-D SOLID  42
 SX,SY,TXY,SZ=   241.94           .10888        -16.885           1183.0    SMX,SMN,TMX=    263.11        -1.0644        122.09

EL=  121  NODES=   71   76   77   72          MAT=  1   VOL=  26.06
XC,YC=  34.75      -1.750          TEMP=  70.0  A= -44.3  S.I.=  1094.1              SIGE=  1055.2                                        2-D SOLID  42
 SX,SY,TXY,SZ=  -11.655          -9.5288        -41.342          -1063.3    SMX,SMN,TMX=    30.764        -51.948        41.356

EL=  122  NODES=   72   77   78   73          MAT=  1   VOL=  26.06
XC,YC=  34.75      -1.250          TEMP=  70.0  A= -16.4  S.I.=  836.87              SIGE=  731.21                                        2-D SOLID  42
 SX,SY,TXY,SZ=  -268.19           2.2811        -86.884          -889.08    SMX,SMN,TMX=    27.786        -293.69        160.74

EL=  123  NODES=   73   78   79   74          MAT=  1   VOL=  26.06
XC,YC=  34.75      -.7500          TEMP=  70.0  A=  -7.6  S.I.=  573.30              SIGE=  554.76                                        2-D SOLID  42
 SX,SY,TXY,SZ=  -497.54           17.907        -70.055          -546.05    SMX,SMN,TMX=    27.259        -506.89        267.07

EL=  124  NODES=   74   79   80   75          MAT=  1   VOL=  26.06
XC,YC=  34.75      -.2500          TEMP=  70.0  A=  -3.2  S.I.=  758.97              SIGE=  661.39                                        2-D SOLID  42
 SX,SY,TXY,SZ=  -747.93           6.4389        -41.694          -297.12    SMX,SMN,TMX=    8.7363        -750.23        379.48

EL=  125  NODES=   80  171  USEP=  .000081  USLIDE= -.000193  FN= 0.              FS= 0.              STAT=  3  OLDST=  3   2-D GAP  12
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EL= 126  NODES=  166  171  172  167        MAT=  1   VOL=  26.06                                              2-D SOLID  42
XC,YC=  34.75        .2500        TEMP=  70.0  A= -86.9  S.I.=  489.79            SIGE=  425.29
 SX,SY,TXY,SZ=   492.17         5.2585        -26.524        217.87      SMX,SMN,TMX=    493.61        3.8178         244.98

EL= 127  NODES=  167  172  173  168        MAT=  1   VOL=  26.06                                              2-D SOLID  42
XC,YC=  34.75        .7500        TEMP=  70.0  A= -87.4  S.I.=  529.24            SIGE=  478.92
 SX,SY,TXY,SZ=   376.75        -25.026        -18.617        503.36      SMX,SMN,TMX=    377.61       -2[illegible].887        201.75

EL= 128  NODES=  168  173  174  169        MAT=  1   VOL=  26.06                                              2-D SOLID  42
XC,YC=  34.75       1.250         TEMP=  70.0  A= -82.3  S.I.=  827.42            SIGE=  722.80
 SX,SY,TXY,SZ=   302.23        -5.1474        -42.528        816.49      SMX,SMN,TMX=    308.01       -10.923         159.47

EL= 129  NODES=  169  174  175  170        MAT=  1   VOL=  26.06                                              2-D SOLID  42
XC,YC-  34.75       1.750         TEMP=  70.0  A= -83.8  S.I.=  1114.2            SIGE=  1033.3
 SX,SY,TXY,SZ=   182.29        -.74331        -19.964        1111.3      SMX,SMN,TMX=    184.45       -2.8955         93.671

EL= 130  NODES=   76   81   82   77        MAT=  1   VOL=  27.19                                              2-D SOLID  42
XC,YC=  36.25       -1.750        TEMP=  70.0  A= -7[illegible].5  S.I.=  1126.0            SIGE=  1042.4
 SX,SY,TXY,SZ=   166.13        -9.9062        -41.542       -950.58      SMX,SMN,TMX=    175.44       -19.217         97.327

EL= 131  NODES=   77   82   83   78        MAT=  1   VOL=  27.19                                              2-D SOLID  42
XC,YC=  36.25       -1.250        TEMP=  70.0  A= -23.9  S.I.=  775.56            SIGE=  684.85
 SX,SY,TXY,SZ=  -212.48        -41.682        -94.013       -775.63      SMX,SMN,TMX=  -.70882E-01  -254.09         127.01

EL= 132  NODES=   78   83   84   79        MAT=  1   VOL=  27.19                                              2-D SOLID  42
XC,YC=  36.25       -.7500        TEMP=  70.0  A= -10.5  S.I.=  600.53            SIGE=  585.30
 SX,SY,TXY,SZ=  -613.59        -52.582        -107.12       -661.61      SMX,SMN,TMX=   -32.825       -633.35         300.26

EL= 133  NODES=   79   84   85   80        MAT=  1   VOL=  27.19                                              2-D SOLID  42
XC,YC=  36.25       -.2500        TEMP=  70.0  A=  -1.1  S.I.=  897.52            SIGE=  781.83
 SX,SY,TXY,SZ=  -914.23        -17.341        -16.759       -381.47      SMX,SMN,TMX=   -17.028       -914.55         448.76

EL=  134  NODES=   85  176  USEP=  .003054  USLIDE= -.000117  FN= 0.          FS= 0.           STAT=  3  OLDST=  3   2-D GAP  12

EL= 135  NODES=  171  176  177  172        MAT=  1   VOL=  27.19                                              2-D SOLID  42
XC,YC=  36.25        .2500        TEMP=  70.0  A=  88.1  S.I.=  569.44            SIGE=  493.47
 SX,SY,TXY,SZ=   539.10        -29.024        19.338         237.35      SMX,SMN,TMX=    539.76       -29.681         284.72

EL= 136  NODES=  172  177  178  173        MAT=  1   VOL=  27.19                                              2-D SOLID  42
XC,YC=  36.25        .7500        TEMP=  70.0  A= -81.3  S.I.=  508.07            SIGE=  478.16
 SX,SY,TXY,SZ=   474.22         53.171        -65.977        551.16      SMX,SMN,TMX=    484.31        43.094         220.61

EL= 137  NODES=  173  178  179  174        MAT=  1   VOL=  27.19                                              2-D SOLID  42
XC,YC=  36.25       1.250         TEMP=  70.0  A= -80.9  S.I.=  768.07            SIGE=  677.46
 SX,SY,TXY,SZ=   268.90         26.142        -39.910        787.82      SMX,SMN,TMX=    275.29        19.749         127.77

