SAFETY ANALYSIS REPORT
FOR THE
NUPAC SERIES A CASKS
TO
10 CFR 71 TYPE "A" PACKAGING REQUIREMENTS

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NRC CERTIFICATE OF COMPLIANCE
AUTHORIZING SHIPMENT OF NUCLEAR MATERIAL
IN THE
NUPAC SERIES A CASKS

1.0 GENERAL INFORMATION

The "NuPac Series A Casks" have been developed around the very successful 7 and 14 drum casks referenced in Certificate of Compliance No. 9080 and 9079 respectively. These casks are extensively used for radwaste shipment throughout North America. The purpose of this Safety Analysis Report is to expand the number of available configurations from two to nine. All nine are identically configured and vary only in cavity size and shielding thickness. Each is capable of safely transporting Type A quantities of radioactive materials or greater than Type A quantities meeting the definition of Low Specific Activity material. Fissile material is limited to those exempt quantities licensed under 10 CFR 71.7. Authorization is sought for shipment by cargo vessel, motor vehicle and rail.

1.2 Package Description

1.2.1 Packaging

1.2.1.1 General Description

The NuPac Series A Casks form a family of nine individual reuseable shipping packages designed to protect radioactive material from normal conditions of transport. The nine packages are of identical construction, but have varying dimensions and shielding capabilities as shown in Table 1.2.1-1.

The NuPac Series A Casks are top loading shields designed specifically for the safe transport of Type A levels of radioactive materials. The shields can accommodate full capacity liners, or miscellaneous form cargo such as wooden crates, etc.

1.2.1.2 Materials of Construction, Dimensions and Fabricating Methods

General Arrangement drawings of the NuPac Series A Casks are included in Appendix 2.10.1. They show the overall dimensions as well as the material of construction.

The cask body consists of external and internal steel shells separated by a lead biological shield in the annular space between these two shells. The top and bottom ends of the cylindrical cask are constructed of a pair of stacked steel plates.

Table 1.2.1-1

NUPAC SERIES A CASKS

	BASIC DATA						DIMENSIONS (in.)						
	Characteristics			Weights (lbs)			Cavity Dim.		Thicknesses			Outer Dim.	
MODEL	Drum Cap.	P/L Vol.	Lead Equiv.	Empty	P/L	Loaded	Inner Dia.	Inner Hght.	Outer Lid Plate	Inner Lid Plate	Lead	Dia.	Height
							A	B	C	D	U	W	Z
NuPac 14/210L	14	217	2.0	28600	25000	53600	77.25	80.25	2.00	1.0	1.25	82.25	86.25
NuPac 14/210H	14	217	2.73	38400	25000	63400	77.25	80.25	2.00	2.00	1.88	83.50	88.25
NuPac 14/190L	14	190	2.0	26300	20000	46300	75.50	73.38	2.00	1.00	1.25	80.50	79.38
NuPac 14/190M	14	190	2.25	33500	20000	53500	75.50	73.38	2.00	2.00	1.75	81.50	81.38
NuPac 14/190H	14	190	3.5	45200	20000	65200	75.50	73.38	2.00	3.00	2.63	83.25	83.38
NuPac 10/140	10	144	3.6	41500	15000	56500	66.00	73.00	2.00	3.00	2.75	74.77	83.00
NuPac 7/100	7	104	3.5	35900	13000	48900	75.50	40.75	2.00	3.50	3.00	84.00	51.75
NuPac 6/100L	6	105	3.25	30900	12000	42900	61.00	62.00	2.00	2.50	2.43	69.11	71.00
NuPac 6/100H	6	105	4.40	41900	12000	53900	61.00	62.00	3.00	3.00	3.56	71.37	74.00

The top serves as a removable cask lid and is secured to the cylindrical cask body by eight high strength ratchet binders. An optional 16 or 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 tiedowns are a structural part of the package.

1.2.1.3 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 crates or other suitable palletized forms.

1.2.1.4 Neutron Absorbers

There are no materials used as neutron absorbers or moderators in the NuPac packages.

1.2.1.5 Package Weight

The gross, net and payload weights of the NuPac Packages are given in Table 1.2.1-1.

1.2.1.6 Receptacles

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

1.2.1.7 Containment Penetrations

The casks can be provided with a 1/2 inch NPT pipe plug and a 3/4" pipe drain line. Its use is for removal of entrapped liquids, such as rain or decontamination fluids. The drain is not used on the 14/210L or 14/190L casks.

An optional pressure tap is also included in the primary lid design. It consists of a .25 inch diameter hole drilled at a 60° angle through the lid top plate sealed with a pipe plug as shown in the General Arrangement Drawing, Appendix 2.10.1.

1.2.1.8 Tiedowns

Tiedowns are a structural part of the package. From the attached general arrangement drawing, it can be seen that four reinforced tiedown locations are provided. Refer to Section 2.4.4 for a detailed analysis of their structural integrity.

1.2.1.9 Lifting Devices

Lifting devices are a structural part of the package. From the general arrangement 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.

1.2.1.10 Pressure Relief System

There are no pressure relief valves.

1.2.1.11 Heat Dissipation

There are no special devices used for the transfer or dissipation of heat. The package maximum design capacity is 400 watts. However, this value may be exceeded if it can be demonstrated that actual equilibrium temperatures with the higher heat load are still within allowable limits.

1.2.1.12 Coolants

There are no coolants involved.

1.2.1.13 Protrusions

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

1.2.1.14 Shielding

The contents will be limited such that the radiological

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shielding provided will assure compliance with DOT and IAEA regulatory requirements. Should lead slump occur, as the result of a flat end drop, the deeply stepped lid will provide full shielding protection.

1.2.2 Operational Features

Refer to the General Arrangement drawing of the packaging, in Appendix 1.10.1. There are no complex operational requirements connected with the NuPac packages and none that have any transport significance.

1.2.3 Contents of Packaging

This application is for transporting the following radioactive materials as defined in 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 10 CFR 71.7;
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 radioactive solid waste materials such as pipe, wood, metal scrap, etc. All solidified resins will be contained within a disposable liner.

These liners will isolate the contents from the cask. Resin liners used for any solidification process that could create a significant chemical, galvanic or other reaction, will be lined with an inert protective coating.

2.0 STRUCTURAL EVALUATION

This Section identifies and describes the principal structural engineering design features of the packaging, components, and systems important to safety in compliance with the performance requirements of 10 CFR 71.

2.1 Structural Design

2.1.1 Discussion

The principal structural member of the NuPac Series A packages is the containment vessel described in Section 1.2.1. The above components are identified on the drawing as noted in Appendix 2.10.1. A detailed discussion of the structural design and performance of these components will be provided below.

2.1.2 Design Criteria

The NuPac Series A casks have been designed to be simple, strong packages that will provide maximum flexibility for usage as well as minimum potential exposure to operating personnel. The sizes and shielding capacities will allow a variety of payloads to be safely transported. The shield top and bottom are constructed of two steel plates laminated together.

Cylindrical side walls have an external skin of .875 or 1.13 inches and an internal skin of .375 or .5 inches thick plate. These two plates encase a variable thickness of lead. Pertinent dimensions of the nine versions of the NuPac Series A package are as given in Table 1.2.1-1. In all cases, 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 analytic evaluation. All analytic 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 NuPac Type A Family of packages. Material properties used in the analysis can be found in Section 2.3.

2.2 Weights and Center of Gravity

The weight of each of the nine cask versions and payloads are summarized in Table 1.2.1-1. The center of gravity for the assembled package is located at the approximate geometric center of gravity.

2.3 Mechanical Properties of Materials

The NuPac Series A packages are fabricated of ASTM A516 Gr. 70 steel except as noted below. Material properties of the A516 steel are as follows:

$F_{tu} = 70,000$

$F_{ty} = 38,000$ psi

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

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

The vertical plates of the lifting/tiedown lugs are constructed of ASTM A514 or A517 steel. Material properties used for these steels are as follows:

$F_{tu} = 110,000 - 135,000$ psi

$F_{ty} = 100,000$ psi

$F_{su} = 66,000 - 81,000$ psi $(.6\ F_{tu})$

$F_{sy} = 60,000$ psi $(.6\ F_{ty})$

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 $(.6\ F_{ty})$

Lead shielding will possess those properties referenced in ORNL-NSIC-68, Table 2.6, page 84.

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

<u>Bar Properties</u> (Per ASTM A320-78)

$F_{tu} = 125,000$ psi

$F_{ty} = 105,000$ psi

2.4 General Standards for All Packages

This section demonstrates that the general standards for all packages are met.

2.4.1 Chemical and Galvanic Reactions

The shield is constructed from heavy structural steel plates. All exterior surfaces are primed and painted with high quality epoxy. 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 an optional secondary lid affixed with eight 3/4 inch diameter studs. In addition, each package will be sealed with an approved tamper indicating seal and suitable locks 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 71.31(c).

2.4.3.1 Package Lifting Lugs

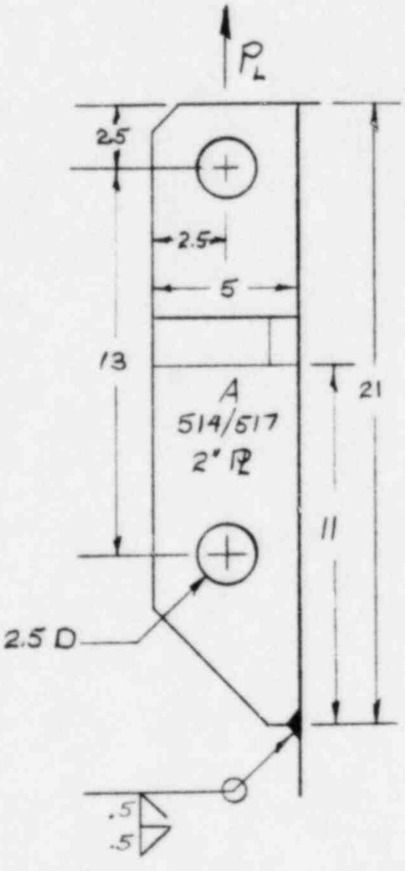
For conservatism, the package is assumed to be lifted by only two of the four identical lifting lugs. The maximum package weight is 65,200 lbs. (14/190H). The lug load is calculated as:

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

a_g = Load Factor, 3 g's (per Para. 71.31(c)(1) 10CFR71)

N = Number of lugs

$$P_L = (65200)(3)/2 = 97,800 \text{ lbs.}$$



Using the conventional 40° shear expression:

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

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

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

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

$$= \frac{370{,}200}{97{,}800} - 1 = \underline{+\ 2.79}$$

The shear stress in the lug-to-shell weld may be estimated as:

$$F_s = \frac{P_A}{A_W}.$$

The bending stress in the lug-to-shell weld may be estimated as:

$$F_B = \frac{P_A e}{Z}$$

A conservative approach is to equate the combined stress to the allowable shear stress:

$$F_{sy} = \frac{F_B}{2} + \sqrt{\left(\frac{F_B}{2}\right)^2 + {F_S}^2}$$

Substituting and rearranging, the shear-yield lug capacity is:

$$P_{ay} = \frac{F_{sy}}{\frac{e}{2z} + \sqrt{\left(\frac{e}{2z}\right)^2 = \left(\frac{1}{A_W}\right)^2}}$$

Where:

A_W = Weld Area = $L_w \cdot t_w$

L_W = 2(8" + 11") = 38" Considering only the vertical welds attaching the T-1 plate to the cask.

t_w = 2(.5")(.707") = .707"

A_w = 38" (.707") = 26.9 in.^{2}

e = 2.5"

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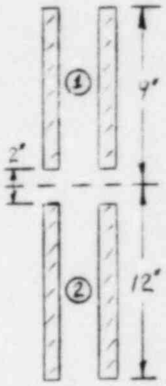
Z = Weld section modulus = $\frac{I}{C}$

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

Section	A	d	A·d
①	(.707)(8) =5.66	5	28.28
②	(.707)(11)=7.78	-6.5	-50.55
	13.44		-22.27



$$\bar{d} = \frac{-22.27}{13.44} = -1.66 \text{ in.}$$

$$I_{①} = 2\left\{\left(\frac{1}{12}\right)(.707)(8)^3 + (5.66)(5+1.66)^2\right\} = 562 \text{ in.}^4$$

$$I_{②} = 2\left\{\left(\frac{1}{12}\right)(.707)(11)^3 + (7.78)(6.5-1.66)^2\right\} = 521 \text{ in.}^4$$

$$I = I_{①} + I_{②} = 562 + 521 = 1083 \text{ in.}^4$$

$C(\max) = 10.66$ in.

$$Z = \frac{1083}{10.66} = 101.6 \text{ in.}^3$$

$$P_{ay} = \frac{22{,}800}{\frac{2.5}{2(101.6)} + \sqrt{\left(\frac{2.5}{2(101.6)}\right)^2 + \left(\frac{1}{26.9}\right)^2}} = 443{,}055 \text{ lbs.}$$

$$\text{M.S.} = \frac{P_{ay}}{P_a} - 1$$

$$= \frac{443{,}055}{97{,}800} - 1 = \underline{+\ 3.53}$$

Therefore, it can be safety 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.

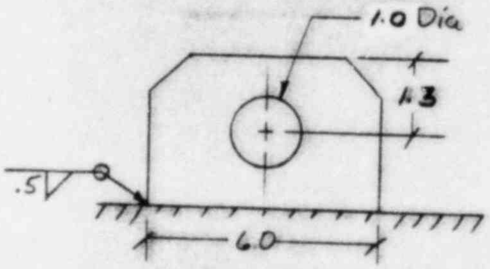
The maximum lid weight is 8,200 lbs.(for the NuPac 7/100 cask). Using three lugs the load per lug is:

$$P = (8200 \text{ lbs})(3 \text{ g's})/3 \text{ lugs}$$

$$P_L = 8200 \text{ lbs/lug}$$

This is greater than the secondary lug load of:

$$3(1500 \text{ lbs}) = 4500 \text{ lbs.}$$



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

$$P_s = F_{sy} 2t \quad (e_d - \frac{d}{2} \cos 40^\circ)$$

Where: F_{sy} = 22,800 psi (yield)
t = 1.0 in.
d = 1.0 in.
E_d = 1.3 in.

$$P_s = (22,800)(2)(1.0)(1.3 - \frac{(1.0)}{2}\cos 40^\circ)$$

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

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

$$\text{M.S.} = P_s/P - 1$$
$$= 41,810/8,200 - 1$$
$$= \underline{+\ 4.10}$$

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

$P_A = F_{sy} \cdot A_w$; F_{sy} = 22,800 psi
$A_w = L_w \cdot t_w$
$L_w = 2(6+1.0) = 14.0$
$t_w = (.38)(.707) = .269$ (Fillet Weld)

$$P_A = (22,800)(14.0)(.269) = 85,756 \text{ lbs.}$$

The lug to lid weld margin of safety is:

$$\text{M.S.} = 85,756/8,200 - 1 = \underline{+\ 9.46}$$

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 (10 CFR 71 Para. 71.31(d)(A)). 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:

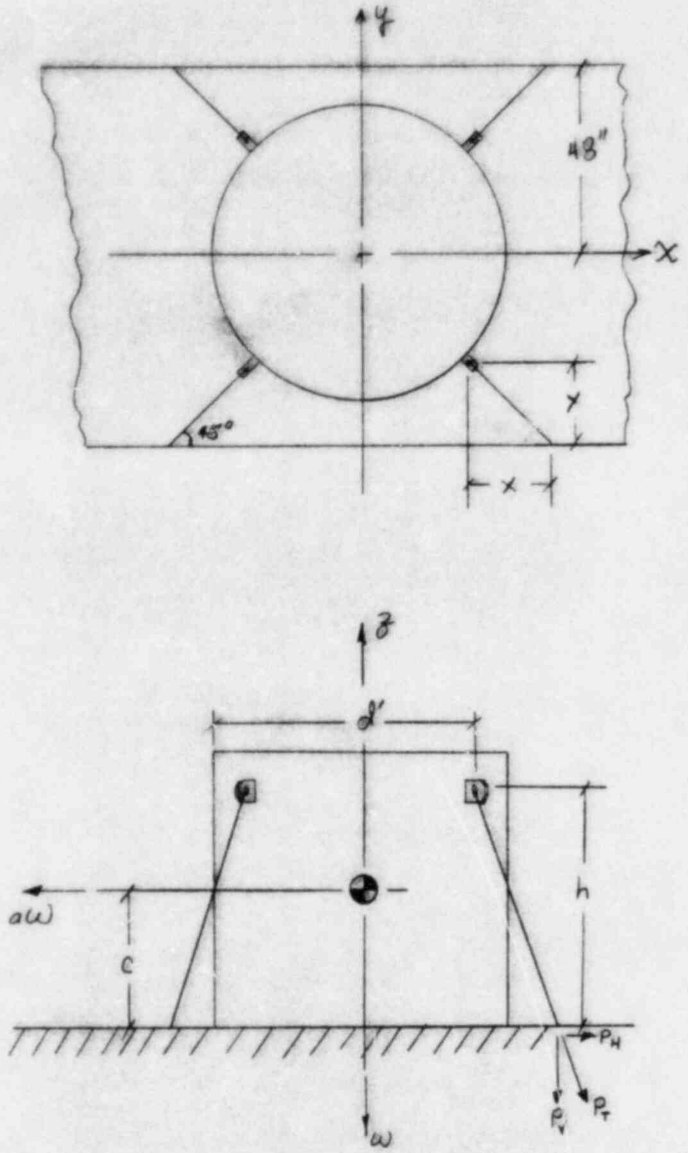
A_x = 10g (longitudinal)

A_y = 5g (lateral)

A_z = 2g (vertical)

The four tiedown lugs are located at 90° intervals around the package sidewall at elevations ranging from 33.5" to 70.6" above the package base, depending upon the version, as shown in Column h of Table 2.4.4-1. The tiedown arrangment for the NuPac Series A Casks is shown in Figure 2.4.4-1. Tiedown cables are assumed to be fastened to the transporter at the same elevation as the base of the cask as shown (i.e., top of transporter deck).

From the geometry given in the sketch, the cable tension due to horizontal accelerations can be determined by summing



B_x, B_y, B_z are cable direction cosines

If l is the cable length:

$B_x = X/l$ $\qquad$ $P_H = B_x P_T$ or $B_y P_T$

$B_y = Y/l$ $\qquad$ $P_V = B_z P_T$

$B_z = h/l$

FIGURE 2.4.4-1

moments about the opposite bottom corner of the package. For the longitudinal acceleration case:

$$A_xWc = 2(P_vd' + P_hh)$$

But,

$$A_xWc = 2P_T(B_zd' + B_xh)$$

Solving for P_T:

$$P_{T_{long}} = \frac{W}{2}\left(\frac{A_xc}{B_zd' + B_xh}\right)$$

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

$$P_{T_{lat}} = \frac{W}{2}\left(\frac{A_y}{B_zd' + B_yh}\right)$$

The cable tension due to the vertical acceleration is simply:

$$4P_v = A_zW = 4B_zP_T$$

Solving for P_T:

$$P_{T_{vert}} = \frac{A_zW}{4B_z}$$

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

$$P_T = \frac{W}{2}\left(\frac{A_xc}{B_zd' + B_xh} + \frac{A_yc}{B_zd' + B_yh} + \frac{A_z}{2B_z}\right)$$

Cable forces were calculated for each of the nine casks and are given in Table 2.4.4-1.

TABLE 2.4.4-1

CASK TIEDOWN CABLE FORCES

NuPac Cask Model	Gross Weight (lb.)	Outside Diameter (in.)	Outside Height (in.)	d* (in.)	h* (in.)	Cable Length (in.)	Bx, By*	Bz*	Cable Tension (lb.)
14/210L	53,600	82.25	86.25	72.0	68.6	72.8	.236	.942	234,800
14/210H	63,400	83.5	88.25	73.0	70.6	74.5	.224	.948	280,200
14/190L	46,300	80.5	79.38	70.5	61.7	66.6	.267	.926	193,600
14/190M	53,500	81.5	81.38	71.3	63.7	68.3	.255	.933	225,900
14/190H	65,200	83.25	83.38	72.8	65.7	69.9	.240	.940	276,800
10/140	56,500	74.77	83.00	65.6	45.5	53.4	.371	.852	275,000
7/100	48,900	84.00	51.75	73.5	34.1	41.5	.400	.826	157,300
6/100L	42,900	69.11	71.00	60.8	33.5	45.5	.479	.736	217,200
6/100H	53,900	71.37	74.00	62.7	36.5	47.1	.446	.775	265,200

*Refer to Figure 2.4.4-1

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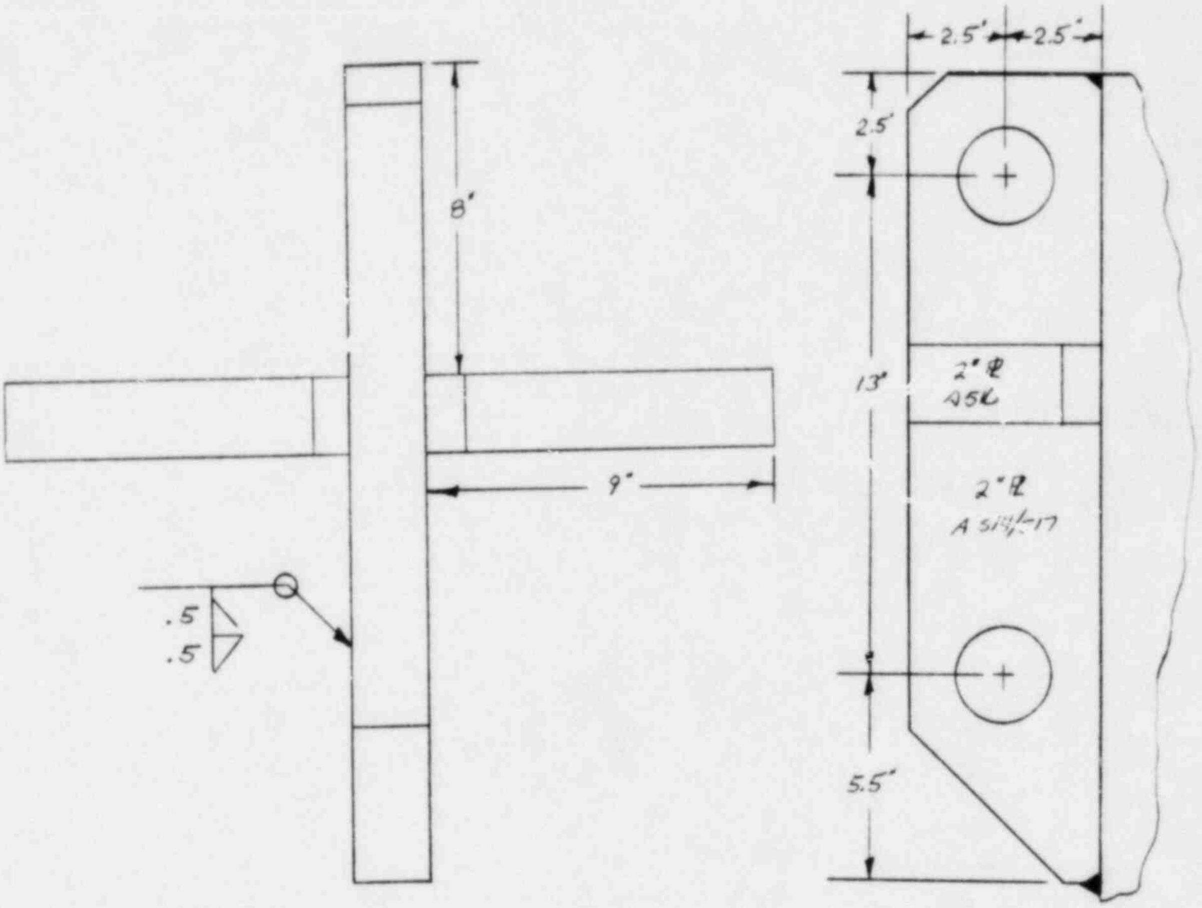
The tiedown lug is made of three plates welded together as shown in the sketch below. The tiedown cable is attached to the lower hole. The cable lies in a near vertical plane which also is the lug plane of symmetry. Therefore, no twisting moments are induced in the lug.



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

$$P_L = 2F_{sy}t\left(e_d - \frac{d}{2}\cos 40^\circ\right)$$

From the figure above:

$t = 2"$

$e_d = 2.5"$

$d = 2.5"$

Then:

$$P_L = 2(60,000)(2")(2.5 - \frac{2.5}{2} \cos 40^\circ)$$
$$= 370,200$$

Using the maximum cable tension of 278,500 lb. from Table 2.4.4-1, the yield Margin of Safety is:

$$M.S. = \frac{370,200}{280,200} - 1 = \underline{+ .32}$$

The cable load consists of both horizontal and vertical components. As shown in Table 2.4.4-1, the 14/210H cask produces the largest cable load, introducing both a bending moment and a shear load into the outer shell through the lug to shell weld.

The shear stress in the lug-to-shell weld may be expressed as:

$$F_S = \frac{P_V}{A_W}$$

The bending stress in the lug-to-shell weld may be expressed as:

$$F_B = \frac{P_V e_V}{z} - \frac{P_H e_H}{z}$$

A conservative approach is to equate the combined stress to the allowable shear stress:

$$F_{sy} = \frac{F_B}{2} + \sqrt{\left(\frac{F_B}{2}\right)^2 + F_S^{\,2}}$$

Where: $$P_H = P\sqrt{B_X^{\,2} + B_Y^{\,2}}$$

$$P_V = B_Z P$$

From Section 2.4.3.1, Package Lifting Lugs:

$A_W = 26.9$ in.

$Z = 101.6$ in.^{3}

$e_V = 2.5$ in.

$e_H = 4.84$ in.

From Table 2.4.4-1

$B_x = B_y = .224$

$B_z = .948$

Then: $$F_s = \left(\frac{.948}{26.9}\right) P = .0352P$$

$$F_B = P\left(\frac{.948(2.5)}{101.6} - \frac{.317(4.84)}{101.6}\right) = .0082P$$

$$F_{sy} = \frac{P(.0082)}{2} + \sqrt{\left(\frac{P(.0082)}{2}\right)^2 + (P(.0352))^2} = .0395P$$

The shear-yield lug capacity is:

$$P_y = \frac{22,800}{.0395} = 576,661 \text{ lbs.}$$

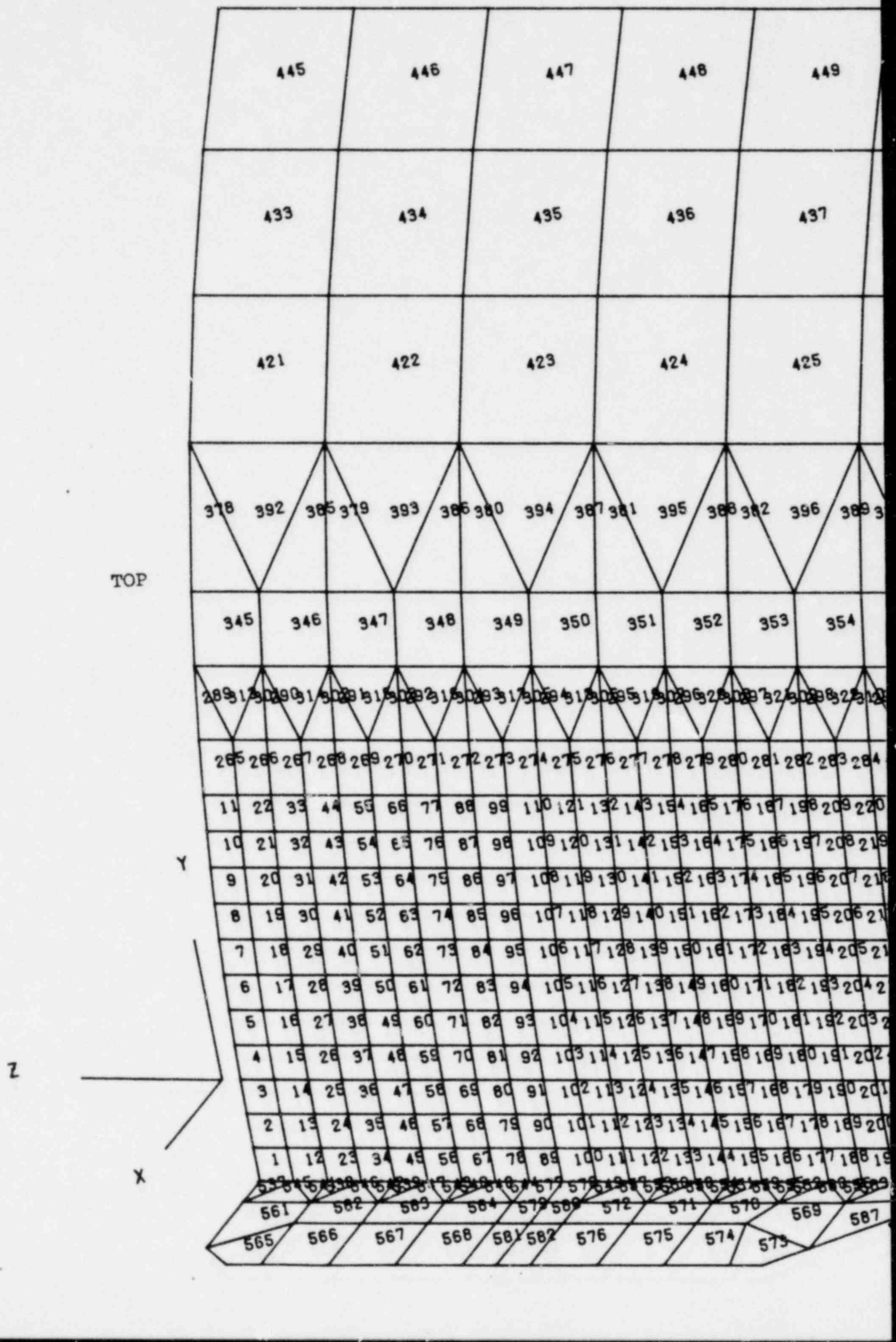
$$\text{M.S.} = \frac{P_y}{P} - 1$$

$$= \frac{576,661}{280,200} - 1 = \underline{+\,1.06}$$

The stresses induced into the outer shell by the tiedown lugs were determined using the finite element analysis program ANSYS, Revision 3, Update 672, available on the Boeing Computer Services (BCS) National Network, MAINSTREAM - EKS.

