SECTION 4.0

CONTAINMENT

4.0 CONTAINMENT

4.1 CONTAINMENT BOUNDARY

The following components of Model FSV-1 in Configurations A, B, C and D form the containment boundary as described in Section 1.0:

Cask body
Cask closure with O-rings
Center plug with O-rings
Purge connection cover with O-rings

4.2 CONTAINMENT DURING THE NORMAL CONDITIONS OF TRANSPORT

The radioactive contents of Configurations A, B, C and D will be solid, nonfissile, irradiated, and contaminated hardware removed from various light water nuclear reactors. Irradiated hardware from a light water nuclear reactor is assumed to have corrosion products, known as crud, on the surface. Dry crud can be in the form of small respirable particles and thus is the basis for the containment requirements. The radionuclide content of crud was obtained from an Electric Power Research Institute document, EPRI-NP-2735, and the quantity of crud was estimated from the quantity of crud found on spent fuel assemblies. Identities and characteristics of the radionculides in the crud are provided in Table 4-1.

The actual quantity of crud can vary with each shipment, and the quantity used for this containment evaluation is based on the surface area of 12 BWR control rod blades and is realistic for the shipment of solid, nonfissile, irradiated, and contaminated hardware.

TABLE 4-1
RADIONUCLIDE INVENTORY

Radionuclide	Curies/Cask (2 yr decay)	A_2 (curies)	A_2/Cask
Co-60	44.91	7	6.42
Co-58	0.39	20	19.5×10^{-3}
Mn-54	31.59	20	1.59
Fe-59	12.0×10^{-4}	10	12.0×10^{-5}
Fe-55	1464	1000	1.47
Cr-51	3.0×10^{-6}	600	5.01×10^{-9}
Ni-63	0.54	100	5.4×10^{-3}
Total	1542		9.51

$$\text{Composite } A_2 = \frac{1542 \text{ curies/cask}}{9.51\ A_2\text{/cask}} = \underline{162.10 \text{ curies}}$$

The regulatory limit for release of radioactive material during the normal conditions of transport is $A_2 \times 10^{-6}$ curies per hour. ANSI N14.5 - 1977 provides the following formula for determining the corresponding allowable leakage rate.

$$L_N = \frac{R_N}{C_N}$$

where L_N = leakage rate in cm^3 per sec,

R_N = release rate in curies per sec, and

C_N = specific activity in the package in curies per cm^3.

Therefore:

$$R_N = \frac{A_2 \times 10^{-6}\ \text{Ci}}{1\ \text{h}} \times \frac{1\ \text{h}}{60\ \text{min}} \times \frac{1\ \text{min}}{60\ \text{sec}}$$

$$= \frac{162 \times 10^{-6}}{3600} = 4.5 \times 10^{-8}\ \frac{\text{Ci}}{\text{sec}}$$

$$C_N = \frac{\text{total curies}}{\text{volume of package }(\text{cm}^3)}$$

$$= \frac{1542\ \text{Ci}}{650{,}000\ \text{cm}^3} = 2.4 \times 10^{-3}\ \frac{\text{Ci}}{\text{cm}^3}$$

and

$$L_N = \frac{4.5 \times 10^{-8}\ \text{Ci/sec}}{2.4 \times 10^{-3}\ \text{Ci/cm}^3} = \underline{\underline{1.9 \times 10^{-5}\ \frac{\text{cm}^3}{\text{sec}}}}$$

This is a conservative containment evaluation since all of the crud is assumed to consist of dry particles that behave as a gas and no credit is taken for lack of a driving force.

4.3 CONTAINMENT DURING THE HYPOTHETICAL ACCIDENT CONDITIONS

The regulatory limit for the release of radioactive material for the hypothetical accident conditions is A_2 curies in one week. ANSI N14.5-1977 provide the following formula for determining the corresponding allowable leakage rate.

$$L_A = \frac{R_A}{C_A} \quad ,$$

where L_A = leakage rate in cm^3 per sec,

R_A = release rate in curies per sec, and

C_A = specific activity in the package in curies per cm^3.

Therefore:

$$R_A = \frac{A_2 \text{ Ci}}{\text{week}} \times \frac{\text{week}}{7 \text{ days}} \times \frac{\text{days}}{24 \text{ h}} \times \frac{1 \text{ h}}{60 \text{ min}} \times \frac{\text{min}}{60 \text{ sec}}$$

$$= \frac{162.1}{604{,}800} = 2.7 \times 10^{-4} \frac{\text{Ci}}{\text{sec}}$$

$$C_A = \frac{\text{total curies}}{\text{volume of package (cm}^3\text{)}}$$

and

$$L_A = \frac{2.7 \times 10^{-4}\ \text{Ci/sec}}{2.4 \times 10^{-3}\ \text{Ci/cm}^3} = 1.1 \times 10^{-1}\ \text{cm}^3\text{/sec}\ .$$

In Table 3-3 and Fig. 3-4, the seal temperature during the hypothetical fire accident is shown to reach 1220°F and remain above 1200°F for 15 minutes. Reference 2-19 indicates that the metal O-ring seals can perform their function up to 1300°F. Therefore, containment will be maintained during the hypothetical fire accident conditions.

4.4 CONTAINMENT DESIGN AND TEST CRITERIA

The allowable release of radioactive material increases following the hypothetical accident conditions, therefore the allowable leakage rate also increases. Following the hypothetical accident conditions, the allowable leakage rate is 1.1×10^{-1} cm^3/s, compared to an allowable leakage rate of 1.9×10^{-5} for the normal conditions of transport. The lower allowable leakage rate of 1.9×10^{-5} cm^3/s is therefore the basis for containment design and containment test criteria.

4.4.1 Periodic Leakage Testing

ANSI N14.5-1977 requires that the periodic (or annual) leakage test be accomplished with a test procedure that has a sensitivity that is one-half of the maximum permissible leakage rate. The maximum permissible leakage rate is 1.9×10^{-5} cm^3/s and, therefore the minimum test sensitivity must be 1×10^{-5} cm^3/s. After consideration of the containment boundary and the packaging design, a sniffer type, Helium Mass Spectrometer leakage test with a senstivity of 1×10^{-7} atm.cm^3/s is selected as the appropriate test procedure.

4.4.2 Assembly Verification Leakage Testing

Prior to each shipment of radioactive material, a leakage test of the containment boundary seals will be accomplished in compliance with ANSI N14.5-1977. Because the maximum allowable leakage is less than 1×10^{-3} cm^3/s, a soap bubble leak test with a sensitivity of 1×10^{-3} $atm.cm^3/s$ has been selected.

SECTION 5.0

SHIELDING EVALUATION

5.0 SHIELDING EVALUATION

5.1 MODEL FSV-1, Configurations A, B, C, and D

5.1.1 Discussion and Results

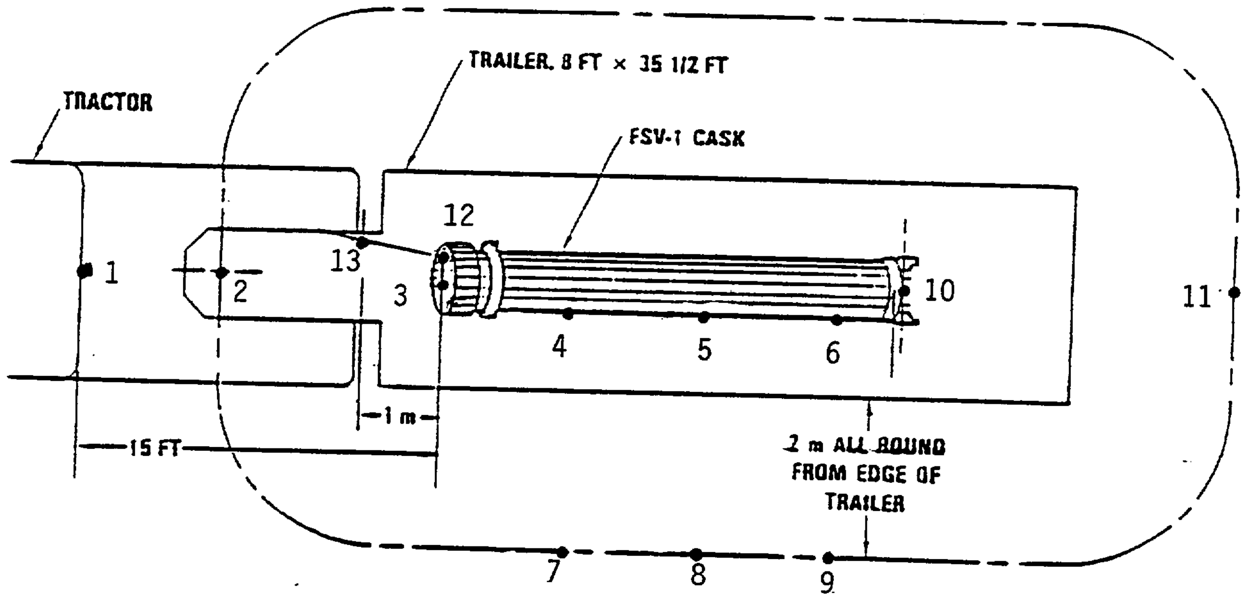
The shielding evaluation considered the worst-case waste loading with ten flattened BWR control rod blades (CRB) and 48 upper roller ball/axle corners (corner) removed from the BWR control rods. The waste was assumed to contain a total of 27,000 Ci of Co-60 gamma source distributed as 1500 Ci per CRB and 250 Ci per corner. These activity levels are about 25% to 50% above the average activities measured at a number of commercial BWR plants. The curie content assumed for the shielding evaluation envelopes all possible waste loadings with and without additional shielding requirements. A lower curie content will require that less or no shielding to be added.

Figure 5-1 shows the normal loading configuration for the above-specified waste contents. The roller ball/axle corners are contained in a closed stainless steel tube 6 in. O.D., 2 in. thick, and 153 in. long, and axially spaced 3 in. apart for dose reductions purposes. The flattened CRBs surround the shield tube, as illustrated in Fig. 5-1. The CRBs and shield tube are topped with three or four velocity limiters removed from the control rods to fill-up the burial liner. To avoid dose peaking outside the cask, five flattened CRBs are inverted as indicated in Fig. 5-1.

The evaluation assumed that shielding for the upper roller ball/axle corners would maintain its effectiveness under both normal and accident conditions. However, movement of the temporary shield tube and CRBs to a worst-case orientation was allowed within the burial liner for the accident conditions. Radiation dose rates external to the cask under normal transport conditions are shown in Fig. 5-2, including the points at the cask surface, at 2 m from the edge of the vehicle, and in normally occupied positions of the vehicle. Figure 5-2 also presents the maximum dose rates at 1 m from the cask surface under hypothetical accident conditions. The dose rates are within the regulatory limit in all cases, demonstrating the adequacy of shielding.

FIGURE WITHHELD UNDER 10 CFR 2.390

Fig. 5-1. Liner loading configuration for shielding analysis



Normal Conditions of Transport		
Point	**Location**	**Dose Rate (mrem/h)**
1	Cab	2*
2	2 m from transporter (front)	3
3	Cask surface (front)	40
4	Cask surface (side)	95
5	Cask surface (side)	70
6	Cask surface (side)	95
7	2 m from transporter (side)	6
8	2 m from transporter (side)	7
9	2 m from transporter (side)	6
10	Cask surface (rear)	150
11	2 m from transporter (rear)	3
12	Cask surface (front)	1
13	1 m from cask surface (front)	<1

Hypothetical Accident Conditions		
Point	**Location**	**Dose Rate (mrem/h)**
13	1 m from cask surface (front)	<100

*Less than 1 mrem/h if the shielding effect of the velocity limiters is considered.

Fig. 5-2. Calculated radiation dose rates for Model FSV-1, Configurations A, B, C and D

5.1.2 Source Specification

For shielding evaluation, a Co-60 source of 27,000 Ci was assumed with a distribution of 1,500 Ci per CRB and 250 Ci per corner. This assumption was conservative, as compared with actual measurements. The source in each CRB was treated as a volume source with an axial variation given in Table 5-1. Each corner was modeled as a point source without self-shielding effect for simplicity and conservatism. The axial activity profile for the CRB is a conservative representation of the variation in the neutron exposure history for each axial segment of the blade.

The velocity limiters placed above the CRBs and shield tube have low activity (about 10 Ci per velocity limiter). Their contribution to the dose rates external to the cask is negligible.

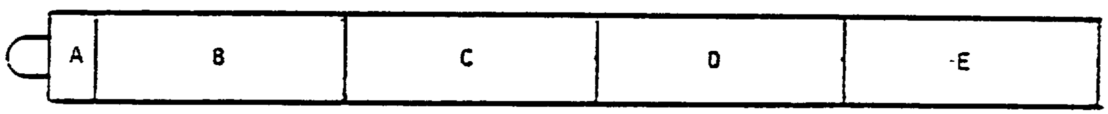
5.1.3 Model Specification

The packaging and the burial liner with shield ring were modeled in explicit detail. Applicable material thicknesses used in the shielding analysis and burial liner are shown in Table 5-2 along with the material densities. The loading configuration used in the shielding evaluation is depicted in Fig. 5-1 for normal transport conditions. The model for the accident condition is similar to that for the normal transport condition except the temporary shield tube is assumed to be in contact with the burial liner lid, which results in the maximum dose rate external to the cask.

5.1.4 Shielding Evaluation

The shielding analysis was performed with the PATH gamma shielding code (Section 5.2 Appendix) for both normal transport and accident conditions. A three-dimensional source-shield configuration was modeled to explicitly represent the cask, burial liner and waste contents.

TABLE 5-1
AXIAL DISTRIBUTION OF GAMMA SOURCE ACTIVITIES FOR CRB



Co 60 Activities				
Segment	Relative Strength	Concentration (Ci/cc)[a]	Volume (cc)	Activity (Ci)
A	1.000[b]	0.695	245	170
B	0.250[b]	0.174	3,847	669
C	0.130	0.090	3,847	346
D	0.090	0.063	3,847	242
E	0.027	0.019	3,847	73
			15,633	1,500

[a] Ci per cc of rod volume.

[b] The factor of 4 difference between segments A and B activities results from differences in steel densities, self-shielding factors and irradiation time.

TABLE 5-2
THICKNESS OF SHIELDING MATERIALS FOR THE
PACKAGING AND BURIAL LINER

Packaging	Thickness (in.)	Material Density (g/cm^3)
Side	3.5 depleted uranium	18.9
	1.625 stainless steel (total)	7.82
Top	2.25 depleted uranium	18.9
	4.313 stainless steel (total)	7.82
Bottom	11.0 stainless steel (total)	7.82
Burial Liner		
Cover	1/2 stainless steel	7.82
Bottom plate	3/4 stainless steel	7.82
Shield ring	13 ID x 17 OD x 4 LG, stainless steel	7.82
Shield tube	2 ID x 6 OD x 150 LG, stainless steel; lid = 5 in. thick; bottom = 4 in. thick	7.82

For normal transport conditions, gamma dose rates were calculated at key points of interest, including the cask surface, 2 m from the edge of the transporter and in the inhabited area of the tractor cab. The shielding effect of the velocity limiters was omitted for conservatism. Inclusion of the velocity limiters in the model would have lowered the dose rate at the closure end of the cask by a factor of 2 or more. Gamma dose buildup factors for iron were used in the PATH calculations. The PATH results at the side of the cask were corrected to account for the composite depleted uranium and stainless steel shields in the cask body.

For hypothetical accident conditions, the shield tube containing the corners was assumed to be free to move axially or radially. The corners remain in the shield tube. The worst-case accident condition occurs when the shield tube moves axially to the burial liner lid, resulting in the maximum accident dose rate at the top head of the cask.

The dose-rate results for both normal transport and accident conditions are summarized in Fig. 5-2. All the dose rates are less than the regulatory radiation limits. The shielding evaluation demonstrates that a waste loading configuration meeting normal transport requirements will comply with the 10CFR71 regulations for accident conditions.

5.2 APPENDIX

The PATH code, primarily a gamma shielding computer program, utilizes the common point-kernel integration technique to perform calculations of dose rates and shielding requirements for complex geometry and various source types. The code has been in production use for in-house shielding analysis and design work at GA Technologies for more than 10 yr.

The heart of the PATH code is the geometry routine, which defines the source-shield configuration by a set of possibly overlapping regions of simple shapes with a mother-daughter ordering scheme, and determines the path length in each region by a direct method. Regions are available in various shapes with any axial orientation including prisms, cylinders, spheres, and frustra of cones. Shield regions may be redefined between dose point calculations for making parameter studies.

The options of source types consist of point, line, disc, polygon, shell, cylinder, and prism sources in any spatial orientation. In addition, the X-Y-Z meshing mode is applicable for modeling geometrically complex source regions such as sphere, hemisphere, quarter cylinder, etc. The source terms can be desribed in two ways: source strengths (MeV/sec or photons/sec per unit mesh) at given energy levels, and/or isotopes with associated activities (Ci/unit mesh). The latter option can lead to output of the percent contribution to the total dose rate from each isotope for identifying the important contributors.

To minimzie the input requirements, a large amount of fixed data is built into the PATH library. The current library contains tables of mass-attenuation coefficients for 25 basic materials, decay gamma spectra of 125 isotopes, gamma buildup factors for 89 materials, and gamma flux-to-dose conversion factors. All these tables are periodically updated and expanded as needed to accommodate special source spectra, new materials, or revised data.

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SECTION 6.0

CRITICALITY EVALUATION

6.0 CRITICALITY EVALUATION

The contents of Model FSV-1 in Configurations A, B, C, and D are restricted to solid, nonfissile, irradiated and contaminated hardward and neutron source components. Therefore, a criticality evaluation is not a part of this design report.

SECTION 7.0

OPERATING PROCEDURES

7.0 OPERATING PROCEDURES

The following information provides generic operating procedures. Specific operating instructions with the necessary administrative and quality assurance provisions should be prepared and followed.

7.1 PROCEDURE FOR LOADING THE PACKAGE (Configuration A - Dry Loading)

The following procedure is applicable for Model FSV-1 in Configuration A when used for the transport of solid, nonfissile, irradiated and contaminated hardware from a hot cell or other facility where dry loading is required.

STEP

1. Receiving the shipping cask.

2. Inspect tractor and semitrailer and clean as necessary.

3. Position the tractor and semitrailer in an area adjacent to the hot cell building designated for cask removal.

4. Removing the cask from the semitrailer.

5. Attach the cask lifting yoke to the truck crane and engage the yoke in the lifting sockets near the top of the cask.

6. Raise the cask to the vertical position.

7. Install the locking block on the inside of the semitrailer bottom support trunnion using the two 1/2" hex head bolts.

8. Remove the four 1-1/4" dia. socket-head cap screws that hold the cask to the bottom support trunnion.

STEP

9. Disengage the cask from the semitrailer and raise the cask over the hot cell roof. Position the cask over the roof plug penetration.

10. Lower the shipping cask onto the cask support in the low level cell.

11. Disengage the cask lifting yoke from the cask and store.

12. Remove the twenty-four 1-1/4" dia. socket head cap screws from the outer closure.

13. Remove the outer closure.

14. Visually inspect the seals and sealing surfaces. Replace any seal if it has nicks, cuts, scratches or other deformations that will adversely affect seal performance.

15. Remove the twelve inner closure cap screws.

16. Remove the inner closure.

17. Visually inspect the inner closure seals and seal surfaces. Replace any seal if it has nicks, cuts, scratches or other deformations that will adversely affect seal performance.

18. Inspect the cavity of the inner container for damage and or debris. Remove debris and evaluate any damage before proceeding.

19. Load irradiated and contaminated hardware into the inner container.

20. Remotely replace the inner closure and visually inspect the closure for damage or poor fit. If necessary, take corrective action before proceeding.

STEP

21. Visually inspect and install the twelve inner closure cap screws. Replace any cap screws found to have stripped or galled threads or any visible deformation of the head or shank. Minor nicks, scrapes or upsets from normal wrench contact or not cause for replacement.

22. Torque the inner closure cap screws to 19-21 ft-lb.

23. Replace the outer closure.

24. Visually inspect and install the 24 1-1/4" dia. socket head cap screws in the outer closure. Replace any cap screws found to have stripped or galled threads or any visible deformation of the head or shank. Minor nicks, scrapes or upsets from normal wrench contact are not cause for replacement.

25. Torque the outer closure cap screws to 10-30 ft-lb.

26. Returning the loaded cask to the semitrailer.

27. Engage the lifting yoke in the cask lifting sockets.

28. Raise the cask through the hot cell roof plug penetration and position it over the semitrailer.

29. Place the bottom of the cask in the trunnion portion of the rear support.

30. Install four cap screws to hold the bottom of the cask to the trunnion. Tighten to 522-550 ft-lb.

31. Remove the trunnion locking block from the rear support.

STEP

32. Lower the cask until it rests on the front support and install the tie-down strap. Tighten the bolts to 120-125 ft-lb.

33. Torque closure bolts to 950-1000 ft-lb and install lockwire and a tamper-proof seal on an adjacent pair of bolts.

34. Preparation for leakage test.

35. Pressurize the cask to 14-16 psig through the purge connection.

36. Install the purge connection cover and torque bolts to 15-20 ft-lb.

37. After waiting 15 minutes, brush the closure head, center plug, and purge connection cover with a liquid soap solution and search for bubbles. No indication of bubbles allowed.

38. Remove the purge connection cover and depressurize the cask.

39. Visually examine the purge cover seals and sealing surface. Replace any seal that has nicks, cuts, scratches or other deformations that will adversely affect seal performance.

40. Visually inspect the purge cover bolts. Replace any bolts found to have stripped or galled threads or any visible deformation of the head or shank. Minor nicks, scrapes or upsets from normal wrench contact are not cause for replacement.

41. Reinstall the purge connection cover and torque bolts to 15-20 ft-lb.

STEP

42. Preparing for departure.

43. Visually inspect the package. Correct any deficiencies before departure.

44. Survey the shipping cask for external radiation and loose contamination. External radiation and loose contamination shall not exceed the limits of 10CFR71.47 and 10CFR71.87.

45. Attach the proper label to the shipping cask.

46. Display the proper placards on the tractor and semitrailer.

47. Prepare the necessary shipping papers.

48. Dispatch the shipment.

7.2 PROCEDURES FOR UNLOADING THE PACKAGE (Configuration A - Unloading)

The following procedure is applicable for Model FSV-1 in Configuration A when used for the transport of solid, nonfissile irradiated and contaminated hardware to a receiving facility or disposal site. The specific procedures for receiving and unloading the cask shall be in compliance with 10CFR20.205.

STEP

1. Receiving the shipping cask.

2. Verify that placards, labels, and shipping papers are correct.

3. Inspect and clean the tractor, semitrailer, and cask as required.

STEP

4. Removing the cask from the semitrailer.

5. Loosen the four socket-head cap screws that attach the bottom of the shipping cask to the rear support.
CAUTION: Do not remove.

6. Remove tie-down strap from front support.

7. Attach the cask lifting apparatus to the crane hook.

8. Engage the cask lifting apparatus in the recessed lifting sockets. Use handcrank to lock the balls into the sockets.

9. Raise the cask to the vertical position.
CAUTION: Do not lift cask while attached to semitrailer.

10. Install the locking block on the inside of the rear support to hold the trunnion in position.

11. Remove the four (4) socket-head cap screws that attach the bottom of the shipping cask to the rear support.

12. Raise the cask to clear the rear support.

13. Move the cask into the hot cell for unloading.

14. Disengage the cask lifting yoke and store.

15. Remove the twenty-four 1-1/4" dia. socket head cap screws from the outer closure.

STEP

CAUTION: The next three steps may have to be done remotely.

16. Remove the outer closure.

17. Remove the twelve inner closure cap screws.

18. Remove the inner closure.

19. Unload the irradiated hardware and verify that the contents and debris have been completely removed from the inner container.

20. Examine the inner closure seals and sealing surfaces. Replace any seal that has nicks, cuts, scratches or other deformations that will adversely affect seal performance.

21. Replace the inner closure and examine it for damage or poor fit. If necessary, take corrective action.

22. Visually inspect and install the twelve inner closure cap screws. Replace any cap screws found to have stripped or galled threads or any visible deformation of the head or shank. Minor nicks, scrapes or upsets from normal wrench contact or not cause for replacement.