EL= 138  NODES=  174  179  180  175        MAT=  1   VOL=  27.19                                              2-D SOLID  42
XC,YC=  36.25       1.750         TEMP=  70.0  A= -82.5  S.I.=  1045.3            SIGE=  987.44
 SX,SY,TXY,SZ=   124.09         .32417        -16.620        1043.4      SMX,SMN,TMX=    126.28       -1.8687         64.075

EL= 139  NODES=   81   86   87   82        MAT=  1   VOL=  21.22                                              2-D SOLID  42
XC,YC=  37.57       -1.750        TEMP=  70.0  A=  77.6  S.I.=  1080.6            SIGE=  993.33
 SX,SY,TXY,SZ=   170.10        -18.434        43.652        -901.06      SMX,SMN,TMX=    179.72       -28.050         103.89

EL= 140  NODES=   82   87   88   83        MAT=  1   VOL=  21.22                                              2-D SOLID  42
XC,YC=  37.57       -1.250        TEMP=  70.0  A=  36.2  S.I.=  667.39            SIGE=  644.26
 SX,SY,TXY,SZ=  -79.411        -64.619        23.387        -714.88      SMX,SMN,TMX=   -47.486       -96.543         24.529

EL= 141  NODES=   83   88   89   84        MAT=  1   VOL=  21.22                                              2-D SOLID  42.
XC,YC=  37.57       -.7500        TEMP=  70.0  A= -18.2  S.I.=  481.32            SIGE=  441.66
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SX,SY,TXY,SZ=  -434.09      -123.04      -114.81      -566.58     SMX,SMN,TMX=  -85.256      -471.88      193.31

L=  142  NODES=   84   89   90   85        MAT=  1   VOL=  21.22                                                 2-D SOLID  42
C,YC=  37.57     -.2500      TEMP=  70.0  A= -10.0  S.I.=  1332.5          SIGE=  1161.0
SX,SY,TXY,SZ= -1270.7       -18.918      -220.39      -517.15     SMX,SMN,TMX=   21.450     -1311.1       646.27

L=  143  NODES=  176  181  182  177        MAT=  1   VOL=  21.22                                                 2-D SOLID  42
C,YC=  37.57      .2500      TEMP=  70.0  A= -70.7  S.I.=  714.25          SIGE=  626.81
SX,SY,TXY,SZ=   784.73      226.36       -222.70       404.16     SMX,SMN,TMX=   862.67      148.42       357.12

L=  144  NODES=  177  182  183  178        MAT=  1   VOL=  21.22                                                 2-D SOLID  42
C,YC=  37.57      .7500      TEMP=  70.0  A= -86.9  S.I.=  377.00          SIGE=  334.09
SX,SY,TXY,SZ=   227.25      110.27       -6.2605       406.93     SMX,SMN,TMX=   227.59      109.93       58.829

L=  145  NODES=  178  183  184  179        MAT=  1   VOL=  21.22                                                 2-D SOLID  42
C,YC=  37.57     1.250       TEMP=  70.0  A=  69.9  S.I.=  738.03          SIGE=  652.17
SX,SY,TXY,SZ=   232.68      50.106       77.384        759.75     SMX,SMN,TMX=   261.07      21.720       11?.67

L=  146  NODES=  179  184  185  180        MAT=  1   VOL=  21.22                                                 2-D SOLID  42
C,YC=  37.57     1.750       TEMP=  70.0  A=  75.9  S.I.=  1032.6          SIGE=  941.83
SX,SY,TXY,SZ=   205.07      10.527       52.031        1030.0     SMX,SMN,TMX=   218.11      -2.5145      110.31

L=  147  NODES=   86   91   92   87        MAT=  1   VOL=  9.595                                                 2-D SOLID  42
C,YC=  38.38    -1.750       TEMP=  70.0  A=  53.4  S.I.=  971.00          SIGE=  931.24
SX,SY,TXY,SZ=   38.423      13.635       40.064       -902.27     SMX,SMN,TMX=   68.731      -16.673      42.702

L=  148  NODES=   87   92   93   88        MAT=  1   VOL=  9.595                                                 2-D SOLID  42
C,YC=  38.38    -1.250       TEMP=  70.0  A=  29.8  S.I.=  776.50          SIGE=  698.88
SX,SY,TXY,SZ=   9.8988      110.24       85.326       -617.46     SMX,SMN,TMX=   159.05      -38.914      98.982

L=  149  NODES=   88   93   94   89        MAT=  1   VOL=  9.595                                                 2-D SOLID  42
C,YC=  38.38     -.7500      TEMP=  70.0  A=  -2.5  S.I.=  539.47          SIGE=  467.28
SX,SY,TXY,SZ=  -121.97      155.63       -12.273      -383.28     SMX,SMN,TMX=   156.19      -122.51      139.35

L=  150  NODES=   89   94   9?   90        MAT=  1   VOL=  9.595                                                 2-D SOLID  42
C,YC=  38.38     -.2500      TEMP=  70.0  [illegible].3  S.I.=  1357.5        SIGE=  1175.7
SX,SY,TXY,SZ=  -532.86     -?17.20       -660.16      -374.57     SMX,SMN,TMX=   303.74      -1053.8      678.77

L=  151  NODES=  181  186  187  182        MAT=  1   VOL=  9.595                                                 2-D SOLID  42
C,YC=  38.38      .2500      TEMP=  70.0  A= -38.2  S.I.=  489.57          SIGE=  407.83
SX,SY,TXY,SZ=  -290.06     -193.50       -199.01      -40.495     SMX,SMN,TMX=  -36.996      -446.56      204.78

L=  152  NOD?S=  182  187  188  183        MAT=  1   VOL=  9.595                                                 2-D SOLID  42
C,YC=  38.38      .7500      TEMP=  70.0  A=  61.5  S.I.=  560.70          SIGE=  490.95
SX,SY,TXY,SZ=   141.46     -71.125       166.50        398.33     SMX,SMN,TMX=   232.71      -162.37      197.54

L=  153  NODES=  183  188  189  184        MAT=  1   VOL=  9.595                                                 2-D SOLID  42
C,YC=  38.38     1.250       TEMP=  70.0  A=  67.8  S.I.=  808.98          SIGE=  701.59
SX,SY,TXY,SZ=   216.93     -44.939       127.80        711.93     SMX,SMN,TMX=   268.97      -96.973      182.97

L=  154  NODES=  184  189  190  185        MAT=  1   VOL=  9.595                                                 2-D SOLID  42
C,YC=  38.38     1.750       TEMP=  70.0  A=  80.2  S.I.=  1067.4          SIGE=  934.28
SX,SY,TXY,SZ=   376.13      1.1013       67.138        1056.9     SMX,SMN,TMX=   387.79      -10.555      199.17