The Finite Element model consisted of a 45° section of the cask outer shell, inner shell, cask wall top plate, and one-half the lug. In addition, 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 $k = AE/L$.

The model, with exception of the spring elements, was defined entirely of quadrilateral shell elements. The geometry plots are illustrated in Figure 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 plate. Sections of the model were segregated by assigned element type numbers. The thickness at each node in an element was defined in a real constant table for each element type.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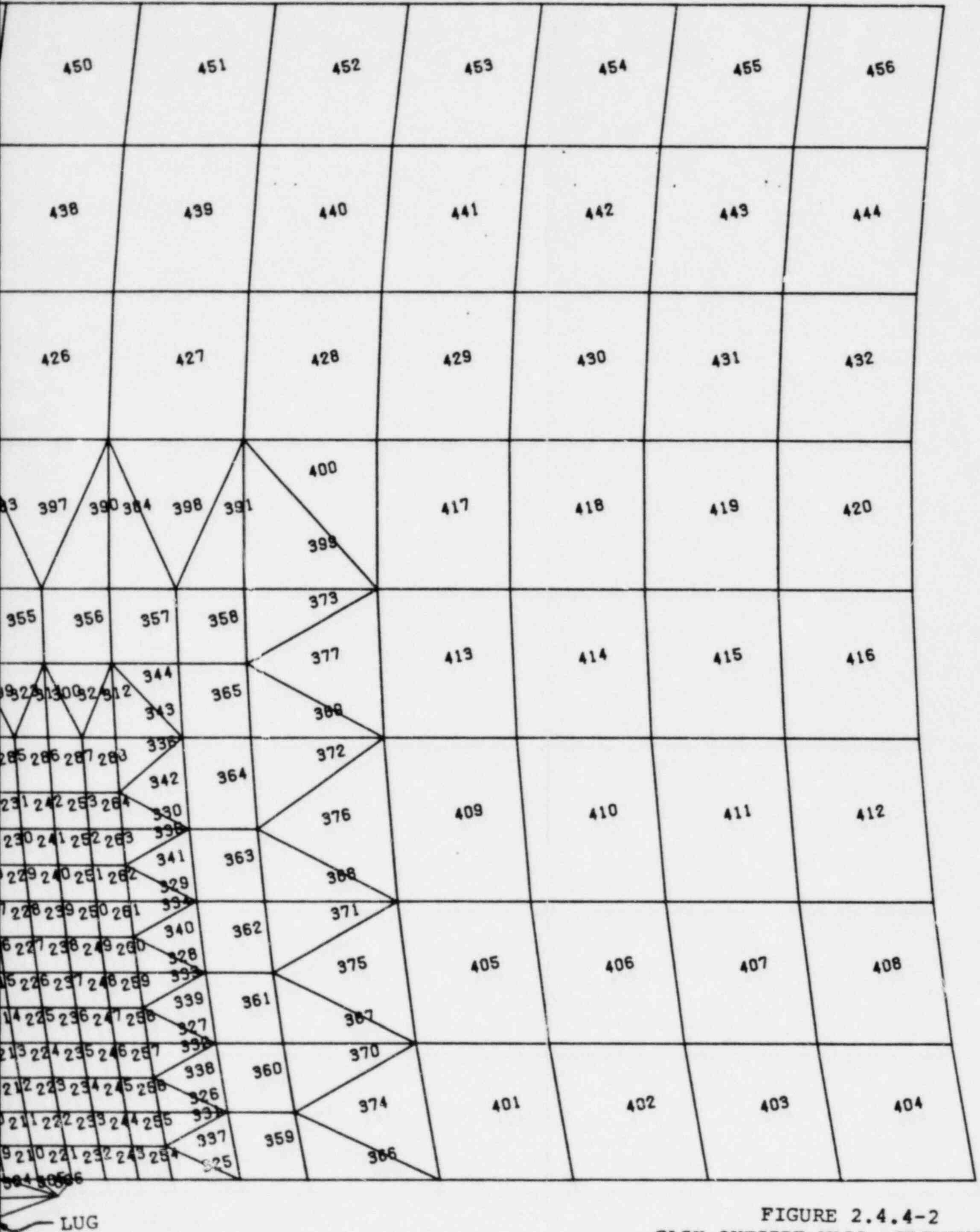
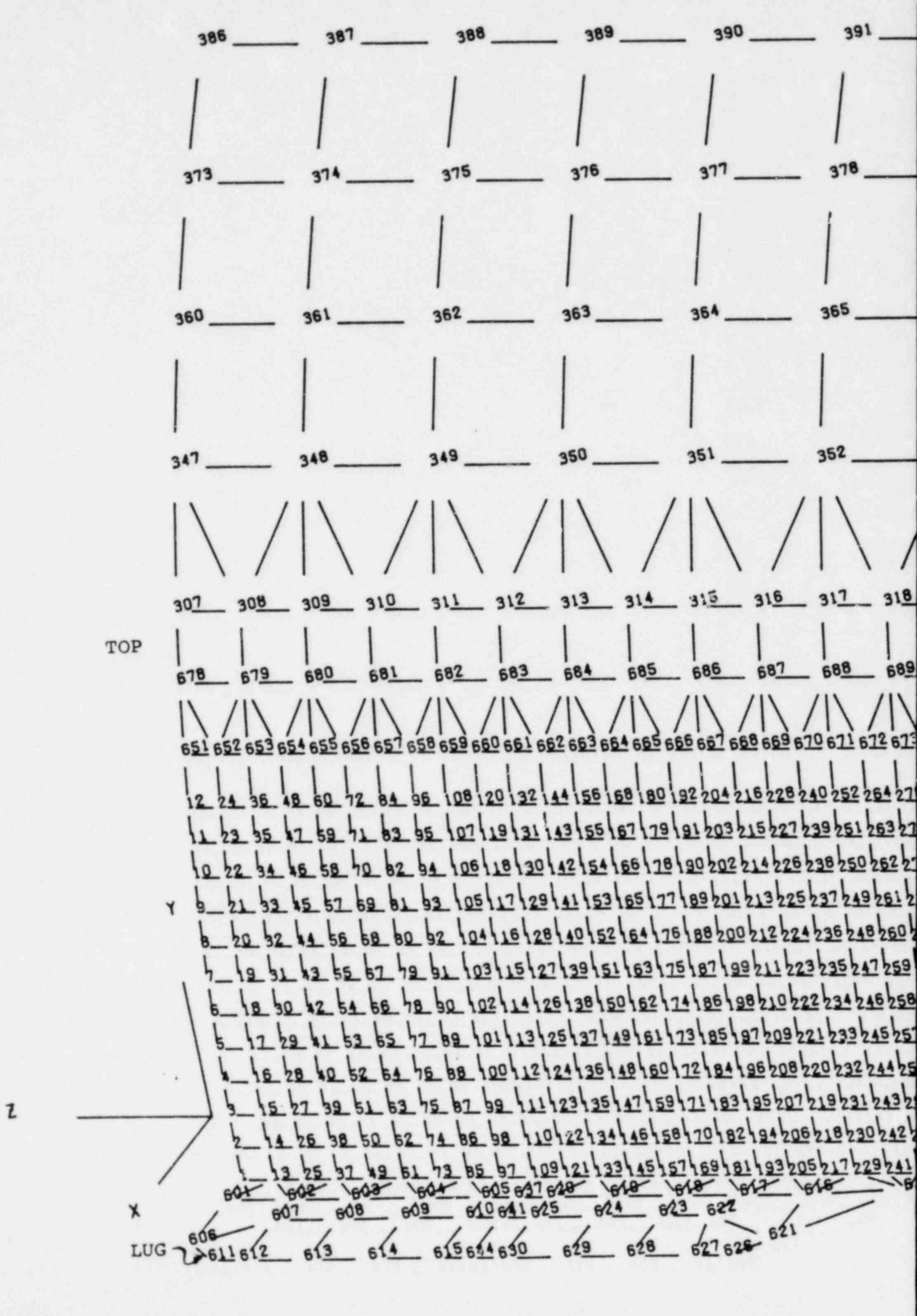


FIGURE 2.4.4-2
CASK OUTSIDE WALL, ELEMENT GEOMETR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360 361 362 363 364 365
347 348 349 350 351 352
307 308 309 310 311 312 313 314 315 316 317 318
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651 652 653 654 655 656 657 658 659 660 661 662 663 664 665 666 667 668 669 670 671 672
12 24 36 48 60 72 84 96 108 120 132 144 156 168 180 192 204 216 228 240 252 264
11 23 35 47 59 71 83 95 107 119 131 143 155 167 179 191 203 215 227 239 251 263
10 22 34 46 58 70 82 94 106 118 130 142 154 166 178 190 202 214 226 238 250 262
Y
9 21 33 45 57 69 81 93 105 117 129 141 153 165 177 189 201 213 225 237 249 261
8 20 32 44 56 68 80 92 104 116 128 140 152 164 176 188 200 212 224 236 248 260
7 19 31 43 55 67 79 91 103 115 127 139 151 163 175 187 199 211 223 235 247 259
6 18 30 42 54 66 78 90 102 114 126 138 150 162 174 186 198 210 222 234 246 258
5 17 29 41 53 65 77 89 101 113 125 137 149 161 173 185 197 209 221 233 245
4 16 28 40 52 64 76 88 100 112 124 136 148 160 172 184 196 208 220 232 244
Z
3 15 27 39 51 63 75 87 99 111 123 135 147 159 171 183 195 207 219 231 243
2 14 26 38 50 62 74 86 98 110 122 134 146 158 170 182 194 206 218 230 242
1 13 25 37 49 61 73 85 97 109 121 133 145 157 169 181 193 205 217 229 241
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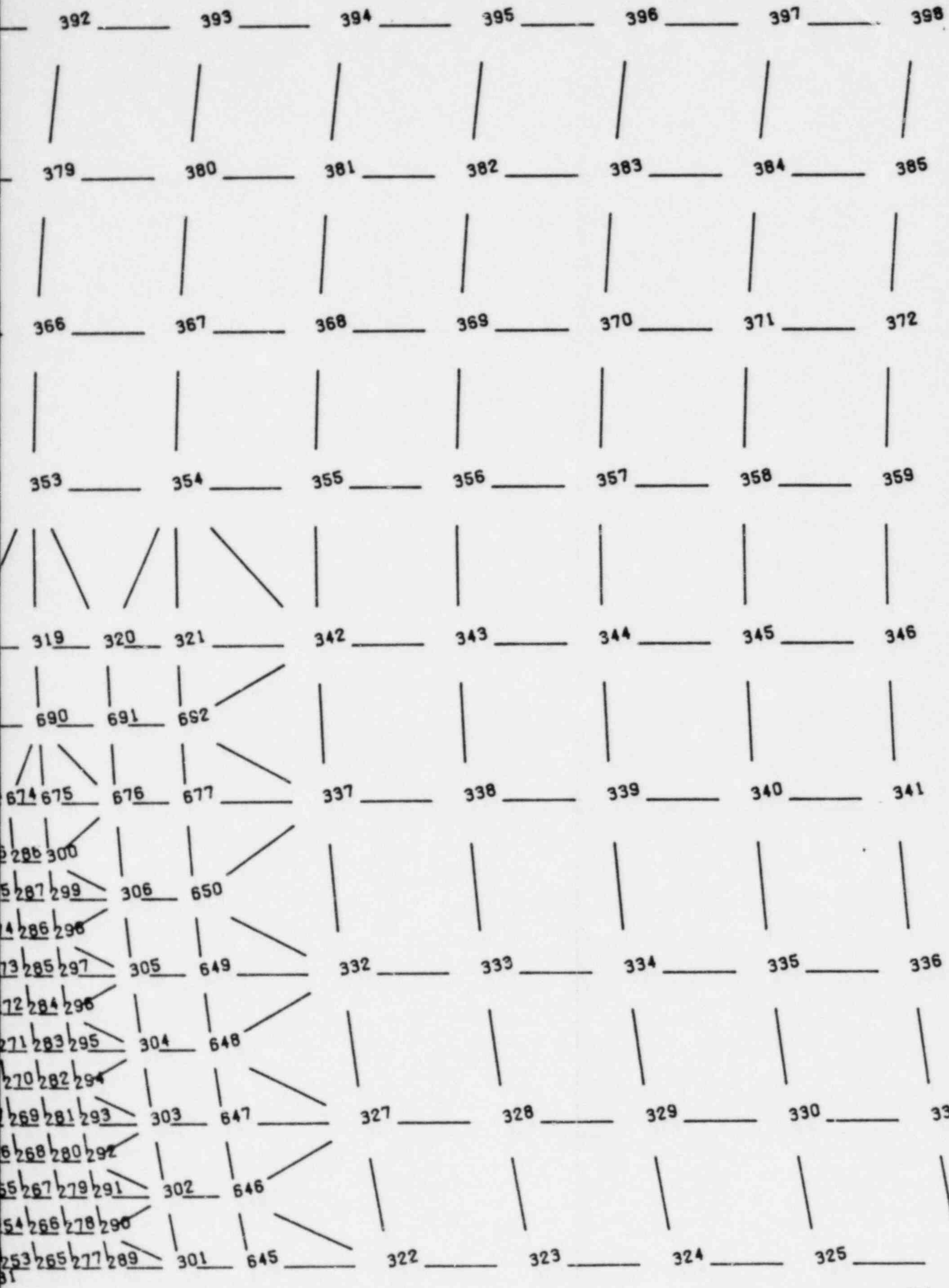
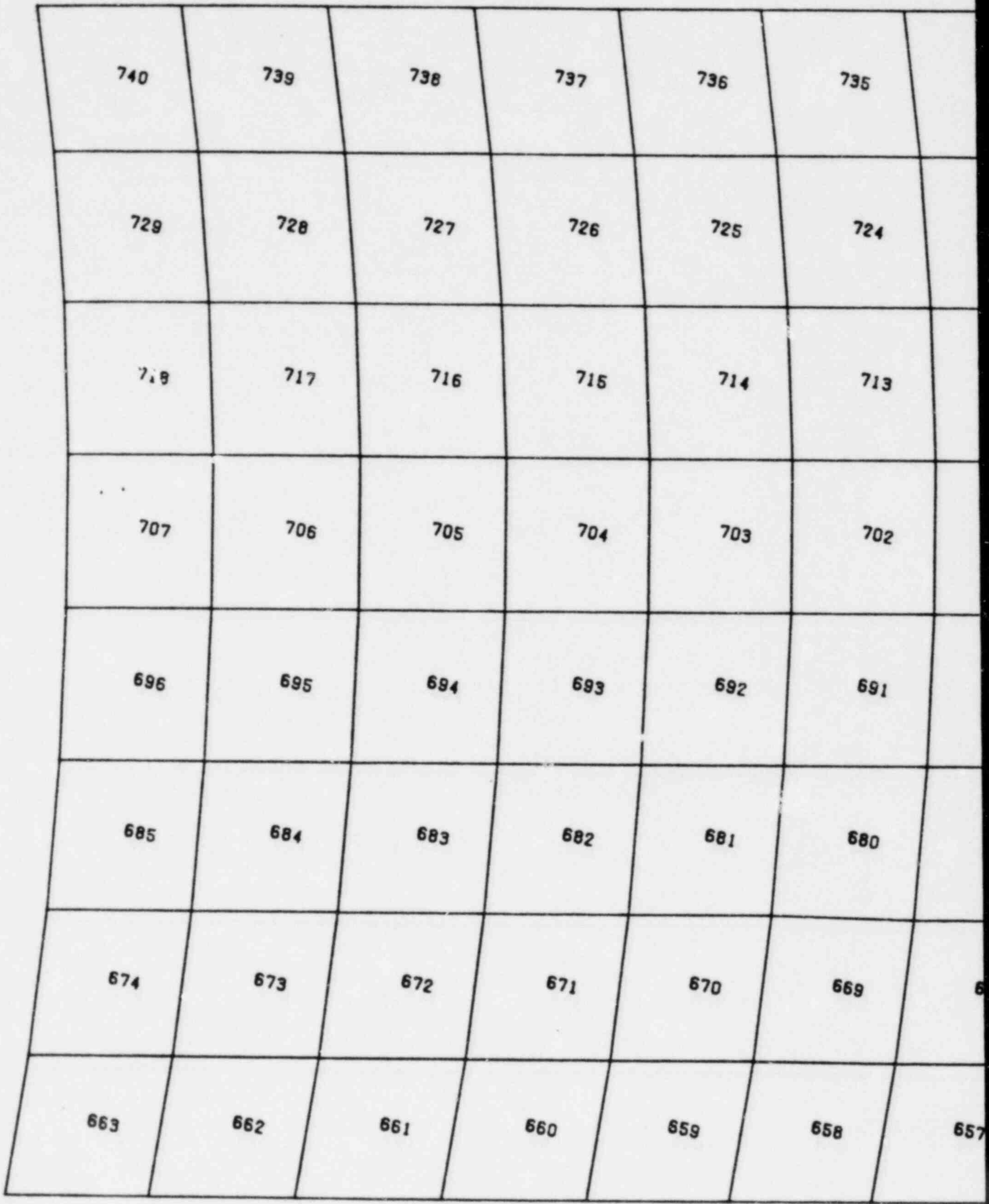


FIGURE 2.4.4-3
CASK OUTSIDE WALL, NODE GEOMETRY



740	739	738	737	736	735	
729	728	727	726	725	724	
718	717	716	715	714	713	
707	706	705	704	703	702	
696	695	694	693	692	691	
685	684	683	682	681	680	
674	673	672	671	670	669	6
663	662	661	660	659	658	657

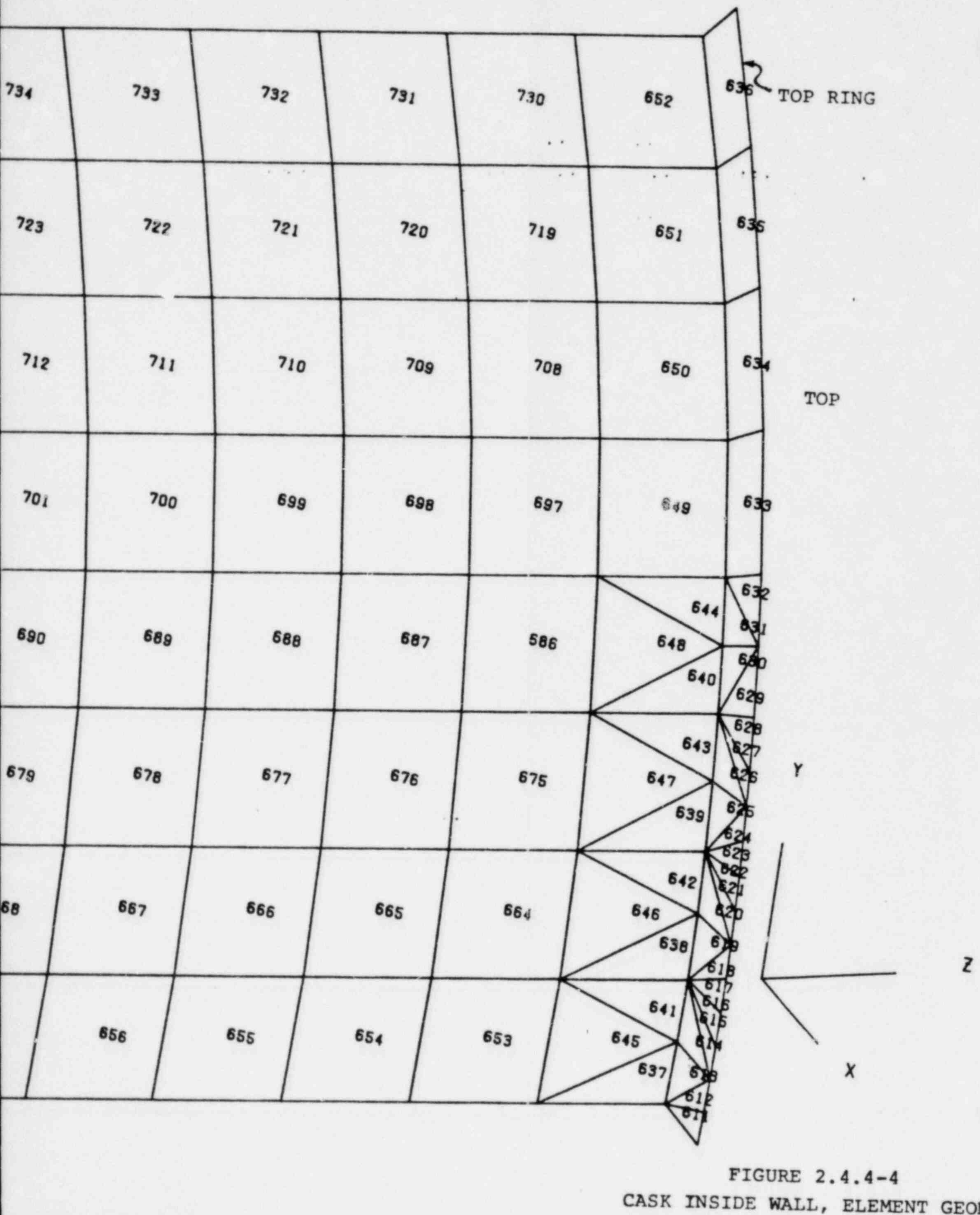
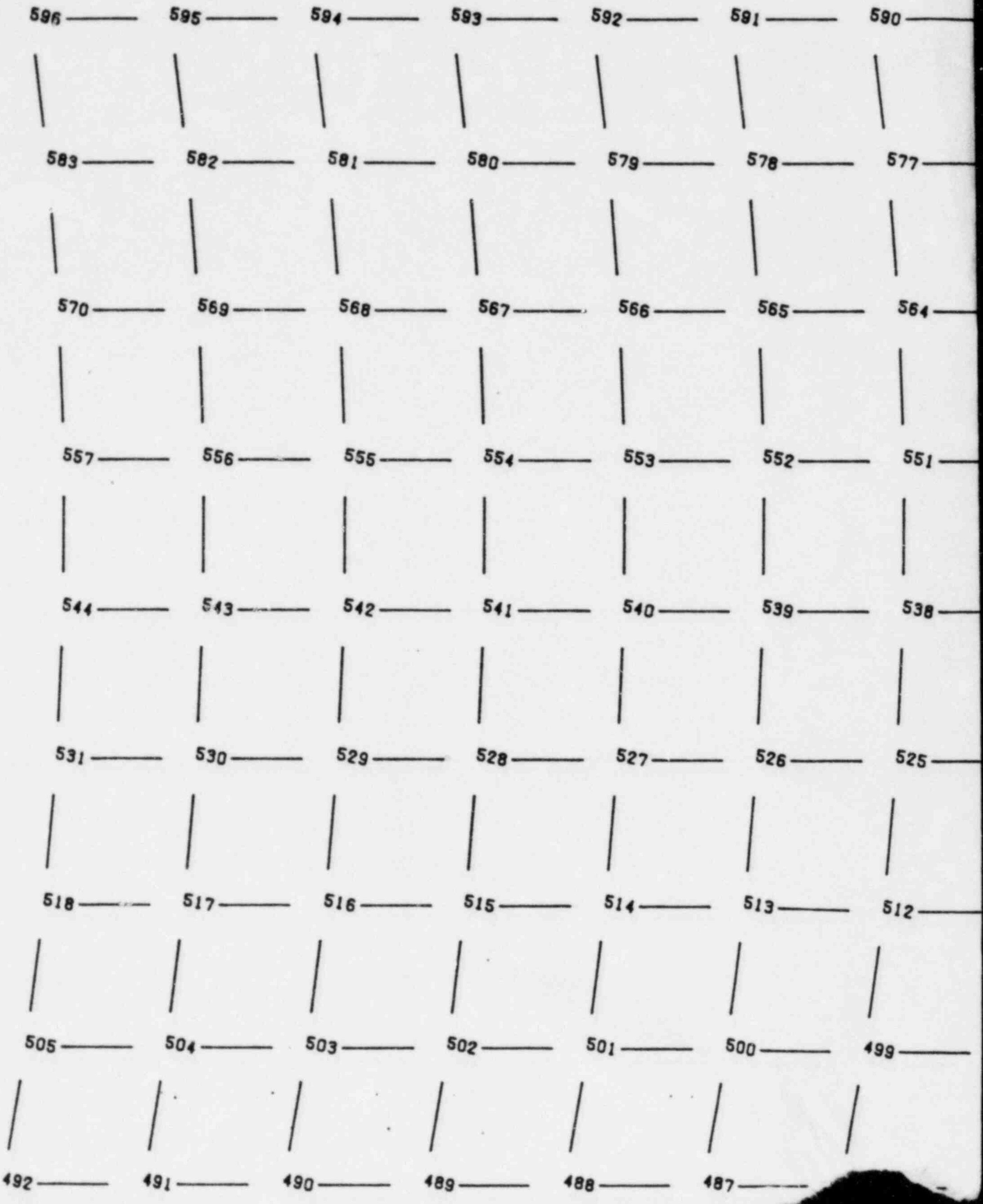


FIGURE 2.4.4-4
CASK INSIDE WALL, ELEMENT GEOMETRY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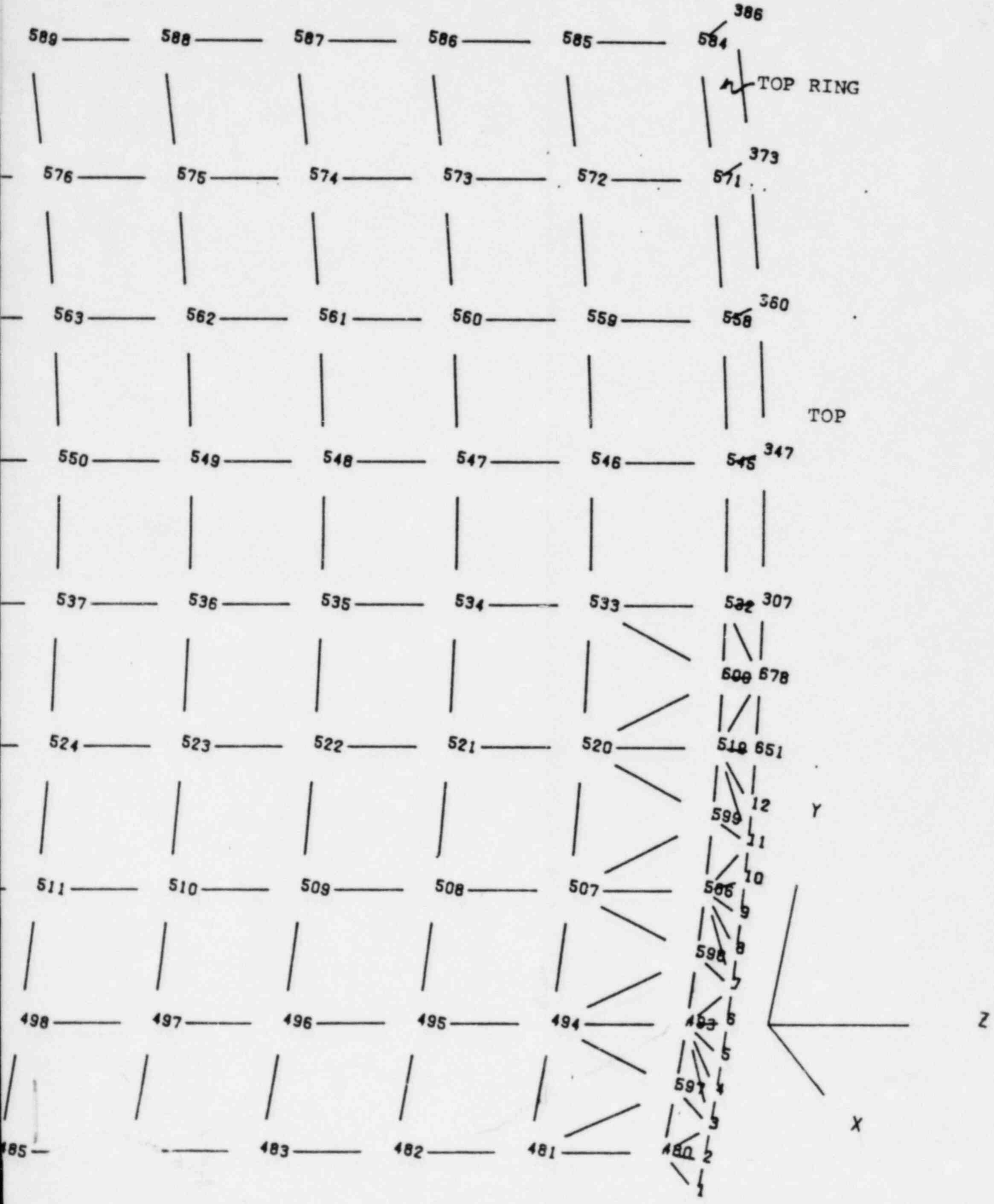

FIGURE 2.4.4-5
CASK INSIDE WALL, NODE GEOMETRY

PROPRIETARY DATA

The element size was decreased in the area of the lug for greater accuracy. Furthermore, to enhance the model definition, the node directly adjacent to each of the lug attachment nodes was linearly 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.

