ENERGY SOLUTIONS INC.

ENGINEERING ANALYSIS COVER SHEET

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RETENTION PERIOD: Life of the Cask + 3 years

TITLE: Structural Evaluation of Misc. Components of 3-60B Cask

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REVIEWED BY: [signature] DATE: 1/30/08

TITLE: Chief Engineer

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ENGINEERING ANALYSIS REVIEW CHECKLIST

Document ID No.: ST-549 Revision No.: 0

	ITEM	YES	N/A *
1.	The purpose or objective is clear and consistent with the analysis.	✓	
2.	Design Inputs such as design bases, regulatory requirements, codes, and standards are identified and documented.	✓	
3.	Effect of design package on compliance with the Safety Analysis Report or Certificate of Compliance identified and documented.		✓
4.	References are complete and accurate.	✓	
5.	Latest version of the drawings is used, and the revision numbers are correct on the list of drawings.	✓	
6.	Assumptions are reasonable, and the list of assumptions is complete and appropriate.	✓	
7.	Assumptions that must be verified as the design proceeds have appropriately identified.		✓
8.	Analysis methodology is appropriate, and correct analysis method used.	✓	
9.	Correct values used from drawings?	✓	
10.	Answers and units correct?	✓	
11.	Summary of results matches calculations?	✓	
12.	Material properties properly taken from credible references?	✓	
13.	Figures match design drawings?	✓	
14.	Computer input complete and properly identified?	✓	
15.	Conclusions are consistent with the analysis results.	✓	
16.	Documentation of all hand calculations attached?	✓	

* Not Applicable, Explain

3. The results of the analyses in this document will be used in the SAR of the cask.
7. No assumptions that need to be verified made in this document.

Independent Reviewer [signature] Date 1/30/08

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ENGINEERING ANALYSIS REVIEW METHOD CHECKLIST

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ITEM		
1.	Alternate or simplified computational method.	
2.	Comparison of results to other calculations of a similar nature.	
3.	Numerical repetition of the calculations.	✓
4.	Comparison of calculations with experimental results.	
5.	Other (specify)	
6.	Comments:	

Independent Reviewer [signature] Date 1/30/08

OBJECTIVE

To evaluate the following components of 3-60B cask:

1. Cask tie-down lugs/brackets for installation of the impact limiters.
2. Impact limiter tie-down attachment.
3. Cask drain port assembly.
4. Buckling of the inner shell.

INTRODUCTION

3-60 Cask is detailed per Reference 1. To evaluate the cask tie-down lug/bracket and the impact limiter tie-down attachment, the maximum applied loading per Table 4 of Reference 2 is utilized. The maximum attachment force is 36,979 lbs and it occurs under regulatory hypothetical accident drop condition in corner drop orientation for cold thermal environment. To evaluate the cask drain port assembly, the maximum applicable loading per Table 3 of Reference 2 is used. The loading that the drain port assembly is examined for is the tributary load caused by the maximum impact limiter reaction under regulatory hypothetical accident drop condition in side drop orientation for cold thermal environment. Evaluating the cask ¾" thick inner shell for buckling under the maximum applied load for normal and hypothetical accident drop conditions. The governing load cases for the regulatory normal and hypothetical accident drop conditions occurs in end drop orientation for cold thermal environment.

REFERENCES

(1) Energy*Solutions* Drawing No. C-002-165024-001, Revision 0, "3-60 Cask General Arrangement and Details."

(2) Energy*Solutions* Document No. ST-557, Rev.0, Drop Analyses of the 3-60B Cask Package Using LS-DYNA Program.

(3) Roark's Formulas for Stress & Strain, 6th Edition.