L=  155  NODES=  186  191  192  187        MAT=  1   VOL=  22.01                                                 2-D SOLID  42
C,YC=  39.19      .2500      TEMP=  70.0  A= -23.2  S.I.=  658.40          SIGE=  641.15
SX,SY,TXY,SZ=  -723.94     -270.45       -238.66      -204.02     SMX,SMN,TMX=  -167.99      -826.39      329.20

L=  156  NODES=  187  192  193  188        MAT=  1   VOL=  22.01                                                 2-D SOLID  42
C,YC=  39.19      .7500      TEMP=  70.0  A= -59.7  S.I.=  558.21          SIGE=  483.42
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 SX,SY,TXY,SZ=  -52.559      -189.77      -121.58       297.45     SMX,SMN,TMX=   18.439      -260.76       139.60

EL=  157  NODES=  188  193  194  189          MAT=  1    VOL=  22.01                                              2-D SOLID  42
XC,YC=  39.19       1.250       TEMP=  70.0  A= -86.3  S.I.=  764.37               SIGE=  669.15
 SX,SY,TXY,SZ=   204.45      -77.616      -18.132       685.60     SMX,SMN,TMX=   205.61      -78.776       142.19

EL=  158  NODES=  189  194  195  190          MAT=  1    VOL=  22.01                                              2-D SOLID  42
XC,YC=  39.19       1.750       TEMP=  70.0  A= -89.7  S.I.=  1075.9               SIGE=  934.69
 SX,SY,TXY,SZ=   438.24      -25.533      -2.4139       1050.3     SMX,SMN,TMX=   438.25      -25.545       231.90

EL=  159  NODES=  191  196  197  192          MAT=  1    VOL=  22.64                                              2-D SOLID  42
XC,YC=  40.31       .2500       TEMP=  70.0  A=  -4.6  S.I.=  355.58               SIGE=  333.44
 SX,SY,TXY,SZ=  -301.10       49.972      -28.209       2.3360     SMX,SMN,TMX=   52.224      -303.35       177.7

EL=  160  NODES=  192  197  198  193          MAT=  1    VOL=  22.64                                              2-D SOLID  42
XC,YC=  40.31       .7500       TEMP=  70.0  A= -30.8  S.I.=  587.74               SIGE=  515.94
 SX,SY,TXY,SZ=  -200.87      -21.512      -166.50       287.44     SMX,SMN,TMX=   77.925      -300.38       189.1

EL=  161  NODES=  193  198  199  194          MAT=  1    VOL=  22.64                                              2-D SOLID  42
XC,YC=  40.31       1.250       TEMP=  70.0  A= -52.1  S.I.=  753.67               SIGE=  659.57
 SX,SY,TXY,SZ=   73.244       4.2773      -136.64       651.51     SMX,SMN,TMX=   179.69      -102.16       140.92

EL=  162  NODES=  194  199  200  195          MAT=  1    VOL=  22.64                                              2-D SOLID  42
XC,YC=  40.31       1.750       TEMP=  70.0  A= -82.8  S.I.=  978.44               SIGE=  865.90
 SX,SY,TXY,SZ=   351.73       50.634      -38.828       1024.1     SMX,SMN,TMX=   356.65       45.708       155.47

EL=  163  NODES=  196  201  202  197          MAT=  1    VOL=  23.27                                              2-D SOLID  42
XC,YC=  41.44       .2500       TEMP=  70.0  A= -25.4  S.I.=  155.29               SIGE=  143.78
 SX,SY,TXY,SZ=  -92.544      -11.363      -49.810       39.081     SMX,SMN,TMX=   12.301      -116.21       64.255

EL=  164  NODES=  197  202  203  198          MAT=  1    VOL=  23.27                                              2-D SOLID  42
XC,YC=  41.44       .7500       TEMP=  70.0  A= -44.8  S.I.=  458.00               SIGE=  397.57
 SX,SY,TXY,SZ=  -46.264      -45.154      -101.43       310.94     SMX,SMN,TMX=   55.720      -147.14       101.43

EL=  165  NODES=  198  203  204  199          MAT=  1    VOL=  23.27                                              2-D SOLID  42
XC,YC=  41.44       1.250       TEMP=  70.0  A= -57.1  S.I.=  779.78               SIGE=  682.79
 SX,SY,TXY,SZ=  -12.338      -130.97      -131.84       563.56     SMX,SMN,TMX=   72.920      -216.22       144.57