The load was introduced as a 84,100 lb. outward radial component combined with a 266,800 lb. downward vertical component at Node 622 to correspond with the cable tension from Table 2.4.4-1 for the 14/210H cask, the maximum case. 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 amount specified for the lighter casks.

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 2-17. The second highest stress area in the outer shell occured around the end of

```
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        10.4      -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        1038.5     SMX,SMN,TMX=  320.27        -4041.6          2180.9        A=  75.8 SIGE=  4210.9
BOT SX,SY,TXY= -1958.0        -3979.5       -517.36     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= -3567.4        -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= -5004.3        -22792.         163.98     SMX,SMN,TMX= -5002.8        -22794.          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.         2440.9        -4478.4     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  266  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= -20896.        -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          597.90        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=  520.25        -7031.1         2467.8     SMX,SMN,TMX=  1255.2        -7766.1          4510.7        A=  73.4 SIGE=  8463.8
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PROPRIETARY DATA

horizontal lug. The highest, 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:

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

From page 2.15 above, the yield capacity of the lug is 370,200 pounds. The ultimate capacity is then:

$$P_{lug} = 370,200 \frac{81,000}{60,000} = 499,800 \text{ lbs.}$$

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

$$P_{weld} = 835,900\ \frac{42,000}{22,800} = 1,540,000 \text{ lb.}$$

$$P_{shell} = 281,290\ \left(\frac{70,000}{20,749}\right)$$

$$= 948,976 \text{ lb.}$$

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

2.5 Standards for Type "B" & Large Quantity Packaging

This section demonstrates that the standards of Section 71.32, 10CFR71, for Type "B" and large quantity packaging 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:

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

Taking the NuPac 14/210H package as the most critical:

$$M = \frac{5WL}{8} = (5)(1/8)(63{,}400)(88.25) = 3.497 \times 10^6 \text{ in-lb}$$

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

$$I = \pi\frac{d_o^4 - d_i^4}{64} = \frac{\pi}{64}(83.5^4 - 81.75^4)$$

$$= 193{,}800 \text{ in}^4$$

and the corresponding stress is:

$$S_f = \frac{MC}{I} = \frac{(3.497 \times 10^6)(41.75)}{193,800} = 753 \text{ psi}$$

which results in a Margin of Safety of:

$$MS = \frac{F_{ty}}{S_f} - 1 = \frac{38,000}{753} - 1 = \underline{+ \text{ Large}}$$

Therefore, the package can safety 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

$r = (84.0 - .875)/2 = 41.56$

$t = .875$ in. (outside shell only)

$F = (25)(41.56)/.875 = 1187$ psi

Margin of Safety:

$$\begin{aligned} M.S. &= F_{ty}/F-1 \\ &= 38,000/1187 - 1 \\ &= \underline{+ \text{ Large}} \end{aligned}$$

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: $W = (25)\ \pi(83.75)^2/4 = 137{,}721$

$t = 2''$

$M = 1/.33 = 3$

$f_r = \left[\ (3)(137{,}721)(10)\ \right] / \left[\ 8\pi\ (3)(2)^2\right]$

$f_r = 13699$ psi

Margin of Safety:

M.S. = 38,000/13,699 - 1

M.S. = $\underline{+\ 1.77}$

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 NuPac Series A casks have been designed and constructed, and the contents are so limited (as described in Section 0.2.3 above) that the performance requirements specified in 10CFR71.35 will be met when a package is subjected to the normal conditions of transport specified in Appendix A of 10CFR71. The ability of the NuPac packages 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 2.4 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 NuPac Series A 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 Para. 5.3.1, NUREG CR-1815, as follows:

1. "By selecting a steel that is made to a 'Fine Grain Practice' or better." Per paragraph 4.1 of ANSI/ASTM A516, all A516 material is made to "fine-grain practice."

2. "By using a steel whose maximum allowable NDT temperature is 10°F." Per Table NC-2311(a)-1, ASME Boiler and Pressure Vessel Code, Section III, 1980 Edition, the NDT temperatures of ASTM A516 are as follows:

	T_{NDT}
A516, Gr. 70 (Q&E)	-10°F
A516, Gr. 70 (N)	0°F

2.6.3 Pressure

A differential pressure of .5 atmospheres will be reacted by the lid and its associated closures comprised of ratchet binders for the primary lid and studs for the secondary lid. Loads on the primary lid ratchet binders are calculated as:

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

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

$$N = 8$$

For the worst case loading:

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

The rated load of the NuPac CB-2 ratchet binder is 85,000 lbs. Thus the margin of safety is:

$$\text{M.S.} = \frac{85{,}000}{4{,}831} - 1 = \underline{+ \text{ Large}}$$

For the secondary lid studs, the load is:

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

The tensile strength of the 3/4-10 UNC, ASTM A320 Grade L-7 studs is:

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

Thus, the margin of safety is:

$$\text{M.S.} = 32{,}450/828 - 1 = \underline{+ \text{ Large}}$$

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

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

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

Assuming these biaxial stresses are additive,

$F_{max} = 1136$ psi

The margin of safety is:

M.S. = 38000/1136 - 1 = <u>+ Large</u>

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: $W = (7.35)\ (\pi)\ (83.57)^2/4 = 40{,}320$ lbs.

$t = 2''$

$M = 1/.33 = 3$

$f_r = (3)(40320)(10)/8\pi\ (3)(4)$

$f_r = 4010$ psi

Margin of Safety:

$$M.S. = 38{,}000/4010 - 1 = \underline{+\ 8.48}$$

It can therefore be concluded that the packaging can safely react an atmospheric pressure of .5 times standard atmospheric pressure.

2.6.4 Vibration

Shock and vibration normally incident to transport are considered to have neglible effects on the NuPac packages.

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 Appendix A.6 of 10CFR71 for all NuPac Series A packages is 12 inches, since all packages are greater than 30,000 lb. 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 condition 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.)
R = Outer lead radius (in.)
W = Weight of Lead (lbs.)
r = Inner lead radius (in.)
t_s = Thickness of external steel shell (in.)
σ_s = Steel dynamic flow stress, 50,000 psi
σ_{pb} = Lead dynamic flow stress, 5,000 psi

For the nine package versions, variables and settlement results are tabulated in Table 2.6.6.1-1.

Table 2.6.6.1-1

FLAT END DROP RESULTS

Model	Outer Radius, R (in.)	Inner Radius, r (in.)	Outer Wall Thickness, t_s (in.)	Lead Weight, W (lbs.)	Lead Settlement, (in.)
NUPAC 14/210L	40.25	39.00	.875	10,460	.066
NUPAC 14/210H	40.88	39.00	.875	16,290	.068
NUPAC 14/190L	39.38	38.13	.875	9,366	.060
NUPAC 14/190M	39.88	38.13	.875	13,550	.062
NUPAC 14/190H	40.75	38.13	.875	21,090	.064
NUPAC 10/140	36.26	33.50	1.13	19,330	.059
NUPAC 7/100	41.13	38.13	.875	14,040	.037
NUPAC 6/100L	33.43	31.00	1.13	13,390	.049
NUPAC 6/100H	34.56	31.00	1.13	20,420	.050

These modest settlement "voids" in the lead shield, .05 to .06 inches, cannot transmit radiation because of the stepped design of the package ends. The innermost solid steel and plates completely back (shield) lead settlement regions at both ends of the package. Thus, lead settlement due to flat end drop does not compromise, nor alter, the integrity of radiation shielding in any fashion.

2.6.6.2 Side Drop

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:

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

Where: W = cask weight (lbs.)

H = 12 in.

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

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

$$\left.\begin{array}{r} \sigma_s = 50{,}000 \text{ psi} \\ \sigma_{pb} = 5{,}000 \text{ psi} \end{array}\right\} \quad \text{ORNL-NSIC-68, Page 60}$$

The flattening of the cask is equal to:

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

Results are shown in Table 2.6.6.2-1.

TABLE 2.6.6.2-1

SIDE DROP RESULTS

Cask Model	Weight W (lbs)	Outside Diameter, R (in.)	Length L (in.)	Thickness t_s (in.)	Thickness t_e (in.)	Theta θ (deg)	Deformation d (in.)
NUPAC 14/210L	53,600	82.25	86.25	.88	3.00	6.52	.266
NUPAC 14/210H	63,400	83.50	88.25	.88	4.00	6.46	.265
NUPAC 14/190L	46,300	80.50	79.38	.88	3.00	6.40	.251
NUPAC 14/190M	53,500	81.50	81.38	.88	4.00	6.39	.251
NUPAC 14/190H	65,200	83.25	83.38	.88	5.00	6.38	.257
NUPAC 10/140	56,500	74.77	83.00	1.13	5.00	6.49	.239
NUPAC 7/100	48,900	84.00	51.75	.88	5.50	6.09	.237
NUPAC 6/100L	42,900	69.11	71.00	1.13	4.50	6.50	.222
NUPAC 6/100H	53,900	71.37	74.00	1.13	6.00	6.48	.228

Shielding is reduced by side impact as indicated below:

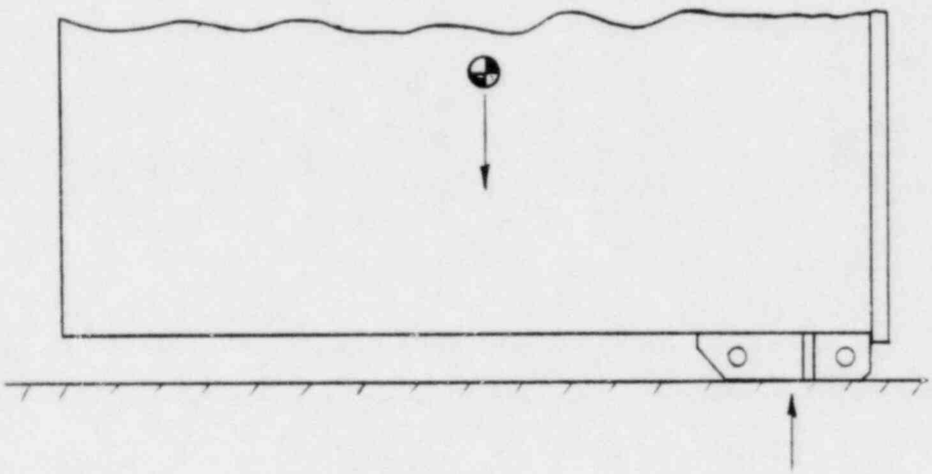
Version	% Shield Reduction (1)
14/210L	.48
14/210H	.35
14/190L	.45
14/190M	.40
14/190H	.26
10/140	.24
7/100	.23
6/100L	.25
6/100H	.19

(1) Note: $\% = \frac{d}{T_s} \cdot \left(\frac{2\theta}{360}\right) \cdot 100$

Where T_s = Nominal Shield Thickness

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

The potential for damage to the cask seal resulting from a side drop onto a tiedown lug is also evaluated. The worst case impact is assumed to be that of the 14/210H because of its gross weight. 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, however, that the lug carries the entire load, an estimate 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 50,000 psi:

$U = V\sigma_s$

Where U = Total energy = 63,400 (12) = 760,800 in-lbs.

V = Crush volume

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

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

Substituting and transposing:

$$\delta = \frac{760{,}800}{42(50{,}000)} = .362 \text{ in.}$$

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,

$$a = \frac{v^2}{2g\delta} = \frac{96.3^2}{2(386.4)(.362)} = 33.1 \text{ g's}$$

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

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.

PROPRIETARY DATA

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:

- The plastic flow pressure concept

- 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, Cask Designer's Guide, ORNL NSIC-68, Section 2.7.1:

$\sigma_{pb} = 5000$ psi

$\sigma_s = 50{,}000$ 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 these estimates are outlined in Appendix 2.10.2. Prediction results are summarized in Table 2.6.6.3-1; detailed computer analysis results for all nine configurations 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.

PROPRIETARY DATA

TABLE 2.6.6.3-1

Version	Drop Height (in)	Weight (lbs)	Radius (in)	Crush Zone Geometry Volume (in^3)	Area (in^2)	Depth (in)	Load Factor (g's) (1)
14/210L	12	53,600	41.125	14.0	32.5	1.08	33.4
14/210H		63,400	41.785	16.7	36.2	1.15	31.4
14/190L		46,300	40.25	12.1	29.4	1.03	34.9
14/190M		53,500	40.76	14.1	32.3	1.14	33.2
14/190H		65,200	41.66	17.3	36.6	1.18	30.9
10/140		56,500	37.385	14.9	33.3	1.12	32.4
7/100		48,000	41.66	12.8	31.0	1.03	34.8
6/100L		42,900	34.56	11.2	27.3	1.02	35.1
6/100H		53,900	35.69	14.2	31.8	1.12	32.4

Corner Impact Deformation & Deceleration Estimates

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

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ASKCRN(CORNER)                 CORNER IMPACT OF A CYLINDRICAL  SHIELDED CASK          15.32.09.    82/06/21.   PAGE   1

         NUPAC 14-210L , 2.0 EQ SHIELDING

           PACKAGE WEIGHT              = 53600.00 (LBS)
           DROP HEIGHT                 =    12.000 (IN)
           PACKAGE RADIUS              =    41.125 (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      =     3.000 (IN)

           ORIENTATION ANGLE           =     43.64 (DEG)
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ASKCRN(CORNER)                  CORNER IMPACT OF A CYLINDRICAL  SHIELDED CASK              15.32.09.    82/06/21.   PAGE   2

          NUPAC 14-210L , 2.0 EQ SHIELDING

                         ++CRUSH VOLUME++      +FLOW STRESS BASIS+     +++  CRUSH AREA  +++        ++ IMPACT ++   ++CRUSH STRESS BASIS++
CRUSH    KINETIC                                  STRAIN ENERGY                                                       STRAIN ENERGY
DEPTH     ENERGY       TOTAL    STEEL      LEAD     ENERGY   RATIO      TOTAL    STEEL     LEAD         FORCE ACCEL.        ENERGY  RATIO
 (IN)    (IN-LB)       (IN3)    (IN3)     (IN3)    (IN-LB) (SE/KE)      (IN2)    (IN2)    (IN2)         (LBS)   (G)        (IN-LB) (SE/KE)

  .05    645880.         .0       .0       0.0        326.    .00         .3       .3      0.0          17917.     .3          448.    .00
  .10    648560.         .0       .0       0.0       1843.    .00         .9       .9      0.0          50664.     .9         2162.    .00
  .15    651240.         .1       .1       0.0       5077.    .01        1.7      1.7      0.0          93050.    1.7         5755.    .01
  .20    653920.         .2       .2       0.0      10419.    .02        2.6      2.6      0.0        14[illegible]222.    2.7        11662.    .02
  .25    656600.         .4       .4       0.0      18198.    .03        3.6      3.6      0.0         200106.    3.7        20245.    .03
  .30    659280.         .6       .6       0.0      28701.    .04        4.8      4.8      0.0         262977.    4.9        31822.    .05
  .35    661960.         .8       .8       0.0      42188.    .06        6.0      6.0      0.0         331301.    6.2        46679.    .07
  .40    664640.        1.2      1.2       0.0      58896.    .09        7.4      7.4      0.0         404664.    7.5        65078.    .10
  .45    667320.        1.6      1.6       0.0      79047.    .12        8.8      8.8      0.0         482734.    9.0        87263.    .13
  .50    670000.        2.1      2.1       0.0     102848.    .15       10.3     10.3      0.0         565235.   10.5       113463.    .17
  .55    672680.        2.6      2.6       0.0     130495.    .19       11.9     11.9      0.0         651933.   12.2       143892.    .21
  .60    675360.        3.2      3.2       0.0     162175.    .24       13.5     13.5      0.0         742626.   13.9       178756.    .26
  .65    678040.        4.0      4.0       0.0     198065.    .29       15.2     15.2      0.0         837139.   15.6       218250.    .32
  .70    680720.        4.8      4.8       0.0     238334.    .35       17.0     17.0      0.0         935317.   17.4       262561.    .39
  .75    683400.        5.7      5.7       0.0     283147.    .41       18.9     18.9      0.0        1037022.   19.3       311870.    .46
  .80    686080.        6.7      6.7       0.0     332660.    .48       20.8     20.8      0.0        1142129.   21.3       366349.    .53
  .85    688760.        7.7      7.7       0.0     387027.    .56       22.7     22.7      0.0        1250526.   23.3       426165.    .62
  .90    691440.        8.9      8.9       0.0     446393.    .65       24.8     24.8      0.0        1362110.   25.4       491481.    .71
  .95    694120.       10.2     10.2       0.0     510902.    .74       26.9     26.9      0.0        1476787.   27.6       562453.    .81
 1.00    696800.       11.6     11.6       0.0     580692.    .83       29.0     29.0      0.0        1594470.   29.7       639235.    .92
 1.05    699480.       13.1     13.1       0.0     655898.    .94       31.2     31.2      0.0        1715079.   32.0       721973.   1.03
 1.10    702160.       14.7     14.7       0.0     736651.   1.05       33.4     33.4      0.0        1838540.   34.3       810814.   1.15
 1.15    704840.       16.5     16.5       0.0     823080.   1.17       35.7     35.7      0.0        1964783.   36.7       905897.   1.29
 1.20    707520.       18.3     18.3       0.0     915309.   1.29       38.1     38.1      0.0        2093742.   39.1      1007360.   1.42
 1.25    710200.       20.3     20.3       0.0    1013461.   1.43       40.5     40.5      0.0        2225358.   41.5      1115338.   1.57
 1.30    712880.       22.4     22.4       0.0    1117654.   1.57       42.9     42.9      0.0        2359573.   44.0      1229961.   1.73
 1.35    715560.       24.6     24.6       0.0    1228006.   1.72       45.4     45.4      0.0        2496333.   46.6      1351359.   1.89
 1.40    718240.       26.9     26.9       0.0    1344631.   1.87       47.9     47.9      0.0        2635587.   49.2      1479657.   2.06
 1.45    720920.       29.4     29.4       0.0    1467642.   2.04       50.5     50.5      0.0        2777286.   51.8      1614978.   2.24
 1.50    723600.       31.9     31.9       0.0    1597148.   2.21       53.1     53.1      0.0        2921385.   54.5      1757445.   2.43
 1.55    726280.       34.7     34.7       0.0    1733258.   2.39       55.8     55.8      0.0        3067839.   57.2      1907176.   2.63
 1.60    728960.       37.5     37.5       0.0    1876077.   2.57       58.5     58.5      0.0        3216603.   60.0      2064287.   2.83
 1.65    731640.       40.5     40.5       0.0    2025711.   2.77       61.2     61.2      0.0        3367651.   62.8      2228893.   3.05
 1.70    734320.       43.6     43.6       0.0    2182261.   2.97       64.0     64.0      0.0        3520931.   65.7      2401108.   3.27
 1.75    737000.       46.9     46.9       0.0    2345829.   3.18       66.8     66.8      0.0        3676411.   68.6      2581041.   3.50
 1.80    739680.       50.3     50.3       0.0    2516513.   3.40       69.7     69.7      0.0        3834057.   71.5      2768803.   3.74
 1.85    742360.       53.9     53.9       0.0    2694412.   3.63       72.6     72.6      0.0        3993835.   74.5      2964500.   3.99
 1.90    745040.       57.6     57.6       0.0    2879621.   3.87       75.6     75.6      0.0        4155714.   77.5      3168239.   4.25
 1.95    747720.       61.4     61.4       0.0    3072236.   4.11       78.5     78.5      0.0        4319662.   80.6      3380124.   4.52
 2.00    750400.       65.4     65.4       0.0    3272349.   4.36       81.6     81.6      0.0        4485650.   83.7      3600256.   4.80
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CASKCRN(CORNER)                CORNER IMPACT OF A CYLINDRICAL  SHIELDED CASK                15.32.09.   82/06/21.   PAGE    3

          NUPAC 14-210H , 2.75 EQ SHIELDING

            PACKAGE WEIGHT              = 63400.00 (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)
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PROPRIETARY DATA

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ASKCRN(CORNER)                    CORNER IMPACT OF A CYLINDRICAL  SHIELDED CASK               15.32.09.    82/06/21.   PAGE   4

             NUPAC 14-210H , 2.75 EQ SHIELDING

                         ++CRUSH VOLUME++     +FLOW STRESS BASIS+     +++  CRUSH AREA  +++        ++ IMPACT ++   ++CRUSH STRESS BASIS++
CRUSH    KINETIC                                  STRAIN ENERGY                                                      STRAIN ENERGY
DEPTH     ENERGY        TOTAL    STEEL     LEAD       ENERGY  RATIO      TOTAL    STEEL     LEAD         FORCE ACCEL.       ENERGY  RATIO
 (IN)    (IN-LB)        (IN3)    (IN3)    (IN3)      (IN-LB) (SE/KE)     (IN2)    (IN2)    (IN2)         (LBS)  (G)        (IN-LB) (SE/KE)

   .05    763970.          .0       .0      0.0         330.     .00        .3       .3      0.0        18132.     .3          653.     .00
   .10    767140.          .0       .0      0.0        1865.     .00        .9       .9      0.0        51273.     .8         2188.     .00
   .15    770310.          .1       .1      0.0        5138.     .01       1.7      1.7      0.0        94170.    1.5         5825.     .01
   .20    773480.          .2       .2      0.0       10545.     .01       2.6      2.6      0.0       144946.    2.3        11802.     .02
   .25    776650.          .4       .4      0.0       18417.     .02       3.7      3.7      0.0       202515.    3.2        20489.     .03
   .30    779820.          .6       .6      0.0       29047.     .04       4.8      4.8      0.0       266143.    4.2        32205.     .04
   .35    782990.          .9       .9      0.0       42696.     .05       6.1      6.1      0.0       335290.    5.3        47241.     .06
   .40    786160.         1.2      1.2      0.0       59605.     .08       7.4      7.4      0.0       409538.    6.5        65862.     .08
   .45    789330.         1.6      1.6      0.0       79999.     .10       8.9      8.9      0.0       488549.    7.7        88314.     .11
   .50    792500.         2.1      2.1      0.0      104036.     .13      10.4     10.4      0.0       572045.    9.0       114829.     .14
   .55    795670.         2.6      2.6      0.0      132067.     .17      12.0     12.0      0.0       659789.   10.4       145625.     .18
   .60    798840.         3.3      3.3      0.0      164129.     .21      13.7     13.7      0.0       751577.   11.9       180909.     .23
   .65    802010.         4.0      4.0      0.0      200451.     .25      15.4     15.4      0.0       847232.   13.4       220879.     .28
   .70    805180.         4.8      4.8      0.0      241206.     .30      17.2     17.2      0.0       946596.   14.9       265725.     .33
   .75    808350.         5.7      5.7      0.0      286559.     .35      19.1     19.1      0.0      1049530.   16.6       315628.     .39
   .80    811520.         6.7      6.7      0.0      336670.     .41      21.0     21.0      0.0      1155907.   18.2       370764.     .46
   .85    814690.         7.8      7.8      0.0      391692.     .48      23.0     23.0      0.0      1265615.   20.0       431302.     .53
   .90    817860.         9.0      9.0      0.0      451775.     .55      25.1     25.1      0.0      1378549.   21.7       497406.     .61
   .95    821030.        10.3     10.3      0.0      517062.     .63      27.2     27.2      0.0      1494614.   23.6       569235.     .69
  1.00    824200.        11.8     11.8      0.0      587695.     .71      29.3     29.3      0.0      1613721.   25.5       646943.     .78
  1.05    827370.        13.3     13.3      0.0      663809.     .80      31.6     31.6      0.0      1735791.   27.4       730681.     .88
  1.10    830540.        14.9     14.9      0.0      745538.     .90      33.8     33.8      0.0      1860747.   29.3       820595.     .99
  1.15    833710.        16.7     16.7      0.0      833010.    1.00      36.2     36.2      0.0      1988520.   31.4       916826.    1.10
  1.20    836880.        18.5     18.5      0.0      926354.    1.11      38.5     38.5      0.0      2119043.   33.4      1019515.    1.22
  1.25    840050.        20.5     20.5      0.0     1025691.    1.22      41.0     41.0      0.0      2252255.   35.5      1128793.    1.54
  1.30    843220.        22.6     22.6      0.0     1131144.    1.34      43.4     43.4      0.0      2388098.   37.7      1244807.    1.48
  1.35    846390.        24.9     24.9      0.0     1242830.    1.47      45.9     45.9      0.0      2526518.   39.9      1367672.    1.62
  1.40    849560.        27.2     27.2      0.0     1360866.    1.60      48.5     48.5      0.0      2667462.   42.1      1497522.    1.76
  1.45    852730.        29.7     29.7      0.0     1485364.    1.74      51.1     51.1      0.0      2810882.   44.3      1634480.    1.92
  1.50    855900.        32.3     32.3      0.0     1616437.    1.89      53.8     53.8      0.0      2956731.   46.6      1778671.    2.08
  1.55    859070.        35.1     35.1      0.0     1754194.    2.04      56.5     56.5      0.0      3104965.   49.0      1930213.    2.25
  1.60    862240.        38.0     38.0      0.0     1898742.    2.20      59.2     59.2      0.0      3255542.   51.3      2089226.    2.42
  1.65    865410.        41.0     41.0      0.0     2050187.    2.37      62.0     62.0      0.0      3408423.   53.8      2255825.    2.61
  1.70    868580.        44.2     44.2      0.0     2208633.    2.54      64.8     64.8      0.0      3563567.   56.2      2430125.    2.80
  1.75    871750.        47.5     47.5      0.0     2374182.    2.72      67.7     67.7      0.0      3720940.   58.7      2612237.    3.00
  1.80    874920.        50.9     50.9      0.0     2546934.    2.91      70.6     70.6      0.0      3880505.   61.2      2802273.    3.20
  1.85    878090.        54.5     54.5      0.0     2726988.    3.11      73.5     73.5      0.0      4042230.   63.8      3000342.    3.42
  1.90    881260.        58.3     58.3      0.0     2914441.    3.31      76.5     76.5      0.0      4206080.   66.3      3206549.    3.64
  1.95    884430.        62.2     62.2      0.0     3109390.    3.52      79.5     79.5      0.0      4372027.   69.0      3421002.    3.87
  2.00    887600.        66.2     66.2      0.0     3311930.    3.73      82.5     82.5      0.0      4540039.   71.6      3643804.    4.11
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ASKCRN(CORNER)                CORNER IMPACT OF A CYLINDRICAL  SHIELDED CASK          15.32.09.    82/06/21.   PAGE   5

          NUPAC 14-190L , 2.0 EQ SHIELDING

            PACKAGE WEIGHT               = 46300.00 (LBS)
            DROP HEIGHT                  =    12.000 (IN)
            PACKAGE RADIUS               =    40.250 (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       =     3.000 (IN)

            ORIENTATION ANGLE            =     45.41 (DEG)
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ASKCRN(CORNER)                 CORNER IMPACT OF A CYLINDRICAL  SHIELDED CASK                  15.32.09.    82/06/21.   PAGE   6

          NUPAC 14-190L , 2.0 EQ SHIELDING

                      ++CRUSH VOLUME++       +FLOW STRESS BASIS+      +++  CRUSH AREA  +++          ++ IMPACT ++    ++CRUSH STRESS BASIS++
CRUSH    KINETIC                                  STRAIN ENERGY                                                        STRAIN ENERGY
DEP*H     ENERGY       TOTAL    STEEL     LEAD       ENERGY  RATIO     TOTAL    STEEL     LEAD         FORCE ACCEL.      ENERGY  RATIO
 ,       (IN-LB)       (IN3)    (IN3)    (IN3)      (IN-LB) (SE/KE)    (IN2)    (IN2)    (IN2)         (LBS)   (G)      (IN-LB) (SE/KE)

  .05    557915.          .0       .0      0.0          317.    .00       .3       .3      0.0        17431.     .4         436.    .00
  .10    560230.          .0       .0      0.0         1793.    .00       .9       .9      0.0        49290.    1.1        2104.    .00
  .15    562545.          .1       .1      0.0         4939.    .01      1.6      1.6      0.0        90528.    2.0        5599.    .01
  .20    564860.          .2       .2      0.0        10137.    .02      2.5      2.5      0.0       139341.    3.0       11346.    .02
  .25    567175.          .4       .4      0.0        17705.    .03      3.5      3.5      0.0       194684.    4.2       19697.    .03
  .30    569490.          .6       .6      0.0        27924.    .05      4.7      4.7      0.0       255851.    5.5       30960.    .05
  .35    571805.          .8       .8      0.0        41045.    .07      5.9      5.9      0.0       322325.    7.0       45414.    .08
  .40    574120.         1.1      1.1      0.0        57300.    .10      7.2      7.2      0.0       393702.    8.5       63315.    .11
  .45    576435.         1.5      1.5      0.0        76905.    .13      8.5      8.5      0.0       469658.   10.1       84899.    .15
  .50    578750.         2.0      2.0      0.0       100062.    .17     10.0     10.0      0.0       549926.   11.9      110389.    .19
  .55    581065.         2.5      2.5      0.0       126960.    .22     11.5     11.5      0.0       634277.   13.7      139994.    .24
  .60    583380.         3.2      3.2      0.0       157782.    .27     13.1     13.1      0.0       722515.   15.6      173914.    .30
  .65    585695.         3.9      3.9      0.0       192700.    .33     14.8     14.8      0.0       814471.   17.6      212338.    .36
  .70    588010.         4.6      4.6      0.0       231879.    .39     16.5     16.5      0.0       909994.   19.7      255450.    .43
  .75    590325.         5.5      5.5      0.0       275478.    .47     18.3     18.3      0.0      1008947.   21.8      303423.    .51
  .80    592640.         6.5      6.5      0.0       323652.    .55     20.2     20.2      0.0      1111212.   24.0      356427.    .60
  .85    594955.         7.5      7.5      0.0       376546.    .63     22.1     22.1      0.0      1216678.   26.3      414625.    .70
  .90    597270.         8.7      8.7      0.0       434306.    .73     24.1     24.1      0.0      1325245.   28.6      478173.    .80
  .95    599585.         9.9      9.9      0.0       497069.    .83     26.1     26.1      0.0      1436822.   31.0      547224.    .91
 1.00    601900.        11.3     11.3      0.0       564970.    .94     28.2     28.2      0.0      1551325.   33.5      621928.   1.03
 1.05    604215.        12.8     12.8      0.0       638141.   1.06     30.3     30.3      0.0      1668675.   36.0      702428.   1.16
 1.10    606530.        14.3     14.3      0.0       716710.   1.18     32.5     32.5      0.0      1788800.   38.6      788865.   1.30
 1.15    608845.        16.0     16.0      0.0       800800.   1.32     34.8     34.8      0.0      1911632.   41.3      881376.   1.45
 1.20    611160.        17.8     17.8      0.0       890535.   1.46     37.0     37.0      0.0      2037109.   44.0      980094.   1.60
 1.25    613475.        19.7     19.7      0.0       986031.   1.61     39.4     39.4      0.0      2165171.   46.8     1085151.   1.77
 1.30    615790.        21.7     21.7      0.0      1087407.   1.77     41.7     41.7      0.0      2295762.   49.6     1196674.   1.94
 1.35    618105.        23.9     23.9      0.0      1194774.   1.93     44.2     44.2      0.0      2428830.   52.5     1314739.   2.13
 1.40    620420.        26.2     26.2      0.0      1308246.   2.11     46.6     46.6      0.0      2564325.   55.4     1439618.   2.32
 1.45    622735.        28.6     28.6      0.0      1427931.   2.29     49.1     49.1      0.0      2702200.   58.4     1571281.   2.52
 1.50    625050.        31.1     31.1      0.0      1553936.   2.49     51.7     51.7      0.0      2842410.   61.4     1709896.   2.74
 1.55    627365.        33.7     33.7      0.0      1686367.   2.69     54.3     54.3      0.0      2984913.   64.5     1855580.   2.96
 1.60    629680.        36.5     36.5      0.0      1825326.   2.90     56.9     56.9      0.0      3129669.   67.6     2008444.   3.19
 1.65    631995.        39.4     39.4      0.0      1970916.   3.12     59.6     59.6      0.0      3276639.   70.8     2168602.   3.43
 1.70    634310.        42.5     42.5      0.0      2123235.   3.35     62.3     62.3      0.0      3425786.   74.0     2336162.   3.68
 1.75    636625.        45.6     45.6      0.0      2282383.   3.59     65.0     65.0      0.0      3577074.   77.3     2511234.   3.94
 1.80    638940.        49.0     49.0      0.0      2448456.   3.83     67.8     67.8      0.0      3730471.   80.6     2693923.   4.22
 1.85    641255.        52.4     52.4      0.0      2621548.   4.09     70.7     70.7      0.0      3885943.   83.9     2884333.   4.50
 1.90    643570.        56.0     56.0      0.0      2801754.   4.35     73.5     73.5      0.0      4043459.   87.3     3082568.   4.79
 1.95    645885.        59.8     59.8      0.0      2989166.   4.63     76.4     76.4      0.0      4202990.   90.8     3288729.   5.09
 2.00    648200.        63.7     63.7      0.0      3183874.   4.91     79.4     79.4      0.0      4364507.   94.3     3502917.   5.40
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        NUPAC 14-190M , 2.25 EQ SHIELDING

          PACKAGE WEIGHT              = 53500.00 (LBS)
          DROP HEIGHT                 =   12.000 (IN)
          PACKAGE RADIUS              =   40.760 (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      =    4.000 (IN)

          ORIENTATION ANGLE           =    45.05 (DEG)
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PROPRIETARY DATA

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ASKCRN(CORNER)              CORNER IMPACT OF A CYLINDRICAL  SHIELDED CASK              15.32.09.    82/06/21.   PAGE   8

           NUPAC 14-190M , 2.25 EQ SHIELDING

                       ++CRUSH VOLUME++      +FLOW STRESS BASIS+     +++  CRUSH AREA  +++         ++ IMPACT ++   ++CRUSH STRESS BASIS++