MATERIAL PROPERTIES

<u>Cask Shell and Attachments</u>

Specification: ASTM A-240 Type 304L

Minimum Yield Strength, S_y = 25,000 psi

Minimum Ultimate Strength, S_u = 70,000 psi

Bolts

Specification: ASTM A-193, Grade B7

Minimum Yield Strength, S_y = 70,000 psi

Minimum Ultimate Strength, S_u = 90,000 psi

ALLOWABLE STRESSES

The following allowable values are utilized for the evaluations performed in this document:

Material Type	Normal Stress Allowable, psi	Shear Stress Allowable, psi
ASTM A-240 Type 304L	25,000	15,000
ASTM A-193, Grade B7	70,000	42,000

The allowable stresses in the weld are conservatively taken to be the same as the base metal.

STRUCTURAL EVALUATION

A. Cask Tie-Down Lugs/Brackets for the Installation of the Impact Limiters

Each impact limiter is attached to the cask at eight locations, as detailed per Reference 1, using 1" diameter bolts. Figure – 1 of this document shows the location and detail of a typical cask tie-down lug/bracket. Each bracket consists of a 1" × 5" × 4" top plate and two ½"×5" ×6" gusset plates. To install the 1" diameter bolt, the top plate is equipped with a 1 3/8" diameter hole centered in one direction and 1 ½" from the edge of the plate.

Conservatively a maximum attachment force of 37,000 lbs is used for the evaluation herein. Evaluating the top plate using an expression from Roark (Reference 3) for a rectangular plate simply supported along three sides and free on the other side with the uniform pressure (q) applied over entire plate, Table 26, case 2a,

a/b = 4/5 = 0.8

ß=0.538

q=37,000/(4×5)=1,850 psi

The maximum bending stress is:

$$\sigma_{\max} = \frac{\beta q b^2}{t^2} = \frac{0.538 \times 1{,}850 \times 5^2}{1^2} = 24{,}883 \text{ psi} < 25{,}000 \text{ psi} \qquad \text{O.K.}$$

Calculating the bearing stress on the top plate using the washer projection on the plate. The bearing stress is:

$f_{bearing} = 37{,}000/[(\pi/4) \times (2^2 - 1.375^2)] = 22{,}334$ psi < 25,000 psi O.K.

Assuming each gusset plate to react to ½ of the 37,000 psi load, the gusset plate bending stress is:

$$\sigma_{\max} = \frac{(37{,}000 \times 0.5) \times 2.5 \times 6}{0.5 \times 6^2} = 15{,}417 \text{ psi} < 25{,}000 \text{ psi} \qquad \text{O.K.}$$

Examining the weld connecting the 1" top plate to the cask outer shell, assuming simply supported edge and using the tributary shear load (F),

$F = 1{,}850 \times (0.5 \times 2.5 \times 5) = 11{,}563$ lbs

Using 5/16" continuous fillet weld all around connecting the 1" top plate to the 1 ¼" cask outer shell, assuming credit only for 4" of weld on top and bottom of the plate and conservatively ignoring the end welds, the weld shear stress is:

$$\tau = \frac{11{,}563}{0.707 \times 0.3125 \times 2 \times 4} = 6{,}542 \text{ psi} < 15{,}000 \text{ psi} \qquad \text{O.K.}$$

Using 5/16" continuous fillet weld all around connecting the ½" gusset plates to the 1 ¼" cask outer shell, considering a 45º bevel at corner of the gusset plate to allow for the 5/16" weld connecting the 1" top plate to 1 ¼" cask outer shell and assuming credit for a 5 ½" long line weld on each side of the gusset plate and conservatively ignoring the end welds, the weld shear stress is calculated using the following tributary loads:

The tributary shear load reacted by the gusset plate (V) is:

$$V = 1{,}850 \times [(4 \times 5 - 0.5 \times 2.5 \times 5) \times 0.5] = 12{,}719 \text{ lbs.}$$

Consider the load V centered on the 4" wide gusset plate, the bending moment is:

$M = 12{,}719 \times 2 = 25{,}438$ in-lbs.