EL=  166  NODES=  199  204  205  200          MAT=  1    VOL=  23.27                                              2-D SOLID  42
XC,YC=  41.44       1.750       TEMP=  70.0  A= -77.3  S.I.=  1070.0               SIGE=  943.32
 SX,SY,TXY,SZ=   127.38      -196.50      -77.060       856.15     SMX,SMN,TMX=   144.78      -213.90       179.34
```

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3. THERMAL EVALUATION

A thermal analysis for the 14-215 cask has been conducted for normal transport conditions. The performance of the packaging under normal conditions of transport is described below.

3.1 Discussion

The mechanical features of the packaging have been described in Section 1.2.1. There are no special thermal protection sub-systems or features.

A very conservative internal heat load of 400 watts is used in the evaluation of maximum cask temperatures. However, a much lower heat load is used to calculate the difference in temperature between the payload centerline and the cask surface. This load is much more realistic because it is based upon the shielding limits of the cask.

The external surface of the packaging is predicted to exhibit maximum temperatures ranging from 176°F to 190°F, depending upon the quantity of internal decay heat assumed. The lower temperature prediction assumes zero internal decay heat load, the higher prediction assumes an internal decay heat load of 400 watts. These maximum temperature predictions assume conditions consistent with the Normal Transport "Heat" requirements, specifically:

- Direct sunlight (mid summer)
- Ambient Air at 130°F
- Still air

Solar flux is calculated from insolation values given in N.R.C. Regulatory Guide 7.8. The solar flux is assumed constant so that conservative steady state conditions are analyzed. Further conservatism is incorporated in the analysis by assuming the cask base is an adiabatic boundary (no heat loss). Finally, the analysis shows that, at the maximum internal decay heat load (400 watts) inside surface temperatures exceed the external temperatures by less than 0.3°F.

The analysis presented bounds the case wherein an insert is temporarily slipped into the cask to augment shielding of the rest of the contents. This insert is described in

Chapter 1.0. An air gap between the O.D. of the insert and I.D. of the cask has an insulating effect which would tend to reduce the 0.3°F difference in temperature between the internal and external cask surfaces in the case of the maximum 400 watt internal heat load (see Section 3.4.2). This effect is of no consequence to the conclusions of this analysis. With no internal heat source, the presence of this insert would not change the predicted temperatures in the analysis.

The maximum realistic decay heat load for the 14-215 cask is given below. It is based on a "worst-case" payload of Cesium 137 solidified in concrete. The other payload isotope of interest, Cobalt 60, is shielding limited to much lower Curie levels and thus is not considered here. The total activity is limited by the shielding capability of the cask assuming a 10mR/hr dose rate at 6 feet from the cask. The Cesium 137 value for the 14-215 cask is given in the table on the following page.

Cask	Specific Activity uCi/cm^3	Cask Volume cm^{3}x10^{+6}	Total Activity (Curies)	Decay Total Heat* (Watts)	Heat Limit (Watts)
14-215	152	6.15	934	4.5	9.0

*Based on a conversion of .0048 Watts/Curie for Cesium 137.

The decay heat limit assumed in the following analysis is roughly twice the calculated decay heat above to ensure that loading of the cask is governed by shielding vs. heat load considerations and to give added conservatism to the centerline temperatures calculated below.

The temperature at the center of the cask can be calculated if we can conservatively assume that the heat flow is entirely radial. The problem can then be treated as a long circular cylinder with uniformly distributed heat sources (Page 53, Krieth, Principles of Heat Transfer, 3rd Ed.)

The maximum temperature is given as:

$$T_o = T + \frac{\dot{g} r_0^2}{4K}$$

Where:

T_o = outer surface temp. (°F)

r_o = radius of outer surface (ft)

k = Thermal conductivity of cylinder material (BTU/hr.ft.°F)

Then: $$\Delta T = \frac{\dot{g} r_o^2}{4k}$$

The differences between cask centerline temperature and the temperature at the payload outer surface are calculated below assuming the above decay heat limit:

Cask	Decay Heat Limit		r_o	ΔT (°F)	
	Watts	$\frac{BTU/hr}{ft^3}$	(ft)	concrete (k=0.8)	Asphalt (k=0.1)
14-215	9.0	.142	3.22	.46	3.68

The centerline temperature increase is very small for the solidified concrete payload. The centerline temperature is significantly higher for an asphalt payload, but these temperatures are based on a Cesium 137 activity level which could not be attained in practice because of the lower self shielding of the asphalt.

These results show that the maximum temperatures possible under normal conditions of transport do not have any significant effect on the cask or its payload.

3.2 Summary of Thermal Properties of Materials

Only four materials were employed in this analysis. They were obtained from conventional handbooks as follows:

Thermal Conductivity

Steel	25.0 BTU/hr ft-°F
Lead	18.6 BTU/hr ft-°F
Concrete	0.8 BTU/hr ft-°F
Asphalt	0.1 BTU/hr ft-°F

Surface Emissivity/Absorbitivity

Steel	0.8

3.3 Technical Specification of Components

Not applicable - no special thermal sub-systems.

3.4 Thermal Evaluation for Normal Conditions of Transport

The thermal analysis for Normal Transport "Heat" and "Cold" conditions is presented in Section 3.6, Appendix.

3.4.1 Thermal Model

As outlined in Section 3.6, the unknown external cask temperature was determined by solving for the temperature at which the heat input to the cask system equaled heat output. Input heat consisted of a solar flux (calculated from Reg. Guide 7.8) plus the internal decay heat. Heat output consisted of the sum of free-convection losses and radiation losses to a prescribed ambient air sink temperature (130°F-"Hot", -40°F "Cold"). Heat loss was allowed only over the vertical cylindrical sides and the top. Convective film coefficients were taken from McAdams empirical values for free convection.

The analysis to determine cask centerline temperature conservatively assumes that only radial conduction takes place (i.e., as an infinitely long cylinder). The decay heat sources are assumed to be distributed evenly throughout the cask interior.

3.4.2 Maximum Temperatures

Predicted maximum temperatures are:

	External Surfaces	Internal Surfaces
No Internal Heat Source	185.6°F	185.6°F
400 Watts Internal Heat Source	190.3°F	190.6°F

3.4.3 Minimum Temperatures

Predicted minimum temperatures are:

	External Surfaces	Internal Surfaces