CRUSH    KINETIC                                   STRAIN ENERGY                                                     STRAIN ENERGY
DEPTH     ENERGY       TOTAL    STEEL     LEAD     ENERGY  RATIO      TOTAL    STEEL     LEAD       FORCE ACCEL.       ENERGY  RATIO
 (IN)    (IN-LB)       (IN3)    (IN3)    (IN3)    (IN-LB) (SE/KE)     (IN2)    (IN2)    (IN2)       (LBS)  (G)        (IN-LB) (SE/KE)

  .05    644675.          .0       .0      0.0       320.    .00         .3       .3      0.0       17594.     .3         440.    .00
  .10    647350.          .0       .0      0.0      1809.    .00         .9       .9      0.0       49752.     .9        2124.    .00
  .15    650025.          .1       .1      0.0      4985.    .01        1.7      1.7      0.0       91376.    1.7        5652.    .01
  .20    652700.          .2       .2      0.0     10232.    .02        2.6      2.6      0.0      140645.    2.6       11452.    .02
  .25    655375.          .4       .4      0.0     17871.    .03        3.6      3.6      0.0      196507.    3.7       19881.    .03
  .30    658050.          .6       .6      0.0     28185.    .04        4.7      4.7      0.0      258247.    4.8       31250.    .05
  .35    660725.          .8       .8      0.0     41429.    .06        5.9      5.9      0.0      325344.    6.1       45840.    .07
  .40    663400.         1.2      1.2      0.0     57837.    .09        7.2      7.2      0.0      397390.    7.4       63908.    .10
  .45    666075.         1.6      1.6      0.0     77625.    .12        8.6      8.6      0.0      474059.    8.9       85694.    .13
  .50    668750.         2.0      2.0      0.0    100999.    .15       10.1     10.1      0.0      555679.   10.4      111423.    .17
  .55    671425.         2.6      2.6      0.0    128150.    .19       11.6     11.6      0.0      640222.   12.0      141305.    .21
  .60    674100.         3.2      3.2      0.0    159260.    .24       13.3     13.3      0.0      729289.   13.6      175543.    .26
  .65    676775.         3.9      3.9      0.0    194505.    .29       14.9     14.9      0.0      822108.   15.4      214328.    .32
  .70    679450.         4.7      4.7      0.0    234052.    .34       16.7     16.7      0.0      918528.   17.2      257844.    .38
  .75    682125.         5.6      5.6      0.0    278060.    .41       18.5     18.5      0.0     1018411.   19.0      306267.    .45
  .80    684800.         6.5      6.5      0.0    326685.    .48       20.4     20.4      0.0     1121637.   21.0      359768.    .53
  .85    687475.         7.6      7.6      0.0    380076.    .55       22.3     22.3      0.0     1228095.   23.0      418512.    .61
  .90    690150.         8.8      8.8      0.0    438378.    .64       24.3     24.3      0.0     1337683.   25.0      482656.    .70
  .95    692825.        10.0     10.0      0.0    501730.    .72       26.4     26.4      0.0     1450309.   27.1      552356.    .80
 1.00    695500.        11.4     11.4      0.0    570269.    .82       28.5     28.5      0.0     1565889.   29.3      627761.    .90
 1.05    698175.        12.9     12.9      0.0    644127.    .92       30.6     30.6      0.0     1684344.   31.5      709017.   1.02
 1.10    700850.        14.5     14.5      0.0    723433.   1.03       32.8     32.8      0.0     1805600.   33.7      796265.   1.14
 1.15    703525.        16.2     16.2      0.0    808314.   1.15       35.1     35.1      0.0     1929589.   36.1      889645.   1.26
 1.20    706200.        18.0     18.0      0.0    898391.   1.27       37.4     37.4      0.0     2056248.   38.4      989291.   1.40
 1.25    708875.        19.9     19.9      0.0    995285.   1.40       39.7     39.7      0.0     2185517.   40.9     1095335.   1.55
 1.30    711550.        22.0     22.0      0.0   1097613.   1.54       42.1     42.1      0.0     2317339.   43.3     1207907.   1.70
 1.35    714225.        24.1     24.1      0.0   1205990.   1.69       44.6     44.6      0.0     2451662.   45.8     1327132.   1.86
 1.40    716900.        26.4     26.4      0.0   1320529.   1.84       47.1     47.1      0.0     2588435.   48.4     1453134.   2.03
 1.45    719575.        28.8     28.8      0.0   1441339.   2.00       49.6     49.6      0.0     2727611.   51.0     1586035.   2.20
 1.50    722250.        31.4     31.4      0.0   1568529.   2.17       52.2     52.2      0.0     2869145.   53.6     1725954.   2.39
 1.55    724925.        34.0     34.0      0.0   1702205.   2.35       54.8     54.8      0.0     3012994.   56.3     1873008.   2.58
 1.60    727600.        36.8     36.8      0.0   1842472.   2.53       57.4     57.4      0.0     3159117.   59.0     2027310.   2.79
 1.65    730275.        39.8     39.8      0.0   1989432.   2.72       60.1     60.1      0.0     3307475.   61.8     2188975.   3.00
 1.70    732950.        42.9     42.9      0.0   2143185.   2.92       62.9     62.9      0.0     3458032.   64.6     2358113.   3.22
 1.75    735625.        46.1     46.1      0.0   2303831.   3.13       65.7     65.7      0.0     3610750.   67.5     2534832.   3.45
 1.80    738300.        49.4     49.4      0.0   2471467.   3.35       68.5     68.5      0.0     3765598.   70.4     2719241.   3.68
 1.85    740975.        52.9     52.9      0.0   2646190.   3.57       71.3     71.3      0.0     3922540.   73.3     2911445.   3.93
 1.90    743650.        56.6     56.6      0.0   2828093.   3.80       74.2     74.2      0.0     4081547.   76.3     3111547.   4.18
 1.95    746325.        60.3     60.3      0.0   3017270.   4.04       77.1     77.1      0.0     4242589.   79.3     3319650.   4.45
 2.00    749000.        64.3     64.3      0.0   3213813.   4.29       80.1     80.1      0.0     4405635.   82.3     3535856.   4.72
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NUPAC 14-190H , 3.5 EQ SHIELDING

  PACKAGE WEIGHT              = 65200.00 (LBS)
  DROP HEIGHT                 =   12.000 (IN)
  PACKAGE RADIUS              =   41.660 (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      =    5.250 (IN)

  ORIENTATION ANGLE           =    44.98 (DEG)
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PROPRIETARY DATA

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           NUPAC 14-190H , 3.5 EQ SHIELDING

                       ++CRUSH VOLUME++      +FLOW STRESS BASIS+     +++  CRUSH AREA  +++        ++ IMPACT ++   ++CRUSH STRESS BASIS++
CRUSH     KINETIC                               STRAIN ENERGY                                                        STRAIN ENERGY
DEPTH      ENERGY     TOTAL    STEEL    LEAD    ENERGY  RATIO     TOTAL    STEEL    LEAD        FORCE ACCEL.         ENERGY  RATIO
 (IN)     (IN-LB)     (IN3)    (IN3)   (IN3)   (IN-LB) (SE/KE)    (IN2)    (IN2)   (IN2)        (LBS)  (G)          (IN-LB) (SE/KE)

  .05     785660.        .0       .0     0.0      324.    .00        .3       .3     0.0       17799.     .3           445.    .00
  .10     788920.        .0       .0     0.0     1830.    .00        .9       .9     0.0       50329.     .8          2148.    .00
  .15     792180.        .1       .1     0.0     5043.    .01       1.7      1.7     0.0       92437.    1.4          5717.    .01
  .20     795440.        .2       .2     0.0    10351.    .01       2.6      2.6     0.0      142279.    2.2         11585.    .01
  .25     798700.        .4       .4     0.0    18078.    .02       3.6      3.6     0.0      198791.    3.0         20112.    .03
  .30     801960.        .6       .6     0.0    28512.    .04       4.8      4.8     0.0      261250.    4.0         31613.    .04
  .35     805220.        .8       .8     0.0    41911.    .05       6.0      6.0     0.0      329129.    5.0         46372.    .06
  .40     808480.       1.2      1.2     0.0    58509.    .07       7.3      7.3     0.0      402015.    6.2         64651.    .08
  .45     811740.       1.6      1.6     0.0    78528.    .10       8.7      8.7     0.0      479579.    7.4         86691.    .11
  .50     815000.       2.0      2.0     0.0   102174.    .13      10.2     10.2     0.0      561546.    8.6        112719.    .14
  .55     818260.       2.6      2.6     0.0   129641.    .16      11.8     11.8     0.0      647684.    9.9        142950.    .17
  .60     821520.       3.2      3.2     0.0   161114.    .20      13.4     13.4     0.0      737793.   11.3        177587.    .22
  .65     824780.       3.9      3.9     0.0   196771.    .24      15.1     15.1     0.0      831699.   12.8        216824.    .26
  .70     828040.       4.7      4.7     0.0   236779.    .29      16.9     16.9     0.0      929249.   14.3        260848.    .32
  .75     831300.       5.6      5.6     0.0   281301.    .34      18.7     18.7     0.0     1030304.   15.8        309336.    .37
  .80     834560.       6.6      6.6     0.0   330494.    .40      20.6     20.6     0.0     1134741.   17.4        363963.    .44
  .85     837820.       7.7      7.7     0.0   384509.    .46      22.6     22.6     0.0     1242449.   19.1        423392.    .51
  .90     841080.       8.9      8.9     0.0   443492.    .53      24.6     24.6     0.0     1353325.   20.8        488287.    .58
  .95     844340.      10.2     10.2     0.0   507585.    .60      26.7     26.7     0.0     1467277.   22.5        558802.    .66
 1.00     847600.      11.5     11.5     0.0   576926.    .68      28.8     28.8     0.0     1584218.   24.3        635089.    .75
 1.05     850860.      13.0     13.0     0.0   651649.    .77      31.0     31.0     0.0     1704068.   26.1        717296.    .84
 1.10     854120.      14.6     14.6     0.0   731884.    .86      33.2     33.2     0.0     1826754.   28.0        805567.    .94
 1.15     857380.      16.4     16.4     0.0   817759.    .95      35.5     35.5     0.0     1952206.   29.9        900041.   1.05
 1.20     860640.      18.2     18.2     0.0   909398.   1.06      37.8     37.8     0.0     2080361.   31.9       1000855.   1.16
 1.25     863900.      20.1     20.1     0.0  1006923.   1.17      40.2     40.2     0.0     2211158.   33.9       1108143.   1.28
 1.30     867160.      22.2     22.2     0.0  1110452.   1.28      42.6     42.6     0.0     2344540.   36.0       1222035.   1.41
 1.35     870420.      24.4     24.4     0.0  1220101.   1.40      45.1     45.1     0.0     2480453.   38.0       1342660.   1.54
 1.40     873680.      26.7     26.7     0.0  1335985.   1.53      47.6     47.6     0.0     2618846.   40.2       1470143.   1.68
 1.45     876940.      29.2     29.2     0.0  1458215.   1.66      50.2     50.2     0.0     2759673.   42.3       1604606.   1.83
 1.50     880200.      31.7     31.7     0.0  1586901.   1.80      52.8     52.8     0.0     2902886.   44.5       1746170.   1.98
 1.55     883460.      34.4     34.4     0.0  1722149.   1.95      55.4     55.4     0.0     3048443.   46.8       1894953.   2.14
 1.60     886720.      37.3     37.3     0.0  1864067.   2.10      58.1     58.1     0.0     3196303.   49.0       2051072.   2.31
 1.65     889980.      40.3     40.3     0.0  2012757.   2.26       0.8     60.8     0.0     3346426.   51.3       2214640.   2.49
 1.70     893240.      43.4     43.4     0.0  2168321.   2.43        .6     63.6     0.0     3498775.   53.7       2385770.   2.67
 1.75     896500.      46.6     46.6     0.0  2330860.   2.60      6  4     66.4     0.0     3655313.   56.0       2564572.   2.86
 1.80     899760.      50.0     50.0     0.0  2500473.   2.78      69.3     69.3     0.0     3810007.   58.4       2751155.   3.06
 1.85     903020.      53.5     53.5     0.0  2677257.   2.96      72.2     72.2     0.0     3968822.   60.9       2945626.   3.26
 1.90     906280.      57.2     57.2     0.0  2861307.   3.16      75.1     75.1     0.0     4129728.   63.3       3148089.   3.47
 1.95     909540.      61.1     61.1     0.0  3052718.   3.36      78.0     78.0     0.0     4292694.   65.8       3358650.   3.69
 2.00     912800.      65.0     65.0     0.0  3251582.   3.56      81.0     81.0     0.0     4457691.   68.4       3577410.   3.92
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      NUPAC 10-140 , 3.6 EQ SHIELDING

        PACKAGE WEIGHT             = 56500.00 (LBS)
        DROP HEIGHT                =    12.000 (IN)
        PACKAGE RADIUS             =    37.385 (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      =     1.130 (IN)
        STEEL BOTTOM THICKNESS     =     5.250 (IN)

        ORIENTATION ANGLE          =     41.84 (DEG)
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PROPRIETARY DATA

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ASKCRN(CORNER)                  CORNER IMPACT OF A CYLINDRICAL  SHIELDED CASK                 15.32.09.    82/06/21.   PAGE  12

      NUPAC 10-140 , 3.6 EQ SHIELDING

                           ++CRUSH VOLUME++    +FLOW STRESS BASIS+    +++  CRUSH AREA  +++         ++ IMPACT ++   ++CRUSH STRESS BASIS++
CRUSH    KINETIC                                   STRAIN ENERGY                                                     STRAIN ENERGY
DEPTH     ENERGY       TOTAL    STEEL     LEAD     ENERGY  RATIO      TOTAL    STEEL     LEAD       FORCE ACCEL.      ENERGY  RATIO
 (IN)    (IN-LB)       (IN3)    (IN3)    (IN3)    (IN-LB) (SE/KE)     (IN2)    (IN2)    (IN2)       (LBS)   (G)      (IN-LB) (SE/KE)

  .05    680825.          .0       .0      0.0       318.     .00        .3       .3      0.0      17462.     .3        437.     .00
  .10    683650.          .0       .0      0.0      1796.     .00        .9       .9      0.0      49374.     .9       2107.     .00
  .15    686475.          .1       .1      0.0      4947.     .01       1.6      1.6      0.0      90679.    1.6       5609.     .01
  .20    689300.          .2       .2      0.0     10154.     .01       2.5      2.5      0.0     139568.    2.5      11365.     .02
  .25    692125.          .4       .4      0.0     17734.     .03       3.5      3.5      0.0     194993.    3.5      19729.     .03
  .30    694950.          .6       .6      0.0     27969.     .04       4.7      4.7      0.0     256247.    4.5      31010.     .04
  .35    697775.          .8       .8      0.0     41110.     .06       5.9      5.9      0.0     322811.    5.7      45486.     .07
  .40    700600.         1.1      1.1      0.0     57389.     .08       7.2      7.2      0.0     394280.    7.0      63414.     .09
  .45    703425.         1.5      1.5      0.0     77023.     .11       8.6      8.6      0.0     470329.    8.3      85029.     .12
  .50    706250.         2.0.     2.0      0.0    100212.     .14      10.0     10.0      0.0     556690.    9.7     110554.     .16
  .55    709075.         2.5      2.5      0.0    127147.     .18      11.5     11.5      0.0     635133.   11.2     140200.     .20
  .60    711900.         3.2      3.2      0.0    158010.     .22      13.2     13.2      0.0     723462.   12.8     174165.     .24
  .65    714725.         3.9      3.9      0.0    192973.     .27      14.8     14.8      0.0     815506.   14.4     212639.     .30
  .70    717550.         4.6      4.6      0.0    232201.     .32      16.6     16.6      0.0     911113.   16.1     255805.     .36
  .75    720375.         5.5      5.5      0.0    275853.     .38      18.4     18.4      0.0    1010149.   17.9     303836.     .42
  .80    723200.         6.5      6.5      0.0    324083.     .45      20.2     20.2      0.0    1112491.   19.7     356902.     .49
  .85    726025.         7.5      7.5      0.0    377037.     .52      22.1     22.1      0.0    1218030.   21.6     415165.     .57
  .90    728850.         8.7      8.7      0.0    434860.     .60      24.1     24.1      0.0    1326665.   23.5     478782.     .66
  .95    731675.        10.0     10.0      0.0    497689.     .68      26.2     26.2      0.0    1438304.   25.5     547907.     .75
 1.00    734500.        11.3     11.3      0.0    565659.     .77      28.2     28.2      0.0    1552862.   27.5     622686.     .85
 1.05    737325.        12.8     12.8      0.0    638901.     .87      30.4     30.4      0.0    1670261.   29.6     703264.     .95
 1.10    740150.        14.4     14.4      0.0    717543.     .97      32.6     32.6      0.0    1790428.   31.7     789781.    1.07
 1.15    742975.        16.0     16.0      0.0    801708.    1.08      34.8     34.8      0.0    1913296.   33.9     882374.    1.19
 1.20    745800.        17.8     17.8      0.0    891519.    1.20      37.1     37.1      0.0    2038800.   36.1     981177.    1.32
 1.25    748625.        19.7     19.7      0.0    987093.    1.32      39.4     39.4      0.0    2166880.   38.4    1086319.    1.45
 1.30    751450.        21.8     21.8      0.0   1088546.    1.45      41.8     41.8      0.0    2297482.   40.7    1197928.    1.59
 1.35    754275.        23.9     23.9      0.0   1195992.    1.59      44.2     44.2      0.0    2430551.   43.0    1316128.    1.74
 1.40    757100.        26.2     26.2      0.0   1309542.    1.73      46.7     46.7      0.0    2566038.   45.4    1441045.    1.90
 1.45    759925.        28.6     28.6      0.0   1429304.    1.88      49.2     49.2      0.0    2703896.   47.9    1572792.    2.07
 1.50    762750.        31.1     31.1      0.0   1555386.    2.04      51.7     51.7      0.0    2844079.   50.3    1711491.    2.24
 1.55    765575.        33.8     33.8      0.0   1687891.    2.20      54.3     54.3      0.0    2986545.   52.9    1857257.    2.43
 1.60    768400.        36.5     36.5      0.0   1826924.    2.38      56.9     56.9      0.0    3131252.   55.4    2010201.    2.62
 1.65    771225.        39.5     39.5      0.0   1972584.    2.56      59.6     59.6      0.0    3278163.   58.0    2170437.    2.81
 1.70    774050.        42.5     42.5      0.0   2124971.    2.75      62.3     62.3      0.0    3427239.   60.7    2338072.    3.02
 1.75    776875.        45.7     45.7      0.0   2284184.    2.94      65.1     65.1      0.0    3578446.   63.3    2513214.    3.24
 1.80    779700.        49.0     49.0      0.0   2450316.    3.14      67.8     67.8      0.0    3731749.   66.0    2695969.    3.46
 1.85    782525.        52.5     52.5      0.0   2623465.    3.35      70.7     70.7      0.0    3887115.   68.8    2886441.    3.69
 1.90    785350.        56.1     56.1      0.0   2803721.    3.57      73.5     73.5      0.0    4044514.   71.6    3084731.    3.93
 1.95    788175.        59.8     59.8      0.0   2991178.    3.80      76.4     76.4      0.0    4203914.   74.4    3290942.    4.18
 2.00    791000.        63.7     63.7      0.0   3185925.    4.03      79.4     79.4      0.0    4365287.   77.3    3505172.    4.43
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PROPRIETARY DATA

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NUPAC 7-100 , 3.5 EQ SHIELDING

  PACKAGE WEIGHT            = 48900.00 (LBS)
  DROP HEIGHT               =    12.000 (IN)
  PACKAGE RADIUS            =    41.660 (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    =     5.250 (IN)

  ORIENTATION ANGLE         =     58.66 (DEG)
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ASKCRN(CORNER)                 CORNER IMPACT OF A CYLINDRICAL  SHIELDED CASK                15.32.09.    82/06/21.   PAGE  14

         NUPAC 7-100 , 3.5 EQ SHIELDING

                           ++CRUSH VOLUME++        +FLOW STRESS BASIS+     +++  CRUSH AREA  +++          ++ IMPACT ++   ++CRUSH STRESS BASIS++
CRUSH     KINETIC                                    STRAIN ENERGY                                                              STRAIN ENERGY
DEPTH      ENERGY      TOTAL    STEEL      LEAD       ENERGY  RATIO       TOTAL    STEEL     LEAD         FORCE ACCEL.          ENERGY  RATIO
 (IN)     (IN-LB)      (IN3)    (IN3)     (IN3)      (IN-LB) (SE/KE)      (IN2)    (IN2)     (IN2)         (LBS)   (G)          (IN-LB) (SE/KE)

  .05     589245.         .0       .0       0.0          331.    .00          .3       .3      0.0         18226.     .4            456.    .00
  .10     591690.         .0       .0       0.0         1874.    .00          .9       .9      0.0         51539.    1.1           2200.    .00
  .15     594135.         .1       .1       0.0         5164.    .01         1.7      1.7      0.0         94663.    1.9           5855.    .01
  .20     596580.         .2       .2       0.0        10600.    .02         2.6      2.6      0.0        145712.    3.0          11864.    .02
  .25     599025.         .4       .4       0.0        18514.    .03         3.7      3.7      0.0        203595.    4.2          20597.    .03
  .30     601470.         .6       .6       0.0        29201.    .05         4.9      4.9      0.0        267577.    5.5          32376.    .05
  .35     603915.         .9       .9       0.0        42924.    .07         6.1      6.1      0.0        337114.    6.9          47493.    .08
  .40     606360.        1.2      1.2       0.0        59925.    .10         7.5      7.5      0.0        411787.    8.4          66216.    .11
  .45     608805.        1.6      1.6       0.0        80431.    .13         8.9      8.9      0.0        491258.   10.0          88792.    .15
  .50     611250.        2.1      2.1       0.0       104653.    .17        10.5     10.5      0.0        575246.   11.8         115455.    .19
  .55     613695.        2.7      2.7       0.0       132791.    .22        12.1     12.1      0.0        663515.   13.6         146424.    .24
  .60     616140.        3.3      3.3       0.0       165035.    .27        13.7     13.7      0.0        755860.   15.5         181908.    .30
  .65     618585.        4.0      4.0       0.0       201565.    .33        15.5     15.5      0.0        852104.   17.4         222107.    .36
  .70     621030.        4.9      4.9       0.0       242555.    .39        17.3     17.3      0.0        952089.   19.5         267212.    .43
  .75     623475.        5.8      5.8       0.0       288173.    .46        19.2     19.2      0.0       1055675.   21.6         317406.    .51
  .80     625920.        6.8      6.8       0.0       333579.    .54        21.1     21.1      0.0       1162736.   23.8         372866.    .60
  .85     628365.        7.9      7.9       0.0       393927.    .63        23.1     23.1      0.0       1273158.   26.0         433764.    .69
  .90     630810.        9.1      9.1       0.0       454370.    .72        25.2     25.2      0.0       1386837.   28.4         500264.    .79
  .95     633255.       10.4     10.4       0.0       520051.    .82        27.3     27.3      0.0       1503678.   30.8         572526.    .90
 1.00     635700.       11.8     11.8       0.0       591114.    .93        29.5     29.5      0.0       1623592.   33.2         650708.   1.02
 1.05     638145.       13.4     13.4       0.0       667696.   1.05        31.8     31.8      0.0       1746499.   35.7         734960.   1.15
 1.10     640590.       15.0     15.0       0.0       749931.   1.17        34.0     34.0      0.0       1872324.   38.3         825431.   1.29
 1.15     643035.       16.8     16.8       0.0       837950.   1.30        36.4     36.4      0.0       2000996.   40.9         922264.   1.43
 1.20     645480.       18.6     18.6       0.0       931882.   1.44        38.8     38.8      0.0       2132450.   43.6        1025600.   1.59
 1.25     647925.       20.6     20.6       0.0      1031851.   1.59        41.2     41.2      0.0       2266624.   46.4        1135577.   1.75
 1.30     650370.       22.8     22.8       0.0      1137979.   1.75        43.7     43.7      0.0       2403459.   49.2        1252329.   1.93
 1.35     652815.       25.0     25.0       0.0      1250386.   1.92        46.2     46.2      0.0       2542903.   52.0        1375988.   2.11
 1.40     655260.       27.4     27.4       0.0      1369191.   2.09        48.8     48.8      0.0       2684902.   54.9        1506683.   2.30
 1.45     657705.       29.9     29.9       0.0      1494506.   2.27        51.4     51.4      0.0       2829408.   57.9        1644541.   2.50
 1.50     660150.       32.5     32.5       0.0      1626447.   2.46        54.1     54.1      0.0       2976375.   60.9        1789686.   2.71
 1.55     662595.       35.3     35.3       0.0      1765123.   2.66        56.8     56.8      0.0       3125759.   63.9        1942239.   2.93
 1.60     665040.       38.2     38.2       0.0      1910643.   2.87        59.6     59.6      0.0       3277518.   67.0        2102321.   3.16
 1.65     667485.       41.3     41.3       0.0      2063114.   3.09        62.4     62.4      0.0       3431611.   70.2        2270049.   3.40
 1.70     669930.       44.5     44.5       0.0      2222642.   3.32        65.2     65.2      0.0       3588001.   73.4        2445539.   3.65
 1.75     672375.       47.8     47.8       0.0      2389330.   3.55        68.1     68.1      0.0       3746651.   76.6        2628906.   3.91
 1.80     674820.       51.3     51.3       0.0      2563280.   3.80        71.0     71.0      0.0       3907525.   79.9        2820260.   4.18
 1.85     677265.       54.9     54.9       0.0      2744593.   4.05        74.0     74.0      0.0       4070592.   83.2        3019713.   4.46
 1.90     679710.       58.7     58.7       0.0      2933367.   4.32        77.0     77.0      0.0       4235817.   86.6        3227373.   4.75
 1.95     682155.       62.6     62.6       0.0      3129700.   4.59        80.1     80.1      0.0       4403170.   90.0        3443348.   5.05
 2.00     684600.       66.7     66.7       0.0      3333687.   4.87        83.1     83.1      0.0       4572622.   93.5        3667743.   5.36
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SKCRN(CORNER)              CORNER IMPACT OF A CYLINDRICAL  SHIELDED CASK             15.32.09.    82/06/21.   PAGE  15

          NUPAC 6-105L , 3.25 EQ SHIELDING

            PACKAGE WEIGHT               = 42900.00 (LBS)
            DROP HEIGHT                  =    12.000 (IN)
            PACKAGE RADIUS               =    34.560 (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      =     1.130 (IN)
            STEEL BOTTOM THICKNESS     =     4.750 (IN)

            ORIENTATION ANGLE          =     44.03 (DEG)
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SKCRN(CORNER)                 CORNER IMPACT OF A CYLINDRICAL  SHIELDED CASK                15.32.09.    82/06/21.   PAGE  16

         NUPAC 6-105L , 3.25 EQ SHIELDING

                    ++CRUSH VOLUME++       +FLOW STRESS BASIS+     +++  CRUSH AREA  +++          ++ IMPACT ++  ++CRUSH STRESS BASIS++
RUSH     KINETIC                                STRAIN ENERGY                                                       STRAIN ENERGY
EPTH      ENERGY       TOTAL    STEEL     LEAD      ENERGY  RATIO    TOTAL    STEEL     LEAD        FORCE ACCEL.     ENERGY  RATIO
(IN)     (IN-LB)       (IN3)    (IN3)     (IN3)    (IN-LB) (SE/KE)   (IN2)    (IN2)     (IN2)       (LBS)   (G)     (IN-LB) (SE/KE)

 .05     516945.         .0       .0       0.0        297.    .00       .3       .3      0.0        16357.     .4        409.     .00
 .10     519090.         .0       .0       0.0       1682.    .00       .8       .8      0.0        46250.    1.1       1974.     .00
 .15     521235.         .1       .1       0.0       4634.    .01      1.5      1.5      0.0        84939.    2.0       5254.     .01
 .20     523380.         .2       .2       0.0       9511.    .02      2.4      2.4      0.0       130732.    3.0      10646.     .02
 .25     525525.         .3       .3       0.0      16612.    .03      3.3      3.3      0.0       182646.    4.3      18480.     .04
 .30     527670.         .5       .5       0.0      26198.    .05      4.4      4.4      0.0       240019.    5.6      29047.     .06
 .35     529815.         .8       .8       0.0      38507.    .07      5.5      5.5      0.0       302364.    7.0      42606.     .08
 .40     531960.        1.1      1.1       0.0      53755.    .10      6.7      6.7      0.0       369302.    8.6      59398.     .11
 .45     534105.        1.4      1.4       0.0      72145.    .14      8.0      8.0      0.0       440528.   10.3      79644.     .15
 .50     536250.        1.9      1.9       0.0      93864.    .18      9.4      9.4      0.0       515790.   12.0     103552.     .19
 .55     538395.        2.4      2.4       0.0     119093.    .22     10.8     10.8      0.0       594875.   13.9     131318.     .24
 .60     540540.        3.0      3.0       0.0     147999.    .27     12.3     12.3      0.0       677598.   15.8     163130.     .30
 .65     542685.        3.6      3.6       0.0     180745.    .33     13.9     13.9      0.0       763798.   17.8     199165.     .37
 .70     544830.        4.3      4.3       0.0     217486.    .40     15.5     15.5      0.0       853333.   19.9     239593.     .44
 .75     546975.        5.2      5.2       0.0     258369.    .47     17.2     17.2      0.0       946077.   22.1     284578.     .52
 .80     549120.        6.1      6.1       0.0     303539.    .55     18.9     18.9      0.0      1041915.   24.3     334278.     .61
 .85     551265.        7.1      7.1       0.0     353134.    .64     20.7     20.7      0.0      1140745.   26.6     388845.     .71
 .90     553410.        8.1      8.1       0.0     407287.    .74     22.6     22.6      0.0      1242472.   29.0     448425.     .81
 .95     555555.        9.3      9.3       0.0     466129     .84     24.5     24.5      0.0      1347011.   31.4     513162.     .92
1.00     557700.       10.6     10.6       0.0     529784     .95     26.4     26.4      0.0      1454281.   33.9     583194.    1.05
1.05     559845.       12.0     12.0       0.0     598376.   1.07     28.4     28.4      0.0      1564208.   36.5     658657.    1.18
1.10     561990.       13.4     13.4       0.0     672024.   1.20     30.5     30.5      0.0      1676726.   39.1     739680.    1.32
1.15     564135.       15.0     15.0       0.0     750844.   1.33     32.6     32.6      0.0      1791769.   41.8     826392.    1.46
1.20     566280.       16.7     16.7       0.0     834950.   1.47     34.7     34.7      0.0      1909279.   44.5     918919.    1.62
1.25     568425.       18.5     18.5       0.0     924452.   1.63     36.9     36.9      0.0      2029199.   47.3    1017381.    1.79
1.30     570570.       20.4     20.4       0.0    1019458.   1.79     39.1     39.1      0.0      2151477.   50.2    1121897.    1.97
1.35     572715.       22.4     22.4       0.0    1120075.   1.96     41.4     41.4      0.0      2276062.   53.1    1232586.    2.15
1.40     574860.       24.5     24.5       0.0    1226407.   2.13     43.7     43.7      0.0      2402909.   56.0    1349560.    2.35
1.45     577005.       26.8     26.8       0.0    1338555.   2.32     46.0     46.0      0.0      2531972.   59.0    1472932.    2.55
1.50     579150.       29.1     29.1       0.0    1456619.   2.52     48.4     48.4      0.0      2663210.   62.1    1602812.    2.77
1.55     581295.       31.6     31.6       0.0    1580698.   2.72     50.8     50.8      0.0      2796582.   65.2    1739307.    2.99
1.60     583440.       34.2     34.2       0.0    1710886.   2.93     53.3     53.3      0.0      2932051.   68.3    1882522.    3.23
1.65     585585.       36.9     36.9       0.0    1847279.   3.15     55.8     55.8      0.0      3069578.   71.6    2032563.    3.47
1.70     587730.       39.8     39.8       0.0    1989969.   3.39     58.3     58.3      0.0      3209131.   74.8    2189531.    3.73
1.75     589875.       42.8     42.8       0.0    2139048.   3.63     60.9     60.9      0.0      3350674.   78.1    2353526.    3.99
1.80     592020.       45.9     45.9       0.0    2294606.   3.88     63.5     63.5      0.0      3494177.   81.4    2524647.    4.26
1.85     594165.       49.1     49.1       0.0    2456730.   4.13     66.2     66.2      0.0      3639608.   84.8    2702992.    4.55
1.90     596310.       52.5     52.5       0.0    2625508.   4.40     68.9     68.9      0.0      3786939.   88.3    2883656.    4.84
1.95     598455.       56.0     56.0       0.0    2801025.   4.68     71.6     71.6      0.0      3936140.   91.8    3081733.    5.15
2.00     600600.       59.7     59.7       0.0    2983367.   4.97     74.3     74.3      0.0      4087184.   95.3    3282316.    5.47
```

```
          NUPAC 6-105H , 4.40 EQ SHIELDING

            PACKAGE WEIGHT               = 53900.00 (LBS)
            DROP HEIGHT                  =    12.000 (IN)
            PACKAGE RADIUS               =    35.690 (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        =     1.130 (IN)
            STEEL BOTTOM THICKNESS       =     6.250 (IN)

            ORIENTATION ANGLE            =     43.77 (DEG)
```