23. Torque the inner closure cap screws to 19-21 ft-lb.

24. Replace the outer closure.

STEP

25. Visually inspect and install the 24 1-1/4" dia. socket head cap screws in the outer closure. Replace any cap screws found to have stripped or galled threads or any visible deformation of the head or shank. Minor nicks, scrapes or upsets from normal wrench contact are not cause for replacement.

26. Torque the outer closure cap screws to 10-30 ft-lb.

27. Returning the loaded cask to the semitrailer.

28. Engage the lifting yoke in the cask lifting sockets.

29. Remove the cask from the hot cell receiving facility and return it to the semitrailer.

30. Position the cask above the rear support and lower the cask.

31. Install the four socket-head cap screws which attach the cask to the rear support.

32. Remove the locking block from the rear support.

33. Lower the cask onto the front support.

34. Release the cask lifting apparatus from the cask.

35. Install the tie-down strap at the front support.

36. Torque the four socket head cap screws that attach the bottom of the cask to the rear support to 522-500 ft-lb.

7.3 PROCEDURE FOR LOADING THE PACKAGE (Configuration B, C, and D - Wet Loading)

The following procedure is applicable for Model FSV-1 in Configurations B, C, and D when used for the transport of solid, nonfissile, irradiated and contaminated hardware from a nuclear reactor storage pool.

STEP

1. Receiving the shipping cask.

2. Inspect tractor and semitrailer and clean as necessary.

3. Position tractor and semitrailer in the truck bay area of the reactor building.

4. Removing the cask from the semitrailer.

5. Remove the tie-down strap from the front support.

6. Loosen the four socket-head cap screws that attach the bottom of the cask to the rear support. **CAUTION:** Do not remove.

7. Loosen the (24) socket-head cap screws in the cask closure. **CAUTION:** Do not remove.

8. Remove the three socket-head set screws in the top of the cask closure. Install the closure lifting bail.

9. Remove the center plug and the purge connection cover from the bottom of the cask. Visually inspect the O-ring seals and the sealing surfaces. Examine the seals and sealing surface. Replace the seal if it has nicks, cuts, scratches or other deformations that will adversely affect seal performance.

STEP

10. Attach the lifting yoke/lifting adapter assembly to the crane hook.

11. Open the hydraulic cylinder bypass valve and manually engage the cask lifting yoke into the cask lifting sockets.

12. Raise the cask to a vertical position.
CAUTION: Verify that crane is not lifting trailer.

13. Install the locking block on the inside of the rear support to hold the trunnion in position.

14. Remove the four socket-head cap screws which attach the cask to the rear support.

15. Transfer the cask assembly to the refueling floor.

16. Connect the hydraulic pump unit and hoses to the cask lifting yoke hydraulic cylinder.

17. Preparation of cask for burial liner loading.

18. Remove the twenty-four (24) socket-head cap screws from the cask closure and visually inspect them for damage. Replace any cap screws found to have stripped or galled threads or any visible deformation of the head or shank. Minor nicks, scrapes or upsets from normal wrench contact are not cause for replacement.

19. Remove the cask closure using the previously installed closure lifting bail. Visually inspect the O-ring seals and the sealing surfaces. Replace the seal if it has nicks, cuts, scratches or other deformations that will adversely affect seal performance.

STEP

20. Visually inspect the interior of the cask for damage or debris and to confirm that the bottom interface plate is in place. Remove debris and evaluate any damage and take corrective action if necessary.

21. Preparations to move the cask into the pool.

22. Install the two closure head guide pins in the cask at 90° to the lifting sockets and tighten with a hand wrench to an estimated 100 ft-lb torque.

23. Close the bypass valve on the yoke hydraulic cylinder and attach the hydraulic hand pump and hoses to the cylinder on the yoke.

24. Position the crane over the cask, lower the hook until the positioning guide funnels extending from the lifting yoke pivot pin come to rest on the guide pins. Close the yoke using the bleed valve on the hand pump unit to engage the balls on the yoke into the cask sockets.

25. Attach the liftoff cables for pivoting the lift hangers off the palms of the sister hook when in the pool.

26. Raise the cask.

27. Move cask to proper position over the pool and lower the cask into the pool until it rests on the pool floor.

28. Lower crane hook sufficiently to allow lift hangers to be removed from sister hook.

STEP

29. Actuate the hand pump to open the yoke.

CAUTION: Make certain that the yoke has opened.

30. Raise the yoke/lifting adapter assembly off of the cask and move out of the way.

31. Preparations to place the loaded burial liner into the cask.

31a. Before putting the lid on the burial liner, verify that the liner is filled with waste and appropriate shoring to prevent movement of the contents during transport.

32. Using the hook tool raise the burial liner.

33. Move the burial liner laterally to the proper position over the cask.

34. Lower the burial liner into the cask. Align the keyway in the burial liner cover with the key in the upper end of the cask.

35. Lift the cask closure and place it into the pool over the cask.

36. Orient the closure head by aligning the keyway in the closure head with the key in the cask by using the keyway notch on the cask closure head lifting bail as the indexing mark.

37. Lower the cask closure over the guide pins in the cask and seat the closure on the cask.

STEP

38. Removing the cask from pool.

39. Lower the yoke to enable the yoke positioning guide funnels to engage the two guide pins.

40. Engage the yoke with the cask by opening the bleed valve on the hand pump.

41. Lower the hook, until the two redundant lift hangers can be pulled onto the palms of the sister hook using the liftoff cables.

42. Raise the cask out of the pool and allow to drain. To speedup draining, air may be introduced through the purge connection located in the bottom of the cask. Do not exceed 20 psig. Before application of air pressure, install four (4) equally spaced closure bolts and torque to 10-30 ft-lb. Verify that the cask is fully drained by introducing air through the purge connection (if not already done during draining) and note that air is exiting through the drain hole.

43. Move the cask to the washdown area.

44. Install remaining closure bolts and torque to 10-30 ft-lb.

45. Preparation of the cask for shipment.

46. Move the cask to the hatchway and lower the cask from the refueling floor to the semitrailer located in the truck bay area.

STEP

47. Place the bottom of the cask in the trunnion portion of the rear support.

48. Visually inspect and install four bolts to hold the bottom of the cask to the trunnion. Tighten bolts to 522-550 ft-lb. Replace any bolt found to have stripped or galled threads or any visible deformation of the head or shank. Minor nicks, scrapes or upsets from normal wrench contact are not cause for replacement.

49. Remove the trunnion locking block from the rear support.

50. Lower the cask until it rests on the front support and install the tie-down strap. Tighten the bolts to 120-125 ft-lb.

51. Torque closure bolts to 950-1000 ft-lb and install lockwire and a tamper-proof seal on an adjacent pair of bolts.

52. Install the center plug in the cask. Visually inspect the center plug bolts and replace any bolt found to have stripped or galled threads or any visible deformation of the head or shank. Minor nicks, scrapes or upsets from normal wrench contact are not cause for replacement. Torque the center plug bolts to 35-40 ft-lb. Install lockwire and a tamper-proof seal.

53. <u>Preparation for leakage test</u>.

54. Pressurize the cask to 14-16 psig through the purge connection.

55. Install the purge connection cover and torque bolts to 15-20 ft-lb.

STEP

56. After waiting 15 minutes, brush the closure head, center plug, and purge connection cover with a liquid soap solution and search for bubbles. No indication of bubbles allowed.

57. Remove the purge connection cover and depressurize the cask.

58. Visually inspect the purge cover seals and sealing surface. Replace the seal if it has nicks, cuts, scratches or other deformations that will adversely affect seal performance.

59. Visually inspect the purge cover bolts. replace any bolt found to have stripped or galled threads or any visible deformation of the head or shank. Minor nicks, scrapes or upsets from normal wrench contact are not cause for replacement.

60. Reinstall the purge connection cover and torque bolts to 15-20 ft-lb.

61. Preparing for departure.

62. Visually inspect the package. Correct any deficiencies noted.

63. Survey the shipping cask for external radiation and loose contamination. External radiation and loose contamination shall not exceed the limits of 10CFR71.47 and 10CFR71.87.

64. Attach the proper label to the shipping cask.

65. Display the proper placards on the tractor and semitrailer.

66. Prepare the necessary shipping papers.

67. Dispatch the shipment.

7.4 PROCEDURES FOR UNLOADING THE PACKAGE (Configuration B, C, and D - Unloading)

The following procedure is applicable for Model FSV-1 in Configurations B, C, and D when used for the transport of solid, nonfissile irradiated and contaminated hardware to a disposal site. The specific procedures for receiving and unloading the cask shall be in compliance with 10CFR20.205.

STEP

1. Receiving the shipping cask.

2. Verify that placards, labels, and shipping papers are correct.

3. Inspect and clean the tractor, semitrailer, and cask as required.

4. Removing the cask from the semitrailer.

5. Loosen the four socket-head cap screws that attach the bottom of the shipping cask to the rear support.
   CAUTION: Do not remove.

6. Remove tie-down strap from front support.

7. Attach the cask lifting apparatus to the crane hook.

8. Engage the cask lifting apparatus in the recessed lifting sockets. Use handcrank to lock the balls into the sockets.

9. Raise the cask to the vertical position.
   CAUTION: Do not lift cask while attached to semitrailer.

STEP

10. Install the locking block on the inside of the rear support to hold the trunnion in position.

11. Remove the four (4) socket-head cap screws that attach the bottom of the shipping cask to the rear support.

12. Raise the cask to clear the rear support.

13. Move the cask to the unloading area and lower to the horizontal position on suitable supports.

14. Unloading the shipping cask.

15. Attach suitable lifting fixture to three (3) threaded holes in the outer closure to provide for horizontal removal.

16. Remove the twenty-four socket head cap screws from the closure. **CAUTION:** Next three steps must be performed remotely.

17. Remove the closure.

18. Attach a hook to the bar located in the slot in the cover on the burial liner.

19. Use suitable guide fixture to protect the cask surfaces and slide the burial liner from the cask.

20. Returning the cask to the semitrailer.

21. Remove the guide fixture.

STEP

22. Visually examine the cask sealing surfaces and cask interior for any damage or debris.

23. Visually examine the cask closure, especially the O-ring seals for any damage. Replace any seal that has nicks, cuts, scratches, or other deformations that will adversely affect seal performance.

24. Visually inspect for damage the twenty-four (24) socket head cap screws that hold the outer closure in place. Replace any cap screws found to have stripped or galled threads or any visible deformation of the head or shank. Minor nicks, scrapes or upsets from normal wrench contact are not cause for replacement.

25. Install the cask closure and torque the twenty-four socket head cap screws to 95-100 ft-lb.

26. Raise the cask into the vertical position and return to the semitrailer.

27. Position the cask above the rear support and lower the cask.

28. Visually inspect and install the four socket-head cap screws which attach the cask to the rear support. Replace any cap screws found to have stripped or galled threads or any visible deformation of the head or shank. Minor nicks, scrapes or upsets from normal wrench contact are not cause for replacement.

29. Remove the locking block from the rear support.

30. Lower the cask onto the front support.

STEP

31. Release the cask lifting apparatus from the cask.

32. Install the tie-down strap at the front support.

33. Torque the four socket head cap screws that attach the bottom of the cask to the rear support to 522-550 ft-lb.

7.5 PREPARATION OF AN EMPTY PACKAGE FOR TRANSPORT

The specific procedures for the shipment of an empty cask shall be in accordance with 49CFR173.427.

STEP

1. Visually inspect the package and correct any deficiencies.

2. Survey the shipping cask for loose contamination and external radiation.

3. Attach the proper label to the shipping cask.

4. Display the proper placards on the tractor and semitrailer.

5. Prepare the necessary shipping papers.

6. Dispatch the shipment.

7.6 PROCEDURE FOR LOADING THE PACKAGE (Configuration B, C, and D - Dry Loading)

The following procedure is applicable for Model FSV-1 in Configurations B, C, and D when used for the transport of solid, nonfissile, irradiated and contaminated hardware from facilities in which the cask is loaded dry.

STEP

1. Receiving the shipping cask.
2. Inspect tractor and semitrailer and clean as necessary.
3. Position tractor and semitrailer to facilitate cask removal.
4. Removing the cask from the semitrailer.
5. Remove the tie-down strap from the front support.
6. Loosen the four socket-head cap screws that attach the bottom of the cask to the rear support.
   CAUTION: Do not remove.
7. Loosen the (24) socket-head cap screws in the cask closure.
   CAUTION: Do not remove.
8. Remove the three socket-head set screws in the top of the cask closure. Install the closure lifting bail.
9. Remove the center plug and the purge connection cover from the bottom of the cask. Visually inspect the O-ring seals and the sealing surfaces. Examine the seals and sealing surface. Replace the seal if it has nicks, cuts, scratches or other deformations that will adversely affect seal performance.

STEP

10. Attach the lifting yoke/lifting adapter assembly to the crane hook, as applicable.

11. Manually engage the cask lifting yoke into the cask lifting sockets.

12. Raise the cask to a vertical position.
    CAUTION: Verify that crane is not lifting trailer.

13. Install the locking block on the inside of the rear support to hold the trunnion in position.

14. Remove the four socket-head cap screws which attach the cask to the rear support.

15. Transfer the cask assembly to the loading area of the facility.

16. Connect the hydraulic pump unit and hoses to the cask lifting yoke hydraulic cylinder, as applicable.

17. <u>Preparation of cask for burial liner loading.</u>

18. Remove the twenty-four (24) socket-head cap screws from the cask closure and visually inspect them for damage. Replace any cap screws found to have stripped or galled threads or any visible deformation of the head or shank. Minor nicks, scrapes or upsets from normal wrench contact are not cause for replacement.

19. Remove the cask closure using the previously installed closure lifting bail. Visually inspect the O-ring seals and the sealing surfaces. Replace the seal if it has nicks, cuts, scratches or other deformations that will adversely affect seal performance.

STEP

20. Visually inspect the interior of the cask for damage or debris and to confirm that the bottom interface plate is in place. Remove debris and evaluate any damage and take corrective action if necessary.

21. Install the two closure head guide pins in the cask at 90° to the lifting sockets and tighten with a hand wrench to an estimated 100 ft-lb torque.

22. Preparations to place the burial liner into the cask.

22a. Before putting the lid on the burial liner, verify that the liner is filled with waste and appropriate shoring to prevent movement of the contents during transport.

23. Lift the burial liner.

24. Move the burial liner laterally to the proper position over the cask.

25. Lower the burial liner into the cask. Align the keyway in the burial liner cover with the key in the upper end of the cask.

26. Lift the cask closure and place it over the cask.

27. Orient the closure head by aligning the keyway in the closure head with the key in the cask by using the keyway notch on the cask closure head lifting bail as the indexing mark.

28. Lower the cask closure over the guide pins in the cask and seat the closure on the cask.

29. Install closure bolts and torque to 10 - 30 ft-lb.

30. Removing the cask from facility.

31. Lower the yoke to enable the yoke positioning guide funnels to engage the two guide pins, as applicable.

STEP

32. Engage the yoke with the cask by opening the bleed valve on the hand pump, as applicable.

33. Lower the hook, until the two redundant lift hangers can be pulled onto the palms of the sister hook using the liftoff cables, if applicable.

34. Move the cask to the set down area.

35. Remove guide pins

36. Install remaining closure bolts where the guide pins were and torque to 10-30 ft-lb.

37. Preparation of the cask for shipment.

38. Move the cask to the semitrailer.

39. Place the bottom of the cask in the trunnion portion of the rear support.

40. Visually inspect and install four bolts to hold the bottom of the cask to the trunnion. Tighten bolts to 522-550 ft-lb. Replace any bolt found to have stripped or galled threads or any visible deformation of the head or shank. Minor nicks, scrapes or upsets from normal wrench contact are not cause for replacement.

41. Remove the trunnion locking block from the rear support.

42. Lower the cask until it rests on the front support and install the tie-down strap. Tighten the bolts to 120-125 ft-lb.

43. Torque closure bolts to 950-1000 ft-lb and install lockwire and a tamper-proof seal on an adjacent pair of bolts.

STEP

44. Install the center plug in the cask. Visually inspect the center plug bolts and replace any bolt found to have stripped or galled threads or any visible deformation of the head or shank. Minor nicks, scrapes or upsets from normal wrench contact are not cause for replacement. Torque the center plug bolts to 35-40 ft-lb. Install lockwire and a tamper-proof seal.

45. Preparation for leakage test.

46. Pressurize the cask to 14-16 psig through the purge connection.

47. Install the purge connection cover and torque bolts to 15-20 ft-lb.

48. After waiting 15 minutes, brush the closure head, center plug, and purge connection cover with a liquid soap solution and search for bubbles. No indication of bubbles allowed.

49. Remove the purge connection cover and depressurize the cask.

50. Visually inspect the purge cover seals and sealing surface. Replace the seal if it has nicks, cuts, scratches or other deformations that will adversely affect seal performance.

51. Visually inspect the purge cover bolts. replace any bolt found to have stripped or galled threads or any visible deformation of the head or shank. Minor nicks, scrapes or upsets from normal wrench contact are not cause for replacement.

52. Reinstall the purge connection cover and torque bolts to 15-20 ft-lb.

STEP

53. Preparing for departure.

54. Visually inspect the package. Correct any deficiencies noted.

55. Survey the shipping cask for external radiation and loose contamination. External radiation and loose contamination shall not exceed the limits of lOCFR71.47 and lOCFR71.87.

56. Attach the proper label to the shipping cask.

57. Display the proper placards on the tractor and semitrailer.

58. Prepare the necessary shipping papers.

59. Dispatch the shipment.

SECTION 8.0

ACCEPTANCE TESTS AND MAINTENANCE PROGRAM

8.0 ACCEPTANCE TESTS AND MAINTENANCE PROGRAM

8.1 ACCEPTANCE TESTS

There are no current plans to fabricate any additional units of the Model FSV-1 packaging, therefore, acceptance tests are not provided as a part of this consolidated design report.

8.2 MAINTENANCE PROGRAM

The following information constitutes a generic maintenance program. A specific maintenance plan with the necessary administrative and quality assurance provisions should be prepared and followed.

The maintenance program for the Model FSV-1 in Configurations A, B, C, and D consists of leak tests and visual inspections of the entire packaging. These tests and inspections must be accomplished within the twelve (12) months prior to any use of the packaging. Other inspection techniques may be used to verify the results of the visual inspection.

8.2.1. Visual Inspections

STEP

1. Remove the cask from the transport semitrailer.

2. Visually inspect the external surface of the cask to detect any gouges, dents or cracks.

3. Remove the outer closure from the cask body and remove the metal O-ring and the elastomer O-ring from the closure.

STEP

4. Visually inspect the closure for any damage especially the O-ring grooves.

5. Remove the two lifting sockets from the cask body.

6. Visually inspect the lifting sockets for galling or other damage. Inspect the two attach bolts and the threaded holes for each lifting socket.

7. Remove the purge connection cover from the bottom of the cask.

8. Remove the elastomer and the metal O-rings from the purge connection cover and visually inspect the cover for damage, especially the O-ring grooves.

9. Remove the quick disconnect fitting and visually inspect for damage.

10. Visually inspect the three purge connection cover attach bolts and the threaded holes in the cask body. Inspect the sealing surface for the O-rings in the cask body.

11. Remove the center plug from the bottom of the cask.

12. Remove the elastomer and the metal O-rings from the center plug and visually inspect the plug for damage, especially the O-ring grooves.

STEP

13. Visually inspect the four center plug attach bolts and the threaded holes in the cask body. Inspect the sealing surface for the O-rings in the cask body.

14. Visually inspect the four threaded inserts in the bottom of the cask and the four socket head cap screws used to attach the cask to the rear support on the semitrailer.

15. Visually inspect the interior of the cask body, especially the sealing surface at the open end.

16. Visually inspect the twenty-four closure attach bolts and the twenty-four threaded inserts in the cask body.

8.2.2 Leakage Tests

STEP

1. Install a new metal O-ring and a new elastomer O-ring in the grooves in the cask closure. A light film of vacuum grease may be applied.

2. Install a new elastomer O-ring and a new metal O-ring on the purge connection cover. A light film of vacuum grease may be applied.

3. Install a new elastomer O-ring and a new metal O-ring on the center plug. A light film of vacuum grease may be applied.

STEP

4. Install the cask closure and torque the twenty-four closure bolts to 500 ft-lb.

5. Install the center plug in the bottom of the cask and torque the four attach bolts to 40 ft-lb.

6. Pressurize the cask to 15 psig through the purge connection using helium.

7. Disconnect the supply hose.

8. Install the purge connection cover and torque the three (3) attach bolts to 20 ft-lb. Wait one (1) hour. Use a sniffer type Helium Mass Spectrometer to leak test the seals at the cask closure, the purge connection cover, and the center plug. The minimum test procedure sensitivity is 1×10^{-5} atm.cm^3/s. The maximum allowable leakage rate is 1.9×10^{-5} cm^3/sec.

9. Carefully loosen the twenty-four closure bolts and allow the cask pressure to decrease to ambient.

10. Retorque the twenty-four (24) closure bolts to 500 ft-lb.

11. Install the lifting sockets in the cask body. Torque the retaining bolts to 20 ft-lb.

12. Return the cask to the transport semitrailer.

8.2.3 Repairs

Any discrepancies identified during the visual inspection or the leak test shall be corrected and verified by repeating the appropriate inspection or test procedure. All repair materials and repair procedures shall be the same or equivalent to those used during the original fabrication.

SECTION 9.0

QUALITY ASSURANCE

The maintenance, repair, modification and use of Model FSV-1 in Configurations A, B, C, and D will be accomplished in accordance with a quality assurance program which meets the requirements of the program described in Subpart H of Title 10, Code of Federal Regulations Part 71 (10CFR71).

GENERAL ATOMICS

P. O. BOX 85608 SAN DIEGO, CA 92186-9784 (619) 455-3000

910013 B
GADR 55
VOLUME 2

CONSOLIDATED DESIGN REPORT FOR THE MODEL FSV-1 SHIPPING CASK

CONFIGURATIONS E, F and G

GENERAL ATOMICS

ALL REFERENCES TO MODEL FSV-1 CASK IN THIS DOCUMENT MEAN FSV-1 CASK UNIT NO. 3.

910013 B
GADR 55
VOLUME 2

CONSOLIDATED DESIGN REPORT FOR THE MODEL FSV-1 SHIPPING CASK

CONFIGURATIONS E, F and G

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SECTION 1.0

GENERAL INFORMATION

1.1. INTRODUCTION

Volume II of GADR 55 provides a description and an evaluation of Model FSV-1 in Configurations E, F and G as shown in Table 1-1.

Volume I of the GADR 55 provides a description and an evaluation of Model FSV-1 packaging in Configurations A, B, C and D. Some evaluations and diagrams that apply to configurations E, F and G may be found in Volume I of GADR-55.

1.2. PACKAGE DESCRIPTION

The Model FSV-1 in Configuration E is designed and evaluated for the transport of spent nuclear fuel elements from the Fort St. Vrain High-Temperature Gas-Cooled Reactor. Configurations F and G are designed and evaluated for the transport of large quantities of solid, nonfissile, irradiated and contaminated hardware. These packages have a loaded weight of approximately 47,600 pounds and the maximum weight of the cavity contents is 4430 pounds. The length of the package, with the impact limiter installed is 229.45 inches with a maximum diameter of 46.7 inches at the impact limiter. The remaining 196.6 inches of the package has a diameter of 28 inches. These configurations have been grouped together since the impact limiter is used in each of these shipping configurations.