No Internal Heat Source	-40°F	-40°F
400 Watts Internal Heat Source	-30.7°F	-30.8°F

3.4.4 Maximum Internal Pressure

Assume the package contains water loaded at 70°F. At maximum temperature (190.87°F), the pressure would increase as shown below:

The partial pressures of water and air at 70°F are:

$P_w = 0.36$ psi*

$P_a = 14.7 - .36 = 14.34$ psi

*Reference: 1967 ASME Steam Tables

The partial pressures at 191°F are:

$P_w = 9.54$ psi

$P_a = 14.34\ (191 + 460)/(70 + 460) = 17.61$ psi

The maximum internal pressure differential is thus:

$P = 9.54 + 17.61 - 14.7 = 12.45$ psi

3.4.5 Maximum Thermal Stresses

In Section 2.6.3, the critical elements of the cask were evaluated for a pressure differential of 0.5 atm (7.35 psi). The internal pressure due to the maximum temperature therefore increases stresses predicted in Section 2.6.3 by the factor: 12.45/7.35 = 1.69. The loads and margins of safety thus become:

Item	Stress	Allowable Load/Stress	Margin
Secondary Lid Stud	1399 lbs.	32,450 lb.	Large
Primary Lid Binders	8165 lbs.	45,000 lb.	Large
Shell	1920 psi	38,000 psi	Large
Lid	6777 psi	38,000 psi	+ 4.61

3.4.6 Evaluation of Package Performance for Normal Conditions of Transport

As the result of the above assessment, it is concluded that under the normal conditions of transport:

1. There will be no release of radioactive material from the containment vessel;

2. The effectiveness of the packaging will not be substantially reduced;

3. There will be no mixture of gases or vapors in the package which could, through any credible increase in pressure or an explosion, significantly reduce the effectiveness of the package.

3.5 Hypothetical Thermal Accident Evaluation

Not applicable for Type "A" packages.

3.6 Appendix

Thermal Analysis - Normal Conditions of Transport

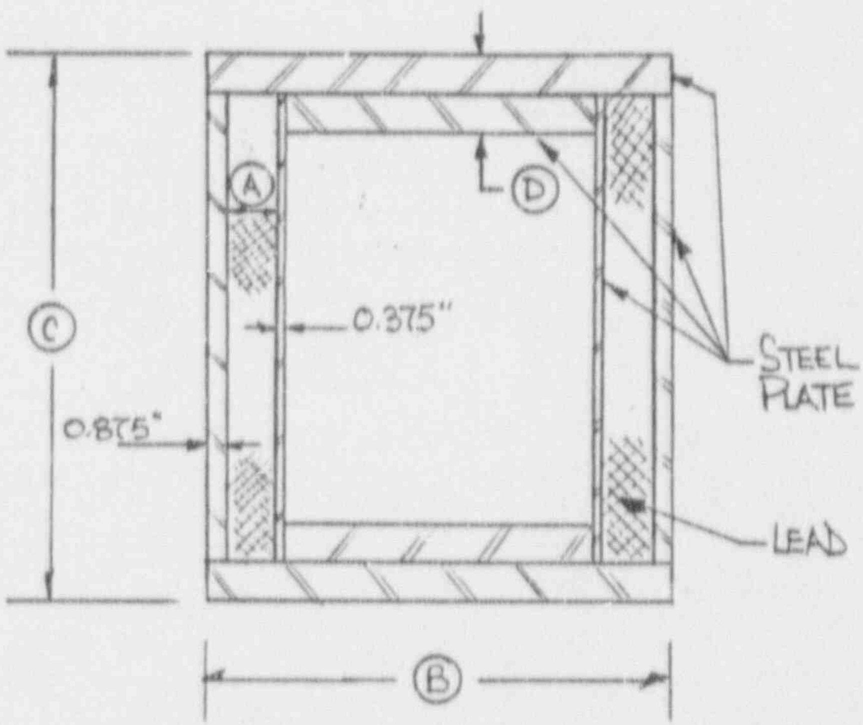
Hot and cold ambient condition cases are analyzed with the following assumptions:

Hot - Direct sunlight
Ambient air @ 130°F
Internal heat load = 0 & 400 Watts

<u>Cold</u> - Shade
Ambient air @ -40°F
Internal heat load = 0 & 400 Watts

Steady state solutions of the above conditions with maximum heating loads are obtained which yield conservative temperature predictions.

Simplified cask geometry used in the analysis:



DIMENSIONS (ft)

CASK MODEL	L(A)	L(B)	L(C)	L(D)
14-215	0.157	6.96	7.39	0.354

External Convective & Radiative Heat Transfers

Heat is lost to surroundings via convective and radiative heat transfer. No heat transfer through the cask base is considered.

Convection

$$q = hA(T_{ext} - T_{oo}) \qquad \Delta T = T_{ext} - T_{oo}$$

For free convection McAdams (W.H. McAdams, Heat Transmission, 3rd Ed., McGraw-Hill, NY, 1954.) gives:

$$h = 0.29 \left(\frac{\Delta T}{L}\right)^{1/4} \quad \text{for vert. cylinders}$$

$$= 0.27 \left(\frac{\Delta T}{L}\right)^{1/4} \quad \text{for horiz. plates (upheated)}$$

Thus:

$$q = h_s A_s \Delta T + h_T A_T \Delta T = (h_s A_s + h_T A_T)\,\Delta T$$

$$= \left[.29 \left(\frac{\Delta T}{L_c}\right)^{1/4} A_s + .27 \left(\frac{\Delta T}{L_B}\right)^{1/4} A_T \right] \Delta T$$

Where:

L_c = outside height

L_B = outside diameter

$A_s = \pi L_c L_B$

$A_T = \pi/_4 L_B^2$

Radiation

$$q = G A_s \epsilon (T_{ext}^4 - T_{oo}^4) = K (T_{ext}^4 - T_{oo}^4)$$

Where:

$C = 2.14 \text{ E-09}$

$\epsilon = .8$

$A_E = A_s + A_T$

Evaluating K:

Cask Model	L_B (ft)	L_c (ft)	A_{top} (ft^2)	A_{side} (ft^2)	A_E (ft^2)	K BTU/HR/°F^4
14-215	6.96	7.39	40.11	161.67	201.78	.2769 E-06

Solar Heat Load

Solar loads are calculated using insulation values given in U.S.N.R.C. Regulatory Guide 7.8.

They are:

$2950\ BTU/ft^2$ for the top surface

$1475\ BTU/ft^2$ for the vertical projected area of the cylinder

These values are total insolation for a 12 hour day.

The vertical surface insolation value must be multiplied by the projected vertical area (height & diameter) and both are converted to heat flux, $BTU/ft^2/hr$.

$$solar = \frac{2950}{12} A_T + \frac{1475}{12} L_c L_B$$

$$= 245.83\ A_T + 122.92\ L_c L_B$$

Steady State Solution

Setting total energy flow equal to zero:

$$q_{in} - q_{out} = 0$$

Payload decay heat is taken as 400 Watts or 1365 BTU/hr.

Solar load is assumed constant at maximum flux found above.

Thus:

$$q_{in} = q_{solar} + q_{internal}$$

$$= 245.83\ A_T + 122.92\ L_c L_b + 1365$$

$$q_{out} = q_{radiation} + q_{convection}$$

$$= K(T_{ext}^4 - T_{oo}^4) + \left[.29\left(\frac{T_{ext} - T_{oo}}{L_c}\right)^{1/4} A_s + .27\left(\frac{T_{ext} - T_{oo}}{L_B}\right)^{1/4} A_T\right](T_{ext} - T_{oo})$$

T_{ext} values for the packages under three load cases are given in the Table on Sheet 3-9.

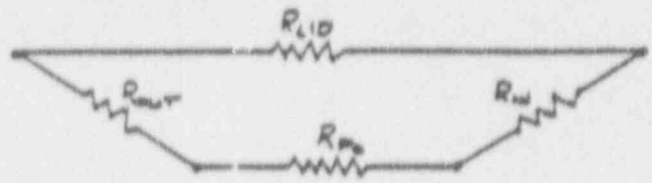
The load cases are:

1. Direct sunlight, ambient air at 130°F, 400 Watt internal heat load.
2. Direct sunlight, ambient air at 130°F, no internal heat load.
3. No sunlight, ambient air at -40°F, 400 Watt internal heat load.

CASK EXTERNAL TEMPERATURES

Cask Model	Load Case	L_C (FT)	L_B (FT)	A_S (FT^2)	A_T (FT^2)	q_{in} (BTU/HR)	K	T_{ext} (°F)
	1					17,545		179.9
14-215	2	7.39	6.96	161.7	40.1	16,180	$.2769x10^{-6}$	176.6
	3					1,365		-30.7

Conductive Heat Transfer Evaluation



$$R_{eff} = \frac{R_{lid}\,R_{wall}}{R_{lid} + R_{wall}} \qquad R_{wall} = R_{out} + R_{pb} + R_{in}$$

$$\Delta T = R_{eff}\, q$$

$$R_{lid} = \frac{t}{kA_1} \quad ; \quad k = 25 \text{ BTU/HR FT °F}$$

$$A_1 = \frac{\pi}{4}(L_B)^2 \quad (ft^2)$$

$$t = L_D \quad (ft)$$

Steel $R_{in} = {}^{t}/kA_w$ $\qquad A_w = \pi(L_B - 2(L_A \frac{+.375}{12} + \frac{.375}{12}))L_C$

$$t = .375'' = .0313 \text{ ft}$$

$R_{out} = {}^{t}/kA_w$ $\qquad A_w = \pi\, L_B\, L_C$

$$t = .875/12 = .0729 \text{ ft}$$

Lead $R_{pb} = \frac{\ln({}^{r}o/{}^{r}i)}{2\pi\ k\ \ell}$ $\qquad r_o = L_B/2$

$$r_i = [L_B - 2(L_A + \frac{.375 + .875}{12})]/2$$

$$k = 18.6 \text{ BTU/HR FT °F}$$

$$\ell = L_C$$

Values for R_{eff} and ΔT given in the following table, where:

ΔT is calculated by:

$$\Delta T = q\, R_{eff}$$

and $q = 400(3.41) = 1365$ BTU/hr

TEMPERATURE DIFFERENCE ACROSS CASK WALL

Cask Model	R_{WALL} $\frac{HR\ °F}{BTU}$	R_{LID} $\frac{HR\ °F}{BTU}$	R_{EFF} $\frac{HR\ °F}{BTU}$	ΔT (°F)
14-215	89.4	435	74	.101

4.0 CONTAINMENT

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

4.1 Containment Boundary

4.1.1 Containment Vessel

The containment vessel claimed for the 14-215 cask is the inner shell of the shielded transportation cask ar described in Paragraph 1.2.3 and the cask certification drawing.

4.1.2 Containment Penetration

A pressure tap is included in the design as described in Section 1.2.7. It is sealed with a 3/4" NPT pipe plug.

A drain line is also included in the design as described in Section 1.2.7. It is sealed with a 1/2" NPT pipe plug.

4.1.3 Seals and Welds