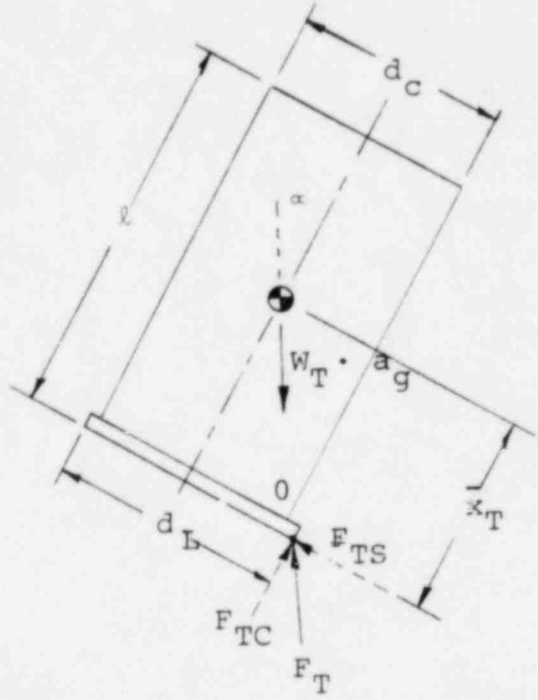
PROPRIETARY DATA

```
               NUPAC 6-105H , 4.40 EQ SHIELDING

                         ++CRUSH VOLUME++        +FLOW STRESS BASIS+     +++  CRUSH AREA  +++          ++ IMPACT ++   ++CRUSH STRESS BASIS++
 CRUSH      KINETIC                                   STRAIN ENERGY                                                            STRAIN ENERGY
 DEPTH       ENERGY         TOTAL    STEEL     LEAD      ENERGY  RATIO    TOTAL    STEEL     LEAD          FORCE ACCEL.         ENERGY  RATIO
  (IN)      (IN-LB)         (IN3)    (IN3)    (IN3)     (IN-LB) (SE/KE)   (IN2)    (IN2)    (IN2)          (LBS)   (G)         (IN-LB) (SE/KE)

   .05      649495.            .0       .0      0.0        303.     .00       .3       .3      0.0         16667.     .3          417.     .00
   .10      652190.            .0       .0      0.0       1714.     .00       .9       .9      0.0         47123.     .9         2012.     .00
   .15      654885.            .1       .1      0.0       4722.     .01      1.6      1.6      0.0         86553.    1.6         5354.     .01
   .20      657580.            .2       .2      0.0       9692.     .01      2.4      2.4      0.0        133216.    2.5        10848.     .02
   .25      660275.            .3       .3      0.0      16927.     .03      3.4      3.4      0.0        186119.    3.5        18831.     .03
   .30      662970.            .5       .5      0.0      26696.     .04      4.4      4.4      0.0        244585.    4.5        29599.     .04
   .35      665665.            .8       .8      0.0      39239.     .06      5.6      5.6      0.0        308118.    5.7        43416.     .07
   .40      668360.           1.1      1.1      0.0      54778.     .08      6.8      6.8      0.0        376333.    7.0        60528.     .09
   .45      671055.           1.5      1.5      0.0      73517.     .11      8.2      8.2      0.0        448920.    8.3        81159.     .12
   .50      673750.           1.9      1.9      0.0      95651.     .14      9.6      9.6      0.0        525620.    9.8       105522.     .16
   .55      676445.           2.4      2.4      0.0     121360.     .18     11.0     11.0      0.0        606217.   11.2       133818.     .20
   .60      679140.           3.0      3.0      0.0     150818.     .22     12.6     12.6      0.0        690523.   12.8       166237.     .24
   .65      681835.           3.7      3.7      0.0     184188.     .27     14.2     14.2      0.0        778374.   14.4       202959.     .30
   .70      684530.           4.4      4.4      0.0     221630.     .32     15.8     15.8      0.0        869625.   16.1       244159.     .36
   .75      687225.           5.3      5.3      0.0     263295.     .38     17.5     17.5      0.0        964148.   17.9       290004.     .42
   .80      689920.           6.2      6.2      0.0     309328.     .45     19.3     19.3      0.0       1061827.   19.7       340653.     .49
   .85      692615.           7.2      7.2      0.0     359871.     .52     21.1     21.1      0.0       1162555.   21.6       396263.     .57
   .90      695310.           8.3      8.3      0.0     415060.     .60     23.0     23.0      0.0       1266238.   23.5       456982.     .66
   .95      698005.           9.5      9.5      0.0     475027.     .68     25.0     25.0      0.0       1372788.   25.5       522958.     .75
  1.00      700700.          10.8     10.8      0.0     539901.     .77     26.9     26.9      0.0       1482124.   27.5       594331.     .85
  1.05      703395.          12.2     12.2      0.0     609806.     .87     29.0     29.0      0.0       1594170.   29.6       671238.     .95
  1.10      706090.          13.7     13.7      0.0     684865.     .97     31.1     31.1      0.0       1708858.   31.7       753814.    1.07
  1.15      708785.          15.3     15.3      0.0     765196.    1.08     33.2     33.2      0.0       1826122.   33.9       842188.    1.19
  1.20      711480.          17.0     17.0      0.0     850914.    1.20     35.4     35.4      0.0       1945901.   36.1       936489.    1.32
  1.25      714175.          18.8     18.8      0.0     942133.    1.32     37.6     37.6      0.0       2068139.   38.4      1036840.    1.45
  1.30      716870.          20.8     20.8      0.0    1038964.    1.45     39.9     39.9      0.0       2192783.   40.7      1143363.    1.59
  1.35      719565.          22.8     22.8      0.0    1141513.    1.59     42.2     42.2      0.0       2319781.   43.0      1256177.    1.75
  1.40      722260.          25.0     25.0      0.0    1249838.    1.73     44.5     44.5      0.0       2449085.   45.4      1375399.    1.90
  1.45      724955.          27.3     27.3      0.0    1364191.    1.88     46.9     46.9      0.0       2580652.   47.9      1501142.    2.07
  1.50      727650.          29.7     29.7      0.0    1484526.    2.04     49.4     49.4      0.0       2714437.   50.4      1633519.    2.24
  1.55      730345.          32.2     32.2      0.0    1610991.    2.21     51.8     51.8      0.0       2850399.   52.9      1772640.    2.43
  1.60      733040.          34.9     34.9      0.0    1743686.    2.38     54.3     54.3      0.0       2988501.   55.4      1918613.    2.62
  1.65      735735.          37.7     37.7      0.0    1882705.    2.56     56.9     56.9      0.0       3128704.   58.0      2071543.    2.82
  1.70      738430.          40.6     40.6      0.0    2028145.    2.75     59.5     59.5      0.0       3270973.   60.7      2231535.    3.02
  1.75      741125.          43.6     43.6      0.0    2180097.    2.94     62.1     62.1      0.0       3415275.   63.4      2393691.    3.24
  1.80      743820.          46.8     46.8      0.0    2338654.    3.14     64.8     64.8      0.0       3561576.   66.1      2573112.    3.46
  1.85      746515.          50.1     50.1      0.0    2503907.    3.35     67.5     67.5      0.0       3709846.   68.8      2754898.    3.69
  1.90      749210.          53.5     53.5      0.0    2675942.    3.57     70.2     70.2      0.0       3860053.   71.6      2944145.    3.93
  1.95      751905.          57.1     57.1      0.0    2854849.    3.80     72.9     72.9      0.0       4012171.   74.4      3140951.    4.18
  2.00      754600.          60.8     60.8      0.0    3040714.    4.03     75.7     75.7      0.0       4166170.   77.3      3345409.    4.43
```

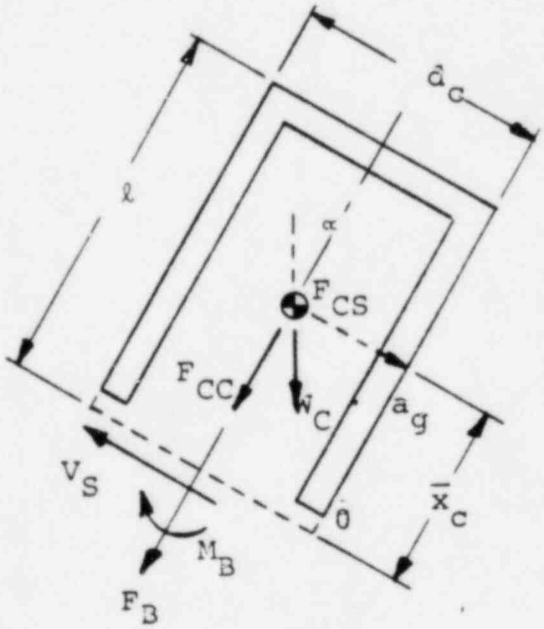
These decelerations impose body force loads upon the cask, payload and lid as indicated in the following free body diagrams:



Where:

$\alpha = \tan^{-1}(d_L/\ell)$
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
d_c = Cask Body diameter
d_L = Maximum Lid dimension

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



Where:

W_c = weight of cask
$F_{cc} = W_c \cdot a_g \cos\alpha$
$F_{cs} = W_c \cdot a_g \sin\alpha$

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

Similarly the payload forces are:

$$\left.\begin{aligned} F_{pc} &= W_p a_g \cos \alpha \\ F_{ps} &= W_p a_g \sin \alpha \end{aligned}\right\} \text{ at } \bar{x}_p$$

Where:

W_p = payload weight

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

<u>Longitudinal</u>: $F_B + F_{cc} + F_{pc} = 0$

$$\therefore \underline{F_B = -a_g (W_c + W_p) \cos \alpha}$$

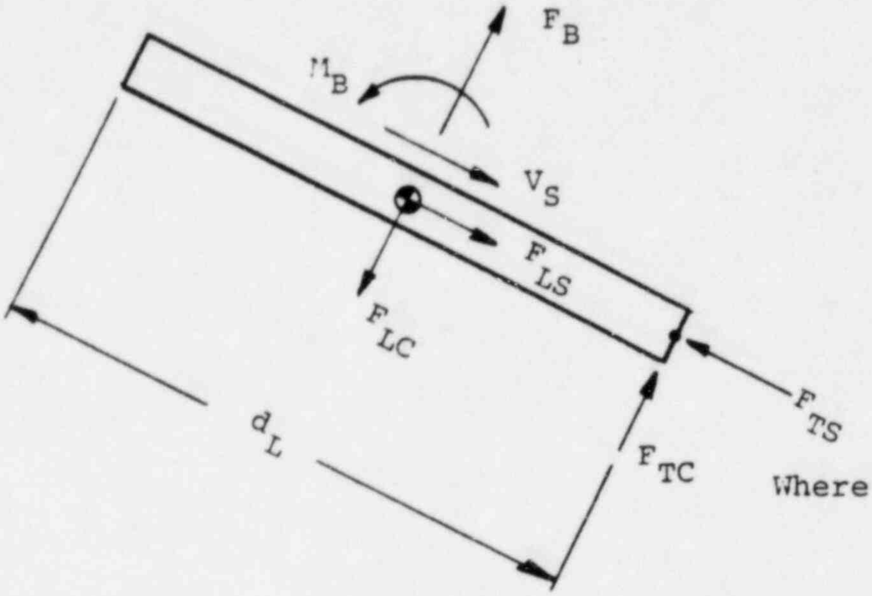
<u>Lateral</u>: $V_S - F_{cs} - F_{ps} = 0$

$$\therefore \underline{V_S = a_g (W_c + W_p) \sin \alpha}$$

<u>Moment</u>: $M_B + F_{cs} \cdot \bar{x}_c + F_{ps} \cdot \bar{x}_p = 0$

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

Comparable relations can be derived from lid equilibrium:



Where: W_L = weight of lid

$F_{LS} = W_L a_g \sin\alpha$

$F_{LC} = W_L a_g \cos\alpha$

Longitudinal: $F_{TC} - F_{LC} + F_B = 0$

$$F_B = F_{LC} - F_{TC}$$

$$F_B = a_g(W_L - W_T)\cos\alpha$$

But: $W_T = W_L + W_P + W_C;\ (W_T - W_L) = (W_P + W_C)$

Thus: $\underline{F_B = -a_g(W_C + W_P)\cos\alpha}$

Lateral: $F_{TS} - V_X - F_{LS} = 0$

$$V_S = F_{TS} - F_{LS}$$

$$V_S = ag(W_T - W_L)\sin\alpha$$

Or: $\underline{V_S = ag(W_P + W_C)\sin\alpha}$

<u>Moment</u>: $M_B + F_{TC}\ (d_L/2) = 0$

$$M_B = \frac{-d_L}{2} a_g (W_T) \cos\alpha$$

But: $\frac{d_L}{\ell} = \tan\alpha$; $d_L = \ell \tan\alpha = \ell \frac{\sin\alpha}{\cos\alpha}$

$$\underline{M_B = -\frac{\ell}{2} a_g (W_T) \sin\alpha}$$

This appears to differ from the expression derived on the basis of the cask and payload free body which was:

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

However:

$$\bar{x}_T = \bar{x}_p = \ell/2 \quad ; \quad \bar{x}_L = 0$$

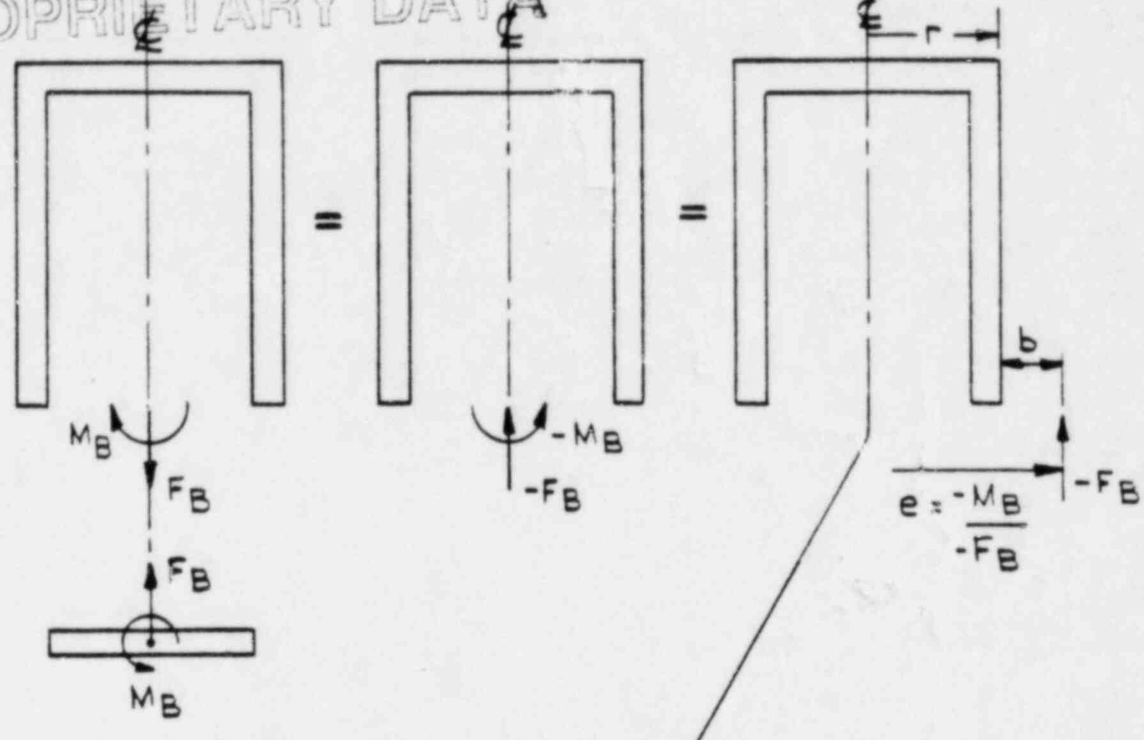
And:

$$W_T \cdot \bar{x}_T = W_C \cdot \bar{x}_c + W_P \cdot \bar{x}_p + W_L \cdot \cancelto{0}{\bar{x}_L}$$

$$W_T \cdot \bar{x}_T = (W_c \bar{x}_c + W_p \bar{x}_p) = W_T \ell/2$$

Thus, the two moment expressions are identical.