1.2.1. <u>Packaging</u>

Model FSV-1 in Configurations E, F and G all use the same cask body and impact limiter as shown on GA Technologies Inc. drawings GADR 55-2-1 Issue C, GADR 55-2-2 Issue A, and GADR 55-2-3 Issue B. Only Model FSV-1 in Configuration E uses the inner container as shown on the above referenced

TABLE 1-1
MODEL FSV-1A CASK AND CONFIGURATIONS
CONFIGURATIONS E THROUGH G

Configuration	Reference Drawings	Authorized Contents	Allowable Weight-Cask Cavity	Allowable Weight-Contents	Remarks
E	70086F, Rev. 7 (a) 1501-003, Rev. C (b) 70296F, Rev. 2 (a) GADR55-2-1 Issue C GADR55-2-2 Issue A GADR55-2-3 Issue B	Irradiated fuel elements with graphite body-1.4 kg of U 235 and 11.3 kg thorium - wt 300 lb	4430 lb	1800 lb	Requires impact limiter Requires inner container Loaded wt 47,600 lb
F	70086F, Rev. 7 1501-003, Rev. C 70296F, Rev. 2 GADR55-2-1 Issue C GADR55-2-2 Issue A GADR55-2-12 Issue C GADR55-2-13 Issue A	Solid, nonfissile, irradiated and contaminated hardware	4430 lb	Depends on spacer up to 2800 lb	Inner container not required. Wt of burial canister with shield plug is 1635 lb Loaded wt 47,600 lb
G	70086F, Rev. 7 1501-003, Rev. C 70296F, Rev. 2 GADR55-2-1 Issue C GADR55-2-2 Issue A GADR55-2-12 Issue C GADR55-2-13 Issue A	Solid, nonfissile, irradiated and contaminated hardware	4430 lb	900 lb	Requires impact limiter Inner container not required. Wt of burial canister plus spacer with supplemental shielding is 3530 lb Loaded wt 47,600 lb

(a) National Lead Company drawing.
(b) General Atomics drawing.

drawings and Fig. 1-1. Configuration F uses a burial canister with a suitable spacer and a shield plug that provides supplemental shielding as shown on Fig. 1-2. Configuration G uses the same burial canister and shield plug as the Configuration F, and in addition uses a spacer that provides supplemental shielding as shown on Fig. 1-3.

1.2.2. Operational Features

Model FSV-1 package has a smooth external surface that simplified decontamination. Lifting attachments on the package consist of sockets rather than trunnions since sockets are less likely to be damaged in a manner that would impair any safety function of the package. Tie-down of the package to the rear support on the transport semitrailer is by means of four (4) socket head cap screws which are installed into threaded inserts located in the base of the cask body. This attachment arrangement prevents any damage that is likely to impair any safety function of the package.

1.2.3. Contents of Packaging

The contents of Model FSV-1 in Configuration E consist of six spent fuel elements from the Fort St. Vrain, High Temperature Gas-Cooled Reactor. Each fuel element is a hexagonal graphite block approximately 31 inches long and 14 inches across the flats. Each fuel element has a weight of approximately 300 pounds and contains a maximum of 1.4 kilograms of 93.5% enriched uranium and about 11.3 kilograms of thorium, with a thorium/uranium ratio of at least 8.1/1.

The contents of Model FSV-1 in Configurations F and G consist of solid, nonfissile, irradiated and contaminated hardware. Examples of such reactor hardware include, but are not limited to, control rods, fuel channels, poison curtains, shrouds, power range monitors, and miscellaneous structures.

FIGURE WITHHELD UNDER 10 CFR 2.390

FIGURE WITHHELD UNDER 10 CFR 2.390

FIGURE WITHHELD UNDER 10 CFR 2.390

FIGURE WITHHELD UNDER 10 CFR 2.390

FIGURE WITHHELD UNDER 10 CFR 2.390

FIGURE WITHHELD UNDER 10 CFR 2.390

FIGURE WITHHELD UNDER 10 CFR 2.390

FIGURE WITHHELD UNDER 10 CFR 2.390

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SECTION 2.0

STRUCTURAL EVALUATION

2.0 STRUCTURAL EVALUATION

2.1. STRUCTURAL DESIGN

2.1.1. Discussion

Principal structural components of Model FSV-1 in Configurations E, F and G are the cask body with the outer closure, the inner container with the inner closure and the impact limiter which protects the closure end of the package. These components are shown on the design drawings located in Section 1.0.

Configurations F and G use a burial canister in place of the inner container. This component is shown on the design drawing located in Section 1.

2.1.2. Design Criteria

Model FSV-1 was designed to comply with all regulatory requirements in effect at the time of application for a certificate of compliance. An initial application was submitted to the U.S. Atomic Energy Commission in April 1969. This application described and evaluated the basic package without the impact limiter. A later application, submitted to the U.S. Nuclear Regulatory Commission in August 1977, described and evaluated the package with an impact limiter and with modified inner and outer closures used in Configurations E, F and G.

Table 2-1 lists the structural conditions analyzed. The sections where the analyses are presented are also listed.

TABLE 2-1
GADR 55, VOLUME II CROSS-REFERENCE TO 10CFR71 REQUIREMENTS

	Section
Normal Conditions of Transport:	
Heat (Differential Thermal Expansion)	2.6.1
Cold (Differential Thermal Expansion)	2.6.1
Pressure	2.5.2, 2.6.3
Vibration	2.6.2
Water Spray - not significant for this type of packaging-	
Free Drop	
- Bottom	2.6.4.1
- Side	2.6.4.2
Penetration - not significant for this type of packaging-	
Hypothetical Accident Conditions	
Free Drop	
- End	2.7.1.1
- Side	2.1.4, 2.7.1.2
- Bottom Corner	2.7.1.10
Puncture	2.7.2
Thermal (Differential Thermal Expansion)	2.6.1
Water Immersion - not significant for this type of packaging-	
Package Standards	
Load Resistance	2.5.1
External Pressure	2.5.2

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2.1.3. Plywood Impact Limiter

The impact limiter was designed to fit and protect Model FSV-1 in Configurations E, F and G during the hypothetical accident conditions.

This impact limiter, described in Figure 2-1, is made up with sufficient 3/4-in. plywood circular sections glued together to absorb the kinetic energy of the cask when dropped from a 30-ft height. These plywood sections are then glued in turn to an aluminum cylinder and end cap which serve as load carrying members. The combined limiter fits snugly over the closure end of the cask body and is secured in place by a retaining ring.

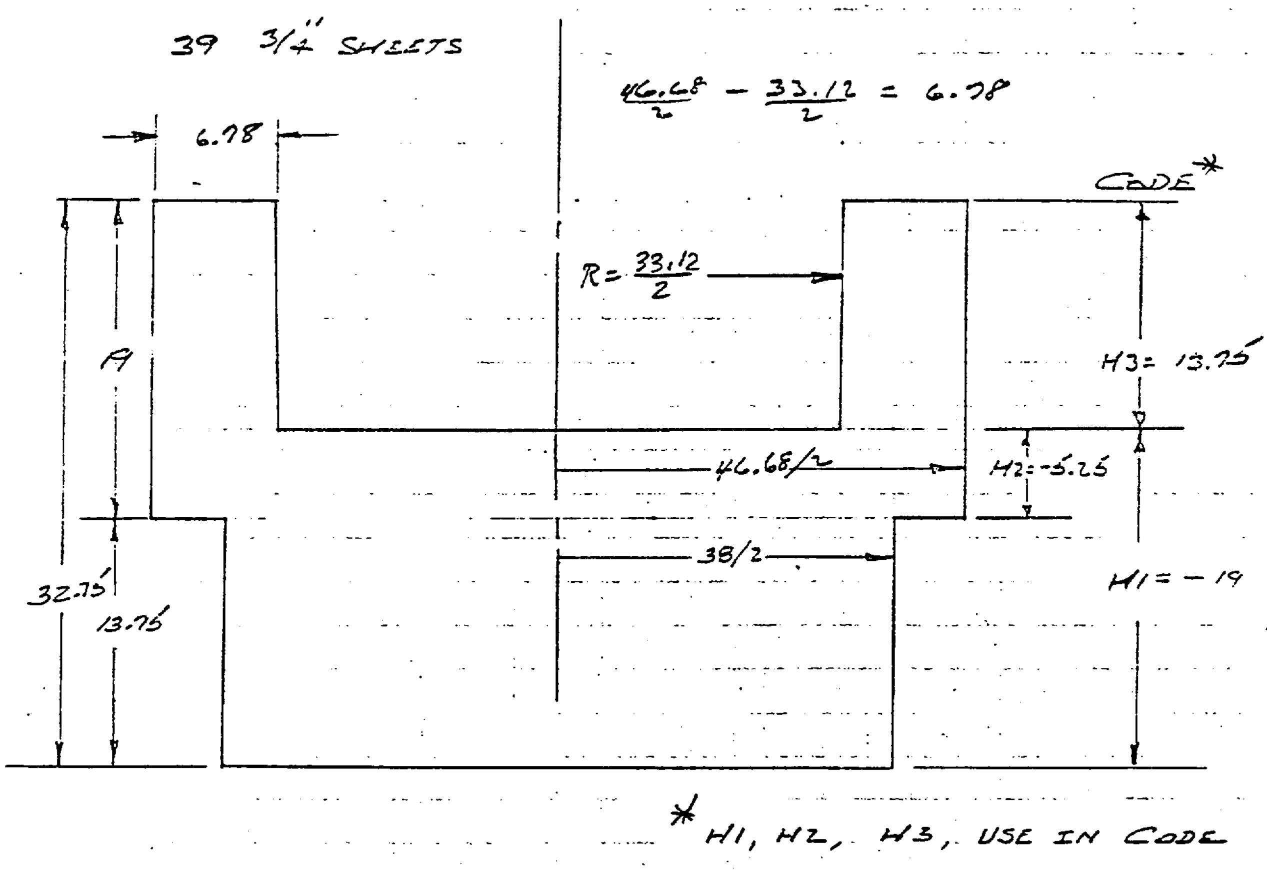
2.1.4. Impact Limiter Loads Analysis

Considerations pertaining to the structural evaluation of the impact limiter are discussed below for the side drop case. The impact loads, although complex, were examined firstly from a most probable standpoint and secondly, discussed from the viewpoint of a later time increment.

The first loading is that of a side drop inducing an uncapping moment by the crushing force that is not balanced by direct reaction loads. This uncapping moment must be balanced by two internally generated forces producing an opposing moment. The internal compressive reacting load is generated by the resulting upper cap-half pressure loading. Lower opposing tension loading is assumed to act over the projected hollow aluminum cylinder arc sector that reacts the compressive plywood crush force. Obviously, this plywood crushing force is not at right angles to the required tension force. These tension forces could be realized but this arrangement is too overly conservative. This is evidenced in light of the

FIGURE 2-1

PLYWOOD IMPACT LIMITER



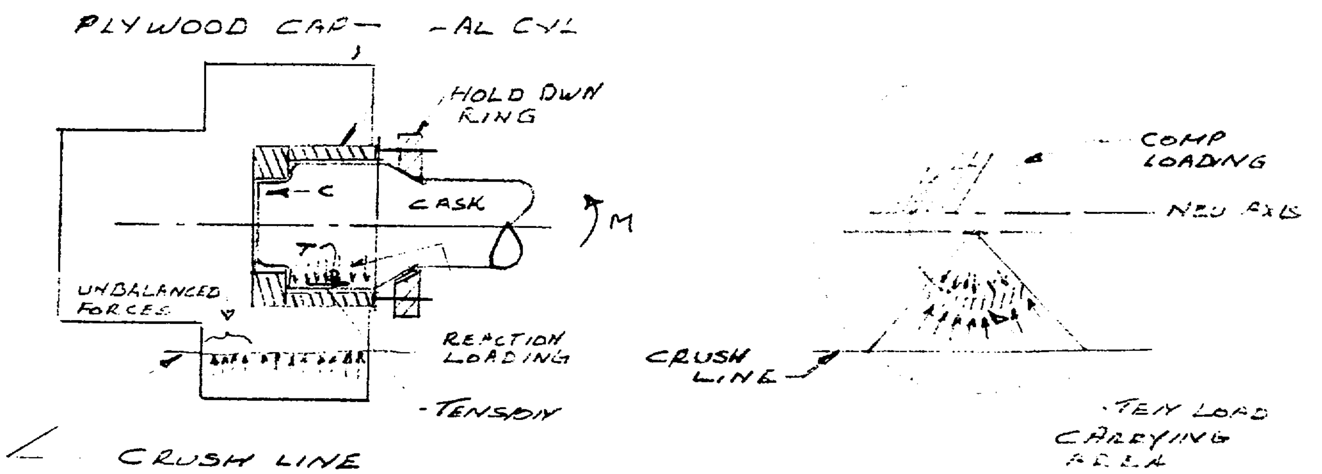
low tension/normal force ratio of 0.049. This in itself is conservative as the assumed arc sector over which the tension force is generated is in reality just about half of the actual projected aluminum cyliner width. Any tension load tails off as the full diameter is approached. A judicious use of approximately 8% of the referenced static friction factor was found to be required for generation of the tension force. This is felt to be the total tension force; resulting in no net tension force required by the tie down studs.

A second consideration of impact limiter reaction loading to the side drop case is that due to a jamming action. This action, initially, is similar to that first discussed. The difference, however, is that the uncapping moment now is considered to be reacted by the upper outer edge and lower inner edge loads. This loading is difficult to analyze but appears to cause local yielding of the upper outer cylinder edge. The resulting yielding allows a redistribution of stress by spreading the applied load over a greater edge or band area. This action tends to induce cylinder bending along with the cylinder hoop tension stress. At some later time interval, the cask body section 'rotates' downward (with respect to the impact limiter cap) since the lower cask body section is free. This rotation causes a reversing affect on the internal reaction loading. But now the plywood crushing load is redistributed.

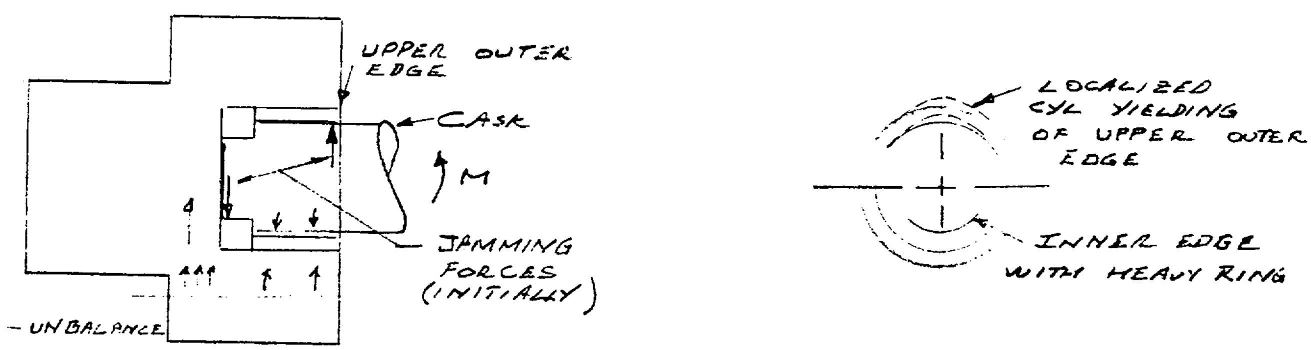
The upcapping moment is reduced somewhat and must be reacted by forces similar to those first discussed.

A most probable occurrence is that the resulting reaction loads are a combination of both the above schemes; compression-tension (tension supplied by friction forces) and jamming. It is felt however that greater emphasis be placed upon the former loading consideration.

Diagram Depicting Loading Considerations



FRICTION SCHEME

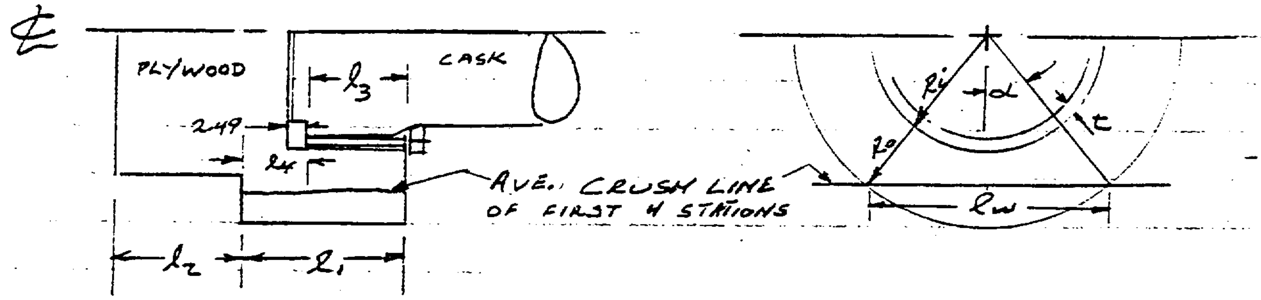


JAMMING SCHEME

2.1.5. Impact Limiter Loads Analysis 30-ft Side Drop

The sketch below shows an axial view of a 90° ground impact with a plywood crush average of 3.925 in. (58%).

$$\sigma_{58\%} = 3500 + 1118(58-50) = 12{,}444 \text{ Psi}$$



ℓ_1 = 19.0 in. $\quad R_i$ = 16.56 in.

ℓ_2 = 13.75 $\quad R_o$ = 23.34 in.

ℓ_3 = 11.26 $\quad t$ = 1.0 in.

ℓ_4 = 7.74

$$\alpha = \cos^{-1} \frac{R_o - 3.925}{R_o} = \cos^{-1} \frac{23.34 - 3.925}{23.34} = \underline{33.71}$$

$$= \underline{(0.5884 \text{ Rad})}$$

$$\ell w = 2 R_o \sin\alpha = 2\,(23.34) \sin 33.71 \quad \underline{25.91 \text{ in.}}$$

2.1.5.1 Unbalanced Load Over Length ℓ_4 (crush < 50% over ℓ_4)

$$P_u = q\,\ell w\,(\ell_4 - 2.49) = 3500\,(25.91)\,5.25 = \underline{4.761 \times 10^5 \text{ lb}}$$

2.1.5.2 Cylinder Moment at Ring (ℓ_4) (Ring Bottom)

$$\mu = P_u \frac{2.49 + \ell_4}{2} + \ell w \frac{2.49^2}{2} (12,444) = \underline{3.446 \times 10^6 \text{ in. lb}}$$

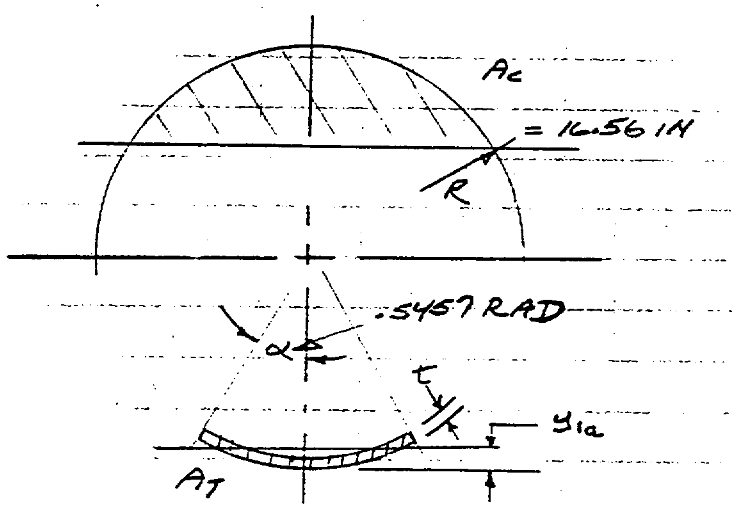
2.1.5.3 Cylinder Bending Stress

$$I_{cy} = \pi/4\,(R^4 - (R - t)^4) =$$

$$= \pi/4\,(16.56^4 - 15.56^4) = \underline{13,026 \text{ in.}^4}$$

$$\sigma_B = \mu / I_{cy} = 3.446 \times 10^6\,(16.56)/13,026 = \underline{4381 \text{ psi}}$$

2.1.6 Impact Limiter Neutral Axis and Inertia Calculations



End View Looking into Impact Limiter Showing
Load Areas for Neutral
Axis Calculation

Coarse cross hatched upper sections reacts compression force; the lower aluminum arc sector determined from 50% plywood crush and supplies the required tension to react the uncapping moment.

$$A_T = \alpha t\ (2R - t),\ I_{y_{oT}} = I_{y_{(R-y_{1a})}},\ y_T = (R - y_{1a})$$

2.1.6.1 <u>Sector Centroidal Axis:</u>

$$y_{1a} = R\left\{1 - \frac{2\ \mathrm{Sin}\alpha}{3\alpha}\left(1 - \frac{t}{R} + \frac{1}{2 - t/R}\right)\right\}$$

$$I_{y_{(R-y_{1a})}} = R^3t\left\{\left(1 - \frac{3t}{2R} + \frac{t^2}{R^2} - \frac{t^3}{4R^3}\right) x \left(\alpha + \sin\alpha\ \cos\alpha - \frac{2\ \sin^2\alpha}{\alpha}\right)\right\} + \frac{t^2\ \sin^2\ \alpha}{3R^2\alpha\ (2-t/R)}\ \left(1 - t/R + t^2/6R^2\right)$$

Equation development for the compressive area is expanded on the following pages due to the greater complexity involved.