$$\tau = \left[\left(\frac{12{,}719}{2 \times 5.5 \times 0.707 \times 0.3125}\right)^2 + \left(\frac{25{,}438}{\frac{5.5^2}{3} \times 0.707 \times 0.3125}\right)^2\right]^{0.5} = 12{,}561 \text{ psi} < 15{,}000 \text{ psi} \qquad \text{O.K.}$$

Examining the weld connecting the 1" top plate to the ½" gusset plates, assuming simply supported edges and using the tributary shear load (V), same as above,

$$V = 1{,}850 \times [(4 \times 5 - 0.5 \times 2.5 \times 5) \times 0.5] = 12{,}719 \text{ lbs.}$$

Using full penetration groove weld connecting the 1” top plate to the ½” gusset plates, allow for corner bevel and assuming 3” weld length, the weld shear stress is:

$$\tau = \frac{12{,}719}{0.5 \times 3} = 8{,}479 \text{ psi} < 25{,}000 \text{ psi} \qquad \text{O.K.}$$

Using the tensile stress area for the 1” diameter tie-down bolt, the maximum bolt tensile stress is:

$$f_t = \frac{37{,}000}{0.606} = 61{,}056 \text{ psi} < 70{,}000 \text{ psi} \qquad \text{O.K.}$$

B. Impact Limiter Tie-Down Attachment

As stated earlier, each impact limiter is bolted to the cask at eight locations as per Reference 1. Figure – 2 of this document shows the arrangement and detail of the impact limiter tie-down attachment. The tie-down attachment consists of a 1 ¾” ×53” I.D. ×59” O.D ring plate and sixteen ½” × 3” × 10” gusset plates. A pair of gusset plates connects the 1 ¾” ring to the ½” thick impact limiter inner plate at each bolt location as per Reference 1.

Examining the 1 ¾” ring using an expression from Roark (Reference 3) for a rectangular plate with three edges simply supported and one edge free with uniform load applied over entire plate, Table 26, case 2a,

a = 3, b = 2 ½”, a/b = 1.2

By interpolation ß = 0.71

q = 37,000/(3×2.5) = 4,934 psi

$$\sigma_{\max} = \frac{0.71 \times 4{,}934 \times 2.5^2}{1.75^2} = 7{,}149 < 25{,}000 \text{ psi} \qquad \text{O.K.}$$

Assuming each gusset plate reacts to one-half of the 37,000 lb load, the gusset plate bending stress is:

$$\sigma_{\max} = \frac{(37{,}000 \times 0.5) \times 1.5 \times 6}{0.5 \times 10^2} = 3{,}330 \text{ psi} < 25{,}000 \text{ psi} \qquad \text{O.K.}$$

Using 5/16” continuous fillet weld all around connecting the 1” gusset plate to the ½” thick impact limiter inner plate, considering a 45º bevel at corner of the gusset plates to allow for the 5/16” weld connecting the 1 ¾” ring plate to ½” impact limiter inner ring and assuming credit for a 9 ½” long line weld on each side of the gusset plate and conservatively ignoring the end welds, the weld shear stress is:

The shear load reacted by the gusset plate (V) is:

V = 37,000×0.5 = 18,500 lbs

The bending moment is:

M = 18,500 ×1.5 = 27,750 in-lbs.

$$\tau = [(\frac{18,500}{2\times 9.5\times 0.707\times 0.3125})^2 + (\frac{27,750}{\frac{9.5^2}{3}\times 0.707\times 0.3125})^2]^{0.5} = 6,071 \text{ psi} < 15,000 \text{ psi} \qquad \text{O.K.}$$

Considering 5/16" continuous fillet weld all around and on both sides to connect the 1 ¾" thick ring plate to ½" thick impact limiter inner plate, conservatively ignoring the gusset plate contribution and assuming only 6" of this weld to react to the shear load of 37,000 lbs, the weld shear stress is:

$$\tau = \frac{37,000}{0.707\times 0.3125\times 2\times 6} = 13,956 \text{ psi} < 15,000 \text{ psi} \qquad \text{O.K.}$$