Ratchet binders, together with the bearing ring, react the interface axial force, F_B, and moment, M_B. Compressive loads are carried in bearing, whereas tensile forces are carried by the ratchet binders. Shear forces, associated with V_S are transferred by the lid step in bearing. The ratchet binder forces are calculated from the interface force, F_B, and moment, M_B, as follows:

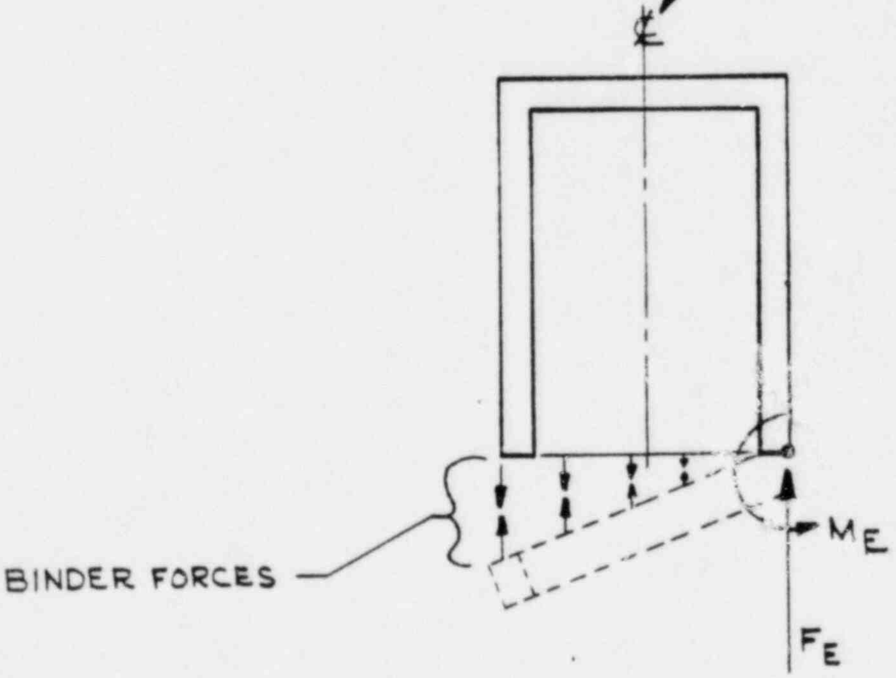


Where: $b = (e-r)$

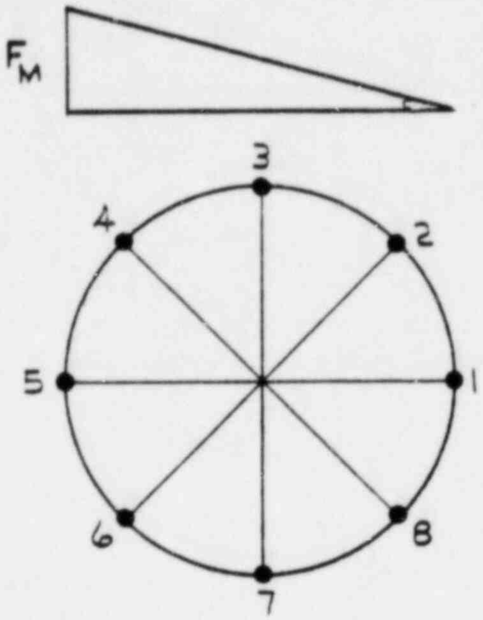
$F_E = -F_B$

$M_E = -F_B\left(\frac{M_B}{F_B} - r\right)$

$r = d_c/2$



Binder forces are calculated by referring to the following sketch:



$$F_i = F_M \frac{1-\cos\theta_i}{2}$$

$$\theta_i = \frac{\pi}{4}(i-1)$$

$$M_i = F_i r (1-\cos\theta_i)$$

$$M_E = \frac{F_M r}{2} \sum_{i=1}^{8} (1-\cos\theta_i)^2 = \frac{F_M r}{2}(12)$$

$$F_M = \frac{M_E}{6r}$$

For the nine versions, the interface loads and binder forces, F_M, are listed in Table 2.6.6.3-2.

TABLE 2.6.6.3-2
LID INTERFACE FORCES

NuPac Model	Dimensions		Load Factor a_g(G's)	Weights		Lid Interface Forces			Binder Force F_M(lbs)
	d (in)	ℓ (in)		Total W_T(lbs)	Lid W_L(lbs)	Axial Tension F_B(lbs) $x10^{-6}$	Moment M_B(in-lb) $x10^{-6}$	Shear V_S(lbs) $x10^{-6}$	
14/210L	82.25	86.44	33.4	53,600	5,200	-1.120	-55.80	1.166	39,530
14/210H	83.50	88.44	31.4	63,400	6,600	-1.241	-63.21	1.281	45,470
14/190L	80.50	79.57	34.9	46,300	5,000	- .965	-47.75	1.070	36,840
14/190M	81.50	81.57	33.2	53,500	6,300	-1.057	-53.47	1.157	42,510
14/190H	83.25	83.57	30.9	65,200	7,700	-1.202	-62.00	1.309	47,970
10/140	74.77	83.19	32.4	56,500	6,200	-1.157	-53.62	1.148	46,200
7/100	84.00	51.94	34.8	48,900	8,400	- .694	-38.46	1.227	36,890
6/100L	69.11	71.19	35.1	42,900	5,000	- .904	-39.32	.976	39,000
6/100H	71.37	74.19	32.4	53,900	6,800	-1.044	-47.26	1.113	46,740

$M_B = \ell/2 \, a_g W_T \sin\alpha$

$F_M = \dfrac{M_E}{6r}$

$r = d/2$

$V_S = a_g (W_T - W_L) \sin\alpha$

$M_E = -F_B \left(\dfrac{M_B}{F_B} - r\right)$

Thus, in this instance, the maximum binder force is 47,970 lbs.

The yield strength of the NuPac CB-2 binder is rated at 85,840 lbs. (see Appendix 2.10.3). Thus, the Margin of Safety is:

$$\text{M.S.} = 85{,}840/47{,}970 - 1 = \underline{+\ 0.79}$$

The capacities stated for the binders are established static allowables. They are manufactured from standard carbon steels and fail in the same manner as a bolt. Numerous studies have been conducted on the behavior of bolts under dynamic or impact loading. ORNL-TM-1312 Volume 12 Structural Analysis of Shipping Casks states that carbon steel bolts "possess better physical properties under conditions of shock than indicated by static tests. Increase 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 references 5, 8, 9, 10 and 11 of the same document.

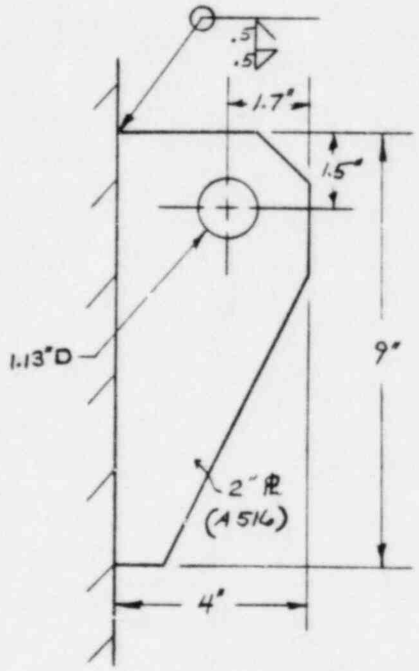
Therefore, it can be concluded that the binders static allowable capabilities will not be lower under shock or dynamic loading.

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 octagonal 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 NuPac 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):

$$P_s = F_s 2t\ (\text{E.M.} - d/2 \cos 40^\circ)$$

Where:

$F_{sy} = 22{,}800$ psi

$t = 2.0$ in.

$EM = 1.5$ in.

$d = 1.125$ in.

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

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

Weld Area:

The shear stress is:

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

The bending stress is:

$$F_b = \frac{P_w e}{z}$$

A conservative approach is to equate the combined stress to the ultimate shear stress:

$$F_{su} = \frac{F_B}{2} + \sqrt{\left(\frac{F_B}{2}\right)^2 + F_S^2}$$

$$= P_w \left[\frac{e}{2z} + \sqrt{\left(\frac{e}{2z}\right)^2 + \left(\frac{1}{A_w}\right)^2}\right]$$

The ultimate lug weld capacity is:

$$P_W = \frac{F_{su}}{\frac{e}{2z} + \sqrt{\left(\frac{e}{2z}\right)^2 + \left(\frac{1}{A_w}\right)^2}}$$

Where: $F_{sy} = 22{,}800$ psi

$e = 2.3$ in.

$A_w = 2(9\text{ in})(.5/\sin 45^\circ + .5/\sin 45^\circ) = 22.45$ in.

(Considering only the vertical welds)

$$z = \frac{I}{C} = \frac{\frac{2}{12}(.5/\sin 45 + .5/\sin 45^\circ (9)^3}{4.5} = 38.18\text{ in.}^3$$

$$P_w = \frac{22{,}800}{\frac{2.3}{2(38.18)} + \sqrt{\left(\frac{2.3}{2(38.18)}\right)^2 + \left(\frac{1}{25.45}\right)^2}} = 238{,}000\text{ lbs.}$$

Plate Area:

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

$$P_p = \frac{F_{su}}{\frac{e}{2z} + \sqrt{\left(\frac{e}{2z}\right)^2 + \left(\frac{1}{A_p}\right)^2}}$$

Where:

$F_{sy} = 22{,}800$ psi

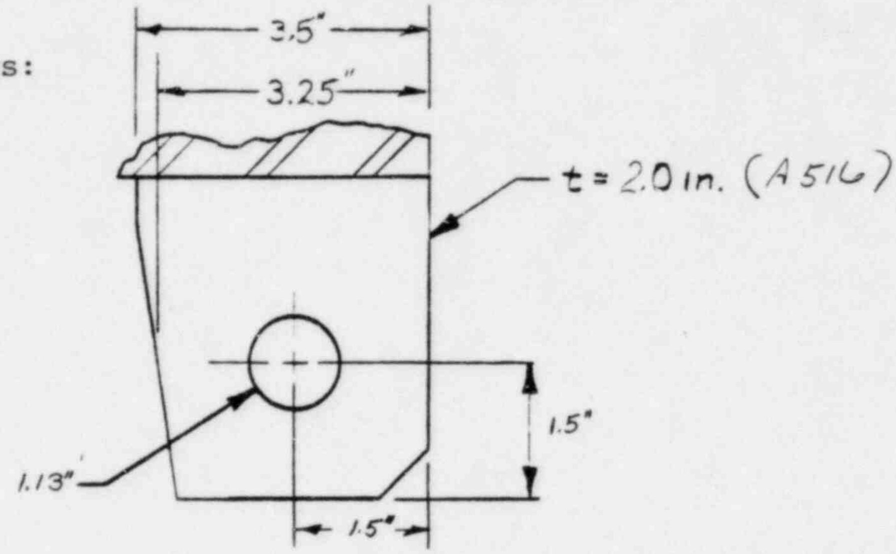
$e = 2.3 - .5 = 1.8$ in.

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

$$z = \frac{I}{c} = \frac{\frac{1}{12}(2)(9)^3}{4.5} = 27\text{ in.}^3$$

$$P_p = \frac{22,800}{\frac{1.8}{2(27)} + \sqrt{\left(\frac{1.8}{2(27)}\right)^2 + \left(\frac{1}{18}\right)^2}} = 232,300 \text{ lbs.}$$

Lid Lugs:



The lug capability in net area is:

$P_t = F_{ty}A$

Where: $F_{ty} = 38,000$ psi

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

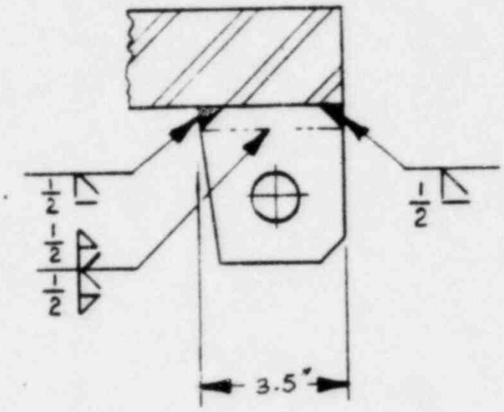
$= 4.25$

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

$P_t = 161,500$ 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:

$P_s = F_s A$ weld

Where:

$F_s = 22{,}800$ psi

$A = (2)(2)(.5)(.707) + (2)(3.5)(.5)(1.414)$

$= 6.36 \text{ in.}^2$

$P_s = (22{,}800 \text{ psi})(6.36 \text{ in}^2)$

$P_s = 145{,}100$ lbs/lug

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

At this location, the minimum Margin of Safety is:

$$\text{M.S.} = \frac{97{,}500}{47{,}970} - 1 = \underline{+\ 1.03}$$

The ratchet binders load the lid top plate (Plate F) with a series of edge moments. The two inch or greater plate of the NuPac A Series casks will be evaluated for these loads. Both local and gross effects on this lid top plate are evaluated.

PROPRIETARY DATA

For a maximum ratchet binder load of 47,970 lbs., the associated moment introduced into the top plate of the lid is estimated as:

$$M = (47,970)(.375 + 3.5 - 1.50) = 113,900 \text{ in-lb.}$$

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

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

Where: $\sigma = 38,000$ psi

$c = 1.0$ inch

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

$$b = (2)(3.8) \tan 67.5^\circ = 18.35$$

Local moment capability is then:

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

Thus, local moment yield margin of safety of the lid is:

$$\text{M.S.} = \frac{464,800}{113,900} - 1 = \underline{+\ 3.08}$$

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 minimum 1.00" interior plate:

$$M = \frac{38,000\ (1.0)^2}{6} = 6,333 \text{ in-lb/in.}$$

The total edge moment capability is: 31,670 in-lb/in.

For the smallest circular lid of 69.11" diameter, the corresponding concentrated moment acting on 1/8th of the edge is:

$$M_g = \frac{(31,670)(69.11)(\pi)}{8} = 859,506 \text{ in-lb.}$$

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

$$\text{M.S.} = \frac{859,506}{113,900} - 1 = \underline{+\ 6.55}$$

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

The bending stress at the center of the lid due to the weight of the payload can be estimated by considering it to be a simply supported circular plate with a uniformly distributed pressure load. The pressure is found to be (using the maximum payload cask, 14/210L):

$$p = \frac{25000(33.4)(\cos 45^{\circ})}{\frac{\pi}{4}(77.25)^2} = 126 \text{ psi}$$

Conservatively assume the plate diameter to be:

$$\text{Dia} = 83.5 + 2\ (.375 + 2.0) = 88.25 \text{ in.}$$

From Roark (5th Edition), Table 24, Case 10a, the maximum moment (which occurs at the center of the plate) is:

$$M = K_{me} ga^2$$

Where: $K_{mc} = .20625$

$q = 126$ psi

$a = 88.25/2 = 44.13$

$$M_c = .20625\ (126)\ (44.13)^2 = 50{,}610 \text{ in-lbs.}$$

The stress at this point is:

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

Where t = plate thickness

Using the lid thickness of 3 inches,

$$f_b = \frac{6(50{,}610)}{3^2} = 33{,}760 \text{ psi}$$

The Margin of Safety is then:

$$\text{M.S.} = \frac{38{,}000}{33{,}760} - 1 = \underline{\underline{+\ .13}}$$

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. The worst case loading considering all nine casks is for the 14/210L cask. Payload weight reacted by the lid is:

$$W_p = 80.25" \; (29")^2 \; \frac{\pi}{4} \; \left(\frac{25000 \text{ lb.}}{217 \text{ ft.}^3}\right) \; \frac{1}{1728 \text{ in}^3/\text{ft}^3} = 3534 \text{ lb.}$$

Secondary lid weight:

$$W_L = 960 \text{ lb.}$$

Total force reacted by the secondary lid lugs is then:

$$\begin{aligned} F_T &= (W_p + W_L) \; a_g \; \cos\alpha \\ &= (3534 + 960)(33.4)(.707) = 106{,}100 \text{ lbs.} \end{aligned}$$

Where a_g is the impact acceleration and α is the impact angle ($\approx 45^\circ$).

Maximum bending stess 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:

$$M_c = wa \; L_9$$

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

giving:

$$\begin{aligned} M_c &= \frac{106{,}100}{\pi(30.75)} \; (35.8)(.1235) \\ &= 4{,}854 \text{ in-lb/in.} \end{aligned}$$

Plate bending stress is given by:

$$\begin{aligned} f_b &= \frac{6 \; M_c}{t^2} \\ &= 6(4854)/1^2 = 29{,}130 \text{ psi} \end{aligned}$$

PROPRIETARY DATA

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

$$M.S. = \frac{38,000}{29,130} - 1 = \underline{\underline{+\ .30}}$$

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:

$$T = 0.20\ F_b d$$

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:

$$F_{bi} = \frac{106,100}{8} = 13,260\ \text{lbs.}$$

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:

$$F_{bx} = 8000 + 13,260$$
$$= 21,260\ \text{lbs.}$$

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

$$P = F_t A = 105,000\ (.309) = 32,450$$

The Margin of Safety for the studs is then:

$$\text{M.S.} = \frac{32,450}{21,260} - 1 = \underline{+\ .53}$$

When impacts occur on the lid end, a normal compressive load of 1,241,000 lbs (NuPac 14/210H, p. 2-58) 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: $R = 41.75$ in.

$$\left.\begin{aligned} \theta &= \cos^{-1}\left(\frac{r}{R}\right) \\ r &= R - \frac{\delta}{\sin\alpha} \end{aligned}\right\} \quad \text{See Appendix 2.10.2}$$

$\delta = 1.15$

$\alpha = 43.28^{\circ}$

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

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

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

PROPRIETARY DATA

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

$$F_B = (23.75)(1.50)(40,000) = 1,425,000 \text{ lbs.}$$

The associated Margin of Safety is:

$$\text{M.S.} = \frac{1,425,000}{1,241,000} - 1 = \underline{+\ 0.15}$$

The lateral load transferred between the lid and the cask is estimated as 1,309,000 lbs. (NuPac 14/190H). 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 smallest circumferential lid weld (6/100L, H) is:

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

$$= (22,800)(\pi)(61.0)(.5) = 2,185,000 \text{ lbs.}$$

The associated Margin of Safety is:

$$\text{M.S.} = \frac{2,185,000}{1,309,000} - 1 = \underline{+\ .67}$$

Therefore, it can be safely 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 lid interface forces given in Table 2.6.6.3-2. The maximum axial force on the base is 1,241,000 lbs. in addition to a maximum moment of 63,210,000 in-lbs. 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.

The worst case load is found to be for the 10/140 cask. Assuming that the base plate-to-outer shell weld carries the entire load:

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

Where: $F_B = 1,157,000$ lbs.

$D = 74.77 - 2(1.125) = 72.52$ in.

$t = .707 (.5 + .75) = .88$ in.

$$f_t = \frac{1,157,000}{\pi(72.52)(.88)} = 5,770 \text{ psi}$$

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

Where: $M_B = 53,620,000$ in-lbs.

$C = 72.52/2 = 36.26$

$I = \pi(r)^3 t = \pi(36.26)^3(.88) = 131,800 \text{ in.}^4$

$$f_b = \frac{53,620,000(36.26)}{131,800} = 14,750 \text{ psi}$$

Summing the forces:

$$f_T = 14,750 + 5,770 = 20,520 \text{ psi}$$

The Margin of Safety is:

$$\text{M.S.} = \frac{22,800}{20,520} - 1 = \underline{\underline{+.11}}$$

Assume that the shear component V_s is carried entirely by the .5 inch fillet weld joining the two base plates. The highest stress occurs in the 6/100H cask.

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

Where: $V_s = 1,113,000$ lbs.

$A_w = \pi(61.0+1.5)(.707)(.5) = 69.41 \text{ in.}^2$

$$f\nu = \frac{1,113,000}{69.41} = 16,040 \text{ psi}$$

Margin of Safety is:

$$\text{M.S.} = \frac{22,800}{16,040} - 1 = \underline{\underline{+ .42}}$$

Thus, the cask base welds are seen to be capable of withstanding the corner drop impact and thus will maintain the cask integrity.

2.6.7 Corner Drop

This requirement is not applicable since the NuPac Series A casks are 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 General Arrangement Drawing of NuPac Series A packaging.

NOTES: UNLESS OTHERWISE SPECIFIED.

1. MATERIAL: NUT, ASTM-A194 GR. 4 OR 7 OR EQUIV.
STUD, ASTM-A320 GR. L-7 OR EQUIV.
PLATE, ASTM-A516 GR. 70 (EXCEPT AS NOTED)
PLATE, ASTM-A514 OR A517
PLATE, AISI 1018 OR EQUIV..

2. WELDING SHALL BE IN ACCORDANCE WITH ASME CODE SECTION IX, OR AWS D1.1 AS APPLICABLE.

3. PAINT PER APPROVED NUPAC PROCEDURES.

4. LEAD FILL SHALL BE IN ACCORDANCE WITH NUPAC APPROVED LEAD POURING PROCEDURES.

5. TWELVE GAUGE 304-SS CASK LINER SHALL BE INSTALLED IN THE CAVITY AND SEAL WELDED ALONG ALL EDGES.

6. INSTALL NUPAC BINDER WITH HANDLE ORIENTATED TO TIGHTEN BINDER AS HANDLE IS PULLED AWAY FROM SHIELD BODY.

7. LOCKWIRE PRIMARY & SECONDARY LIDS AS REQUIRED FOR SHIPMENT.

8. TORQUE 3/4-10UNC NUTS TO 100 FT/LBS.

9. ALL WELDS SHALL BE VISUALLY EXAMINED IN ACCORDANCE WITH ASME CODE SECTION III, DIVISION I, SUBSECTION NB, ARTICLE NB-5000 AND SECTION V, ARTICLE 9 AND AWS D1.1, PARAGRAPH 8.15.1.

10. CONTINUOUS WELDS ON LIFTING AND HOLD DOWN LUGS SHALL BE MAGNETIC PARTICLE OR LIQUID PENETRANT INSPECTED, AFTER 125% LOAD TEST, IN ACCORDANCE WITH ASME CODE SECTION III, DIVISION I, SUBSECTION NB, ARTICLE NB-5000, AND SECTION V, ARTICLE 7 OR 6.

11. TORQUE BINDERS TO 50 FT/LBS. MIN.

12. OPTIONAL .25 DIA VENT HOLE WITH 3/4 NPT PLUG.

13. NUPAC BINDER UPPER PINS ARE 1" DIA WITH A MINIMUM DOUBLE SHEAR YIELD STRENGTH OF 80,000 LBS. LOWER BOLTS ARE 1" DIA SAE GRADE 8.

14. CENTER ALIGNMENT STRIPE ON LID ASSEMBLY OVER GUIDES ON CASK BODY ASSEMBLY.

MODEL	BASIC DATA					
	DRUM CAPACITY	PAYLOAD VOLUME (CU.FT.)	LEAD EQUIV. (IN.)	EMPTY WEIGHT (LBS.)	PAYLOAD WEIGHT (LBS.)	LOADED * WEIGHT (LBS.)
NUPAC 14/210L	14	217	2.00	28,600	25,000	53,600
NUPAC 14/210H	14	217	2.73	38,400	25,000	63,400
NUPAC 14/190L	14	190	2.00	26,300	20,000	46,300
NUPAC 14/190M	14	190	2.25	33,500	20,000	53,500
NUPAC 14/190H	14	190	3.50	45,200	20,000	65,200
NUPAC 10/140	10	144.	3.60	41,500	15,000	56,500
NUPAC 7/100	7	104	3.50	35,900	13,000	48,900
NUPAC 6/100L	6	105	3.25	30,900	12,000	42,900
NUPAC 6/100H	6	105	4.40	41,900	12,000	53,900

* WITH MAXIMUM THEORETICAL PAYLOAD WEIGHT

** REF DIMENSION ONLY.

REVISIONS				
ZONE	LTR	DESCRIPTION	DATE	APPROVED
	A	SEE DCN		

TYPE "A" FAMILY TABLE

DIMENSIONS																	
A	B **	C	D	E	F	G	H	J **	K	L	M	N	P	Q **	R	S
7.25	80.25	1.0	2.0	1.0	2.0	1.25	15.5	82.25	90.00	.38	.88	84.06	83.76	92.25	68.56	.5
7.25	80.25	2.0	2.0	1.0	2.0	1.88	15.5	83.5	92.00	.38	.88	86.06	84.93	93.5	70.56	.88 OR 1.0
75.5	73.38	1.0	2.0	1.0	2.0	1.25	15.5	80.5	83.13	.38	.88	77.19	82.16	90.5	61.69	.5
75.5	73.38	2.0	2.0	2.0	2.0	1.75	15.5	81.5	85.13	.38	.88	79.19	83.09	91.5	63.69	.88 OR 1.0
75.5	73.38	3.0	2.0	3.0	2.0	2.63	15.5	83.25	87.13	.38	.88	81.19	84.70	93.25	65.69	.88 OR 1.0
66.0	73.0	2.0	3.0	3.0	2.0	2.75	51.63	74.77	86.75	.50	1.13	80.81	76.87	84.77	45.5	1.13
75.5	40.75	2.0	3.5	3.5	2.0	3.0	15.5	84.0	55.50	.38	.88	49.56	85.40	94.0	34.06	.88 OR 1.0
61.0	62.0	2.0	2.5	2.5	2.0	2.43	39.63	69.11	74.75	.50	1.13	68.81	71.64	79.11	33.5	1.13
61.0	62.0	3.0	3.0	3.0	3.0	3.56	42.63	71.37	77.75	.50	1.13	70.81	73.73	81.37	36.5	1.13

ITEM	PART NO	DESCRIPTION	MATERIAL
LIST OF MATERIAL			

ASSEMBLY & QUANTITY

UNLESS OTHERWISE SPECIFIED
DIMENSIONS ARE IN INCHES
TOLERANCES
FRACTIONS ±
ANGLES ±
3 PLACE DECIMALS ±
2 PLACE DECIMALS ±
1 PLACE DECIMALS ± .1
DO NOT SCALE THIS DRAWING