The tension area properties are noted below and need only be transferred about the neutral axis developed in the following pages. The lower tension area is

$$A_T = 0.5757 \times 1 \times (2 \times (16.56) - 1) = \underline{17.52788 \text{ in.}^2}$$

and

$$I_y = I_{y_{1a}} = \text{below} = \underline{9.866 \text{ in.}^4}$$

$$y_T = \text{below} = \underline{15.28 \text{ in.}}$$

2.1.6.2 Where Numerics are Substituted into Previous Equations

$$I_{y_{oT}} = 16.56^3\ (1) \left\{ \left(1 - \frac{3(1)}{2\ 16.50} + \frac{1}{16.56^2} - \frac{1^3}{4(16.56)^3} \right) x \right.$$

$$\left(0.5457 + \sin 0.5457 \cos 0.5457 - \frac{2 \sin^2 0.5457}{0.5457} \right)$$

$$+ \frac{1^2 \sin^2 0.5457}{3\ (16.56)^2\ 0.5457\ (2 - 1/16.56)} \left(1 - \frac{1}{16.56} \right.$$

$$\left. \left. + \frac{1}{6\ (16.56)^2} \right) \right\}$$

$$= (4541.308) \left\{ 0.913012\ (0.0020610) + 0.00030935\ (0.94022) \right\}$$

$$(4541.308) \quad (0.00188192 + 0.000290858)$$

$$(4541.308) \quad (0.00217257)$$

$$I_{y_{oT}} = 9.866 \text{ in.}^4$$

$$y_{1a} = 16.56 \left\{1 - \frac{2 \sin 0.5457}{3\,(0.5457)}\left(1 - \frac{1}{16.56} + \frac{1}{2 - 1/16.56}\right)\right\}$$

$$= 16.56\ \{1 - 063407\ (1.4552)\}$$

$$= 16.56\ (0.0773) = \underline{1.28036\ \text{in.}}$$

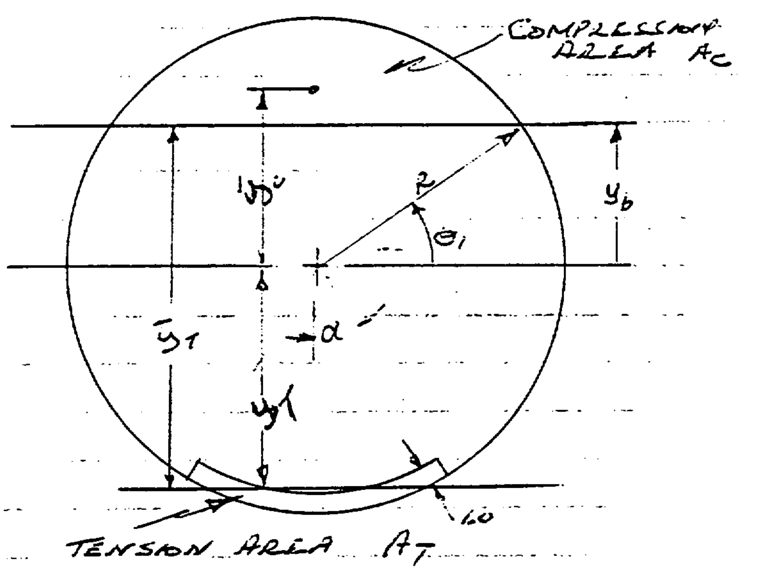
$$R - y_{1a} = 16.56 - 1.28 = \underline{15.28\ \text{in.}}$$

The lower tension inertia is calculated as

$$I_{T_{NA}} = I_o + A_T\ \bar{y}_T^2$$

$$= 9.866 + 17.528\ (24.478)^2 = \underline{10{,}512\ \text{in.}^4}$$

2.1.6.3 Neutral Axis Calculations



$$\bar{Y}_c = \frac{2\int_0^{x = \sqrt{R^2 - y_o^2}} \int_{y_b}^{\sqrt{R^2 - x^2}} dxydy}{2\int_0^{x} \int_{y_b}^{\sqrt{R^2 - x^2}} dx\ dy}$$

$$\bar{y} = \frac{2/3\ (R^2 - y_h^2)^{3/2}}{R^2 \sin^{-1} \frac{\sqrt{R^2 - y^2}}{R} - y_b \sqrt{R^2 - y^2}}$$

An iteration scheme was used to determine (y_b) the neutral axis for the tension/compression areas, i.e.,

$A_c\ (y_c - y_b) = A_T\ (y_T + y_b)$; by assuming a value for 'y_b' then calculating '$\bar{y}$'. 'A_T' and 'Y_t' are known and fixed as is R with y_b = 9.198

'A_c' calculated 142.611, $y_b + y_T$ = 24.478. 'y_c' was calculated 3.0085

$$142.611(3.0085) \stackrel{?}{=} 17.528\ (15.28 + 9.198)$$

$$\underline{429.045 \stackrel{?}{=} 429.050} \qquad \text{o.k.}$$

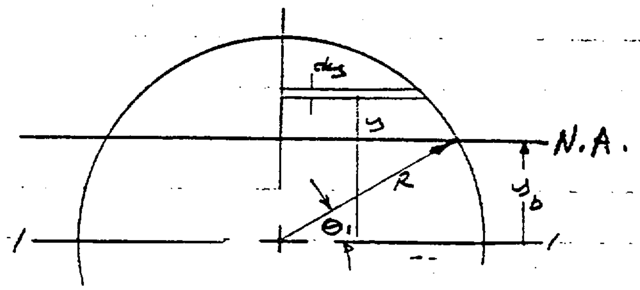
with 'y_b' evaluated, 'θ' may be calculated along with I_{yc} about the neutral axis

2.1.6.4 Compressive Area Section Properties

$$I_1 = 2\int y^2 \, x \, dy = 2\int y^2 \, (R^2 - y^2)^{1/2} \, dy$$

where $y = R \sin\theta$

$dy = R \cos\theta \, d\theta$



$$I_1 = 2\int_{\theta_1}^{\pi/2} R^2 \sin^2 \theta \sqrt{R^2 - R^2 \sin^2 \theta} \, (R \cos\theta \, d\theta)$$

$$= \frac{R^4}{8} (\pi = 2\theta_1 + \sin 2\theta_1 - 4 \sin^3 \theta_1 \cos\theta)$$

I_1 = <u>21,787 in.^{4}</u>

$$I_{NA} = I_{yc} = I_1 - A_c(y_b + y_c)^2 + A_c \, y_b^2$$

$$= 21{,}787 - 142.611 \, [(9.198 + 3.0085)^2 - 3.0085^2]$$

$$= 21{,}787 - 142.611 \, [149 - 9.05] = \underline{1829}$$

2.1.6.5 Total Section Inertia

Combining I_{y_c} and $(I_{y_{OT}} + A_T \, \bar{y}_T^2)$

$$I_{y_b} = I_{y_c} + I_{y_{OT}} + A_T \, \bar{y}_T^2$$

$$1829 + 9.87 + 17.528 \quad 24.478^2 = \underline{12{,}341 \text{ in.}^4}$$

2.1.7 Impact Limiter Loads Analysis

If moment is reacted over the cylinder/cap and hollow sector of the cylinder

$$\sigma = M\, C_{NA}/I_{y_b} ,$$

$$C_{NA} = R_{it}\ \overline{y} = 16.56 + 9.20 = \underline{25.76\ \text{in.}}$$

Tension

$$\sigma_T = 3.446 \times 10^6\ 25.76/12{,}341 = \underline{7195\ \text{psi}}$$

Compression

$$\sigma_c = 3.446 \times 10^6\ (16.56 - 9.20)/12{,}341 = \underline{2055\ \text{psi}}$$

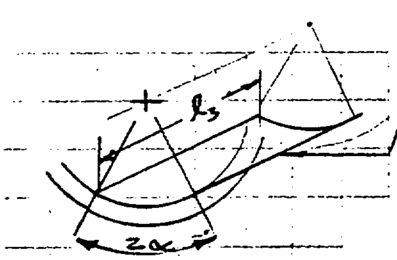
2.1.7.1 Impact Limiter - Stud Loads

Pull down load derived from moment:

$$F(\overline{y}_c + y_T) = M \qquad \overline{y}_c + y_T = \text{centroid/centroid distance}$$

$$y = 12.2065 + 15.28 = 27.49\ \text{in.}$$

$$F = M/(y) = 3.446 \times 10^6/27.49 = \underline{125{,}355\ \text{lb}}$$



Inside Bearing Area of Aluminum Cylinder

Normal Force F_N Aluminum Cylinder/Stainless Steel

Av crush 3.925; 2α = 1.1768 rad; $\sigma_{59\%}$ 12,444 psi

$F_N = R\ (2\alpha)\ \ell_3\ q = (15.56)\ 1.1768\ (11.26)\ 12{,}444 = \underline{2.566 \times 10^6 \text{ lb}}$

$F/F_N = 125{,}355/2.566 \times 10^6 = \underline{0.049}$

Coefficient of function for friction force calculation was taken from the table below which is lifted from "Marks Mechical Engineering Handbook 4th Ed. pg. 234, Table 3.

	Hard Steel	Mild Steel	Platinum	Nickel	Copper	Brass	Aluminum	Glass	Tin	Lead
Hard steel	0.39									
Mild steel	0.41	0.41								
Platinum	0.40	0.43	0.45							
Nickel	0.43	0.43	0.39	0.39						
Copper	0.55	0.53	0.50	0.56	0.60					
Brass	0.54	0.51	0.56	0.50	0.62	0.63				
Aluminum	0.65	0.61	0.80	0.75	0.70	0.71	0.94			
Glass	0.61	0.72	0.57	0.73	0.68	0.87	0.85	0.94		
Tin	0.79	0.77	0.86	0.90	0.88	0.75	0.91	0.94	1.11	
Lead	1.96	1.93	2.07	2.15	1.95	2.11	2.00	2.40	2.20	3.30

The coefficient of friction, μ, for mild steel and aluminum, which is representative of the impact limiter aluminum cylinder and the stainless steel cask is seen to be 0.61.

The friction force F_R that may be realized is:

$F_R = \mu F_N = 0.61 \times 2.566 \times 10^6 = \underline{1.565 \times 10^6 \text{ lb}}$

$F_{req'd}$ = 125,355 lb

Margin:

$F_R/F_{req'd}$ = 15.65/1.25 = 12.5

or approximately 8% of the available friction force is required. Therefore, the tie-down studs provide no net tension load due to the 90° side drop.

However, rotational axial loads do not depend on friction and the loads must be taken up by the hold down studs. Rotational loads are calculated as follows:

2.1.7.2 Centripetal Force Due to Rotation: Assuming total kinetic translational energy is converted to rotational energy:

$$KE = 1/2\ M\ v^2 = 1/2\ I\ \omega^2 \qquad {}_oI = I + M\ (L/2)^2$$

$$v = \sqrt{2gh} = \sqrt{2\ (386.4)\ 360} = 5.275 \times 10^2 \text{ in./sec}$$

$$I = 1/12\ M\ \ell^2 + M\ (\ell/2)^2$$

$$= 1/12\ (120)\ 210^2 + (120)\ 105^2 = 1.764 \times 10^6 \text{ lb sec}^2 \text{ in.}$$

$$\omega^2 = M\ v^2/I = 120\ (5.275 \times 10^2)^2/1.764 \times 10^6 = 18.93 \text{ rad}^2/\text{sec}^2$$

Centrifugal Acceleration

$$n_z = \ell\ \omega^2/g = 210\ (18.93)/386.4 = 10.29 \text{ g}$$

Centripetal Force on Studs

$$F = n_z W = 10.29\ (1060) = \underline{10,910}\ \text{lb total}$$

Stud Load = F/n = 10,910/6 = 1,820 lb/stud

Stud Stress F/A_R = 1820/0.1257 = 14,480 psi

Studs: 1/2 - 13 - A_R = 0.1257 in.^{2} root area

Impact Limiter Insert Strength

Per 'Keensert' Catalog No. 200-A, minimum shear contact area x ult shear of the particular material

Shear ultimate = 60% tension ultimate* | 300°F (6061-T6) 10,000 hr

= 0.6 x 37,400 = 22,440 psi

Pull Out Strength of Insert

Calculated Pull Out Strength = Minimum Shear Stud Engage Area x Minimum Ult Shear Strength of Parent Mat

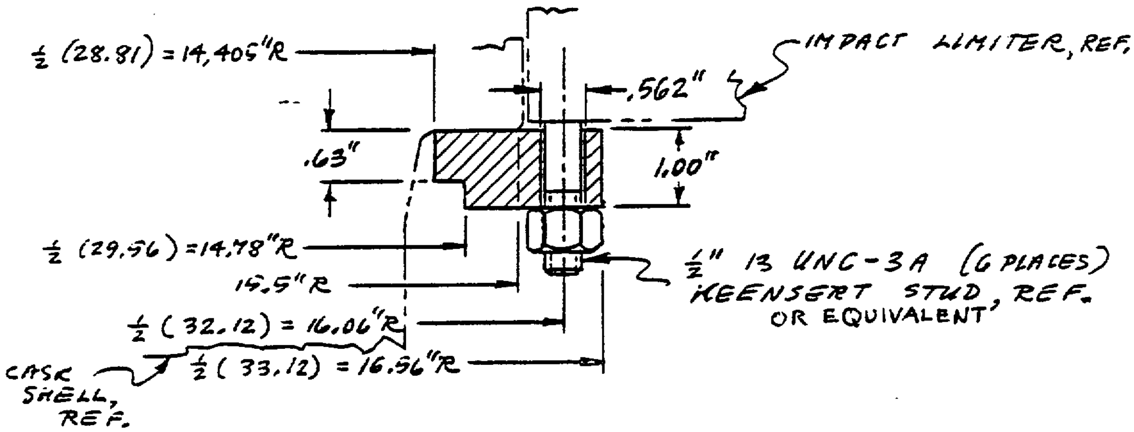
= 0.7172 (22,400) = 16,065 lb

Pull Out Margin

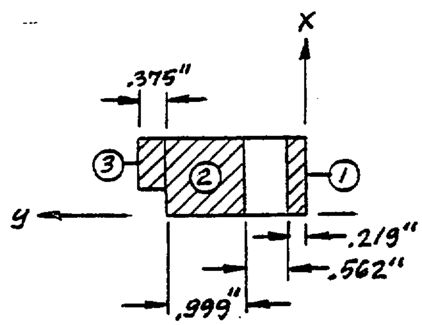
Pull out/applied = 16,065/1820 = 8.8

2.1.8 Impact Limiter Retaining Ring

Material: 6061-T6 Al. alloy



SECTION PROPERTIES



$I_{xo} = \frac{1}{12} b h^3$

Item	A	x	x²	Ax	Ax²	Ixo	Ax² + Ixo	y	Ay
1	0.219	0.50	0.25	0.1095	0.05475	0.01825	0.07300	0.1095	0.02398
2	0.999	0.50	0.25	0.4995	0.24975	0.08325	0.33300	1.2805	1.27922
3	0.23625	0.685	0.4692	0.1618	0.11085	0.00781	0.11866	1.9675	0.46482
Σ	1.45425	--	--	0.7708	0.41535	0.10931	0.52466	--	1.76802

$(\bar{x})\ (\Sigma A) = \Sigma(AX) = (\bar{x})\ (1.45425) = 0.7708\ ;\ \bar{x} = \underline{0.53005\ \text{in.}}$

$I_{NA} = \Sigma(Ax^2 + Ixo) - (\bar{x})\ (\Sigma(AX)) = 0.52455 - (0.530050\ (0.7703)$

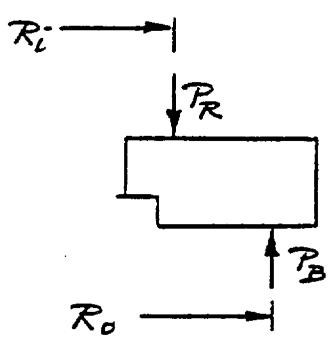
$= \underline{0.1161\ \text{in.}^4}$

$(\bar{y})\ (\Sigma A) = \Sigma\ (Ay) = (\bar{y})\ (1.45425) = 1.76802;\ \bar{y} = \underline{1.21576\ \text{in.}}$

$R = 1/2\ (33.12) - \bar{y} = 16.56 - 1.21576 = \underline{15.344\ \text{in.}}$

2.1.8.1 Inertia Load

$$10{,}350\ \text{lb} \sim \frac{10{,}350}{2\pi\ (15.344)} = \underline{107\ \text{lb/in.}}$$



$R_i = 1/2\ [14.405 + 15.5] = \underline{14.9525\ \text{in.}}$

$R_o = \underline{16.06\ \text{in.}}$

Moment arm $= R_o - R_i$

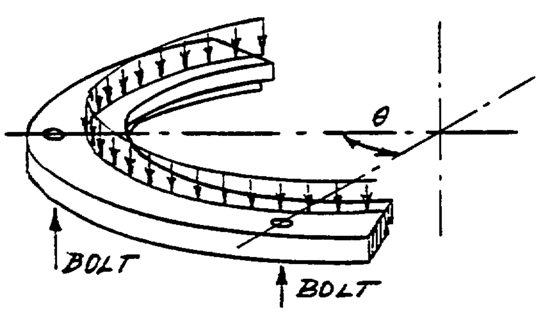
$= 16.06 - 14.9525$

$= \underline{1.1075\ \text{in.}}$

$M = (107)\ (1.1075) = \underline{118.5\ \text{in. lb/in.}}$

Ring bending moment due to couple on section moment = MR

$= (118.5)\ (15.344) = \underline{1818\ \text{lb in.}}$



Ring stress due to redistribution of bolt load as indicated on sketch:

Assume for simplicity a straight beam uniformly loaded and fixed at both ends.

$L = \theta R = (160)\ \pi/180\ (15.344) = \underline{16.07\ in.}$

$p = \underline{107\ lb.in.}$

$M_{max} = 1/12\ p\ L^2 = 1/12\ (107)\ (16.07)^2 = \underline{2310\ in.\ lb}$

Total ring bending moment = 1818 + 2310 = 4128 in. lb

$$\sigma = \frac{M_c}{I} = \frac{(4128)\ (0.53005)}{0.1161} = \underline{18,846\ psi};\ < \sigma_{yield} = 30,000\ psi$$

2.1.8.2 Bolt Preloading

Maximum nut installation torque specified = 12 ft lb

T = 12 ft lb = 12 x 12 = 144 in. lb

13 UNC: coarse threads (1/2 in. diam)

With a friction factor of F = 0.15 a K-value of K = 0.098585 is found from Table I of "Bolt Torque Factors," by R. H. Lipp, Design News, March 8, 1971 issue.

$$P = \text{axial load of bolt} = \frac{T}{K} = \frac{144}{0.098585} = 1461\ lb$$

Total axial load = 6P = 6 x 1461 = 8764 lb

Bolt stress area: A = 0.1416 in.²

$$\sigma_{bolt} = \frac{1461}{0.1416} = \underline{10,315 \text{ psi}}$$

Bolt preloading total = 8764 lb is less than inertia load 10,350 lb: Impact limiter will slide forward a small amount during rotation of cask.

Ring stress for preloading of bolts to 12 ft lb:

$$\sigma = (18.846)\frac{8,764}{10,350} = \underline{15,958 \text{ psi}}; < \sigma_{yield} = 30,000 \text{ psi}$$

2.1.9 Impact Limiter Equation Development.

Two degrees of freedom: vertical translation and pitch rotation about c.g.

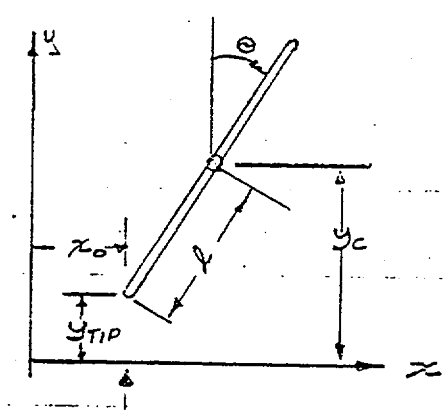
Translation: Upward force - gravity force = m x appar't access.

$$F(u) - m\ g = m\ \ddot{y}_c$$

Expressed in terms of the tip or contact point

$$y_{tip} = y_c - \ell \cos\theta$$

Rates and acceleration may be calculated



F(u) = crush force

$$\dot{y}_{tip} = \dot{y} + \ell\,\dot{\theta}\,\sin\theta$$

and

$$\ddot{y}_{tip} = \ddot{y}_c + \ell\ddot{\theta}\,\sin\theta + \ell\dot{\theta}^2\,\cos\theta$$

Solving for $\ddot{y}_c$ and replacing $\ddot{y}_{tip}$ with $-\ddot{u}$

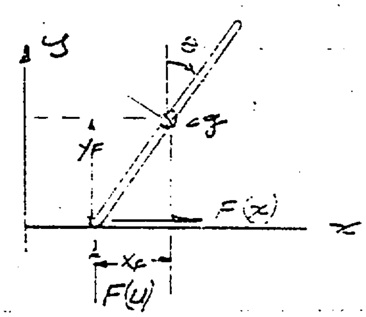
$$\ddot{y}_c = -\ddot{u} - \ell\,(\ddot{\theta}\,\sin\theta + \dot{\theta}^2\,\cos\theta)$$

So that the force Eq. (1) may be written:

$$F(u) - mg - m\ \ddot{u} - \ell\,(\ddot{\theta}\,\sin\theta + \dot{\theta}^2\,\cos\theta) \qquad (2)$$

In similar fashion the horizontal force is described as:

$$F(x) = m\,\ddot{x}_{cg}$$



where $x_{cg} = x_o + \ell\,\sin\theta$

$$\dot{x}_{cg} = \ell\,\dot{\theta}\,\cos\theta$$

$$\ddot{x} = \ell\,\ddot{\theta}\,\cos\theta - \ell\,\dot{\theta}^2\,\sin\theta$$

Then upon substituting

$$F(x) = m\,\ell\,(\ddot{\theta}\,\cos\theta - \dot{\theta}^2\,\sin\theta)$$

The pitch rotation equation is described:

$$M = I\ \ddot{\theta}$$

In terms of previously described forces

$$F(u)\ X_F - F(x)\ Y_F = I\ \ddot{\theta} \qquad (3)$$

where the arms X_F and Y_F are variables and functions of crush distances and are described shortly.

Substituting the previously developed F(x) expression into the moment equation (3) above leads to :

$$F(u)\ X_F - m\ell\ (\ddot{\theta}^2 \cos\theta\ Y_F = \ddot{\theta}^2 \sin\theta)\ Y_F = I\ \ddot{\theta}$$

or

$$F(u)\ X_F + m\ \ell\ \dot{\theta}^2 \sin\theta\ Y_F = \ddot{\theta}\ (I + m\ell\ Y_F \cos\theta)$$

Solving for $\ddot{\theta}$ yields:

$$\ddot{\theta} = \frac{F(u)\ X_F + m\ \ell\ Y_F\ \dot{\theta}^2 \sin\theta}{(I + m\ \ell\ Y_F \cos\theta)}$$

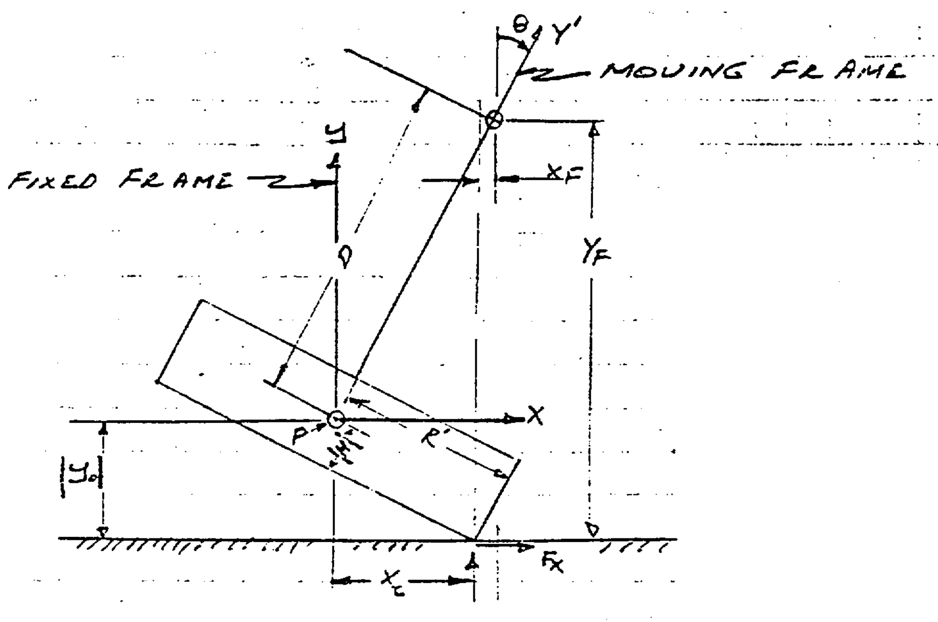
This term may then be substituted into the vertical force expression repeated below.

$$F(u) - mg = m\,[-\ddot{u} - \ell\,(\ddot{\theta}\,\sin\theta + \ddot{\theta}\,\cos\theta)]$$

from which $\ddot{u}$ is described.

$$\underline{\ddot{u} = g - F(u)/m - \ell\,(\theta^2\,\cos\theta + \ddot{\theta}\,\sin\theta)}$$

The arms, X_F and Y_F of the torque equation are described below.