Two neoprene seals are used to seal the cask lids. The first is attached to the primary lid and seals the primary lid cask body interface. The second is also attached to the primary lid and seals the secondary primary lid interface. They are described in Section 1.2.3, above.

The integrity of the seals is demonstrated using a soap bubble leak test done in accordance with operating procedures.

4.1.4 Closure

The closure devices for the primary lid consist of eight 1.25 inch diameter high strength ratchet binders as described in Section 1.2, above and eight 3/4-10 UNC studs and nuts to close the secondary lid.

4.2 Requirements For Normal Conditions of Transport

The following is an assessment of the package containment under normal conditions of transport as a result of the analysis performed in Chapters 2.0 and 3.0, above. In summary, the containment vessel was not affected by these tests. (Refer to Section 2.6, above).

4.2.1 Release of Radioactive Material

Normal conditions of transport will have no effect on pressurizing the containment vessel.

4.2.3 Coolant Contamination

This section is not applicable since there are no coolants involved.

4.2.4 Coolant Loss

Not applicable.

4.3 Containment Requirements For The Hypothetical Accident Conditions

Not applicable for Type "A" packages.

5.0 SHIELDING EVALUATION

5.1 Discussion and Results

The 14-215 cask consists of a lead and steel containment vessel which provides the necessary shielding for the various radioactive materials to be shipped within the package. Tests and analyses performed under Chapters 2.0 and 3.0 above have demonstrated the ability of the containment vessel to maintain its shielding integrity under normal conditions of transport. Prior to each shipment, radiation readings will be taken based on individual loadings to ensure compliance with applicable regulations.

An optional shielding insert is occasionally shipped as part of the contents of this cask. This insert is described in Chapter 1.0. The integrity of this insert under normal conditions of transport is not compromised in any degree. The analyses in Chapters 2.0 and 3.0 bound the case where an insert as described is shipped with a reduced waste payload.

6.0 CRITICALITY EVALUATION

Not applicable for the 14-215 cask.

7. OPERATING PROCEDURES

Cask Selection

Prior to any use of the cask, an evaluation is performed to ensure that the cask is a suitable packaging within which to ship the waste. This evaluation becomes a simple routine for users generating consistent waste products. SEG works closely with users to verify that the contained waste product is suitable in packaged size, form, Curie content and dose levels to be successfully loaded, surveyed, and shipped in the 14-215 cask.

Container envelope dimensions are compared to those of the cask cavity. Containers are typically built to and identified by a model number that correlates with a given series of casks, facilitating this process. The approved waste forms for the cask (Ref. Section 1.4) bound all routine waste forms generated and shipped to the various burial sites. Curie content is determined by generator waste sampling and scaling methods which confirm that the waste does not exceed L.S.A. concentration limits.

Because waste dose levels are highly dependent upon the mixture of isotopes present in the waste and the waste form (e.g., solidified waste, dewatered resins, paper filter cartridges), they are carefully evaluated during the cask selection process to ensure that the container, once placed in and shielded by the cask, will meet the NRC/DOT dose rate limits (200mR/hr contact and 10mR/hr @ 2 meters (sides only)). Typically, based upon previous shipments of a generator's waste stream, this evaluation is accomplished by experienced judgement. If, however, a waste container appears that it would approach these shielded dose rate limits, a more rigorous analysis may be done to more closely predict the dose rate once the liner is placed in the cask.

Options available to the user at this point include:

1. Load the container into the cask and obtain actual readings.

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2. Hold container for decay.

3. Use the 14-215 cask with an insert heating cask payload limit.

4. Use a cask that is more heavily shielded than the 14-215 cask with insert yet provides a sufficient size cavity and payload to accommodate the waste container (not available for all container sizes).

5. Ship the container and cask in a closed transport vehicle.

Regardless of the approach selected, once the container is loaded, the dose rate external to the cask is measured and verified to be in accordance with Section 7.6 prior to shipment.

Cask Usage

The section which follows describes the procedures to be followed in using a 14-215 cask. Any maintenance activity, such as inspections, lubrication, gasket replacement/repair, etc. described in this section is described in more detail in Section 8.2, General Maintenance Program.

7.1 Lifting

7.1.1 The cask shall always be lifted using the four (4) provided lifting lugs only. The lifting lugs are the vertically oriented lugs on the sides of the cask spaced at 90° around the cask circumference.

7.1.2 The primary lid lifting lugs shall only be used to lift the cask lid (primary lid with secondary lid installed) or the primary lid alone. The secondary lid lifting lug shall only be used to lift the secondary lid.

7.2 Removal/Installation of Cask Lids

7.2.1.1 Release each ratchet binder handle from its storage position.

7.2.1.2 Engage the flip block to the sprocket wheel in the direction necessary to loosen the ratchet binder.

7.2.1.3 Loosen the ratchet binder by pulling the handle in the appropriate direction.

7.2.1.4 Remove the retaining pin from the upper ratchet binder pin and then remove the upper ratchet binder pin.

7.2.1.5 Remove the three (3) primary lid lifting lug covers.

7.2.1.6 Using the three (3) primary lid lifting lugs, suitable rigging and exercising caution in the handling of the primary lid due to possible contamination of the underside of the lid, remove the primary lid.

7.2.2 Removal of Secondary Lid

7.2.2.1 Remove the secondary lid holdown stud nuts.

7.2.2.2 Remove the secondary lid lifting lug cover.

7.2.2.3 Exercising caution due to the possible contamination of the underside of the secondary lid, remove the secondary lid.

7.2.3 Installation of Primary Lid

7.2.3.1 Prior to installation, inspect gasket for the following:

a. Gasket fully secured to the cask.

b. Gasket not cut, ripped or gouged.

c. Gasket is resilient.

d. Gasket is free of debris, dirt and/or grease.

7.2.3.2 Prior to installation, verify that the date of gasket change reflects compliance with the annual change requirements for the cask.