Examining the weld connecting the 1 ¾" ring plate to each ½" gusset plate,

V = 37,000×0.5 = 18,500 lbs

Using full penetration groove weld connecting the 1 ¾" ring plate to each ½" gusset plate, allow for corner bevel and assuming 2" weld length, the weld shear stress is:

$$\tau = \frac{18,500}{0.5\times 2} = 18,500 \text{ psi} < 25,000 \text{ psi} \qquad \text{O.K.}$$

C. Cask Drain Port Assembly

The 3-60B cask is equipped with a drain line that is detailed per Reference 1. Figure – 3 of this document shows the drain line connecting to the ¾" thick cask inner bottom cover. The drain line has a 2 ½" outside diameter and 1" inside diameter.

Examining this line for the maximum load that the drain port assembly is subjected to under regulatory hypothetical accident drop condition in side drop orientation for cold thermal environment. Per Table 3 of Reference 2, the maximum impact limiter reaction for this loading condition is 3.431×10^6 lbs.

Using 22" impact limiter coverage of the cask bottom end, and assuming a 60º impact zone, the estimated pressure is:

$$q = \frac{3.431\times 10^6}{22\times (\frac{51\times \pi}{360})\times 60} = 5,840 \text{ psi}$$

Using a 4 ½" diameter nozzle diameter on the side wall, the tributary shear load on the drain port assembly is:

$$F = 5{,}840 \times \frac{\pi}{4} \times 4.5^2 = 92{,}881 \text{ lbs.}$$

Assuming this shear load is reacted equally by the welds connecting the drain port to the cask outer shell and inner bottom cover. The drain line shear stress is:

$$\tau = \frac{92{,}881 \times 0.5}{(\pi/4) \times (2.5^2 - 1^2)} = 11{,}263 \text{ psi} < 15{,}000 \text{ psi} \qquad \text{O.K.}$$

D. Buckling of the Inner Shell

Normal Condition:

Per Table 2 of Reference 2, the governing average acceleration for this loading condition is 31.7g. A conservative acceleration of 35g and the mass of the items loading the shell are used for the evaluations presented here. This mass accounts for the bottom lead pour, bottom cover of inner cask shell and inner cask shell. The inner shell axial compressive stress is compared with its minimum critical buckling stress.

Weight of the bottom lead pour = $W_1 = \frac{\pi}{4} \times 36.5^2 \times 5 \times \frac{1}{12^3} \times 710 = 2{,}150$ lbs.

Weight of the ¾" thick, 36 ½" diameter bottom cover of inner cask shell
$W_2 = (\pi/4)\times36.5^2\times0.75\times0.283 = 222$ lbs.

Weight of ¾" thick, 35" I.D., 106 ¼" long inner cask shell
$W_3 = [(\pi/4)\times(36.5^2-35^2)\times106.25\times0.283 = 2{,}533$ lbs.

Maximum compressive load on the inner shell = (2,150+222+2,533) × 35 = 171,675 lbs.

Mean radius (r_{mean}) = $0.5 \times (18.25 + 17.5) = 17.875$ in

Shell thickness (t) = 0.75 in

Axial compressive stress (σ_{comp}) = $\frac{171{,}675}{2 \times \pi \times 17.875 \times 0.75} = 2{,}038$ psi

Using an expression from Roark (Reference 3) for thin tube with closed ends, under uniform external pressure, lateral and longitudinal, Table 35, case 20

Conservatively using the overall length of the cask (128.625") as the length of the tube (l),

$$\left(\frac{l}{r}\right)^2\left(\frac{r}{t}\right) = \left(\frac{128.625}{17.875}\right)^2\left(\frac{17.875}{0.75}\right) = 1{,}234$$

$$2.5(\frac{r}{t})^2 = 2.5 \times (\frac{17.875}{0.75})^2 = 1{,}420$$

Since $60 < (\frac{l}{r})^2(\frac{r}{t}) = 1{,}234 < 2.5(\frac{r}{t})^2 = 1{,}420$, the critical pressure q' is:

$$q' = \frac{0.92E}{(\frac{l}{r})(\frac{r}{t})^{2.5}} = \frac{0.92 \times 30 \times 10^6}{(\frac{128.625}{17.875})(\frac{17.875}{0.75})^{2.5}} = 1{,}383 \text{ psi}$$