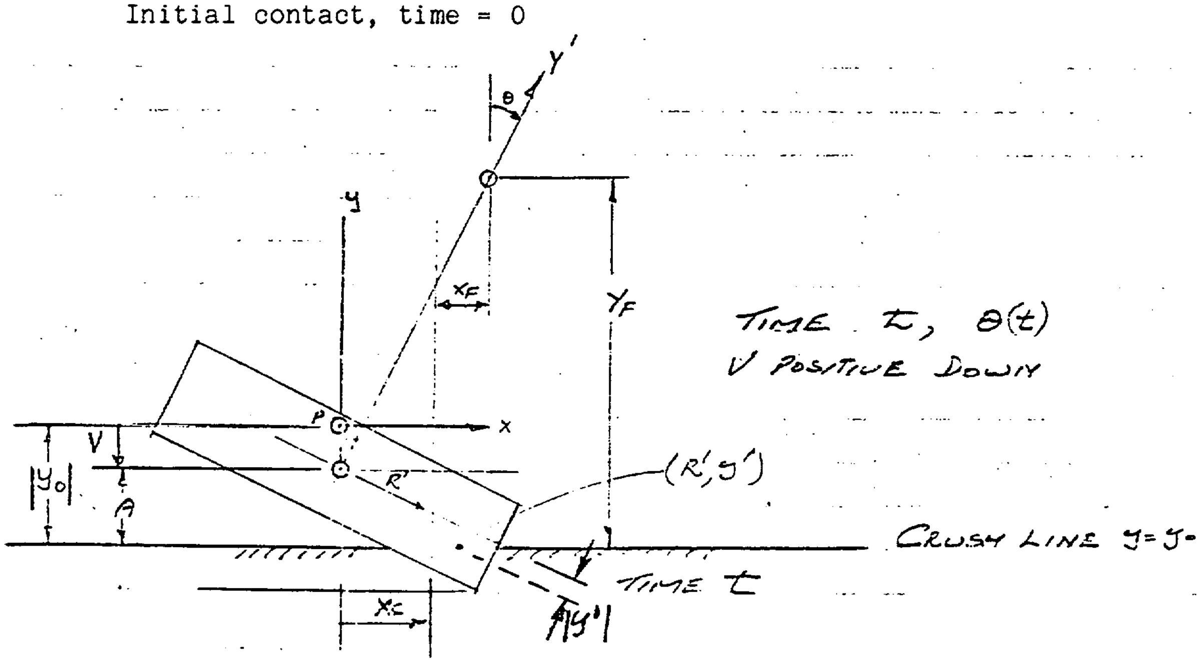


$X_F = D \sin\theta - X_c$

$Y_F = D \cos\theta + R \sin\theta + |H| \cos\theta$

X_c = distance X from reference point P to centroid of contact area

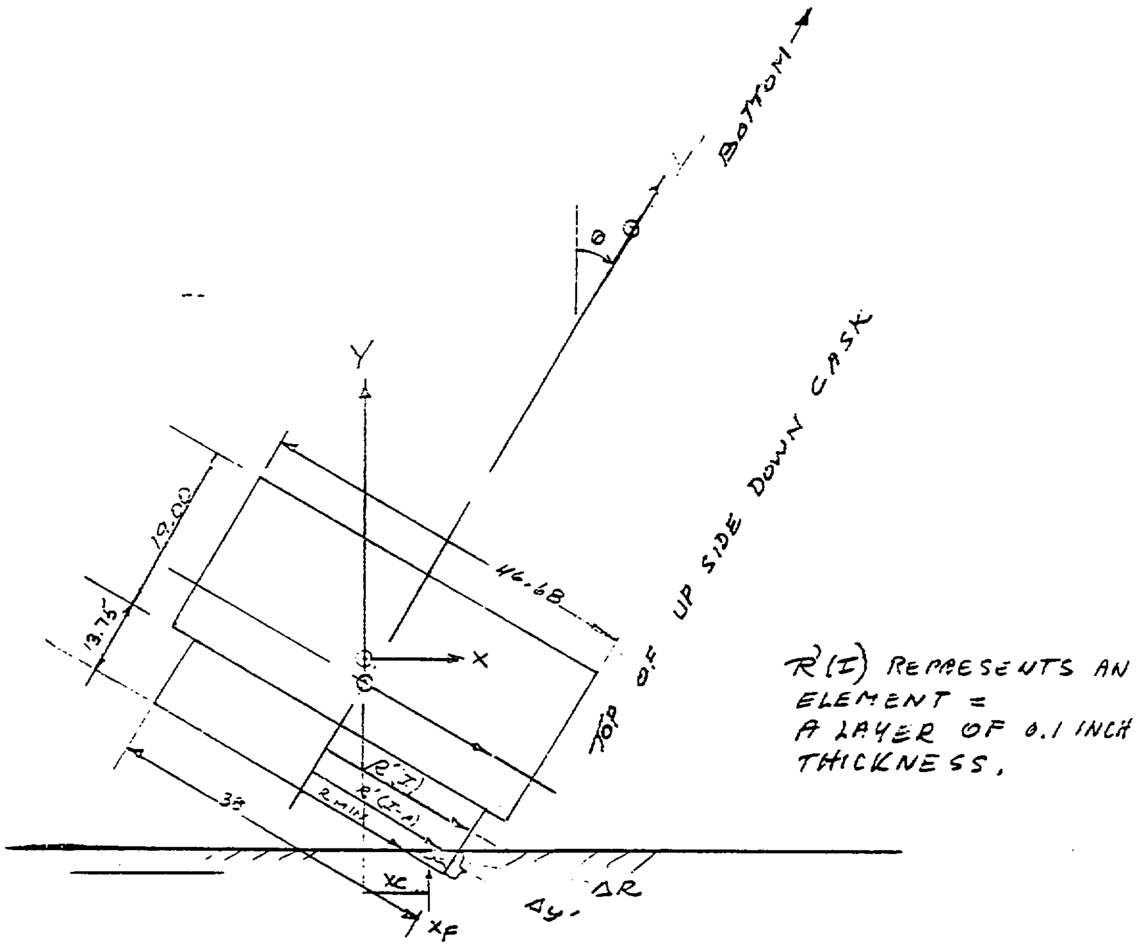
Initial contact, time = 0



For a point (R', y') on the crush line ($y = y_o$);

Dimension $A = R' \sin\theta - y' \cos\theta = - y_o - V$

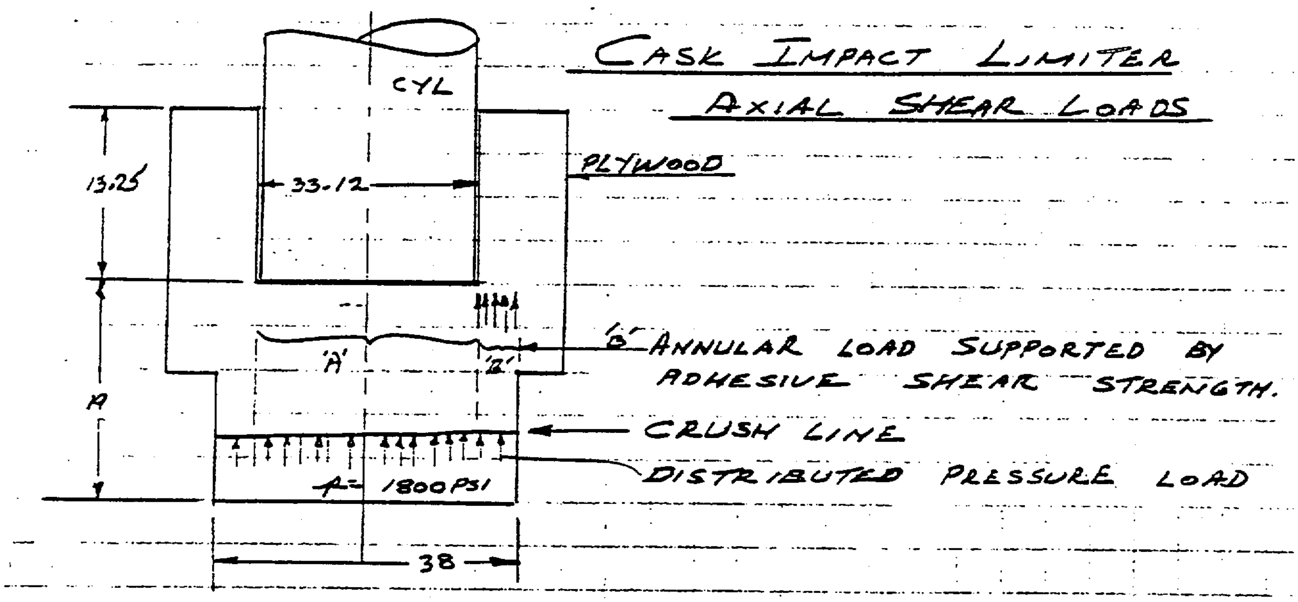
Solving for: $R' = \dfrac{y_o + V - y' \cos\theta}{- \sin\theta}$



R'(I) represents an element of the radius vector at preassigned incremental depths. These vector elements begin at the top and continue every 0.1 in. towards the bottom of the plywood impact limiter.

When the radius vector equals the radius magnitude the point is saved and differenced with the minimum radius. Both of these radii are the 'ground-radius' coincident points. This allows a ΔR calculation and knowing the other coordinate, y (depth), a Δy calculation. The impact area is next calculated with the action arm X_F passing through the centroid of the area. The resulting forces and moments are then calculated and integrated; the process repeated over the ensuing time steps till $\theta = 90°$ or $F(u) = 0$.

2.1.9.1 Impact Limiter Axial Shear Loads



'A' central area supported by cylinder top
'B' annular section contributing to glue shear

Crush $\Delta = PE/A\sigma = 120\ (386)\ 360\ /\ (\pi\ 38^2 \times 1800) = \underline{8.17\ \text{in.}}$

$\% = 8.17/19 < 50\% \therefore \sigma = \underline{272.6\ \text{in.}^2}$

$$\text{Average Acceleration} = \pi \times \frac{38^2}{4} \times \frac{1,800}{46,000} = 44\ g$$

Area B = A $= 0.25\ \pi\ (38^2 - 33.12^2) = 272.6\ \text{in.}^2$

Shear load: $F_{S_{cy}} = p\ A_B = 1800\ (272.6) = \underline{490,680\ \text{lb}}$

Shear Stess-Adhesive

$\sigma_{S_{AD}} = F_{S_{cy}} / \pi D \cdot \ell$

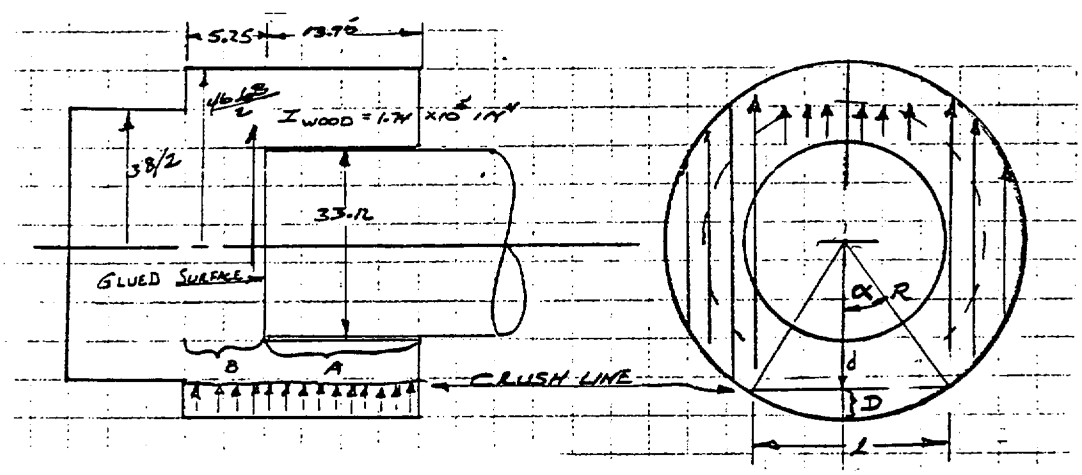
ℓ is glued length wood shear is ignored

490,680 / (π)(33.12) (13.75) = 342 psi

342 < 1000 psi

Reference Roark 5th Ed., Table 38

2.1.9.2 Impact Limiter Plywood Shear and Bending Stress



D_{max} (Estimated) = 4.49 in.

$\ell = 2R \sin (\cos^{-1} d/R)$

$= (23.34) \sin (\cos^{-1} 18.85/23.34 =$ <u>27.527 in.</u>

B Contact Area = $\ell \cdot B = s$

$= 27.527 (5.25) =$ <u>144.5 in.²</u>

Section B sees uniform σ_{11} = 3500 psi

Crush/diam percent very small.

Load on Section 'B': $F_B = \sigma_{11} S = 3500 (144.5) = 5.058 \times 10^5$ lb

Shear Stress:

$$\sigma_S = F_B/(\pi\, D_o^2/4) = 5.058 \times 10^5/(\pi\; 46.68^2/4) = \underline{296 \text{ psi}}$$

Per Engineering Material Handbook C. L. Mantell allowable wood shear 1000 psi.

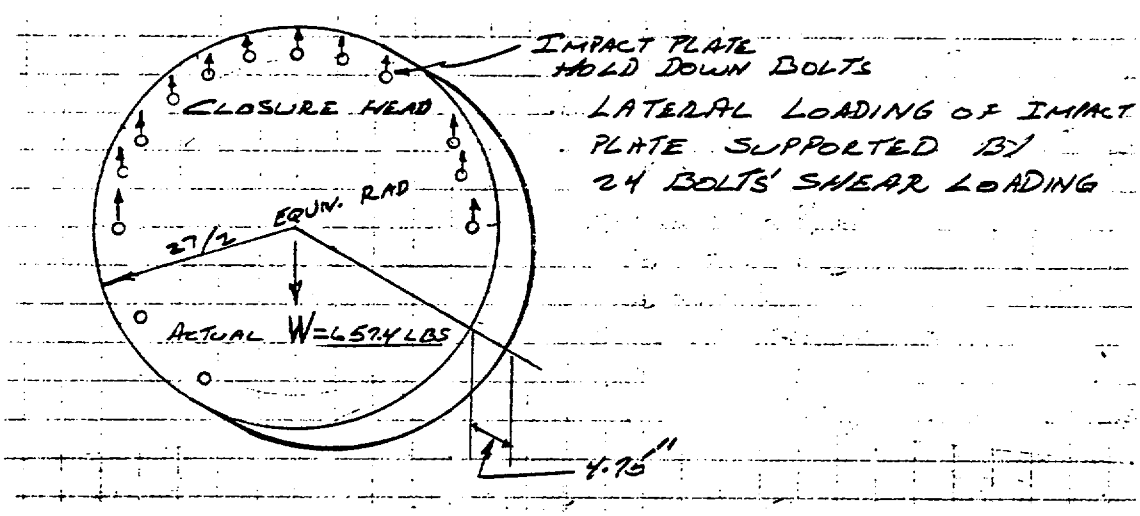
Bending Stress (wood):

$$\sigma_B = \frac{M_c}{I_{wood}} = \frac{5.058 \times 10^5 \; (5.25)}{2} \; \frac{(23.34)}{1.74 \times 10^5} = 180 \text{ psi}$$

Per same reference: tension perpendicular to grain: <u>340 psi</u>

Margin: 340/180 = <u>1.9</u>

2.1.9.3 <u>Impact Plate Lateral Loading</u>



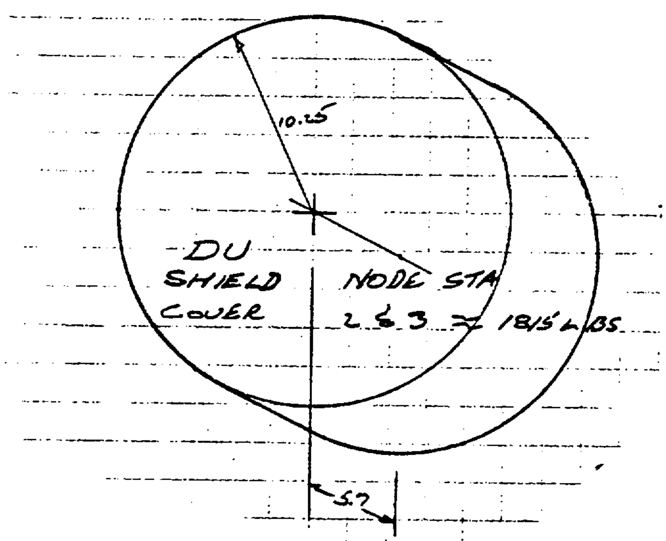
Impact Plate does not move. Impact plate lateral loads supported by bolt shear.

Lateral Load: $L_L = \mu_y \sin\theta W = \mu_s W$

$L_L = 272.1 (657.4) = \underline{178,770 \text{ lb}}$

Bolt Shear: $\sigma_S = L_L/(24)(0.8920) = \underline{8350 \text{ psi}}$

2.1.9.4 Shield Lid Lateral Load



Rad = 10-1/4 in.

t = 5.7 in.

w = 1815 lb

n_y = 2721.1 gs

$P = Wn_y = 1815 (272.1) = \underline{4.939 \times 10^5 \text{ lb}}$

$(D_1 - D_2) = 20\text{-}5/8 - 20\text{-}1/2 = 1/8 = 0.125$ in.

$K_D = D_1 D_2/(D_1 - D_2) = (20\text{-}5/8 \times 20\text{-}1/2)/0.125 = \underline{3382.5 \text{ in.}}$

$$C_E = 2 \frac{1 - \nu^2}{E} = 2 \frac{1 - 0.3^2}{30 \times 10^6} = \underline{6.067 \times 10^{-8}}$$

(E stainless and uranium = 30.10^6)

$$\sigma_c = 0.798 \left[\frac{4.939 \times 10^5 \times 10^8}{5.7 \times 3382.5 \times 6.067} \right]^{1/2} = \underline{16{,}400 \text{ psi}}$$

σ_{yield} = 31,500 psi at 300°F

2.2. WEIGHTS AND CENTERS OF GRAVITY

A summary of the weights of Model FSV-1 in Configurations E, F and G is presented in Table 2-2. Model FSV-1 in Configurations E, F and G has been evaluated for the normal conditions of transport and hypothetical accident conditions while containing a total weight of 4430 pounds. This total weight consists of 2630 pounds for the inner container and 1800 pounds for the radioactive contents.

TABLE 2-2
ALLOWABLE WEIGHTS

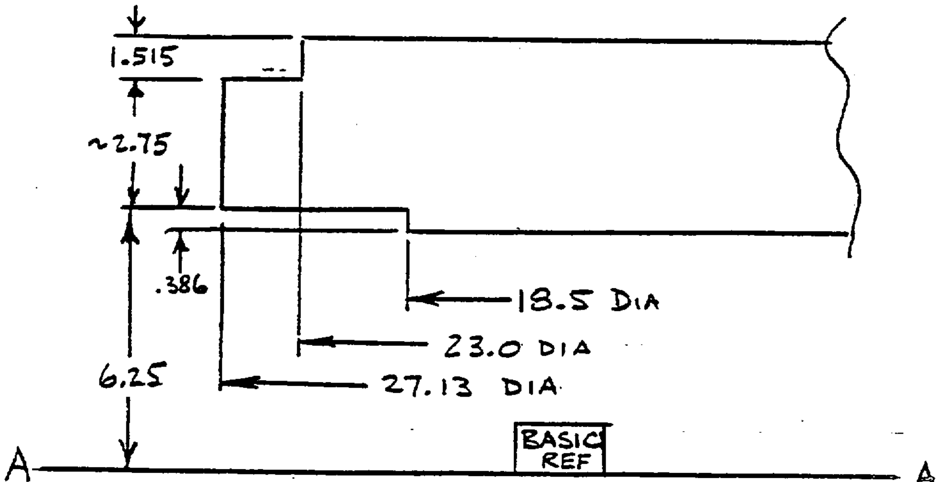
	Configuration E	Configuration F	Configuration G
Cask Body	43,160	43,160	43,160
Inner Container	2,630	not used	not used
Burial Canister/Spacer	not used	2,195	3,525
Contents-Allowable Weight	1,800	2,235	905
Total	47,590	47,590	47,590

The center of gravity of Model FSV-1 in Configurations E, F and G is located 109 inches from the bottom of the package.

2.2.1. Weight Calculations - Model FSV-1 Configurations E, F, and G

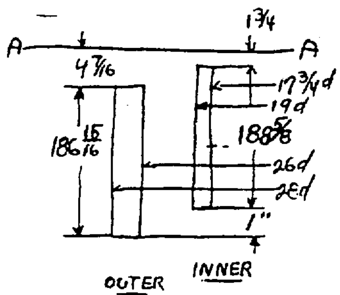
2.2.1.1. Outer Closure

ASSUME BOLTS ARE IN PLACE AND NEGLECT HOLES AND BOLT HEADS



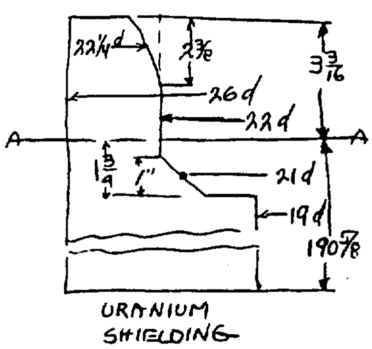
				V		y		Vy
TOP	23d	$\pi d^2/4 (1.515)$	=	629.4 in^3	X	-9.76	=	-6143.
MIDDLE	27.13d	$\pi d^2/4 (2.75)$	=	1589.7 in^3	X	-7.63	=	-12130.
BOTTOM	18.5d	$\pi d^2/4 (.386)$	=	103.8 in^3	X	-6.06	=	-629.
				2322.9				-18,902.
				X 0.283				X 0.283
			WT =	657.4 LB			M =	-5349. IN-LB

2.2.1.2 Cask Body



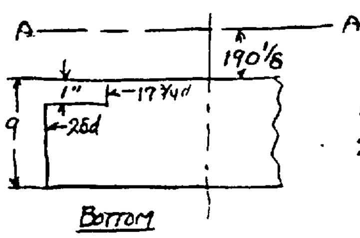
28d 613 in²
−26d −530
83 in² × 186 15/16 = 15,500 in³ × +97 29/32 = +1,511,000
(outer) wt ×.29 = 4500 lbs M = ×.29 = +439,000

19d 283.5 in²
−17 3/4 d −247
36.5 in² × 188 5/8 = 6870 in³ × +96.06 = +660,000
(inner) wt = ×.29 = 1990 lbs M = ×.29 = 191,200 "lb



26d	530 in²	× 193 13/16 =	+102,750 in³	× +93 23/32 =	+9,630,000
−19d	−283.5	× 188 5/8 =	−53,500	× +96 3/16 =	−5,150,000
−21d	−346	× 1 =	−346	× +1 1/4 =	−433
−22d	−380	× 1 9/16 =	−594	× −1/32 =	+19
−22 1/4 d	−389	× 2 3/8 =	−925	× −2 =	+1850
			−55,365		−5,148,563
			+47,385		+4,481,437
			×.683		×.683

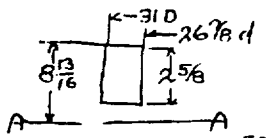
URANIUM wt 32,400 lbs M = +3,060,000"



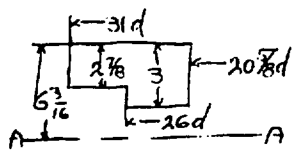
17 3/4 d	247 in²	× 1	= 247 in³	× +190 5/8 =	+47,100
28 d	613	× 8	= 4904	× +195 1/8 =	+960,000
			+5151		+1,007,100

wt = ×.29 = 1494 lbs M = ×.29 = 292,060 in-lb

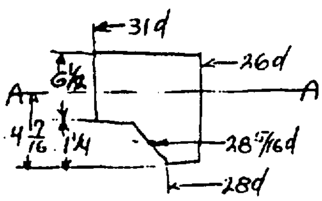
2.2.1.2 Cask Body (Continued)



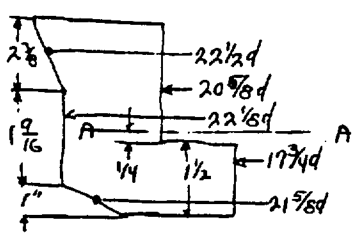
31d +752 in²
26⅞d −568
184 × 2⅝ = 483 in³ × −7½" = −3622
.29 .29
wt = 140 lbs M = −1050 in lbs



31d +752 in² × 2⅞ = 2160 in³ × −4¾" = −10,250.
26d +530 × ⅛ = 66 × −3¼ = − 216.
+2226 −10,466
−20⅞d −335 × 3 = −1005 × −$4\frac{11}{16}$ = + 4850
+1221 in³ − 5616.
.29 .29
wt = 354. lbs M = −1628 in lbs



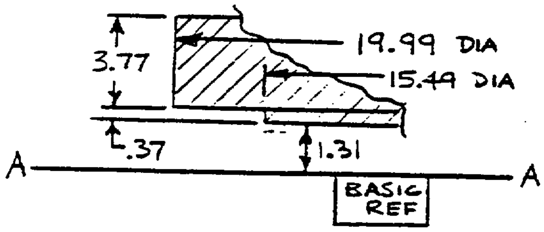
31d 752 in² × 6.5 = 4880. × −1/16 = − 305.
28$\frac{5}{16}$d 630 × 1¼ = 787 × +$3\frac{13}{16}$ = + 3000.
+5667 +2695
−26d −530 × 7¾ = −4100 × + 9/16 = −2300
+1567 in³ + 395.
.29 .29
wt = 455 lbs M = +114 in lbs



22½d 397 in² × 2⅞ = 942 in³ × −2¼ = −2120
22⅛d 385 × 1 9/16 = 601 × − 9/32 = − 169
21⅝d 367 × 1 = 367 × +1¼ = + 458
+1910 − 1831
−20⅝d −335 × 3 7/16 = −1154 × −$1\frac{15}{32}$ = +1670
−17¾d −247 × 1½ = − 370 × +1 = − 370
−1524 +1300
+386 − 531
.29 .29
wt = 112 lbs W = −154 in lbs