7.2.3.3 Using the three (3) lifting lugs on the primary lid and suitable rigging, lift and place lid on cask using alignment guides to ensure proper positioning. Take care not to damage gasket.

7.2.3.4 Secure the primary lid to the cask as follows:

a. Install the upper ratchet binder pin through the upper ratchet binder connector and the lid closure lug.

b. Tighten the ratchet binder by engaging the flip block to the sprocket wheel and rotate the ratchet binder. Torque to 100 (± 10) ft-lbs.

c. Disengage the flip block. Rotate and secure the handle to its storage position.

d. Install the three (3) primary lid lifting covers.

7.2.4 Installation of Secondary Lid

7.2.4.1 Prior to installation, inspect gasket for the following:

a. Gasket fully secured to the primary lid.

b. Gasket not cut, ripped or gouged.

c. Gasket is resilient.

d. Gasket if free of debris, dirt and/or grease.

7.2.4.2 Prior to installation, verify that the date of gasket change reflects compliance with the annual change requirements for the cask.

7.2.4.3 Using the one (1) lifting lug on the secondary lid and suitable rigging, lift and place lid into the opening on the primary lid. Use alignment pins to ensure proper positioning. Take care not to damage gasket.

7.2.4.4 Install the secondary lid stud nuts and torque to 100 (+10,-0) ft-lbs.

7.2.4.5 Install the secondary lid lifting lug cover.

7.3 Cask Loading

7.3.1 Survey empty cask and the vehicle carrying it to determine the loose and fixed contamination levels. Limitations pertaining to contamination levels shall be defined by regulations imposed on the user by the applicable governing bodies.

7.3.2 Inspect cask lid fasteners to ensure that all are present and undamaged.

7.3.3 Check to ensure that cask lid (primary and secondary) lifting lug covers are with the cask.

7.3.4 Remove primary lid in accordance with Section 7.2.1.

7.3.5 Remove secondary lid in accordance with Section 7.2.2, if required.

7.3.6 Inspect interior of cask for standing water.

NOTE: Water must be removed prior to shipment.

7.3.7 Inspect interior of cask for obstructions to loading.

7.3.8 Inspect interior of cask for defects which might affect the cask integrity or shielding afforded by the cask.

7.3.9 If loading drums on drum pallets, proceed as follows:

a. Load drums on each pallet.

b. For maximum shielding, position higher dose rate drums in the center of the pallet and toward the front and rear of the trailer.

c. Place slings around or along side drums to prevent pinching or damage to the slings by the lids or top pallet in the cask.

d. Place the loaded pallets in the cask.

e. For the cask lids removed for the loading process, inspect cask lid gaskets, install lids and secure as described in respective sections.

7.3.10 If loading preloaded containers, proceed as follows:

a. Ensure all lids, plugs, caps, etc. are installed on container.

b. Place container into the cask.

c. Install shims/storing between container and cask as necessary to secure the container in position.

d. For the cask lids removed for the loading process, inspect cask lid gaskets, install lids and secure as described in respective sections.

7.3.11 If loading into container inside cask, proceed as follows:

a. Place empty container in the cask.

b. Install shims/shoring between container and cask as necessary to secure the container in position.

c. Inspect primary cask lid gasket, install and secure primary lid as described in respective section.

d. Load the waste into the container through the secondary lid opening.

e. Install the liner lid, plugs, caps, etc. onto the container.

f. Inspect secondary lid gasket, install and secure secondary lid as described in respective section.

7.3.12 Install tamper-proof seals on the cask lids.

7.4 <u>Removal/Installation of Cask from Trailer</u>

7.4.1 <u>Cask Removal from Trailer</u>

7.4.1.1 Loosen ratchet binders/turnbuckles as necessary to remove pins from shackles at the cask end of tiedown system.

7.4.1.2 Remove pins from shackles.

7.4.1.3 Using four (4) cask lifting lugs and suitable rigging, lift cask off trailer.

<u>NOTE:</u> Do not use cask lid lifting lugs to lift the cask.

7.4.2 <u>Cask Installation on Trailer</u>

7.4.2.1 Using four (4) cask lid lugs and suitable rigging lift cask and place cask in proper position within the shear ring.

NOTE: Do not use cask lid lifting lugs to lift the cask.

7.4.2.2 Inspect tiedown lugs and shackles on cask and trailer for cracks and wear which would affect their strength.

7.4.2.3 Inspect tiedown cables to ensure they are not damaged (crimped, frayed, etc.)

7.4.2.4 Inspect tiedown ratchets/turnbuckles to ensure they are in proper working condition.

7.4.2.5 Install a shackle through the cask end of each tiedown cable and attach the shackle to the cask tiedown lug.

7.4.2.6 Tighten ratchet binders/turnbuckles as necessary to secure cask on trailer.

7.5 Containment Penetration Seals

If the tamper-proof seal on the cask cavity drain line or vent line has been removed, the pipe plug used to seal that line must be removed and properly reinstalled. Installation of the pipe plugs used to seal the cavity drain line and vent line shall be done using a pipe joint sealing compound. Pipe plugs shall be torqued to 20 (±2) ft-lbs. Immediately after installation of the plug a new tamper-proof seal shall be installed.

7.6 Preparation for Shipment

7.6.1 Perform radiation surveys of cask and vehicle, including a determination of surface contamination, to ensure compliance with 10CFR71.47 and 10CFR71.87 and complete the necessary shipping papers, certifications, and checklists.

7.6.2 Placard vehicle and label cask as necessary.

7.7 Receiving a Loaded Cask

The receiver, carrier and shipper are to follow the instructions of 10CFR20.205 when a package is delivered. These instructions include surveying the external surface of the cask for radioactive contamination.

8.0 ACCEPTANCE AND MAINTENANCE

8.1 Acceptance Tests

Fabrication of the 14-215 cask meets the requirements of Subpart D of 10CFR71. Fabrication is implemented and documented under a Quality Assurance program in accordance with the applicable requirements of 10CFR71, Subpart H.

8.1.1 Visual Inspection

The packaging shall be inspected visually for any adverse condition in materials or fabrication using applicable codes, standards, and drawings. Materials are specified under the ASTM code. Weld procedure and welder qualifications are in accordance with ASME Section IX. Prior to painting, non-destructive testing of welds is accomplished as described in the cask drawings.

8.1.2 Structural and Pressure Tests