A recommended probable minimum critical pressure is $0.8\,q' = 0.8\times1{,}383 = 1{,}106$ psi

$$\sigma_{critical} = \frac{pr}{2t} = \frac{1{,}106 \times 17.875}{2 \times 0.75} = 13{,}180 \text{ psi}$$

F.S. = $\frac{13{,}180}{2{,}038} = 6.47$ O.K.

Hypothetical Accident Condition:

Per Table 3 of Reference 2, the governing average acceleration for this loading condition is 104.8g. Using a conservative acceleration of 110g for the evaluations presented here, and the same approach as for the normal condition shown above, the inner shell axial compressive stress is compared with its minimum critical buckling stress.

Axial compressive stress (σ_{comp}) = $2{,}038 \times \frac{110}{35} = 6{,}405$ psi

F.S. = $\frac{13{,}180}{6{,}405} = 2.06$ O.K.

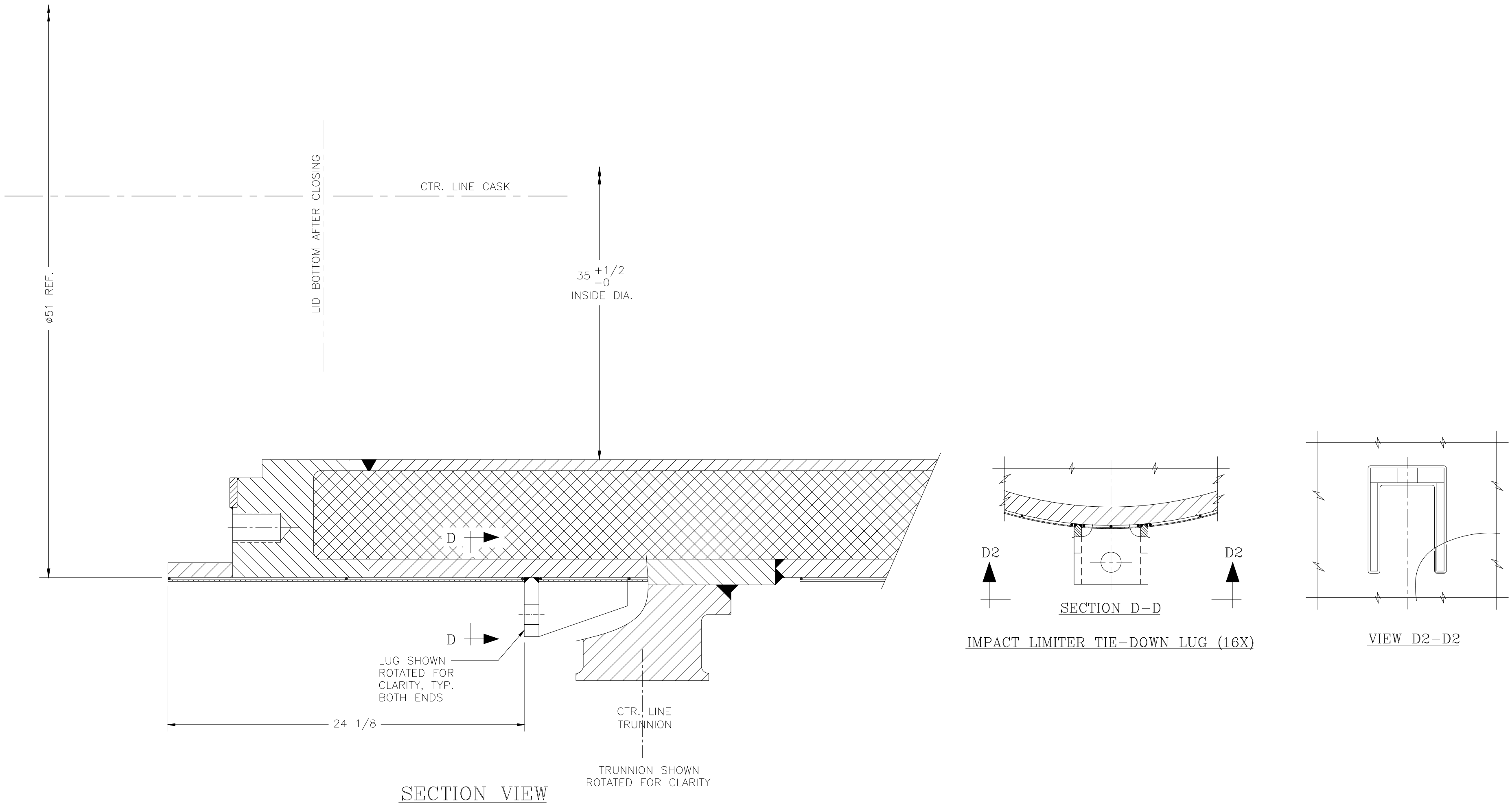


Figure – 1: 3-60B Cask Tie-Down/Bracket Details for the Installation of the Impact Limiter