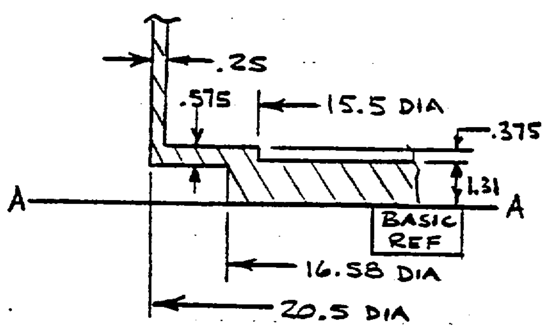
2.2.1.3. Inner Closure

DEPLETED URANIUM



				V	y	Vy
TOP	19.99 d	313.8 in²	x 3.77 =	1183.2 in³	x −3.565 =	−4218.1
BOTTOM	15.49 d	188.4	x .37 =	69.7	x −1.4975 =	−104.4
HOLES	−18 (.94)(3.77)(.75)		=	−47.8	X −3.565 =	+ 170.5
				1205.1		4152.
				X .683		X .683
				WT. = 823.1 LBS		M = −2835.8 IN-LB

SHELL



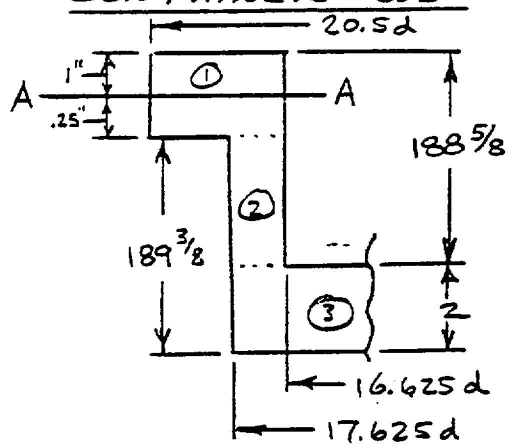
				V	y	Vy
TOP PLATE	20.5d	330 in²	X .25 =	82.5 in³	X −5.585 =	− 460.9
CYLINDER	20.25 π X .25		X 4.46 =	70.9	X −3.355 =	− 238.
BOTTOM PLATE	16.58d	215.9 in²	X 1.31 =	282.8	X −.655	− 185.3
RING AT BOTTOM	20 d	314.2	X .575 =	180.6	X 1.3975	− 252.4
	−15.5d	188.7	X .575 =	− 108.5	X 1.3975	+ 151.6
BOLTS & SLEEVES	16 (3.77)(.75)(.92)		=	41.6	X −3.355	− 139.6
				550.		−1124.6
				X .29		X .29
				WT = 159.5 LBS		M = −326.1 IN-LB

TOTALS

WT = 982.6 LBS   M = −3162

2.2.1.4. Inner Container

CONTAINER BODY

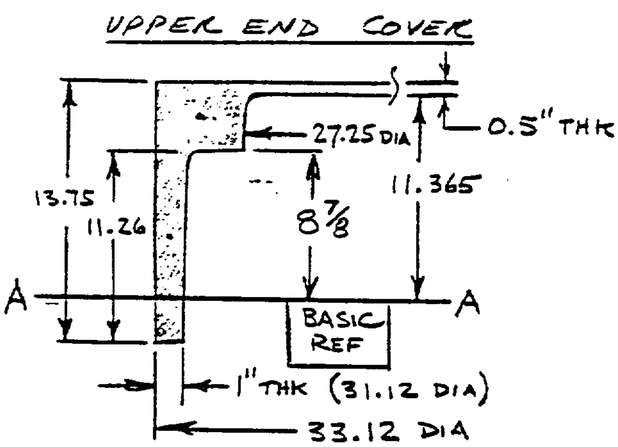


		V		y		Vy
①	$\frac{\pi}{4}(20.5^2 - 16.625^2)(1.25)$ =	141.2 in^3	X	-.375	=	-53
②	$\pi/4\,(17.625^2 - 16.625^2)(187.375)$ =	5040.4 in^3	X	+93.94	=	473,495
③	$\pi/4\,(17.625)^2\,(2)$ =	488. in^3	X	+188.625	=	92,040
		5669.6				565,482
		X .29				X .29
		WT = 1644.2 LB			M =	163,990 IN-LB

CONTENTS OF CONTAINER

300# x 6 = 1800 LB x 93.844 = 168,919 IN-LB

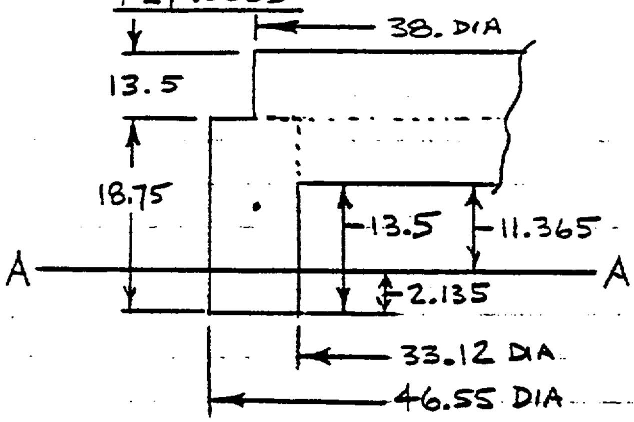
2.2.1.5. Impact Limiter



		V		y	Vy
OUTER	32.12 d	$\pi d (11.26)(1) = 1136.2$	in^3	X −3.245	= −3687.
TOP	27.25	$\pi d^2/4 (0.5) = 291.6$	in^3	X −11.615	= −3387.
REMAINDER	27.25	$\pi (30.185)(2.935)(2.49) = 693.0$	in^3	X −10.12	= −7013.
		2120.8			−14087
		X .098			X .098
		WT = 207.8 LB			M = −1380.5 IN-LB

2.2.1.5. Impact Limiter (Continued)

PLYWOOD



			V	y	Vy
OUTER	39.835d	$\pi d(6.715)(18.75)$	= 15,757 in^3	X −7.24	= −114078.
TOP	38d	$\pi d^2/4\ (13.5)$	= 15,311 in^3	X −23.365	= −357,742
INNER	33.12d	$\pi d^2/4\ (5.25)$	= 4523 in^3	X −13.99	= −63,277
			35,591		−535,097.
			X .0208		X .0208

ALUMINUM SHEATH

			V	y	Vy
BOTTOM PLATE	39.835d,	$\pi d(6.715)(0.25)$	= 210.1 in^3	X +2.26 =	+ 474.8
TOP PLATE	46.55d	$\pi d^2/4\ (0.25)$	= 425.5 in^3	X −27.24 =	−11,590.
CYLINDER	46.63d	$\pi d(.06)(32.75)$	= 287.9 in^3	X −13.99 =	−4027.
MTG RING	30.97d	$\pi d(.63)(2.16)$	= 132.4 in^3	X 2.8 =	+370.7
(90-H1501-106)	31.34d	$\pi d(.37)(1.78)$	= 64.8 in^3	X 3.3 =	+214.
			1120.7 in^3		−14,558
			X .098		X .098
TOTALS FOR			109.8 LB		−1427

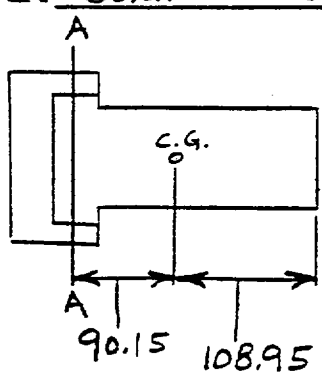
TOTALS FOR IMPACT LIMITER ASSEMBLY WT = 1057.9 LB M = −13,938

$$C.G. = \frac{-13,938}{1057.9} = 13.18 \text{ ABOVE A-A}$$

OR 17.18 BELOW TOP

2.2.1.6. Weight Summary

E. SUMMATION



	WT	MOMENT
HEAD	657.	− 5349.
CASK	140.	− 1050.
	354.	− 1628.
	455.	+114.
	112.	−154.
	4500.	+ 439,000.
	1990.	+ 191,200.
	32,400.	+ 3,060,000.
	1494.	+ 292,060.
CONT LID	983.	− 3162.
CONT BODY	1644	+ 163,990.
CONTENTS	1800	+ 168,919.
IMPACT LIMITER	1058	− 13938

CASK TOTAL (LOADED) 47,587 LB 4,290,002 IN-LB
DISTANCE FROM A-A = 4,290,002/47,587 = 90.15"
C.G. IS 108.95" FROM BOTTOM OF CASK

2.2.2. Weight Calculations - Configurations F and G

Configurations F and G use the same burial canister.

Burial canister body	980 lb
Closure plug	655
total	1635 lb

2.2.2.1. Configuration F Spacer

The proposed spacer consists of six (6) steel tubes that are 4.75 inches in diameter, have a wall thickness of 0.125 inches and are 179.5 inches long.

Spacer	560 lb

2.2.2.2. Configuration G Spacer

This spacer is shown in Section 1. on drawing GADR 55-2-13 provides supplemental shielding.

Spacer with shielding	1890 lb

2.2.2.3. Weight Summary

The total allowable weight in the cask body for Model FSV-1 in Configurations E, F and G is 4430 lb and the allowable weight of any radioactive contents is 4430 lb less the weight of the burial canister and the spacer.

For Configuration F:

Total allowable	4430 lb
Burial canister	-1635
Spacer	-560
Radioactive contents	2235 lb

For Configuration G:

Total allowable	4430 lb
Burial canister	-1635
Spacer	-1890
Radioactive contents	905 lb

2.3 MECHANICAL PROPERTIES OF MATERIALS

2.3.1. Depleted Uranium (0.2% Mo)

Shielding Sleeve - Cask Body:

Density: 18.9 grams/cc or 0.683 lb/in.^{3}

Mechanical Properties:	Room Temperature	250°F
Ultimate Tensile Strength	60,000 to 100,000 psi	
Yield Strength	25,000 to 45,000 psi (tension)	73,000 psi (compression)
Reduction in Area	10% to 40%	
Elongation	8% to 15%	
Modulus of Elasticity	24 $(10)^6$ psi	22.73 x 10^6
Poisson's Ratio	0.21	
Shear Modulus	12 $(10)^6$ psi	
Hardness	Rockwell B 65 to 90	

Melting Point:	2070°F	
Thermal Expansion:	6.5 $(10)^{-6}$ in./in./°F	

Shielding Desk - Inner Closure:
Same properties as above except:

Ultimate Tensile Strength	75,900 psi	59,200 psi
Yield Strength (tension)	41,500 psi	36,300 psi
Modulus of Elasticity	23.3 x 10^6 psi	21.1 x 10^6 psi

2.3.2. Stainless Steel Pipe, Type 304 per ASTM Spec. A-351, Grade CF-8

Physical Properties:	Room Temp.	250°F	300°F
Density	0.287 lb/in.^{3}		
Melting Range	2550° to 2650°		
Modulus of Elasticity	28 x 10^6 psi	27.4 x 10^6 psi	27.1 x 10^6 psi
Specific Heat (32° to 212°F)	0.12 Btu/lb/°F		

Thermal Conductivity:

At 200°F	9.4 Btu/hr/ft^2/°F/ft
At 1000°F	12.5 Btu/hr/ft^2/F/ft

Mean Coefficient of Thermal Expansion:

32° to 212°F	9.6 in./in./°F x 10^{-6}
32° to 600°F	9.9 in./in./°F x 10^{-6}
32° to 1000°F	10.2 in./in./°F x 10^{-6}

Mechanical Properties:	Room Temp. (72°F)	250°F	300°F
Ultimate Tensile Strength	70,000 psi		
Yield Strength	30,000 psi	23,700 psi	22,500 psi
Elongation	35%		
Reduction of Area (approx.)	60%		
Hardness	R_B-88		

2.3.3. Stainless Steel Forgings, Type 304 per ASTM Spec. A-182, Grade F-304

Physical Properties:

Same as 2.3.2. above:

Mechanical Properties:

Ultimate Tensile Strength	70,000 psi
Yield Strength	30,000 psi
Elongation	40%
Reduction of Area	50%
Hardness (approx.)	R_B-88

2.3.4. ASTM A579 Alloy Steel [HY140(T)]

Physical Properties:	Room Temp.	300°F
Density	0.285 lb/in.^{3}	
Modulus of Elasticity	29.5 x 10^6 psi	28.5 x 10^6 psi
Ultimate Tensile Strength	150,000 psi	140,000 psi
Yield Strength	140,000 psi	130,000 psi
Elongation	15%	

2.3.5. 6061-T6 Aluminum Alloy

Modulus of Elasticity at 300°F	10.4×10^6 psi
Ultimate Tensile Strength at 300°F	35,000 psi
Yield Strength at 300°F	30,000 psid
Elongation at 300°F	20%

2.3.6. Douglas Fir Plywood

Crushing Stress parallel to Grain	3500 psi
Crushing Stress perpendicular to Grain	1800 psi
Shear stress allowable (Ref. 12, Table 38)	1000 psi
Tensile strength perpendicular to Grain (Ref. 13)	340 psi

The crushing stress remains nearly constant up to approximately 50% reduction of the original thickness. Beyond approximately 50% the crushing stress increases rapidly.

For the structural evaluation the lower of either the adhesive strength or the wood shear stress parallel to the grain was used for the shear stress allowable.

2.3.7. Uranium Welds

All uranium welding will be accomplished using single V-butt joints and inert direct current tungsten arc welding. The inert gas used for shielding and trailing shields shall be of welding grade argon. The filler and base metals shall be depleted uranium.

2.3.8. Stainless Steel Welds (Refs. 1 and 2)

All stainless steel welds will be in accordance with the "Rules for Construction of Nuclear Vessels" (Ref. 1). All of the welding procedures and welders will be qualified in accordance with "Welding Qualifications" (Ref. 2).

2.3.9. Seals (Refs. 3, 4 and 27)

a) Seal Assemblies, Gask-O-Seal, Parker Seal Company.
Material: Parker Compound S455-70 Silicone rubber or equivalent.

Outer Closure Seal - GA Technologies Inc. Drawing 1501-108, Issue C - o.d. = 23.63 and i.d. = 21.34
Inner Closure Seal - GA Technologies Inc. Drawing 1501-093, Issue D - o.d. = 18.72 and i.d. = 16.62

b) All metal O-rings shall be self-energized for use in bolted flange assemblies. These O-rings will be made of silver plated Inconel tubing. Service temperature is -320° to +1300°F. The following metal O-rings have been selected for sealing the Model FSV-1 in Configurations E, F, and G.

Cask Center Plug Seal - United Aircraft Products, Inc. Cat. No. U-6420-02813-SEA; o.d. = 2.81, i.d. = 2.56, Tube Diameter = 0.125.
Cask Purge Connection Cover Seal - United Aircraft Products, Inc. Cat. No. U-6420-02630-SEA; o.d. = 2.63, i.d. = 2.38; Tube Diameter = 0.125.

c) All elastomer O-rings shall be molded per AMS Specification 3304 of silicone rubber. Service temperature for this material is

-100° to +500°F. The material will resist temperatures up to 700°F for short periods. The compression force used to install these O-rings will be as recommended by the manufacturer (Ref. 4). The following silicone rubber O-rings have been selected for sealing Model FSV-1 in Configurations E, F, and G.

Cask Center Plug Seal - Parco No. PRP-568-236 (or equivalent) o.d. = 3.500; i.d. = 3.25, Diameter = 0.125.

Cask Helium Connection Cap Seal - Parco No. PRP-568-233 (or equivalent) o.d. = 3.125; i.d. = 2.875; Diameter = 0.125.

2.3.10 <u>Fasteners (Refs. 5, 6, 7)</u>

a) The bolts used in the assembly of the inner container are high alloy steel per AMS 5737, which corresponds to SA-453, Grade 660 in Ref. 1. These bolts are heat treated to 130 ksi/min ultimate tensile strength. The 1/2-in. size used in fastening the inner closure to the container body has a minimum ultimate axial tensile strength of 18,400 lb.

b) The bolts of the inner closure are threaded into "screw-lock" inserts made of Type 18-8 stainless steel (per AMS-7245B) wire having an ultimate tensile strength of approximately 200,000 psi. These "screw-lock" inserts meet military specification for locking torque and vibration. The internal thread conforms to thread form standards issued by the Department of Commerce (Ref. 6).

c) The bolts used in the assembly of the outer closure to the cask body alloy steel per AMS 5737 with the following physical properties for the 1-1/4-7 UNC size:

Tensile Strength, min.	130,000 psi
Yield Strength, min.	95,000 psi

2.3.11 Adhesives

The assemblies formed by laminating the plywood and then bonding the laminated plywood to the aluminum end cap are structurally important.

The plywood sheets have been laminated with Resorcinol resin to provide a waterproof joint that is stronger than the wood. Resorcinol is recommended by the American Plywood Association for structural assemblies fabricated in the field designed to withstand adverse environmental conditions.

An epoxy (Furane Epibond 1210/9861) is used between the aluminum end cap and plywood to provide a structural bond with a minimum shear strength of 1200 psi at 230°F for the maximum (130°F ambient) temperature condition. This particular expoxy was selected because it bonds well to diverse materials and retains sufficient strength at elevated temperatures.

2.3.12 Note:

The original analysis for Model FSV-1 in Configurations E, F and G was completed using 4340 Low Alloy Steel for the outer closure. Because the large billet of 4340 could not be heat treated properly to guarantee the required material conditions, the material was changed to ASTM A579 [HY140(T)]. Table 2-3 compares the properties of the two materials. Third column lists test

TABLE 2-3

COMPARISON OF 4340 AND ASTM A579 OUTER CLOSURE MATERIAL

Physical Properties	4340	ASTM A579 (Nominal)	ASTM A579 (Actual)
Density, lb/in.^{3}	0.285	0.285	
Modulus of Elasticity, psi			
At room temperature	--	29.5×10^6	
At 300°F	29.0×10^6	28.5×10^6	
Ultimate Tensile Strength, psi			
At room temperature	175,000	150,000	171,000
At 300°F	--	140,000	164,500
Yield Strength, psi			
At room temperature	165,000	140,000	160,500
At 300°F	150,000	130,000	154,300
Elongation, %			
At room temperature	17	15	16.5
At 300°F	18		13.

data from the actual material that was used for fabrication of the parts. An analytical check, using the data in column 2, showed the alternate material to be adequate for all conditions covered in the structural evaluation.

2.4. GENERAL STANDARDS FOR ALL PACKAGES

2.4.1. Iron-Uranium Eutectic Prevention (Reference 8)

Investigations have shown that uranium combines with stainless steel by solid state diffusion at temperatures above 1000°F. The iron-uranium eutectic melts at 1337°F so that if the two materials are in intimate contact at this temperature a molten alloy will be formed (Ref. 8).

Other investigations have shown that uranium in contact with stainless steel will penetrate the stainless steel by solid state diffusion in 24 h of 1400°F. At 1355°F there was no attack on the stainless steel.

Recent tests of stainless steel--uranium--stainless steel assemblies where the surfaces of the stainless steel next to the uranium were spray coated with a 0.005-in. thick coating of copper showed this coating to be an effective barrier to diffusion between the stainless steel and uranium at temperatures of up to 1750°F (Ref. 8). All surfaces of stainless steel in contact with the depleted uranium shielding will be coated with 0.005-in. thick copper coating for Model FSV-1 cask.

2.4.2. Positive Closure

Twelve (12) high strength socket head cap screws, torqued to 20 ft-lb are used to secure the inner closure to the inner container body. The inner container is transported within the cask body which is closed by the outer closure. The outer closure is secured to the cask body with twenty four (24) high strength socket head cap screws.

2.4.3. Lifting Devices

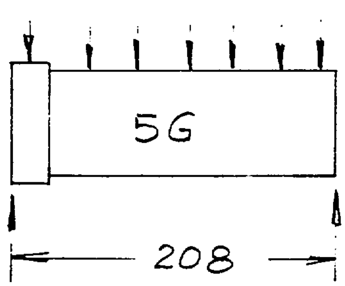
Model FSV-1 in Configurations E, F and G are lifted by means of two sockets installed in machined recesses located in the enlarged diameter section of the closure end of the cask body. A dedicated lifting device with a ball located on each arm is used to lift the package. The sockets are removable and can be replaced if damaged in anyway.

2.4.4. Tiedown Devices

During transport Model FSV-1 in Configurations E, F and G is attached to the rear support on the semitrailer by four (4) high strength socket head cap screws which are installed in threaded holes located in the base of the cask. The upper end of the package rests on a saddle mounted on the semitrailer and is restrained by a semicircular strap.

2.5. STANDARDS FOR TYPE B AND LARGE QUANTITY PACKAGING

2.5.1. Load Resistance



5g - Uniformly Distributed

WT = 46024 lb

W = 5(46024) = 230,120 lb

$$\text{Max at center} = \frac{W\ell}{8} = \frac{230120}{8}(208) = 6{,}000{,}000 \text{ in. lb}$$

Assume only outer shell is stressed

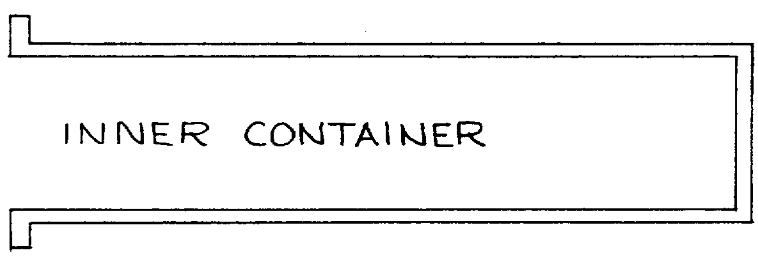
o.d. = 28" i.d. = 26" $I = \frac{\pi}{4}(R^4 - r^4) = \frac{\pi}{4}(14^4 - 13^4) = \underline{7750} \text{ in.}^4$

$$Z = \frac{7750}{14} = 554 \text{ in.}^3$$

$S_b = \frac{M}{Z} = \frac{6{,}000{,}000}{554} = \underline{\underline{10{,}800 \text{ psi}}}$ ok, less than 30,000 psi

2.5.2 External Pressure

25 psig Roark XVI Case 3c (Stability)



17-5/8 OD - 16-5/8 ID - 1/2 wall - 190-5/8 long

$$p^1 = \frac{1}{4}\ \frac{E}{1-\nu^2}\ \frac{t^3}{r^3} = \frac{1}{4}\ \frac{30(10^6)}{(1-.09)}\ \frac{(1/2)^3}{(8.31)^3} = \underline{1795} \text{ psi}$$

2.6. NORMAL CONDITIONS OF TRANSPORT

2.6.1 Differential Thermal Expansions

2.6.1.1 Clearances

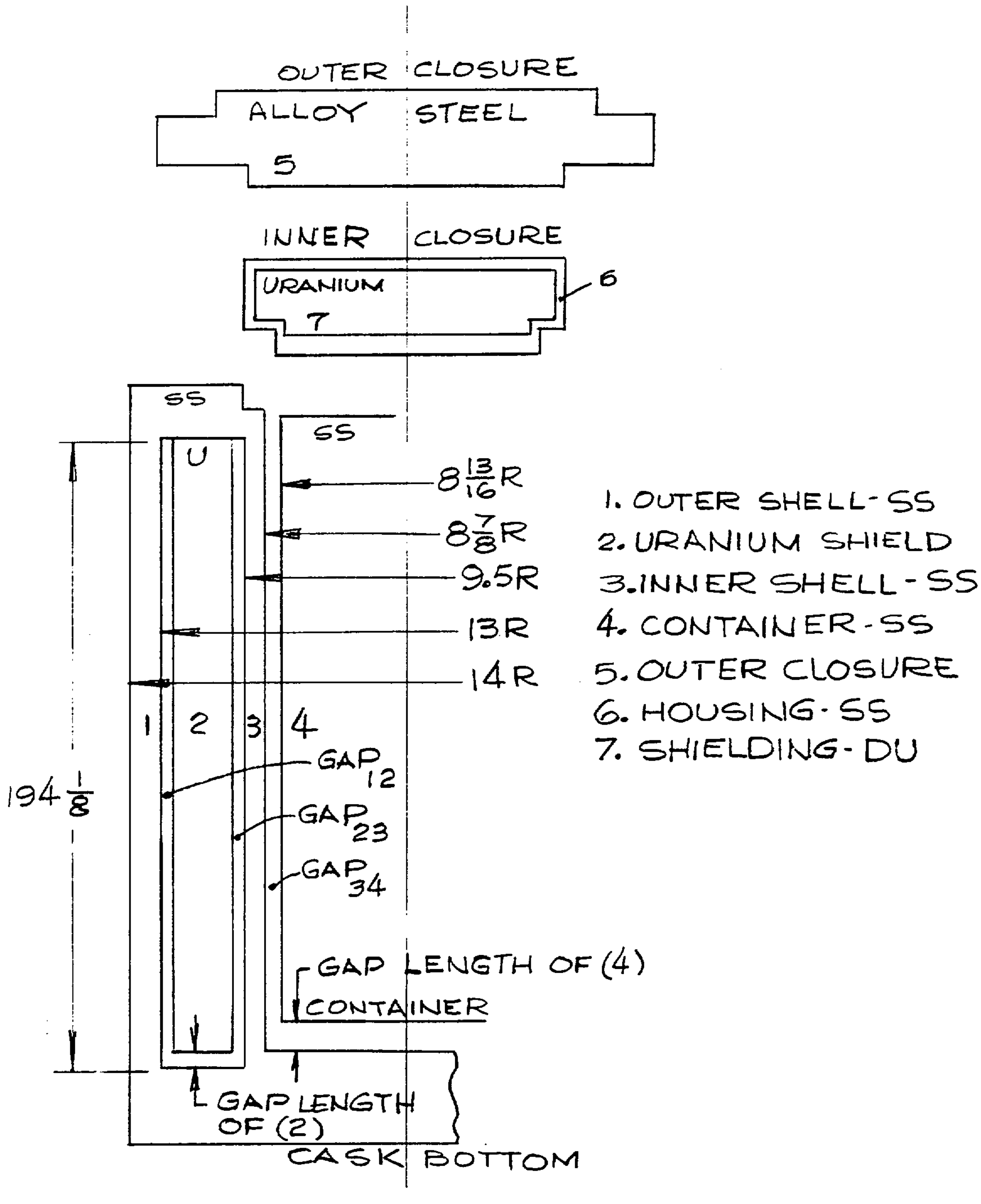
The cask and its container assemblies are stainless steel and uranium constructions. No lead is present and thus there are no problems associated with voids of this kind, which vary greatly in volume with changes in temperatures and also shift in position within the cask. The uranium is monolithic and jacketed by the steel. The dimensional proportions of the cask shielding cylinder uranium require that there be minimal clearances for machining and assembly purposes. These clearances are a substantial part of the differential expansions which developed in several of the cases examined. Materials and the associated gaps are identified on Fig. 2-2.