NEXT ASSY	USED ON
	540-1

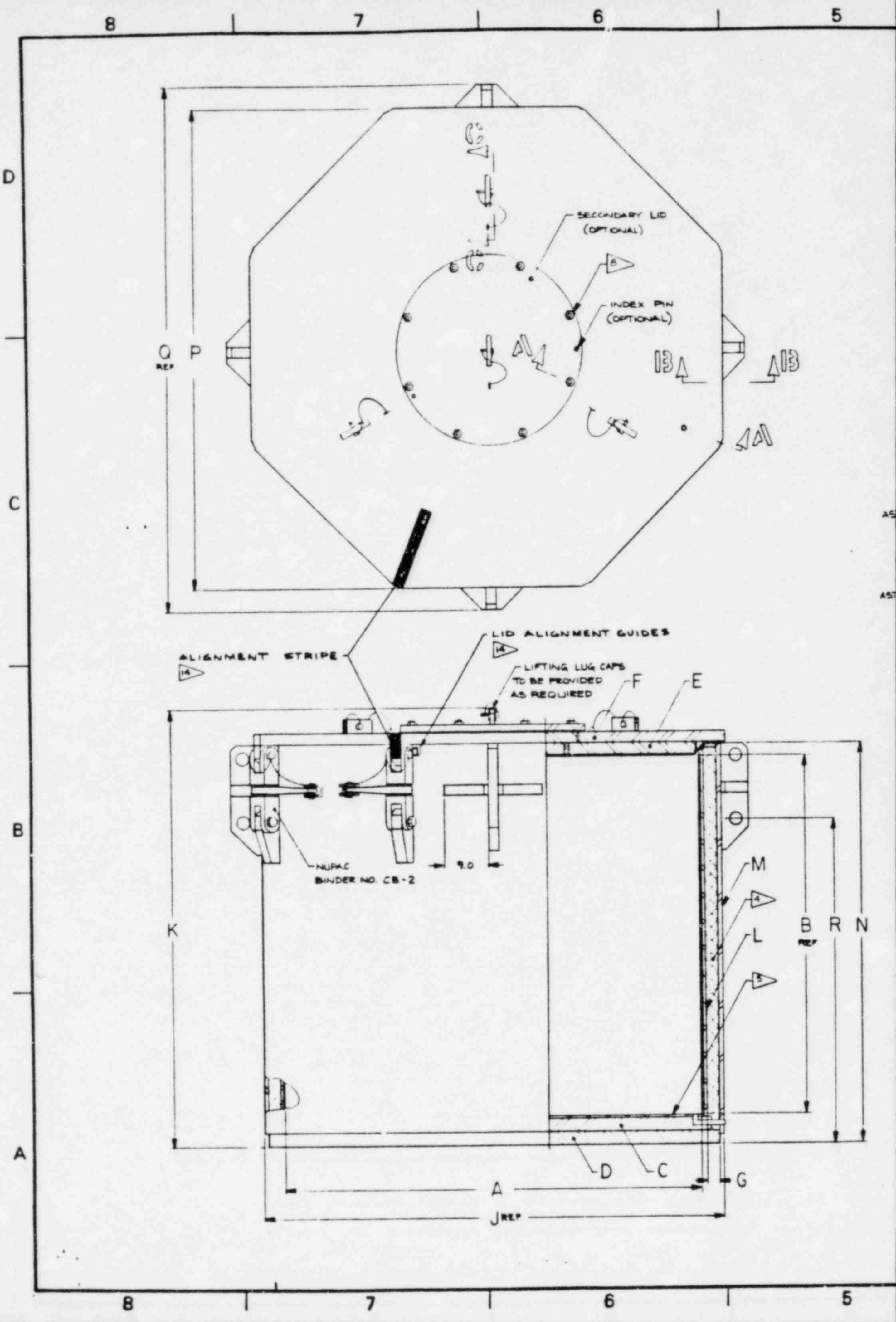
APPLICATION

NUCLEAR PACKAGING, INC.
TACOMA, WASHINGTON

NUPAC SERIES A CASKS

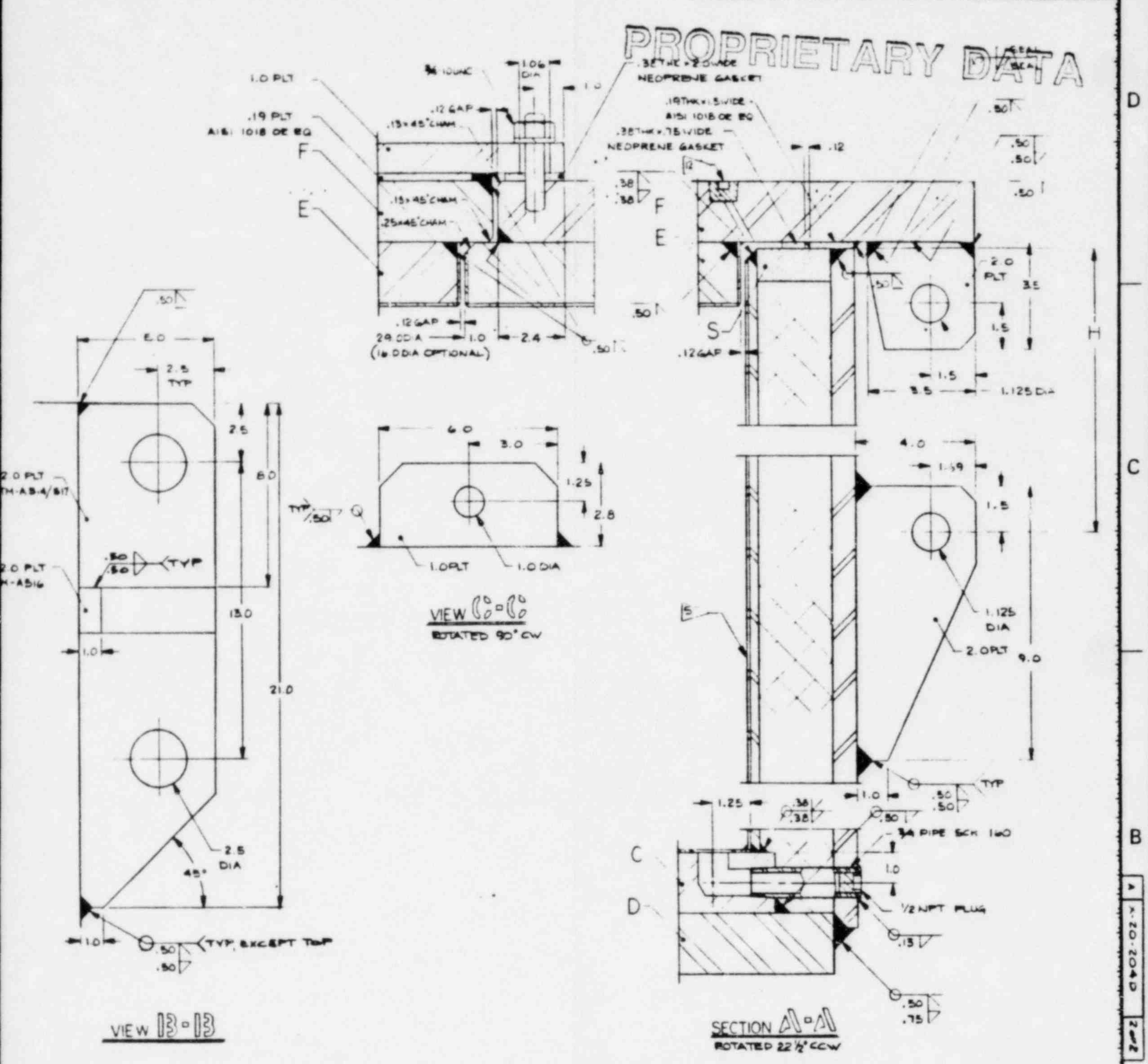
DRAWN S.C.	6-82	QA		SCALE	WT
CHECK		DWG REL Ⓐ		REV A	SHEET 1 OF 2
ENGR		PROG REL		DWG SIZE D	DWG NO X-20-204D

A X-20-204D 1 of 2


8
7
6
5
D
C
B
A
SECONDARY LID (OPTIONAL)
INDEX PIN (OPTIONAL)
Q REF
P
B
B
A
A
C
C
ALIGNMENT STRIPE
14
LID ALIGNMENT GUIDES
14
LIFTING LUG CAPS TO BE PROVIDED AS REQUIRED
F
E
NUPAC BINDER NO. CB-2
9.0
K
M
4
L
5
B REF
R
N
D
C
A
G
J REF

REVISIONS				
ZONE	LTR	DESCRIPTION	DATE	APPROVED
	A	SEE DCN	[illegible]	[illegible]

PROPRIETARY DATA



VIEW C-C
ROTATED 90° CW

VIEW B-B

SECTION A-A
ROTATED 22 1/2° CCW

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ASSEMBLY & QUANTITY

UNLESS OTHERWISE SPECIFIED
DIMENSIONS ARE IN INCHES
TOLERANCES
FRACTIONS ±
ANGLES ±
3 PLACE DECIMALS ±
2 PLACE DECIMALS ±
1 PLACE DECIMALS ±

DO NOT SCALE THIS DRAWING

NEXT ASSY | USED ON
APPLICATION

ITEM	PART NO	DESCRIPTION	MATERIAL

LIST OF MATERIAL

NUCLEAR PACKAGING, INC.
TACOMA, WASHINGTON

NUPAC SERIES A CASKS

DRAWN PCP	10/12/82	Q.A. [illegible]	10/14/82
CHECK PHIL PEARSON	10/11/82	DWG REL Ⓐ [illegible]	01 OCT 82
ENGR. [illegible]	10/10/82	PROD [illegible]	10/18/82

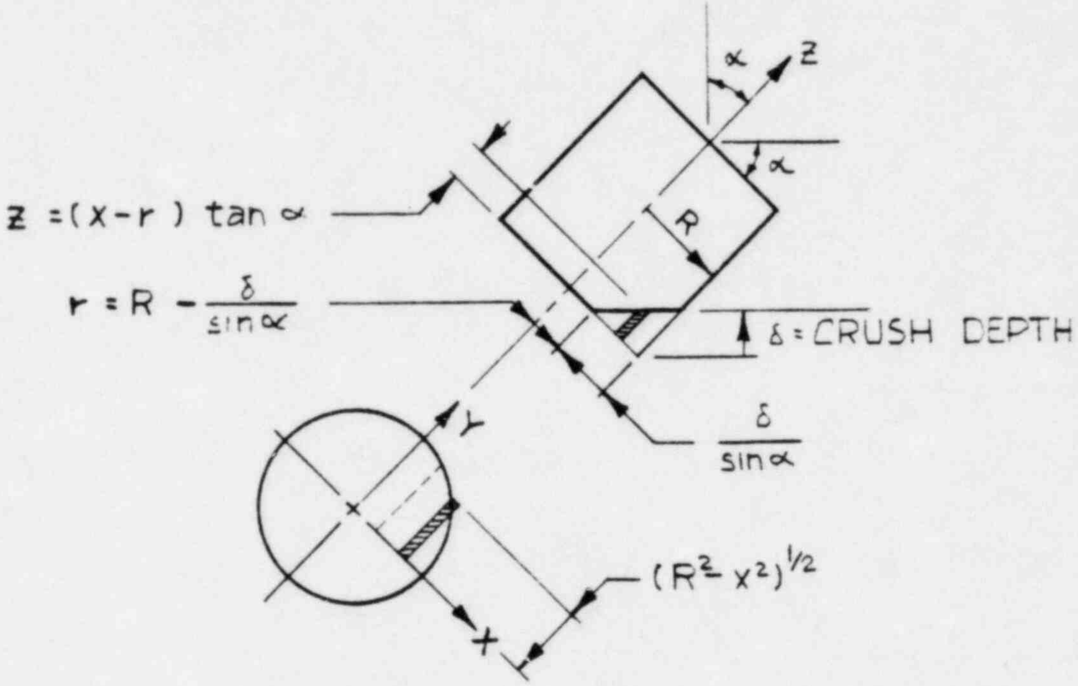
SCALE NONE
WT
REV A
SHEET 2 OF 2
DWG SIZE D
DWG NO X-20-204D

Appendix 2.10.2
Volume and Area Estimates
Corner Impact on a Cylinder

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

1.2 Component Volumes

The steel volume is composed of side and bottom portions:

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

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

$$V_{bot} = t_b \cdot \left[\theta R^2 - rR \sin\theta\right]$$

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

t_s = external steel side thickness (in)

t_b = steel and thickness (in)

The lead area represents the residual

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

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

2. 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:

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

The lead area is the residual:

$$\begin{aligned} A_\ell &= A_t - A_s \quad ; \quad (A_t - A_s) > 0 \\ &= 0 \quad ; \quad (A_t - A_s) < 0 \end{aligned}$$

3. Strain Energy Estimates

3.1 Flow Stress Approach

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

where: σ_{sp} = steel flow stress

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

3.2 Crush Stress Approach

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

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

PROPRIETARY DATA

APPENDIX 2.10.3

NUPAC CASK BINDER SPECIFICATIONS

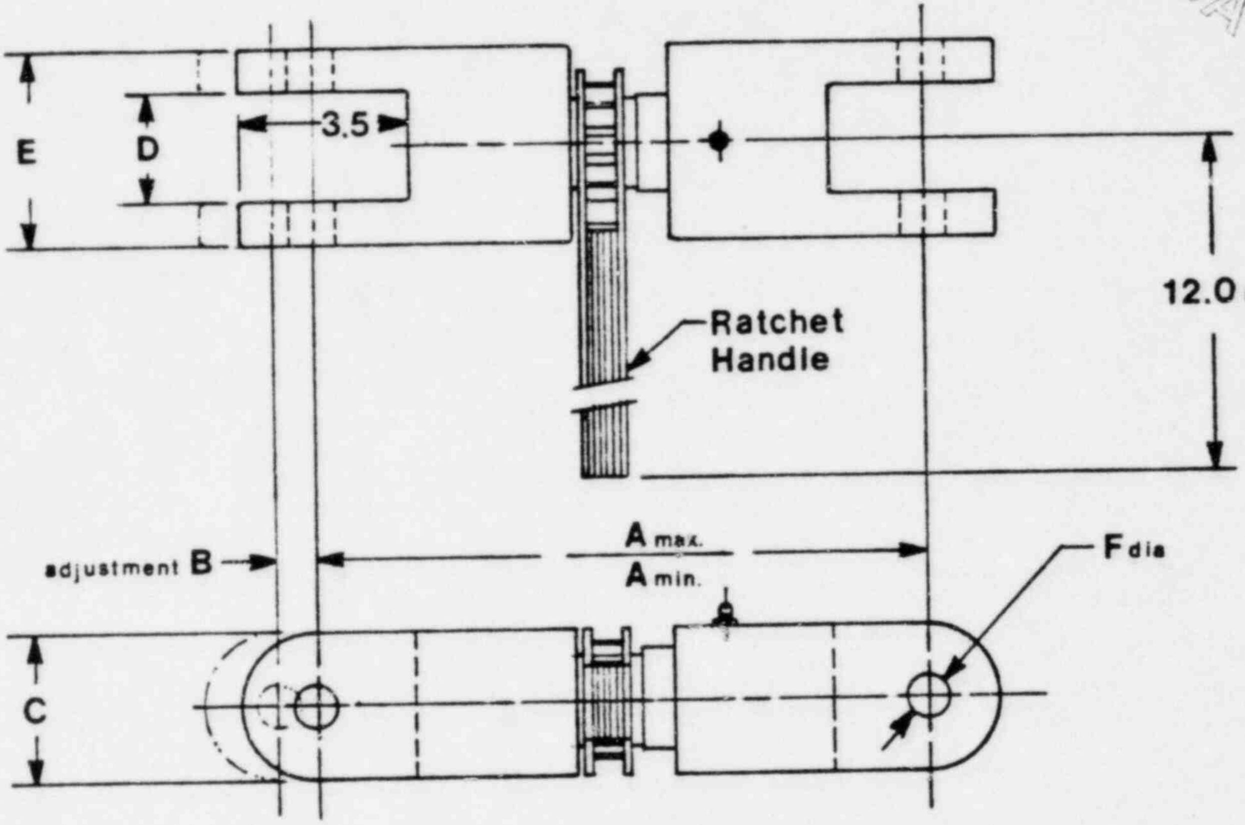
NuPac series CB

Revision 1
October, 1982

PROPRIETARY DATA

NUPAC CASK BINDER

MODEL CB-1, CB-2, CB-3



MODEL NO.	RATCHET SCREW DIAMETER	RATED* CAPACITY	LENGTH		DIMENSIONS **				
			A MAX	A MIN	B	C	D	E	F
NUPAC CB-1	1.00	53,040	48.00	12.75	1.75	3.00	1.63	3.13	.88
NUPAC CB-2	1.25	85,840	48.00	12.75	1.25	3.00	2.13	4.00	1.13
NUPAC CB-3	1.50	126,400	48.00	12.75	1.00	3.50	2.63	5.13	1.25

* YIELD IN LBS.

** DIMENSIONS SHOWN ARE IN INCHES.

MATERIAL: JAW BODY - ASTM-516, GRD. 70
THREADED SHAFT - ASTM-A320, L GRD.

3.0 THERMAL EVALUATION

A thermal analysis for the NuPac Series A casks 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 subsystems or features.

A very conservative heat load of 400 watts is used to evaluate cask temperatures. However, a heat load of only 4.5 watts is used to calculate the difference in temperature between the payload centerline and the cask surface. This is a much more realistic value 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 no internal heat whereas the higher temperature assumes an internal decay heat load of 400 watts. These maximum temperature prediction 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). The analysis also shows that the internal decay heat (400 watts) raises inside surface temperatures above the external temperatures by less than 0.3°F.

Centerline temperatures are calculated based on payloads containing primarily Cobalt 60 and Cesium 137. The analysis considered the maximum amount of these elements allowed based on shielding limits as follows:

Isotope	Gamma Energy MEV	Total Activity Curies
Cobalt 60	1.33	30
Cesium 137	0.66	650

These values are based on cement solidified waste in the 14/190H cask and 10 MR/hr at six feet from the cask. The analysis conservatively assumes all heat is conducted radially outward through an asphalt solidified payload, rather than concrete, because of the poorer thermal conductivity of asphalt. The centerline temperature is shown to be less than 3°F above the outside temperature of the cask.

3.2 Summary of Thermal Properties of Materials

Only three basic properties of the cask materials were employed in this analysis. They were obtained from conventional handbooks as follows:

Thermal Conductivity

Steel	25 Btu/hr ft-°F
Lead	18.6 "
Concrete	.8 "
Asphalt	.1 "

Surface Emissivity/Absorptivity

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. The analyses show little temperature difference between the nine individual casks which comprise the NuPac Series A Casks.

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 out put consisted of the sum of free-convection losses and radiation losses to a prescribed ambient air sink temperature (130°F-"Heat", -40°F-"Cold"). Heat loss was "allowed" only over the vertical cylindrical sides and the top. Connective 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., 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	185.6°F	185.6°F
400 watts Internal Heat	190.3°F	190.6°F

(All values are for the NuPac 7/100 cask)

3.4.3 Minimum Temperatures

Predicted minimum temperatures are:

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

(400 watt values for the NuPac 14/210H Cask)

3.4.4 Maximum Internal Pressures

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:

$P_{we} = 0.36$ psi*

$P_{ac} = 14.7 - .36 = 14.34$ psi

The partial pressures at 191° are:

$P_{wh} = 9.54$ psi

$P_{Ac} = 14.34\ (191 + 460)/(70 + 460) = 17.61$ psi

The internal pressure differential is thus:

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

---

*Reference: 1967 ASME Steam Tables

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 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	Load/ 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	Large
Lid	6777 psi	38,000	+ 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 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

PROPRIETARY DATA

Thermal Analysis - Normal Conditions of Transport

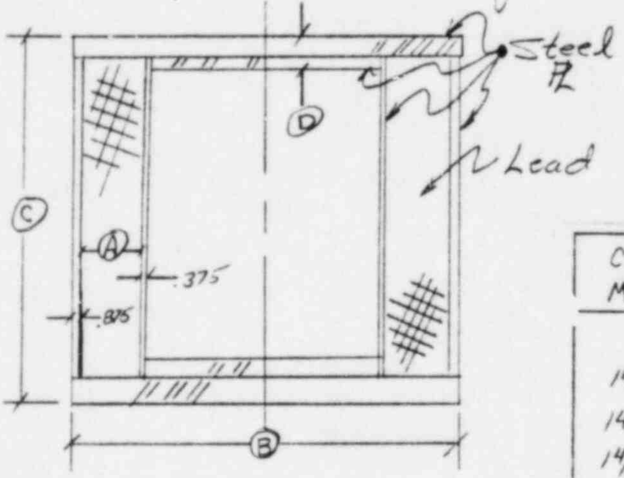
Hot and Cold ambient condition cases are analyzed with the following assumptions:

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

Cold - Shade
Ambient air @ -40°F
Internal heat = 0 & 400 Watts

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

Simplified cask geometry used in the analysis:



Dimensions (ft)

Cask Model	LⒶ	LⒷ	LⒸ	LⒹ
14/210L	.104	6.85	7.19	.250
14/210H	.157	6.96	7.39	.354
14/190 L	.104	6.71	6.61	.250
14/190M	.146	6.79	6.78	.333
14/190H	.219	6.94	6.98	.438
10/140	.229	6.23	6.96	.433
7/100	.250	7.00	4.31	.458
6/100L	.203	5.76	5.96	.396
6/100H	.297	5.96	6.21	.521

External Convective & Radiative Heat Transfer

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

Convection

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

For free convection McAdams gives

$$h = .29\left(\frac{\Delta T}{L}\right)^{1/4} \quad \text{for vert. cylinders}$$

$$= .27\left(\frac{\Delta T}{L}\right)^{1/4} \quad \text{for horiz. plates (up-heated)}$$

Thus:

$$q = h_S A_S \Delta T + h_T A_T \Delta T = (h_S A_S + h_T A_T)\Delta T$$

$$= \left[.29\left(\frac{\Delta T}{L_{\textcircled{C}}}\right)^{1/4} A_S + .27\left(\frac{\Delta T}{L_{\textcircled{B}}}\right)^{1/4} A_T\right]\Delta T$$

where

$L_{\textcircled{C}}$ = outside height

$L_{\textcircled{B}}$ = outside dia

$A_S = \pi L_{\textcircled{C}} L_{\textcircled{B}}$

$A_T = \pi/4 \, L_{\textcircled{B}}^2$

Radiation

$$q = \sigma A_{\Sigma} \epsilon \left(T_{ext}^4 - T_{\infty}^4\right) = K\left(T_{ext}^4 - T_{\infty}^4\right)$$

where

$\sigma = .1714 \times 10^{-8}$

$\epsilon = .8$

$A_{\Sigma} = A_S + A_T$

Evaluating K:

Cask Model	L_B (ft)	L_C (ft)	A_{Top} (ft²)	A_{side} (ft²)	A_{Σ} (ft²)	K BTU/HR/°R⁴
14/210L	6.85	7.19	38.92	154.77	193.69	$.2656 \times 10^{-6}$
14/210H	6.96	7.39	40.11	161.67	201.78	.2769 ✓
14/190L	6.71	6.61	37.28	139.40	176.68	.2423 ✓
14/190M	6.79	6.78	38.21	144.69	182.90	.2508 ✓
14/190H	6.94	6.98	39.87	152.11	191.98	.2632 ✓
10/140	6.23	6.96	32.16	136.21	168.37	.2309 ✓
7/100	7.00	4.31	40.59	94.84	135.43	.1857 ✓
6/100L	5.76	5.96	27.48	107.80	135.28	.1855 ✓
6/100H	5.95	6.21	29.30	116.00	145.30	.1992 ✓

Solar Heat Load

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

2950 BTU/ft² for the top surface

1475 BTU/ft² 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 x dia.) and both are converted to heat flux, BTU/ft²/hr

$$q_{solar} = \frac{2950}{12} A_T + \frac{1475}{12} L_{\textcircled{c}} L_{\textcircled{B}}$$

$$= 245.83 A_T + 122.92 L_{\textcircled{c}} L_{\textcircled{B}}$$

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:

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

$$= 245.83\,A_T + 122.92\,L_c L_B + 1365$$

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

$$= K\left(T_{ext}^4 - T_\infty^4\right) + \left[.29\left(\frac{T_{ext} - T_\infty}{L_{\textcircled{c}}}\right)^{1/4} A_S + .27\left(\frac{T_{ext} - T_\infty}{L_{\textcircled{B}}}\right)^{1/4} A_T\right]\left(T_{ext} - T_\infty\right)$$

T_{ext} values for the packages under three load cases are given in Table .

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.

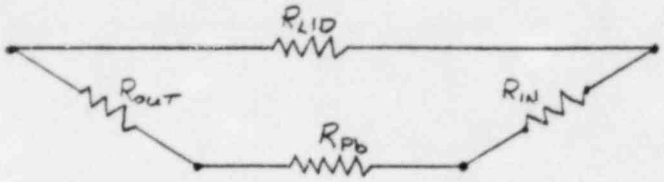
PROPRIETARY DATA

Cask External Temperature

Cask Model	Load Case	LⒸ (FT)	LⒷ (FT)	A_S (FT^2)	A_T (FT^2)	q_{in} (BTU/HR)	K	T_{EXT} ($^\circ F$)
14/210L	①	7.18	6.85	154.8	38.9	16982	$.2656 \times 10^{6}$	180.2
	②					15617		176.7
	③					1365		-30.3
14/210H	①	7.39	6.96	161.7	40.1	17545	$.2769 \times 10^{-6}$	179.9
	②					16180		176.6
	③					1365		-30.7
14/190L	①	6.61	6.71	139.4	37.3	15986	$.2423 \times 10^{-6}$	181.4
	②					14621		177.6
	③					1365		-29.6
14/190M	①	6.78	6.79	144.7	38.2	16414	$.2508 \times 10^{-6}$	181.1
	②					15049		177.4
	③					1365		-29.9
14/190H	①	6.98	6.94	152.1	39.9	17128	$.2632 \times 10^{-6}$	181.0
	②					15763		177.4
	③					1365		-30.3
10/140	①	6.96	6.23	136.2	32.2	14611	$.2309 \times 10^{-6}$	179.7
	②					13246		175.6
	③					1365		-29.1
7/100	①	4.31	7.00	94.8	40.6	15054	$.1357 \times 10^{-6}$	190.3
	②					13689		185.6
	③					1365		-27.2
6/105L	①	5.96	5.76	107.8	27.5	12345	$.1855 \times 10^{-6}$	181.5
	②					10980		176.5
	③					1365		-27.0
6/105H	①	6.21	5.95	116.0	29.3	13110	$.1992 \times 10^{-6}$	181.1
	②					11745		176.4
	③					1365		-27.7

PROPRIETARY DATA

Conductive Heat Transfer Evaluation



$$R_{EFF} = \frac{R_{LID}\,R_{WALL}}{R_{LID} + R_{WALL}} \qquad R_{WALL} = R_{OUT} + R_{Pb} + R_{IN}$$

$$\Delta T = R_{eff}\,q$$

Steel

$R_{LID} \simeq \frac{t}{kA_L}$; $k = 25$ BTU/HR·FT °F

$A_L = \frac{\pi}{4}(L_{\textcircled{B}})^2$ (ft^2)

$t = L_{\textcircled{D}}$ (ft)

$R_{IN} = t/kA_\omega$ $A_\omega = \pi\left(L_{\textcircled{B}} - 2\left(L_{\textcircled{A}} + \frac{.375}{12} + \frac{.875}{12}\right)\right)L_{\textcircled{C}}$

$t = .375'' = .0313'$

$R_{OUT} = t/kA_\omega$ $A_\omega = \pi L_B L_C$

$t = .875/12 = .0729'$

Lead $R_{Pb} = \frac{\ln(r_o/r_i)}{2\pi k l}$ $r_o = L_{\textcircled{B}}/2$

$r_i = \left[L_{\textcircled{B}} - 2\left(L_{\textcircled{A}} + \frac{.375 + .875}{12}\right)\right]/2$

$k = 18.6$ BTU/HR·FT °F

$l = L_{\textcircled{C}}$

Values for Reff and ΔT given in the following table, where:

ΔT is calculated by:

$$\Delta T = q\,R_{eff}$$

and $q = 400(341) = 1365$ BTU/hr

PROPRIETARY DATA

Temperature Difference
across Cask Wall

Cask Model	R_{WALL} $\left(\frac{HR\ ^\circ F}{BTU}\right)$	R_{LID} $\left(\frac{HR\ ^\circ F}{BTU}\right)$	R_{EFF} $\left(\frac{HR\ ^\circ F}{BTU}\right)$	ΔT ($^\circ F$)
14/210L	70.04	307	57	.078
14/210 H	89.4	435	74	.101
14/190 L	78.3	322	63	.086
14/190M	95.7	429	78	.107
14/190 H	125.6	563	103.7	.140
10/140	159	737	131	.190
7/100	249	590	175	.239
6/100L	186	780	150	.205
6/100 H	244	1027	197	.269

Decay Heat Load Determination

Maximum Activity, 650 Curies of Cesium 137. Taking the total Cesium decay energy of 1.176 MeV/disintegration times 3.7×10^{10} disintegrations/curie-sec gives

$$43.5 \times 10^{9} \text{ MeV/curie-sec}$$

Converting to ergs/curie-sec

$$(43.5 \times 10^{15} \text{ eV/curie-sec})(1.602 \times 10^{-12} \text{ erg/eV})$$

$$= 69.71 \text{ erg/curie-sec}$$

Converting to watts

$$(69.71 \text{ erg/curie-sec})(10^{-7} \text{ watts/erg/sec})$$

$$= .00697 \text{ watts/curie}$$

Converting to BTU/curie-hour

$$.00697 \text{ watts/curie} \left(3.415 \frac{\text{BTU/hr}}{\text{watts}}\right)$$

$$= .0238 \text{ BTU/curie-hr}$$

With a total payload activity of 650 curies

$$Q = (.0238 \text{ BTU/curie-hr})(650 \text{ curies})$$

$$= 15.47 \text{ BTU/hr} =$$

Assuming the heat sources are uniformly distributed in the 190 ft^3 volume

$$\dot{q} = \frac{15.47}{190} = .081 \text{ BTU/hr} \cdot ft^3$$

Cask Centerline Temperature

The temperature at the center of the cask can be calculated if we 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

$$T = T_o + \frac{\dot{q} r_o^2}{4k}$$

where: T_o = outer surface temp.

r_o = radius of outer surface

k = conductivity of cylinder material

Assuming the payload is solidified in asphalt ($k = .1$ BTU/hr ft °F) with $r_o = 3.15$ ft (14/190H) and $\dot{q} = .081$ BTU/hr-ft^3

$$T = T_o + \frac{.081(3.15)^2}{4(.1)}$$

$$= T_o + 2.01°F$$

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 NuPac Series A Casks is the inner shell of the shielded transportation cask as described in Paragraph 1.2.1.3 and the general arrangement drawing in Appendix 2.10.1.

4.1.2 Containment Penetration

An optional pressure top is included in the design as described in Section 1.2.1.7. It is sealed with a 3/4" NPT pipe plug.

An optional drain line is also included in the design as described in Section 1.2.1.7. 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 1.2.1.3, above. All joints are arc welded.