After fabrication is complete, the cask assembly is subjected to a pneumatic pressure test of 8 psig (-0 psig, +1.0 psig). The cask is visually inspected after the pressure test. The acceptance criterion is no change has occurred to the cask as a result of the test.

8.1.3 Leak Tests

A leak test of a sensitivity of at least 10^{-3} STD cc/sec shall be performed using a test fixture (with calibrated pressure gauge and pre-set relief valve) mounted into the cask body drain plug cavity or the lid vent line. Air is introduced at a maximum rate of 0.5 psig/min until the test pressure of 8 psig (-0 psig, + 1.0 psig) is reached. All joints on the test fixture, primary lid and secondary lid gaskets are bubble tested. The pressure in the isolated cask is also monitored for at least 30 minutes. The acceptance criteria are:

- No leaks evidenced by the bubble solution.

- No pressure loss over a 30 minute time frame.

The system will be depressurized at a rate not exceeding approximately 2 psig/min, the test fixture removed and the drain or vent line plug reinstalled. The installation of the plug is to be done in accordance with Section 7.0.

8.1.4 Component Tests

8.1.4.1 Gaskets

Prior to painting, seating surfaces are to have a 125 RMS minimum finish. Leak testing (See Section 8.1.3) of the cask will be final acceptance for gasket design.

8.1.5 Tests for Shielding Integrity

Upon completion of the lead shielding pour, a gamma scan is done of the cask wall to verify lead thickness and the lack of any voids or impurities in the poured lead. The gamma scan procedure contains acceptance criteria for verification that lead thickness is not less than 1-7/8 inches. All gamma scanning will be conducted on a 2 inch grid system.

8.1.6 Thermal Acceptance Tests

No thermal acceptance testing will be performed on the 14-215 cask.

8.2 General Maintenance Program

8.2.1 General

Maintenance and repair of the 14-215 cask is controlled by the Westinghouse Radiological Services Division Quality Assurance program. The casks and trailers annually undergo three (3) routine technical inspections. These inspections are proceduralized in cask maintenance and repair procedures.

8.2.2 Gaskets

8.2.2.1 Gaskets shall be inspected for resiliency and complete adhesion to the appropriate surface during each use of the respective lids.

8.2.2.2 Gaskets in good condition but not adhered to the appropriate surface shall be reattached as follows:

a. Gently pull gasket away from its normally secured location until it cannot be removed further without damaging the gasket.

b. Remove residual adhesive from the appropriate surface. Clean with solvents which are recommended by the adhesive manufacturer's instructions.

c. Reapply gasket adhesive to the gasket and appropriate surface and reattach in accordance with the adhesive manufacturer's instructions.

8.2.2.3 Gaskets which cannot be sealed or are obviously damaged must be replaced in their entirety. Damage may include cuts, nicks, chips, indentations, or any other defect apparent to the naked eye which would affect sealing integrity. Removal of the gasket, preparation of the lid surfaces, adhesive use and gasket installation shall be performed per Section 8.2.2.2.

8.2.2.4 All gaskets shall be replaced after 12 months of installation on the cask regardless of apparent condition or cask usage.

8.2.2.5 A leak test, according to Section 8.1.3, shall be performed at least once within the twelve (12) months prior to any use.

8.2.2.6 Any painted surface in contact with the gasket shall be maintained in good condition. Any loose, chipped, or scratched painted surface which would affect seal integrity shall be repaired prior to further cask use.

8.2.3 Welds

8.2.3.1 All welds have been completely checked in accordance with ASME Code requirements using visual, magnetic particle and radiographic methods during fabrication. The cask drawing delineates these inspections. In-use inspections should not be required unless the cask has been involved in an accident or has been lifted improperly or in an overloaded condition. In those cases, inspection shall include the following:

a. Drop or accident: All accessible cask body and lug welds and primary lid ratchet binder lug welds shall be magnetic particle inspected in accordance with ASME Code Section III, Division I, Subsection NB, Article NB-5000 and Section V, Article 7. These inspections may be performed with the painted finish in place.

b. Improper or overloaded lift: All welds on the cask primary or secondary lid which were in use at the time of the improper or overload lift shall be magnetic particle inspected per the requirements delineated above.

8.2.3.2 Whenever welding to the cask is required it shall be performed utilizing weld procedures and welders qualified in accordance with ASME Code Section IX requirements.

8.2.4 Studs and Nuts

8.2.4.1 All studs and nuts shall be inspected during each removal of the secondary lid and superficially with each cask use. Replacement shall be made if the following conditions are present:

a. Deformed or stripped threads.

b Cracked or deformed hexs on nuts.

c. Elongated or scored grip length area on studs.

d. Severe rusting or corrosion pitting.

8.2.4.2 In general, all studs and nuts shall be inspected for damage at least once a year under normal usage conditions and replaced when the conditions delineated in Step 8.2.4.1 are present.

8.2.5 Ratchet Binders

8.2.5.1 The ratchet binders are designed for long term use with minimal maintenance. They are inspected for satisfactory operation and general condition before each use.

8.2.5.2 Filling of the lubricant reservoir is accomplished very infrequently on an as needed basis using standard automotive chassis lubricant. A lubricant reservoir is provided. Dry threads or hard operation will indicate the need for additional lubricant.

8.2.5.3 Any ratchet binder which received impact or suspected overloading in an accident must be completely disassembled and inspected or replaced. Causes for rejection during a damage inspection shall include:

a. Cracks in the jaws or joining bolt.

b. Deformation of the jaws or joining bolt.

c. Excessive rust or corrosion pitting in the threads of the jaw or joining bolt.

8.2.6 Painted Surfaces

8.2.6.1 Painted surfaces shall be cleaned using standard commercial equipment, chemical solutions, and procedures.

8.2.6.2 Chipped or scratched surfaces which could affect seal integrity shall be repainted prior to further cask use. Other chipped or scratched surfaces shall be repainted at the time of the next routine technical inspection referenced in Section 8.2.1.

8.2.6.3 Guide stripes and cask identification markings shall be repainted when they are chipped, peeled off, faded or illegible.

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