2.6.1.2 Coefficients of Expansion

Coefficient of thermal expansion used for uranium is 6.5×10^{-6} in./in. °F. This value is obtained from records of the NL Albany plant and refer specifically to as-cast 0.2% molybdenum uranium - unalloyed composition.

Stainless Steel values are from Section III, Table N-426 of the Nuclear Code, as follows:

Figure 2-2. Location of Gaps and Materials for FSV-1, Configurations E, F and G



A = instantaneous values at given temperature

B = mean coefficient (from 70°F to indicated temperature)

A	B	Temp °F
9.11	9.11	70
9.73	9.47	300
10.43	9.82	600
10.90	10.05	800

2.6.1.3 Temperature Distribution

Temperature distribution through the cask under hypothetical accident and fire conditions has been obtained from memorandum III, a part of the specification, dated 18 April 1968, and titled "Heat Transfer Calculations for PSC Fuel Shipping Cask". Heat generation rates were chosen in each case to give the maximum differential temperatures.

2.6.1.4 Cases Investigated

The following cases are investigated relative to axial and to radial differential expansions and contractions for the two uranium bodies contained within the stainless steel structure.

Case 1 - 30 minutes after start of fire (1101 Btu/hr fuel rate)
Case 2 - 10 hours after start of fire (2322 Btu/hr fuel rate)
Case 3 - start up - cask 70° - container and inner shell 240°
Case 4 - Immersion in water 70° - container and inner shell 240°
Case 5 - Low temp. - 40° whole cask - No container
Case 6 - Low temp. - 40° cask - Container and inner shell 240°

2.6.1.5 Analysis of Uranium Shielding in Cask Body

In the calculations + is a clearance or gap
- is an interference (based on original 0 gap)

The various negative (-) dr or dl values thus indicate the minimum initial clearances at 70°F required to prevent interference and stressed conditions. These requirements are reflected in the drawings.

The maximum values required for such clearances for the cask itself are:

Gap 12 = -0.0322 from case 2

Gap 23 = -0.015 from case 2

Gap 34 = -.03670 from case 3

Length container = -0.309 from case 6

Interferences - to be prevented by suitable mfg. clearances.

Case 1

$T_1 = 1120°$ $T_3 = 430°$ $T\theta = 70°$ $T_4 = 370°$

Gap 12 Assume $T_2 = T_3$ for max. diff.

$dr = (13")(T_1 - T\theta)(10.05)10^{-6} - (13")(T_2 - T_0)(6.5)10^{-6}$

$= 0.137 - 0.0304 = +$ 0.1066" SS > U gap

Gap 23 Assume $T_2 = T_3$ for min. clearance

$dr = (9.5")(T_2 - T_0)(6.5)10^{-6} - (9.5")(T_3 - T_0)(9.6)10^{-6}$

$= 0.0222 - 0.328 = -$ 0.0106 U < SS Interference

Gap 34 Assume T_4 = 370° from 2322 Btu/hr fuel rate

dr=(8-7/8")(T_3 - T_0)(9.6)10^{-6} -(8-13/16")(T_4 -T_0)(9.5)10^{-6}

= 0.0306 - 0.0251 = + 0.0055 gap

Length of U. Assume T_2=T_3 for max. differential

dl=(194-1/8)(T_1-T_0)(10.05)10^{-6} -(194 1/8)(T_3-T_0)(6.5)10^{-6}

= 2.05 - 0.455 = 1.595" expansion SS > U gap

Container shows gap.

Case 2

T_1 = 220° T_3 = 340° T_0 = 70° T_4 = 370°

GAP 12 Assume T_2=T_3 for min. clearance

dr=(13")(T_1 - T_0)(9.4)10^{-6} -(13)(T_2 - T_0)(6.5)10^{-6}

= 0.0183 - 0.0228 = -0.0045 U > SS Interference

Gap 23 Assume T_2=T_1 for min. clearance

dr=(9.5")(T_2 - T_0)(6.55)10^{-6} -(9.5)(T_3 - T_0)(9.47)10^{-6}

= 0.00925 - 0.0243 - 0.015 U < SS Interference

Gap 34 Assume T_4 = 370°

dr=(8-7/8")(T_3 - T_0)(8.47)10^{-6} -(8-13/16)(T_4 -T_0)(9.47)10^{-6}

= 0.0227 - 0.025 = 0.0023 Interference

Case 3 Cask at original dimen. T_4 = 241° T_0 = 70° T_3 = 70°

Gap 34 dr=0-(8-13/16)(T_4-T_0)(9.7)10^{-6}

= - 0.0367" container increase - interference

Length Container

$dl=(187-5/8)(T_4-T_0)\ (9.7)10^{-6}$

$=-0.309$ container increase Interference

Case 4

$T_1 = 70°$ T_2 assumed $= T_3 = 450°$ $T_0 = 70°$ $T_4 = 240°$

Gap 12 $= 0 -(13)(T_2-T_0)\ (6.5)10^{-6}$

$= 0 - 0.0322 = -.0322$ SS < U Interference

Gap 23 = 0

Gap 34 = negligible

Length Container - in time same as case 3

Case 5

$T_1=T_2=T_3 = 40°$ $T_0 = +70$

Gap 12 $dr = (13)(T_1 - T_0)(9.11)10^{-6} -(13)(T_1-T_0)(6.5)10^{-6}$

$= -0.013 + 0.0093 = 0.0037$ SS < U Interference

Gap 23 $dr = (9.5)(T_2 - T_0)(6.5)10^{-6} -(9.5)(T_3-T_0)(9.11)10^{-6}$

$= -0.0068 = 0.0095 = + 0.0027$ gap

Case 6

$T_1=T_2 = -40°$ $T_3=T_4 = 240°$ $T_0 = 70°$

Gap 23 $dr = (9.5)(T_2 - T_0)(6.5)10^{-6} -(9.5)(T_3-T_0)(9.11)10^{-6}$

$= -0.0068 - 0.0147 = -0.0218$ Interference

2.6.1.6 Analysis of Uranium Shielding in the Inner Closure

Clearances:

The inner closure is made of depleted uranium encased in type 304 stainless steel. Gaps exist between the stainless and the depleted uranium to allow for installation of the uranium during assembly of the closure.

Coefficients of Expansion:

Coefficient of expansion used is 6.5×10^{-6} in./in. °F for uranium. This value is obtained from records of National Lead Company's Albany plant and refer specifically to as-cast 0.2% molybdenum uranium.

Stainless Steel values are from Section III, table N-426 of the Nuclear Code, as follows:

A = instantaneous values at given temperature
B = mean coefficient (from 70°F to indicated temperature)

A	B	Temp. °F
9.11	9.11	70
9.73	9.47	300
10.43	9.82	600
10.90	10.05	800

Temperature Distribution:

The depleted uranium portion of the inner closure is supported by the stainless housng with small gaps (0.030 in. average) between the stainless and the uranium on the top and sides. The stainless and the uranium temperatures are within 25°F of each other during both the steady state conditions and during the transient condition of the hypothetical fire accident.

Dimensional changes:

The stainless steel housing and depleted uranium shielding of the inner closure both expand with increasing temperature. Since the thermal expansion coefficient of the stainless steel is greater than that of the depleted uranium, the stainless housing will expand at a greater rate and the uranium to stainless gap will tend to grow with increasing temperature. There will be no tendency for the uranium to apply thermal expansion stress loads to its stainless steel housing.

The crystal structure of uranium is orthorhombic. This material may exhibit nonuniform crystal lattice growth upon thermal cycling. This growth may result in dimensional growth for hot or cold worked materials with oriented grain structure. The thermal cyclic growth (of uranium) is negligible if peak temperatures of cycling never exceed 299 to 349°C (570 to 660°F). See Ref. 2-26. From Table 3-2 of this document, the maximum temperature of the depleted uranium shielding is 299°F for the normal conditions of transport, and 486°F for the hypothetical accident conditions. Both of these temperatures are well below the critical temperature cycling range of 570 to 660°F.

2.6.2. Vibration

This cask is designed for transport by semitrailer only. Therefore, the only concern is that the fundamental frequency of vibration for the cask as a simply supported beam, loaded by its own weight, be appreciably higher than the repeatable impulse frequencies for the trailer itself.

The cask is considered to have a total moment of inertia (I) equal to the sum of the individual I values of the two shells and the uranium cylinder.

$$I_{\text{outer shell}} = \pi/4\ (14^4 - 13^4) = 7{,}750\ \text{in.}^4$$

$$I_{\text{inner shell}} = \pi/4\ (9.5^4 - 8.875^4) = 1{,}530$$

$$I_{\text{uranium}} = \pi/4\ (13^4 - 9.5^4) = \underline{16{,}041}$$

$$I_{\text{total}} = 25{,}321\ \text{in.}^4$$

Total weight of cask and contents = 47,600 lb

ℓ = 208 in.

$$\text{Frequency} = \frac{3.55}{\sqrt{\frac{5}{384}\frac{W\ell^3}{EI}}} = \frac{3.55}{\sqrt{\frac{5}{384}\frac{(47{,}600)(208)^3}{29 \times 10^6\ (25{,}321)}}}$$

$$= \underline{40.7} \quad \text{cycles per second (cps)}$$

Fundamental frequencies developed in trailers are generally in the range of 4 to 16 cps (see "Shock and Vibration Handbook, Vol. 3, Sect. 45).

2.6.3 Internal Pressure 50 psig Roark XIII - Case 1

See section 2.5.2 for inner container description

Hoop Stress

$$S_2 = \frac{PR}{t} = \frac{50(8.62)}{1/2} = 872 \text{ psi} \quad \text{ok, less than 30,000 psi}$$

Meridional Stress

$$S_1 = \frac{PR}{2t} = \frac{862}{2} = 481 \text{ psi}$$

Radial Displacement

$$= \frac{R}{E}(S_2 - \nu S_1)$$

$$= \frac{8.62}{30(10^6)}\left[862 - 0.3\ (431)z\right] = \frac{6300}{30(10^6)} = 0.00021 \text{ inches} \quad \text{ok}$$

2.6.4 Free Drop

2.6.4.1 Bottom 1-ft Drop

The integrity of the alternate closure system for a one foot bottom drop was verified through HONDO run No. BOT-11. Details of the HONDO model are presented in 2.7.3. This run is similar to the strain rate sensitive case except for the initial z-velocity v.

$s = 1$ ft = 12 in. for $1/2\ a\ t^2 = 12$

or $t = \dfrac{2 \times 12}{384} = \underline{0.25 \text{ sec}}$

$v = 0 + (384)(0.25) = \underline{96.0 \text{ in./sec}}$

Initial z-velocity = -9.60 in./sec for all nodes except nodes 1 - 11.
The results are summarized in Table 2-4.

2.6.4.2 Side Drop

This section shows the results of a one-foot side free drop of the cask without the impact limiter onto an unyielding surface and verifies the adequacy of the cask closure bolts' shear and inner closure bearing strengths.

Cask Closure:

Cask closure wt = 777 lb

$(\pi/4\ (27.12)^2\ 4.75\ (0.283) = 777$ lb)

Load factor n_s = g's

Ref. computer code run 39370 (2-8-79).

$n_s = 302$

Side Load F_s

$$F_s = W\ n_s = 777\ (302) = \underline{234{,}654\ \text{lb}}$$

Cask Closure Bolts

24 1-1/4 - 7 UNC - 2A x 4.5

Bolt Area:

$$24\ A_{root} = 24 \times 0.892 = \underline{21.408\ \text{in.}^2}$$

Bolt Shear:

$$\sigma = F_s/A_B = \frac{234{,}654}{21.408} = \underline{10{,}960\ \text{psi}}$$

If only 50% bolts loaded (no register)

$$60\%\ \sigma_y > \sigma_s = 21{,}920\ \text{psi}$$

Preload 600 lb - $\sigma_x = 6725$ psi

$$\tau_{max} = 1/2\ (\sigma_x^2 + 4\ \tau_{xy}^2)^{1/2} = 1/2\ \sqrt{672.5^2 + 4(21{,}920)^2}$$
$$= \underline{22{,}175\ \text{psi}}\ \text{max shear}$$

$$\sigma_p = \sigma_x/2 + \tau_{max} = \frac{6725}{2} + 22{,}175 = \underline{25{,}540\ \text{psi}}\ \text{principle stress}$$

Inner Closure:

Inner closure wt** 665 lb

All DU assumed to be concentrated at the node.

g's = 602 Ref. computer run 3970 dated March 8, 1979.

F_s Load = $W\ n_s$ = 665 (602) = <u>400,330 lb</u>

12 bolts 1/2 13 UNC - 2A

Inner closure bolts not loaded in shear.

Closure side hearing area:

$A_B = D \times \ell = 20.5 \times 6 = \underline{123\ in.^2}$

Bearing Stress:

$$\sigma_p = F_s/A_B = \frac{400,330}{123} = \underline{3255\ psi}$$

**Note: The inner closure extends over two mass stations. The DU of mass two and three were summed and the greater load factor of the node is used for loads analysis.

$Wt = \pi/4 \times 18.5^2\ (3 + 1.125)\ 0.6 = 665$ lb

2.7 HYPOTHETICAL ACCIDENT CONDITIONS

2.7.1 Free Drop

The dynamics of the 30-foot free fall requires that a value be found for the maximum stress at impact in order to use structural analysis methods based on statics.

Literature on the subject of dynamic stresses is largely theoretical and seldom of engineering application value. The complexity can be reduced by limiting the problem to (1) compressive stresses on flat impact (2) at 44 ft/sec and (3) to steel, aluminum and uranium materials.

The most promising engineering formula is that for dynamic compression of rigid-plastic cylinders and is the one used herein. It is well authenticated by:

(1) Goldsmith: Impact - eq. 5.97 page 191
(2) Cristensen: Dynamic plasticity - eq 7.8 page 55

TABLE 2-4
STRESS SUMMARY PER HONDO OUPUT FOR 1 FT BOTTOM DROP
(STRAIN RATE SENSITIVE CASE, RUN. NO. BOT-11)

Component	Element No.	Time (10^{-4} sec.)	Predominant Stress Type(s)	Max. or Min. Principal Stress (psi)	Yield Strength at Temp. (psi)
4340 Stl Bulkhead	232(Bot. CL)	17.0	Radial & Hoop	-11,420	150,000 (300°F)
0.2% Mo-U Alloy Shield, Lid	347 (Top CL) 303 (Bot. CL)	14.0 13.5	Radial & Hoop Radial & Hoop	-12,970 12,270	36,300 (300°F)
Top End of Container	205 (Inner Cyl.)	12.5	Axial Compr.	-28,520	30,300 (250°F)
Top End of Container	468 Cylinder Below Flange	17.5	Axial Tens.	21,580	*29,200 (300°F)
Container Lid Housing	281 (Bot. CL)	13.0	Rad & Hoop	11,650	*29,200 (300°F)

$\rho v_1^2 = \varepsilon_1 (P_1 - P_y)$

$\rho = \frac{lb/in^3}{386}$ $v_1^2 = [44 \text{ ft/sec} \times 12]^2 = 278{,}784 \text{ (in/sec)}^2$

where P_1 = initial, and maximum stress corresponding to moment of impact,

ε_1 = max. strain corresponding to P_1, and

P_y = static compressive yield point (log 0.002 in/in strain method)

Values of ρ and ρv_1^2

Aluminum	ρ = 0.097/386 = 0.000251	ρv_1^2 = 70
Steel (incl SS)	ρ = 0.290/386 = 0.0007512	= 209
Copper	ρ = 0.332/386 = 0.00086	= 240
Lead	ρ = 0.41/306 = 0.001062	= 296
Uranium	ρ = 0.683/386 = 0.001769	= 493

TABLE 2-5
TYPICAL DYNAMIC PROPERTIES

Material	Static Curve	P_y 0.002 offset	P_1	ε_1	P_1-P_y	$\varepsilon_1(R-P_y)$	$\frac{P_1-P_y}{P_y}$
Uranium Cast	NLC (Computed)	73,000	90,000	0.029	17,000	493.	0.233
302 SS	Goldsmith Fig. 250	41,350 F_{cy} = 35,000 (304SS)	53,800	0.01675	12,450	208	0.301

$$P_1 = 40,000 + \frac{825,000}{\varepsilon}$$

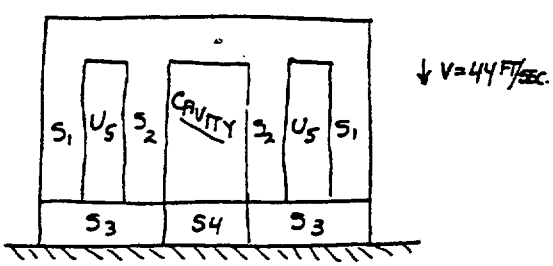
$$\varepsilon_1 = \frac{P_1 - 40,000}{825,000}$$

Material	Static Curve	P_y 0.002 offset	P_1	ε_1	P_1-P_y	$\varepsilon_1(R-P_y)$	$\frac{P_1-P_y}{P_y}$
0.24 Carbon Stl	Goldsmith Fig. 372	35,000	45,000	0.020	10,000	200	
Ni-Cr Stl	Goldsmith Fig. 118	220,000	228.000	0.024	8,000	192	0.036

2.7.1.1 End Drop

The dynamic analysis required for the cask and its parts, in the flat drop attitude, can be based on the concept of simple cylinders which behave as solid rods impacting squarely upon a rigid surface at the velocity of the specified free fall distance of 30 feet. This velocity is 44 ft/sec.

Values for stress, strain, K-E and G loadings can be derived for the individual masses and for the cask as a whole.



MODEL FOR ANALYSIS

S_1 = Outer S.S. shell

S_2 = Inner S.S. shell

U_5 = Uranium cylinder

These are considered separate cylinders

S_1 and S_2 weights include parts of the head weight

S_3 = SS plate - acting as striking plate under S_1, U_5 and S_2

S_4 = part of S.S. plate stressed by impact from container, etc

	Area	Weight
S_1	86.3 in²	5125 lb (includes 860 lb-outer closure)
S_2	36.8 in²	2260 lb (includes 270 lb-inner closure)
U_5	250.9 in.²	32,400 lb
	374 in.²	39,785 lb

S_3	378.5 in.^{2}	990 lb
S_4	248.5 in.^{2}	5,249 lb (1919 container, 1800 contents)
	Total	46,024 lb

Initial and maximum stresses developed by striking a rigid mass are calculated for uranium and steel, derived from

$\rho v_1^2 = \varepsilon(P_1 - P_y)$ as previously shown

P_1 uranium = 90,000 psi

P_1 stainless steel = 53,800 psi

For cylinders S_1, U_5 and S_2, the assumption of striking a rigid mass is conservative. Actually, they strike against an intermediate mass S_3, with some consequential reduction in stress.

S_3, on its under-surface, does strike a rigid mass, and counts S_1 U_5 and S_2 only as added load, considered as an equivalent weight of steel, added to the height of S_3 as a cylinder.

Stress differentials at the interfaces with S_3 are considered localized and quickly find equilibrium, producing a local increase in stress intensity in S_3 to match a reduced stress in U_5.

Total force developed at impacting face $F = P_1$ (area)

For S_1	F_1 = 86.3 in² x 53,800 psi =	4,640,000 lb
S_2	F_2 = 36.8 in² x 53,800 psi =	1,975,000 lb
U_5	F_5 = 250.9 in² x 90,000 psi =	22,581,000 lb

G's Developed — G = F/wt

S_1	4,640,000/5125 =	905 G
S_2	1,975,000/2260 =	875 G
U_5	22,581,000/32,400 =	697 G
S_3	29,196,000/39,785 =	735 G for bottom of cask

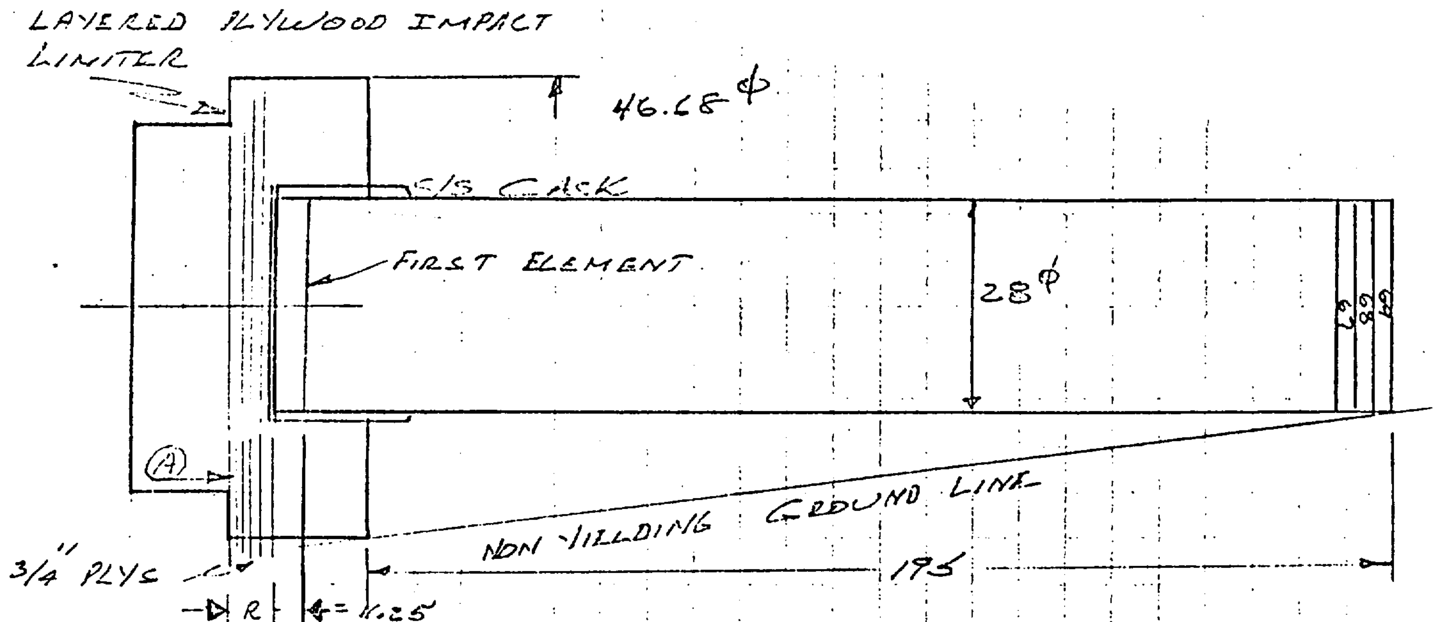
2.7.1.2. Side Drop

Simultaneous impact on the tail and the plywood impact limiter section after release from a 30-ft height induced the side loading of the cask analogous to that of a simply supported beam. This loading, from a bending standpoint, is the most severe loading condition. All the kinetic energy is absorbed by the impact deformation and beam deflection.