The integrity of the seals is demonstrated using a soap bubble leak test done according to NuPac Procedure No. LT-04, General Procedure for Soap Bubble (Low Pressure) Leak Test.

4.1.4 Closure

The clousre 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

There was no release of radioactive material from the containment vessel.

4.2.2 Pressurization of Containment Vessel

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 NuPac Series A casks consist of a lead and steel containment vessel which provides the necessary shielding for the various radioactive materials to be shipped within the package. (Refer to Section 1.2.3 for packaging contents.) 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 assure compliance with applicable regulations.

6.0 CRITICALITY EVALUATION

Not applicable for the NuPac Series A casks.

7.0 OPERATING PROCEDURES

This chapter generally describes the procedures to be followed in using a NuPac Series A Cask.

7.1 Initial Shipment Prior to First Use

7.1.1 The cask shall be mounted to the transportation trailer as follows:

a. If the transportation trailer is the permanent unit the cask shall be secured in accordance with Section 7.4.7 of this procedure utilizing a DOT approved hold down system.

b. If the transportation trailer is for initial delivery only, the cask shall be secured, utilizing standard chain and chain binders normally utilized for heavy loads. The chains shall be secured to the cask hold down lugs.

7.2 Long Term Storage

7.2.1 The casks can be stored for extended period (1 to 3 years) with minimal special preservation. The following precautions should be taken:

a. Ratchet binders and all fasteners should be fully coated with a good quality "automotive chassis" grease.

b. To maintain original finish gloss, the engire cask painted surface may be coated with 2 to 3 layers of any good quality automotive finish wax. The last coat should be allowed to dry without being polished.

c. If required, the cask finish can be further protected from harsh salt spray or chemicals by covering with tarps or storing under other suitable cover.

7.2.2 To maintain the original surface gloss or finish, the interior cavity, painted or stainless steel, may be wax coated as described in 7.2.1.B.

7.2.3 The cask can be prepared for use by standard steam cleaning methods after storage. Ratchet binder threads should be re-greased with good grade automotive chassis lubricant after steam cleaning.

7.3 Lifting

7.3.1 The cask shall always be lifted by the four (4) provided lifting lugs only. The lifting lugs are the vertically oriented lugs on the sides of the casks spaced at 90° around the cask circumference.

7.3.2 All other lifting lugs on the primary and secondary lids shall only be used to lift the lid they are attached to.

7.4 Use of the Cask as a Licensed Type A Container

7.4.1 Removal of the Primary Lid

a. Release the ratchet binder handle from its storage position.

b. Engage the flip block to the sprocket wheel in the direction necessary to loosen the ratchet binder.

c. Loosen the ratchet binder by pulling the handle in the appropriate direction.

d. Remove the retaining pin from the upper ratchet binder pin and then remove the ratchet binder pin.

e. Remove the three (3) primary cask lid lifting lug covers.

f. Using the three (3) primary lifting lugs on the cask lid to accommodate suitable rigging and exercising caution in the handling of the primary cask lid due to possible contamination of the underside of the lid, remove cask lid.

7.4.2 Removal of Secondary Lid

a. Remove the secondary lid holddown fasteners.

b. Remove the secondary lid lifting lug cover(s).

c. Exercising caution due to possible contamination of the underside of the shielding plug, remove the shield plug.

7.4.3 Installation of Primary Lid

a. Prior to installation, inspect gasket for the following:

1. Gasket fully secured to lid sealing surfaces.
2. Gasket not cut, ripped or gouged.
3. Gasket is resilient.
4. Gasket is free of debris, dirt and/or grease.

b. Using the three (3) lifting lugs on the primary lid to accommodate suitable rigging, lift and place lid on cask using alignment guides to assure proper positioning. Take care not to damage gasket.

c. Secure the primary lid to the cask as follows:

1. Install the upper ratchet binder pin through the upper ratchet binder connector and the lid closure lug and install its retaining pin.

2. Tighten the ratchet binder by engaging the flip block to the sprocket wheel and rotate the ratchet binder handle in the direction necessary to tighten the ratchet binder. Tighten to 50 ft-lbs. torque minimum.

3. Disengage the flip block and rotate and secure the handle to its storage position.

4. Install the three (3) primary cask lid lifting covers.

7.4.4 Installation of Secondary Lid

a. Prior to installation, inspect gasket for the following:

   1. Gasket fully secured to lid sealing surface.

   2. Gasket not cut, ripped or gouged.

   3. Gasket is resilient.

   4. Gasket is free of debris, dirt and/or grease.

b. Using the one (1) or three (3) lifting lug(s) on the secondary lid to accommodate suitable rigging, lift and place lid into the opening on the primary lid. Use alignment pins to assure proper positioning. Take care not to damage gasket.

c. Secure the secondary lid by installing and tightening the fasteners to 100 ft-lbs. torque.

d. Install the secondary lid lifting lug cover(s).

7.4.5 Cask Loading

a. Survey empty cask and the vehicle carrying it to determine the loose and fixed contamination levels. Limitations pertaining to contamination levels shall be determined by regulations imposed on the user by the applicable governing bodies.

b. Inspect cask lid fasteners to assure all are present and undamaged.

c. Check to assure that cask lid (primary and secondary) lifting lug covers are with the cask.

d. Remove primary lid in accordance with Section 7.4.1.

e. Remove secondary lid in accordance with Section 7.4.2.

f. Inspect secondary lid holddown studs for damage.

g. Inspect interior of cask for standing water.

NOTE: Water must be removed prior to shipment (see Section 7.5).

h. Inspect interior of cask for obstructions to loading.

i. Inspect interior of cask for defects which might affect the cask integrity or shielding afforded by the cask.

j. If loading drums on 7 drum pallets, proceed as follows:

1. Load seven (7) drums on each pallet (see Figure 3 for general placement on pallet).

2. Place drums within guides provided on the pallet deck to facilitate proper orientation.

3. For maximum shielding, load higher dose rate drums in the center position and the positions toward the front and rear of the trailer.

4. The lifting sling remains attached to the pallet at all times.

5. By loading the center drum first and then three drums on one side, the sling can be placed over the loaded drums while the remaining three are loaded. This technique prevents damage to the sling.

6. The sling assembly should be placed around the drums in such a way to prevent damage to the sling.

7. The sling assembly should be inspected at each loading for damage and general condition.

8. Place loaded pallet into cask, assuring that pallet slings are not caught along side or under the pallet.

9. Place sling around or along side drums to prevent pinching or damage to the sling by the lids or second/top pallet in the cask of the 14 drum cask.

10. In the case of a 14 drum cask, load a second pallet in the same manner described in #1 through #9.

    11. Inspect lid and gaskets, install cask lids and secure as described in Section 7.4.3 for the primary lid and Section 7.4.4 for the secondary lid.

k. If loading preloaded liners, proceed as follows:

    1. If necessary, the cask may be removed from the trailer in accordance with Section 3.4.6.

    2. Assure all lids, plugs or caps are installed on liner.

    3. Using the lifting slings provided, place liner into the cask.

    4. Install shims/shoring between liner and cask as necessary to secure in position.

    5. Inspect lid gaskets, installed cask lids and secure as described in Section 7.4.3 for the primary lid and Section 7.4.4 for the secondary lid.

L. If loading into liner inside cask, proceed as follows:

    1. If necessary, the cask may be removed from the trailer in accordance with Section 7.4.6.
    2. Using the slings provided, place liner in the cask.
    3. Install shims/shoring between liner and cask as necessary to secure in position.
    4. Inspect gaskets, install and secure primary lid as described in Section 7.4.3.
    5. Do not install secondary lid at this time.
    6. Load the waste into the liner through the secondary lid opening.
    7. Install the liner lid, plugs, or caps onto the liner.
    8. Inspect gaskets, install and secure secondary lid as described in Section 7.4.4.

m. Install tamper-proof seals.

7.4.6 Cask Removal from Trailer

a. Loosen ratchet binders/turnbuckles as necessary to remove pins from shackles at cask end of tiedown system.

b. Remove pins from shackles.

c. Using the four (4) cask lifting lugs and suitable rigging lift cask off trailer and place cask in proper position for loading.

NOTE: Do not use cask lid lifting lugs to lift the cask.

7.4.7 Cask Installation on Trailer

a. Using the four (4) cask lift lugs and suitable rigging lift cask and place cask in proper position within the shear blocks provided on the trailer.

NOTE: Do not use cask lid lifting lugs to lift the cask.

b. Inspect tiedown lugs and shackles on cask and trailer for cracks and wear which would affect their strength.

c. Inspect tiedown cables to assure they are not loose, or damaged (crimped, frayed, etc.).

d. Inspect tiedown ratchets/turnbuckles to assure they are in proper working condition.

e. Install shackles through the end of the tiedown cables and attach to cask tiedown lugs by screwing pin through shackle and hole in lug.

f. Tighten ratchet binders/turnbuckles as necessary to secure cask on trailer.

7.4.8 Preparation of Cask for Shipment as Type A Container

a. Perform radiation surveys of cask and vehicle and complete the necessary shipping papers, certifications, and pre-release checklist, or site equivalent.

b. Placard vehicle and label cask as necessary.

7.4.9 Receiving a Loaded Cask

The receiver, carrier and shipper are to follow the instructions of 10 CFR 20.205 when a package is delivered. These instructions include monitoring the external surface of the cask for radioactive contamination.

7.5 Containment Penetration Seals

Installation of pipe plugs used to seal the pressure tap line and the drain line is to be done using a pipe joint sealing compound. Plugs are to be tightened to 20 ft-lbs. torque.

8.0 ACCEPTANCE TESTS AND MAINTENANCE

8.1 Acceptance Tests

Prior to the first use of the cask, the tests and evaluations called out on the General Arrangement Drawing (Appendix 2.10.1) will be performed.

In addition, shielding integrity of the package will be verified using gamma scan procedures called out in NuPac Procedure No's. GS-001 and GS-002 (See Appendices 8.3 and 8.4) seal integrity will be demonstration by Soap Bubble leak test following NuPac Procedure No. LT-04 (Appendix 8.5).

8.2 Maintenance Program

A good sound industrial maintenance program should be followed to assure the integrity of a NuPac Series A Cask. Components such as gaskets, ratchet binders, bolts and other equipment necessary for the safe and easy operation of the packaging should be given regular inspection and repaired or replaced as necessary.

Specific maintenance programs addressing inspection intervals, repair and/or replacement methods and criteria shall be prepared and administered by the user.

APPENDIX 8.3

PROPRIETARY DATA

GENERAL PROCEDURE
FOR
GAMMA SCAN OF SHIELDED CONTAINER
(LABORATORY CALIBRATION METHOD)

PROCEDURE NO. GS-001

REVISION 2

DATE: AUGUST 31, 1981

By
Nuclear Packaging, Inc.
Tacoma, Washington

APPROVALS:

Engineering ______ Date 9/2/81

Quality Engineering: Joe R. Otwodar Date 9/1/81

GAMMA SCAN OF SHIELDED CONTAINERS
(LABORATORY CALIBRATION METHOD)

1.0 SCOPE

This procedure outlines the minimum requirements for the Gamma Scanning of lead lined transportation casks. This procedure is general in nature and will be supplemented for each cask by detailed inspection planning.

2.0 APPLICABLE DOCUMENTS

2.1 AECU 2967 November 1954
2.2 Nondestructive Testing Handbook 1963 Edition
2.3 ANST Recommended Practice No. SNT-TC-IA, 1980 Edition

3.0 PERSONNEL QUALIFICATION

3.1 All personnel conducting Gamma Scanning shall be familiar with this procedure and the requirements set forth in the specific inspection planning for the cask being gamma scanned.

3.2 All personnel conducting gamma scanning shall be Level II or Level III Radiographers in accordance with SNT-TC-1A.

4.0 EQUIPMENT

4.1 Model E120 Eberline 0 to 50 MR/HR, or equivalent.

4.2 IR 192 or Cobalt 60 of sufficient activity in curies to obtain a recordable reading in millirontgen. The actual activity level required will be dependent on the lead shielding thickness being scanned. All actual data will be recorded on the specific inspection planning for the cask being scanned.

5.0 CALIBRATION

5.1 Calibration will be conducted on a piece of defect free lead equal to the design specified shield thickness minus any specified fabrication tolerances. Steel equal to the design specified thickness will be placed on either side of the lead. This will represent the nominal lead shield thickness.

5.2 After the first calibration scan is performed on the nominal standard, 10% of the nominal lead thickness will be removed. A second scan will then be performed. This reading will simulate a loss of 10% of shielding due to defects, voids, suck back, etc.

5.3 Calibration will be performed with the source and meter parallel. The source will be placed at a distance equal to the radius of the cask from its center point to the inside wall surface. The probe will be in contact with the outer surface of the calibration standard described in 5.1 and 5.2.

5.4 The defect free condition of all lead utilized in calibration shall be determined via radiographic or ultrasonic testing.

6.0 PROCEDURE

6.1 All Gamma Scanning will be conducted on a 4" grid system.

6.2 The radiation source will be centered in the cask diameter and then lowered into the cask at 4" intervals. Each location around the circumference will be scanned prior to lowering to the next position.

6.3 The probe will be in contact with the outer surface of cask and lowered at 4" intervals parallel to the source.

7.0 ACCEPTANCE

7.1 Acceptance of shielding quality shall be based on tests showing no readings resulting in more than a 10% loss of shielding. Acceptance cask readings are derived by the following formula:

$$\frac{M_1}{N_1} N_2 = A$$

Where:

M_1 = MR/HR Readings taken from a test block representing minimal allowable thickness, i.e., a 10% loss in shielding

N_1 = MR/HR readings taken from a test block representing nominal cask thickness

N_2 = actual nominal cask readings determined by unweighted average. (See Note 1)

A = A value expressed in MR/HR. Any cask readings below this number are acceptable.

7.2 Lids, plugs or other accessories filled with lead at the same time and utilizing the same process as the gamma scanned cask body shall be accepted if the cask body lead passes the gamma scan. This shall be denoted as acceptance by similar process. Acceptance by similar process shall be allowed when the items can not be economically or reasonably gamma scanned, radiographed, or subjected to other meaningful NDE processes.

NOTE 1: THIS VALUE SHALL BE OBTAINED BY ADDING EACH UNIQUE READING ONE TIME TO OBTAIN A TOTAL AND DIVIDING THAT TOTAL BY THE NUMBER OF ADDED READINGS.

MULTIPLE OCCURANCES OF THE SAME READING SHALL BE TREATED AS ONE READING FOR THE PURPOSES OF AVERAGING.

APPENDIX 8.4

PROPRIETARY DATA

GENERAL PROCEDURE
FOR
GAMMA SCAN FOR SHIELDED CONTAINERS
(FIELD CALIBRATION METHOD)

PROCEDURE NO: GS-002
REVISION 1
DATE: AUGUST 31, 1981

By:
NUCLEAR PACKAGING, INC.
Tacoma, Washington

APPROVALS:

Engineering: ______________ Date: 9/30/81

Quality Engineering: Joe R Olwada Date: 9/1/81

PROPRIETARY DATA

GAMMA SCAN OF SHIELDED CONTAINERS
(Field Calibration Method)

1.0 SCOPE

This procedure outlines the minimum requirements for the Gamma Scanning of lead lined transportation casks. This procedure is general in nature and will be supplemented for each cask by detailed inspection planning.

2.0 APPLICABLE DOCUMENTS

2.1 AECU 2967 November, 1954
2.2 Nondestructive Testing Handbook 1963 Edition
2.3 ANST - Recommended Practice No. SNT-TC-IA, 1980 Edition

3.0 PERSONNEL QUALIFICATION

3.1 All personnel conducting Gamma Scanning shall be familiar with this procedure and the requirements set forth in the specific inspection planning for the cask being Gamma Scanned.

3.2 All personnel conducting Gamma Scanning shall be Level II or Level III Radiographers in accordance with SNT-TC-IA.

4.0 EQUIPMENT

4.1 Model E120 Eberline 0 to 50 MR/HR, or equivalent.

4.2 IR 192 or Cobalt 60 of sufficient activity in curies to obtain a recordable reading in millirontgens. The actual activity level required will be dependent on the lead shielding thickness being Scanned. All actual data will be recorded on the specific inspection planning for the cask being Scanned.

5.0 CALIBRATION

5.1 Calibration will be conducted utilizing a standard test block fabricated with a steel plate equal to the design required thickness on the opposite sides. Cast lead shown to be defect-free will be between the two steel plates. The thickness of the lead shall be .25" thinner than the design required nominal thickness.

5.2 The test block will be installed on the calibration plate and placed in the cask lid installed on the cask as shown in Figure 1.

5.3 The source will be installed in the cask through the cask calibration hole in the calibration plate as shown in Figure 1. The distance from the source to the top of the standard test block surface shall equal the radius of the outside diameter of the cask.

5.4 The gamma probe will be placed next to the block through the center probe hole as shown in Figure 1. A reading will be taken and recorded.

5.5 After the reading described in Step 5.4 is taken, the probe and the source will be removed. The calibration plate will be lifted and the test block attachment bolts loosened.

5.6 A defect free 12" square lead sheet, .125" thick, shall be installed between the test block and the calibration plate as shown in Figure 1. The attachment bolts will then be retightened.

5.7 The calibration plate, source and probe will be reinstalled as delineated in Steps 5.2, 5.3, and 5.4 and a reading taken and recorded.

5.8 A defect free 12" square lead sheet equaling .25" thick shall replace the installed .125" thick sheet as described in Step 5.6. After the calibration plate is reinstalled per Step 5.7, readings shall be taken and recorded.

5.9 A defect free 12" square lead sheet equaling .125" shall be added to the installed .25" thick sheet as described in Step 5.8. After the calibration plate is reinstalled, per Step 5.7, readings shall be taken and recorded.

5.10 The source and the probe shall be parallel during calibration.

5.11 All readings taken and recorded during calibration shall be plotted to establish a calibration curve.

5.12 The defect free condition of all lead utilized in calibration shall be determined via Radiographic or Ultrasonic testing.

6.0 PROCEDURE

6.1 All Gamma Scanning will be conducted on a 4" grid system.

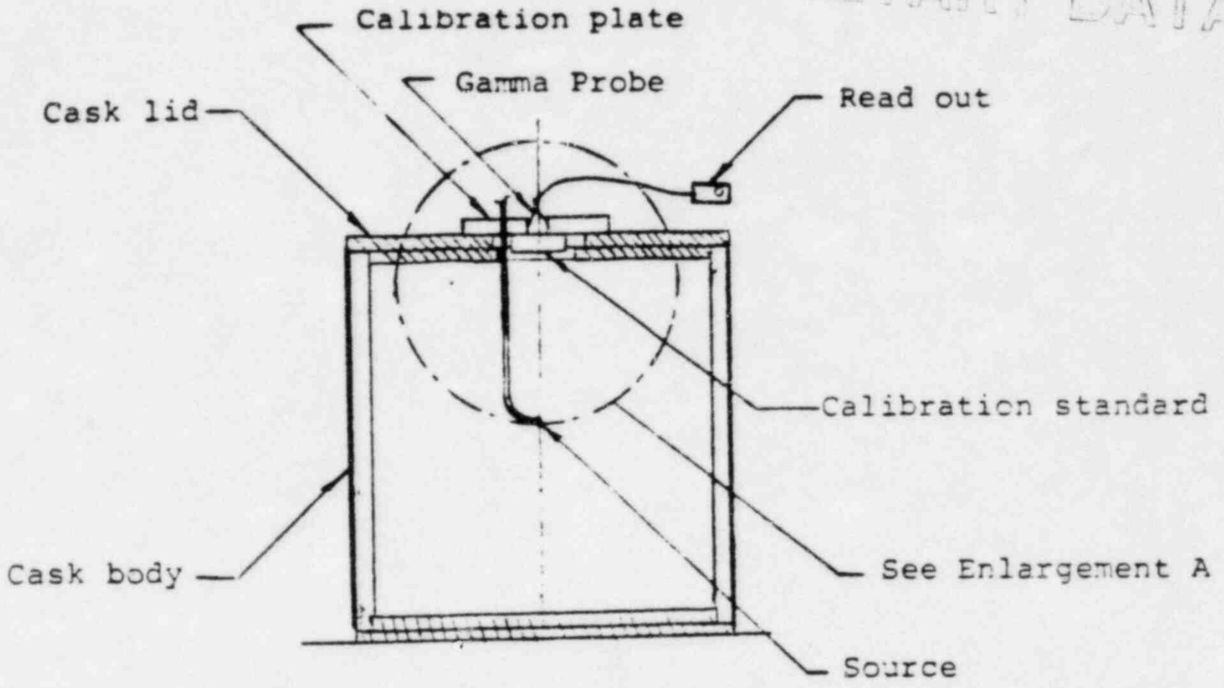
6.2 The radiation source will be centered in the cask and then lowered into the cask at 4" intervals through the calibration plate center hole. Each location around the circumference will be scanned prior to lowering to the next position.

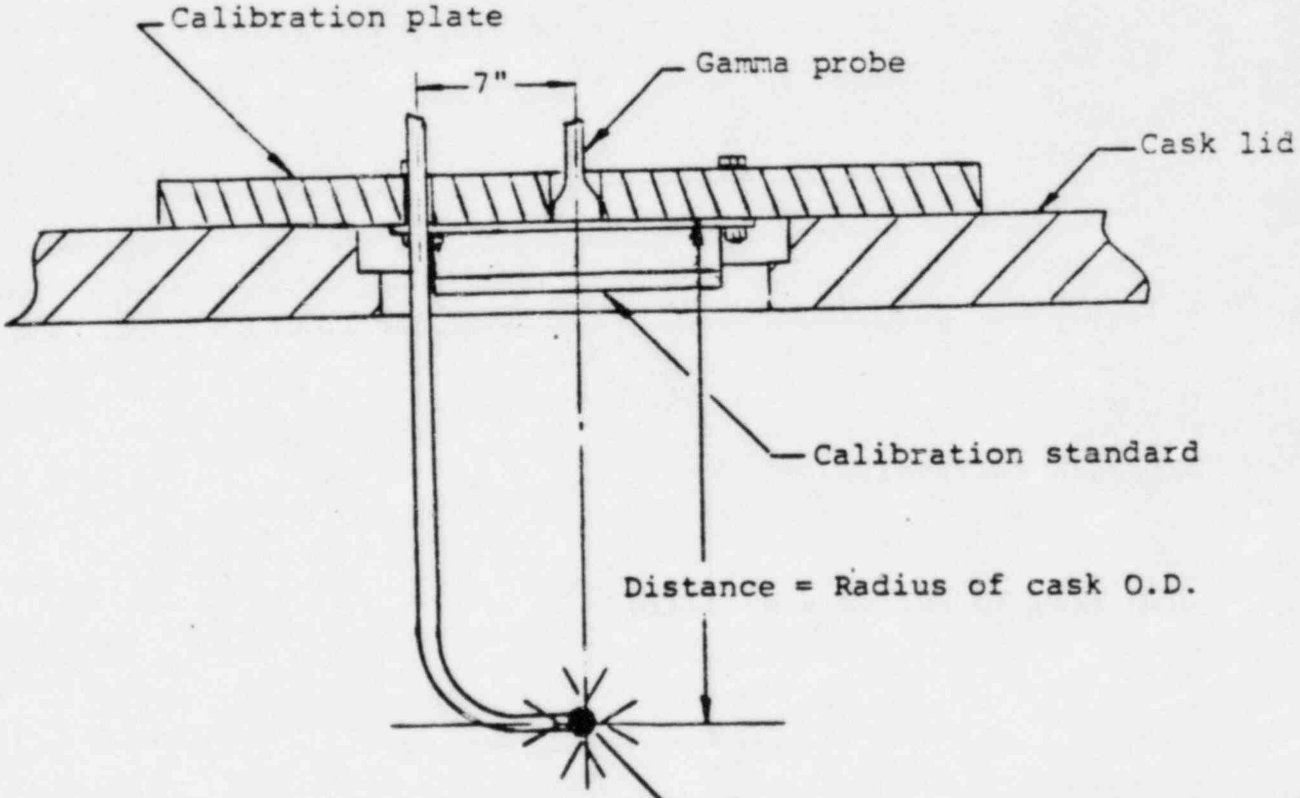
6.3 The probe will be in contact with the outer surface of cask and lowered at 4" intervals parallel to the source.

7.0 ACCEPTANCE

7.1 The values at the point on the curve equal to the nominal lead thickness minus 10% shall not be exceeded during cask lead gamma scan inspection.

FIGURE 1
GAMMA SCAN PROCEDURE NO. GS-002





Enlargement A
No Scale

APPENDIX 8.5

PROPRIETARY DATA

GENERAL PROCEDURE
FOR
SOAP BUBBLE (LOW PRESSURE) LEAK TEST

PROCEDURE NO. LT-04

Revision 2

Date: February 9, 1982

Nuclear Packaging, Inc.

Approvals:

Engineering Date 2/9/82

Quality Assurance Date 2/9/82

1.0 SCOPE

This procedure delineates the requirements for performing a Low Pressure Soap Bubble Leak Test on casks, liners, cannisters and other containers not covered by the requirements of ANSI N14.5.

The purpose of this test will be to prove the integrity of welds, threaded fittings, flanges and any other joints where pressure tests below 8 psi are adequate to meet contractural/function requirements.

2.0 REFERENCED DOCUMENTS

The referenced documents are part of this procedure to the extent specified. If the contents of this procedure appear to conflict with the requirements of a referenced document, the procedure shall govern.

2.1 ANSI N14.5, Draft-American National Standard for Leakage Tests on Packages for Shipment of Radiation Materials.

2.2 RDT Standard, F5-1T, Cleaning and Cleanliness Requirements for Nuclear Components.

2.3 NuPac Quality Procedure No. 5, Quality Planning

2.4 NuPac Quality Procedure No. 6, Inspection and Verification.

2.5 Federal Regulation 10 CFR 71, Appendix E.

3.0 TECHNICAL REQUIREMENTS

3.1 Cleanliness of the internal and external surfaces of the tested unit shall be maintained in accordance with the reference document 2.2 sections as directed by Quality Planning per reference document 2.3.

3.2 Equipment - The following equipment is required for a Low Pressure Soap Bubble Test:

3.2.1 Air Supply - A standard shop compressor or bottle compressed air capable of pressurizing the tested cavity to 8 to 10 psig shall be utilized.

3.2.2 Gauge - A Gauge capable of indicating psi ± .50% of the indicator reading shall be utilized.

3.2.3 Bubble Test Solution - A leak indicating solution equivalent to the following shall be utilized:

Dasco-Kleen Leak-Finding Compound #3183
D. A. Stewart Oil Company
2727 S. Gray Street
Chicago, Illinois 60623

3.3 Test Conditions

3.3.1 The test shall be conducted by NuPac Q.A. approved personnel.

3.3.2 The item shall be leak tested with all lids, gaskets, plugs, valves, and fasteners in place and in the normal closed posotion. The only exception shall be the port or valve utilized to pressure the cavity.

3.3.3 Pressurize the cavity to 8 psi + 1, -0 psi.

3.3.4 The gauge used to monitor the pressure shall be capable of an accuracy of ± 1/2 psi of indicated reading.

3.3.5 Close off or maintain pressure at pressurization location to hold specified pressure in cavity.

3.3.6 Apply the leak detecting solution to all gasketed areas, threads, seal welds, ports or valves by brush or spray. Inspect for bubbles.

3.3.7 Conduct leak test for 5 minutes.

3.4 Acceptance Criteria

3.4.1 No bubbles shall be visable to the unaided eye during the 5 minute test.

3.4.2 If bubbles appear during the test, weld integrity, gasket condition, flange or lid tightness, valve position, plug security, etc., shall be checked and the test rerun.

3.4.3 If the test is failed three consecutive times, a Quality Discrepancy Report (QDR) shall be prepared in accordance with Reference 2.4 for disposition prior to proceeding further.

3.4.4 The results of the leak test shall be recorded on the applicable Inspection Planning. Data recorded shall include:

3.4.4.1 Leak Test Pressure

3.4.4.2 Gauge Model, P/N and S/N, as applicable.

3.4.4.3 Leak Test Duration

3.4.4.4 Date

3.4.4.5 Results, including discrepancies and acceptance.

PROPRIETARY DATA

9.0 QUALITY ASSURANCE

NuPac's quality assurance program used for the design, fabrication, assembly, testing, use and maintenance of the NuPac Series A casks is designed and administered to meet the 18 criteria of 10 CFR 71, Appendix E. A description of this program has been submitted to the N.R.C. under NuPac letter No. QA-78-1, Rev. 1, dated July 31, 1980, and has received Quality Assurance Program Approval No. 0192.