The cask model is made up of 69 disk elements with the appropriate section properties. Side drop geometry is described in Figure 2-3.

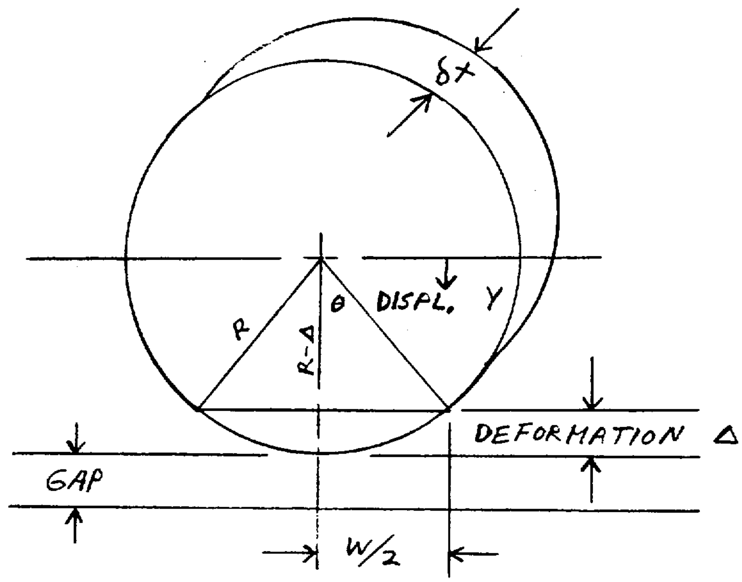
All extreme yielding was below 35% by a good margin in the case of the stainless steel (Ref. computer code DEC 15-002, side drop 02) and below 8% for uranium (side drop only).

FIG. 2-3



PLY LAYERS ABOVE S/S CASK HAVE THEIR CRUSH LOADING TIED TO FIRST CASK ELEMENT

Resistance of Cask to Deformation



$\delta_F = (W\ \delta_x)\ \sigma_F$

$\theta = \cos^{-1}\{(R - \Delta)/R\}$

$W = 2\ R\ \sin\theta$

$\Delta = y$ - GAP (if positive) otherwise $\Delta = 0$

Resistance Function per Code

Force = 2 * R * sinθ * sigma * Dx

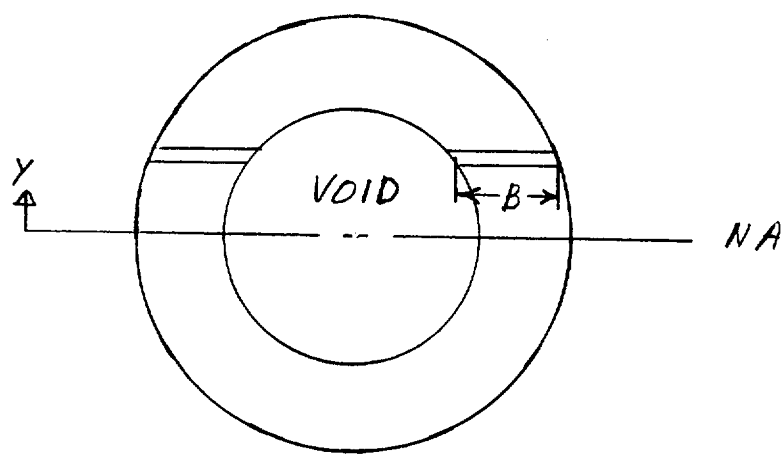
Del = Y-G (if positive)

Theta - A cos ((R - del)/R)

The maximum value of 'del' is saved to be compared to previous value to see if unloading is taking place.

Solid Section

Since type 304 stainless steel lacks a pronounced yield stress, the actual stress-strain curve shown on Figure 2-4 was employed for the moment curvature codes. The standard assumption was made that the strain distribution remains linear.



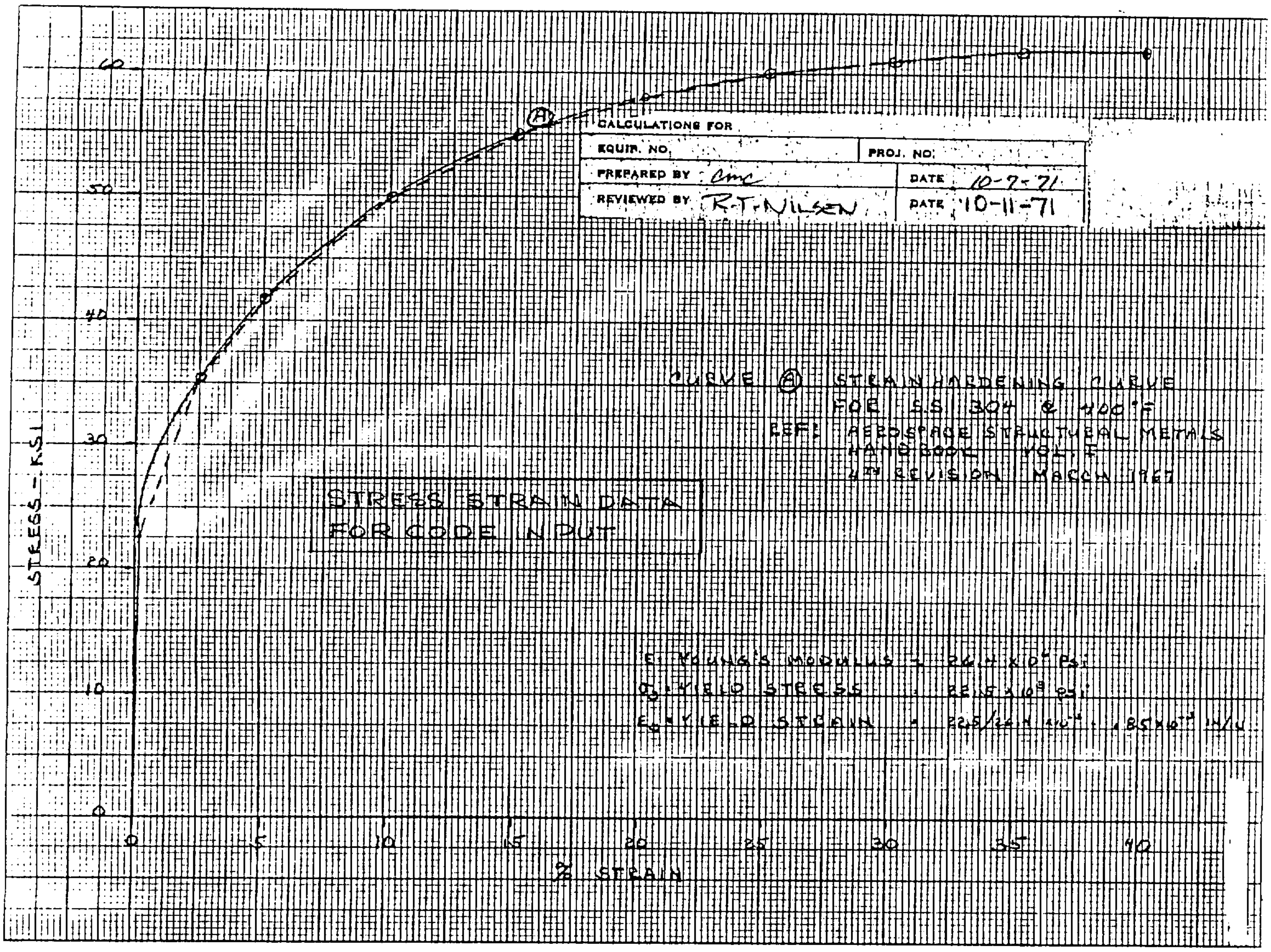
$$\varepsilon(y) = \phi \times y$$

$$F = 2\int_0^R \sigma\, \varepsilon(y) \times B(y)\, dy = 0$$

$$M = \int_0^R y \times \sigma\, (\varepsilon(y) \times B(y)\, dy$$

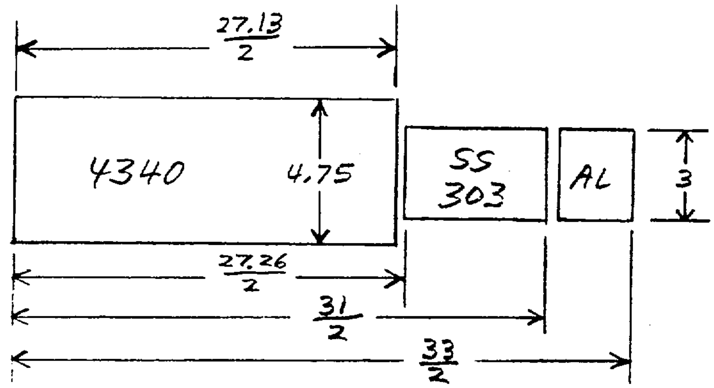
A computer subroutine was used to evaluate the integral in the above moment expression. The stress-strain curve was approximated by the straight line segments shown on Figure 2-5. Linear interpolation was used between the circled points.

FIG. 2-4


CALCULATIONS FOR
EQUIP. NO.
PROJ. NO.
PREPARED BY cmc
DATE 10-7-71
REVIEWED BY R.T. NILSEN
DATE 10-11-71
STRESS - KSI
% STRAIN
0
10
20
30
40
50
60
5
15
25
35
STRESS STRAIN DATA
FOR CODE INPUT

2.7.1.3 Calculation of Mass Point Properties

Point 1 - Total Impact Plate 4.75 in. + 3 in. ss



$W = \pi/4\ (27.13^2 * 4.75 * 2.83 + (31^2 - 27.26^{-2}) * 3 * 0.3$

$+ (33^3 - 31^2)\ 3 \times 0.1$

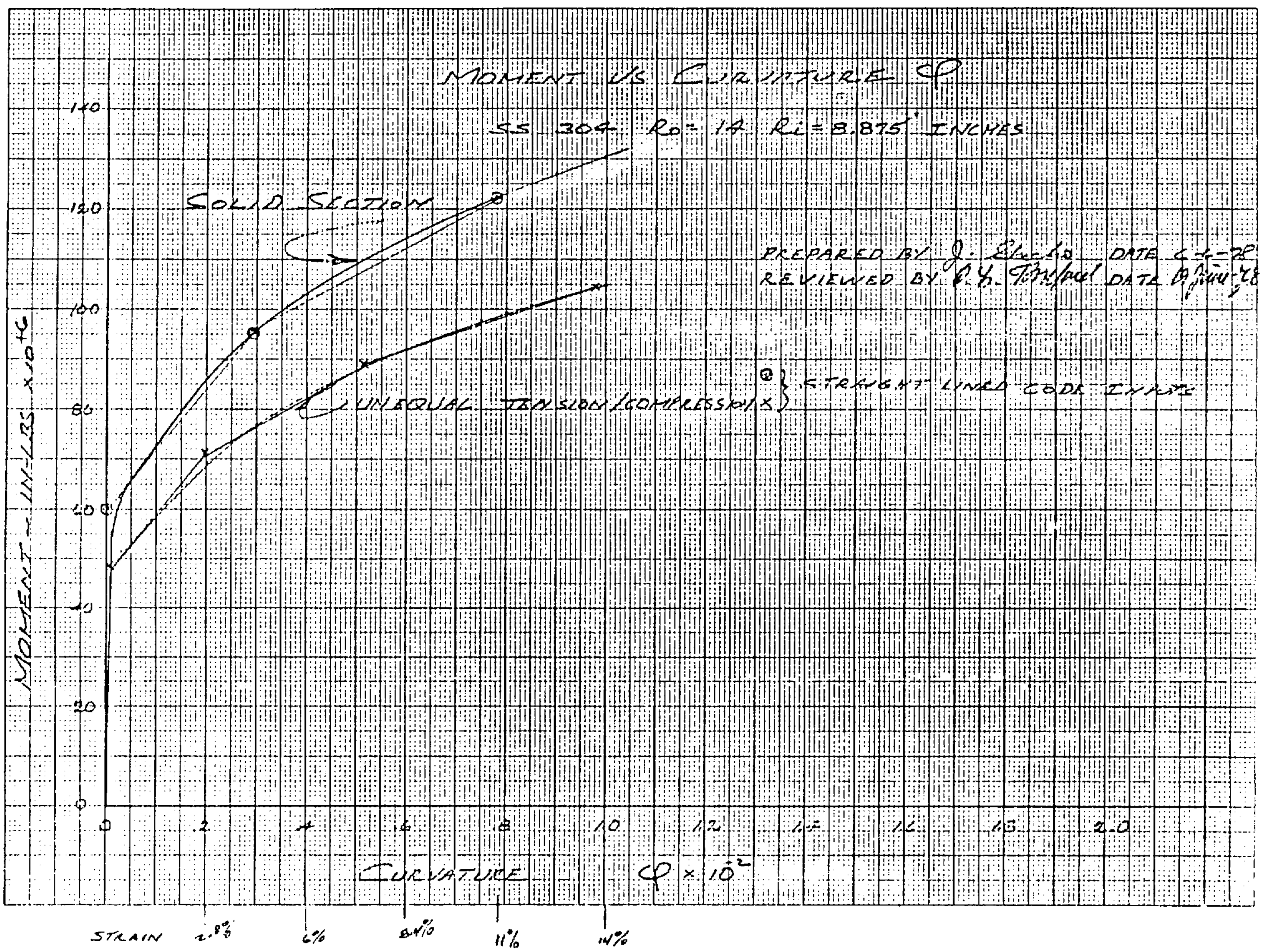
$\pi/4 \quad 989.4 \quad 196.1 + 38.4) = \underline{961\ lb}$

$M = w/g = 961/384 = \underline{2.50\ lb\ sec^2/in.}$

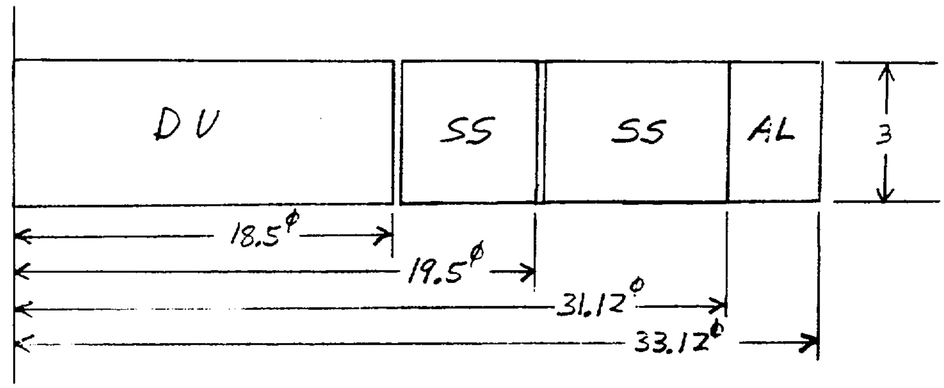
I (SS only) $\qquad E = 27.7 \times 10^6$ psi

$\pi/4\ (R_o^4 - R_i^4) = \pi/4\ (15.5^4 - 13.63^4) = \underline{18{,}227\ in.^4}$

FIG. 2-5


MOMENT VS CURVATURE φ
SS 304 Ro = 14 Ri = 8.875" INCHES
SOLID SECTION
UNEQUAL TENSION/COMPRESSION
PREPARED BY
REVIEWED BY
DATE
STRAIGHT LINED CODE INPUTS
MOMENT ~ IN-LBS x10+6
0
20
40
60
80
100
120
140
CURVATURE φ x 10-2
.2
.4
.6
.8
1.0
1.2
1.4
1.6
1.8
2.0
STRAIN
2.8%
6%
8.4%
11%
14%

Point 2



$W = 3\pi/4\ (18.5^2 * 0.6 + 19.5^2 - 18.5^2)\ 0.3 + 31.12^2 - 19.5^2)\ 0.3$

$+ (33.12^2 - 31.16^2)\ 0.1]$

$3\pi/4\ [205.35 + 11.4 + 176.46 + 12.85] = \underline{957\ \text{lb}}$

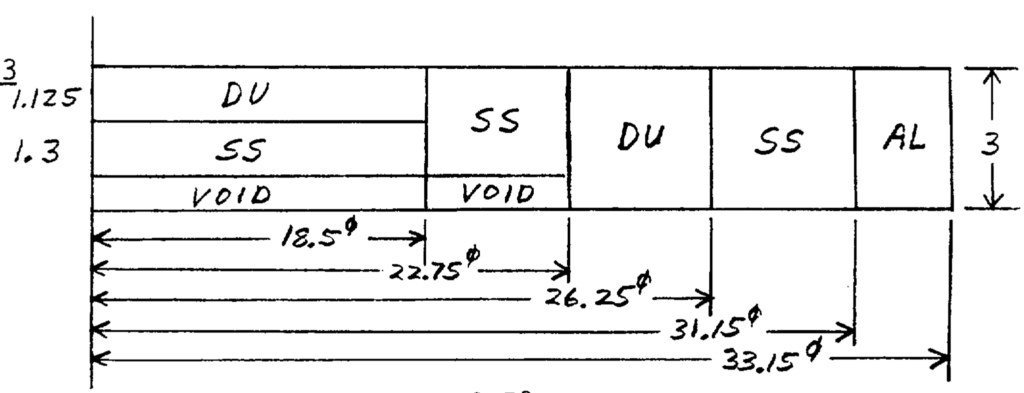
$M = w/g = 957/384 = \underline{2.49\ \text{lb sec}^2/\text{in.}}$

$E = 27.7 \times 10^6$ psi

I - (SS only)

$I = \pi/64\ \{(31.12^4 - 19.5^4) + (19.5^4 - 18.5^4)\} = 40{,}289\ \text{in.}^4$

Point 3



$$w = \pi/4\ (18.5^2 * (1.125 * 0.6 + 1.3 * 0.3) + (22.75^{-2} - 18.5^{-2})\ 2.43 * 0.3 + (26.25^{-2} - 22.75^2) * 3 * 0.6 + (31.15^{-2} - 26.25^{-2}) * 3 * 0.3$$

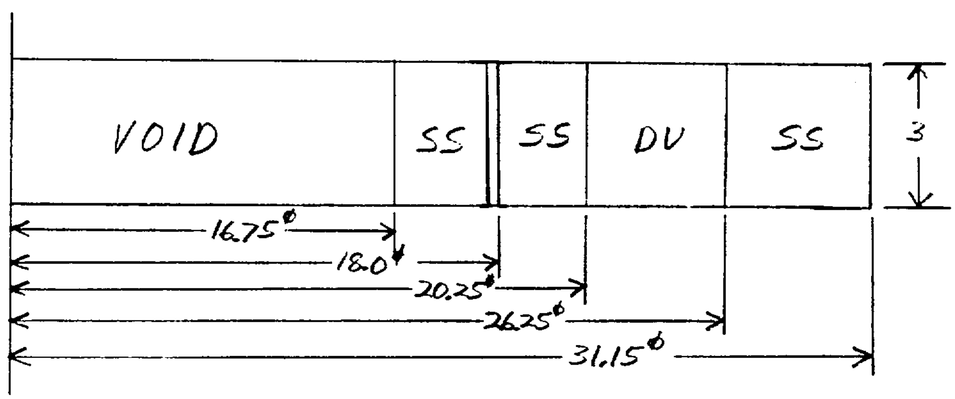
$$(33.15 - 31.15^2) * 3 * 1) = \pi/4\ (1092.7) = 858.2 \text{ lb}$$

$$m = w/g = 838.2/384 = 2.23 \text{ lb sec}^2/\text{in.}$$

$$I = \pi/64\ \{(31.15^4 - 26.25^4) + 26.25^4 - 22.75^4) + (22.75 - 18.5^4)$$

$$\pi/64\ \{824{,}391\} = \underline{40{,}467 \text{ in.}^4}$$

Point 4



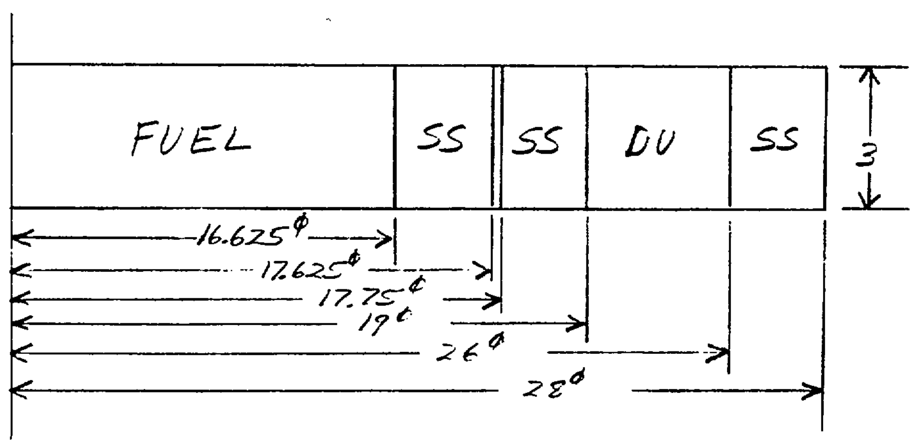
$$w = 3\pi/4\ \{(18^2 - 16.75^2)\ 0.3 + (20.25^2 - 18.0^2)\ 0.3 + (26.25^2 - 20.25^2)\ 0.6 + (31.15^2 - 26.25^2)\ 0.3\}$$

$$= 3\pi/4\ (290.628) = \underline{685 \text{ lb}}$$

$$M = w/g = 685/384 = \underline{1.78 \text{ lb sec}^2/\text{in.}}$$

$I = \pi/64\ (31.15^4 - 18.0^4) = \underline{41{,}064\ \text{in.}^4}$

Points 5 - 66



$W = 3\pi/4\ \{16.625^2 * 0.046 + (17.625^2 - 16.625^2)\ 0.287$

$+ (19^2 - 17.75^2)\ 0.287$

$+ (26^2 - 19^2)\ 0.683 + (28^2 - 26^2)\ 0.287\} = \underline{664\ \text{lb}}$

$I = \pi/64\ \{(28^4 - 26^4) + (26^4 - 19^4) + (19^4) - 17.75^4\} = \underline{25{,}999\ \text{in.}^4}$

Points 67-69

$W = 3 * \pi * 14^2 * 0.287 = \underline{530\ lb}$

$M = w/g = 530/384 = \underline{1.38\ lb\ sec^2/in.^2}$

$I = \pi/4\ 14^4 = \underline{30{,}172\ in.^4}$

2.7.1.4 Code Input Plastic Curvature vs. Moment

(Curve Points)

Point 1

$\underline{M = 60.E6}$ $\underline{\phi^P} \underline{= 0}$

Point 2

$M = \underline{95.E6}$

$\phi^P = 0.003 - 95\ EG/27.7E6\ 30/72$

$= \underline{0.00296}$

Point 3

$\underline{M = 122.E6}$

$\phi^P = 0.0079 - 122\ E6/27.7\ E6\ (30{,}172)$

$= \underline{0.0782}$