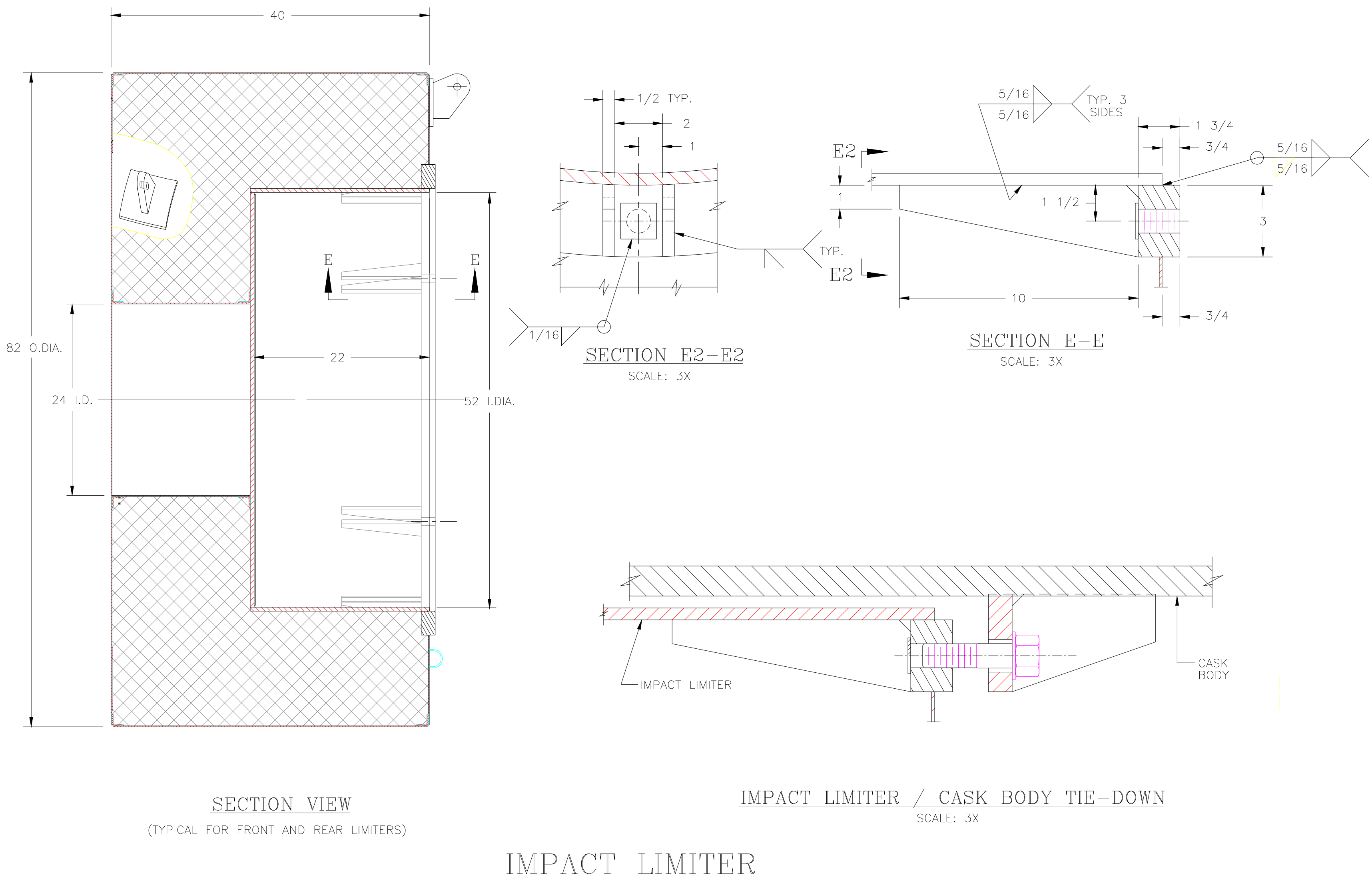
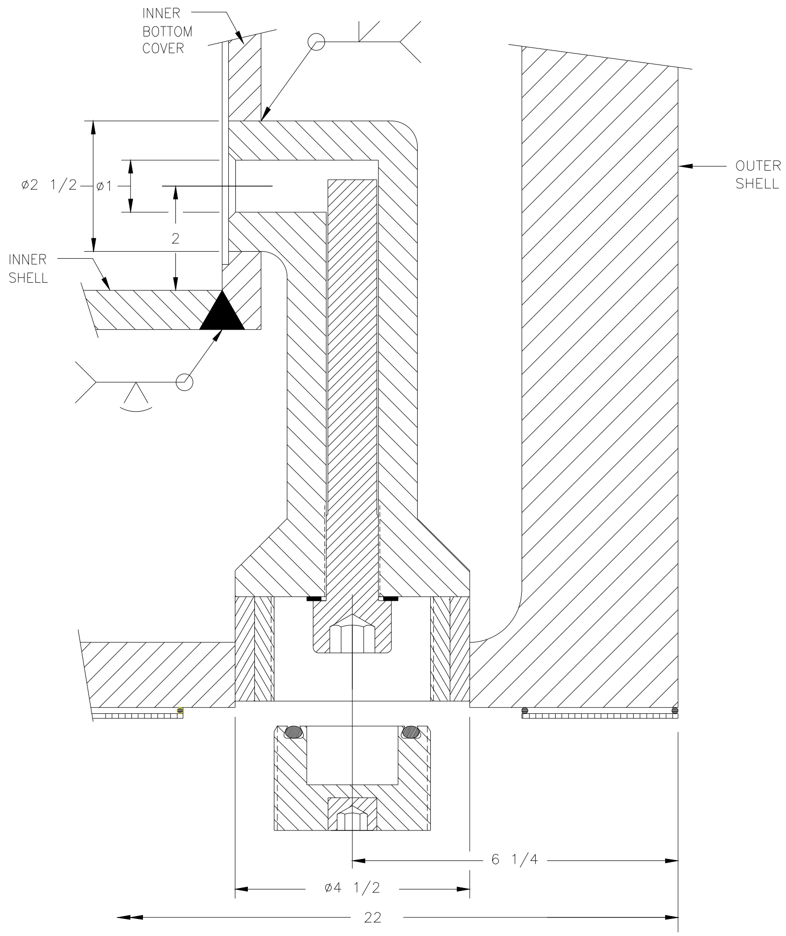


Figure – 2: 3-60B Cask - Impact Limiter Tie-Down Attachment Details



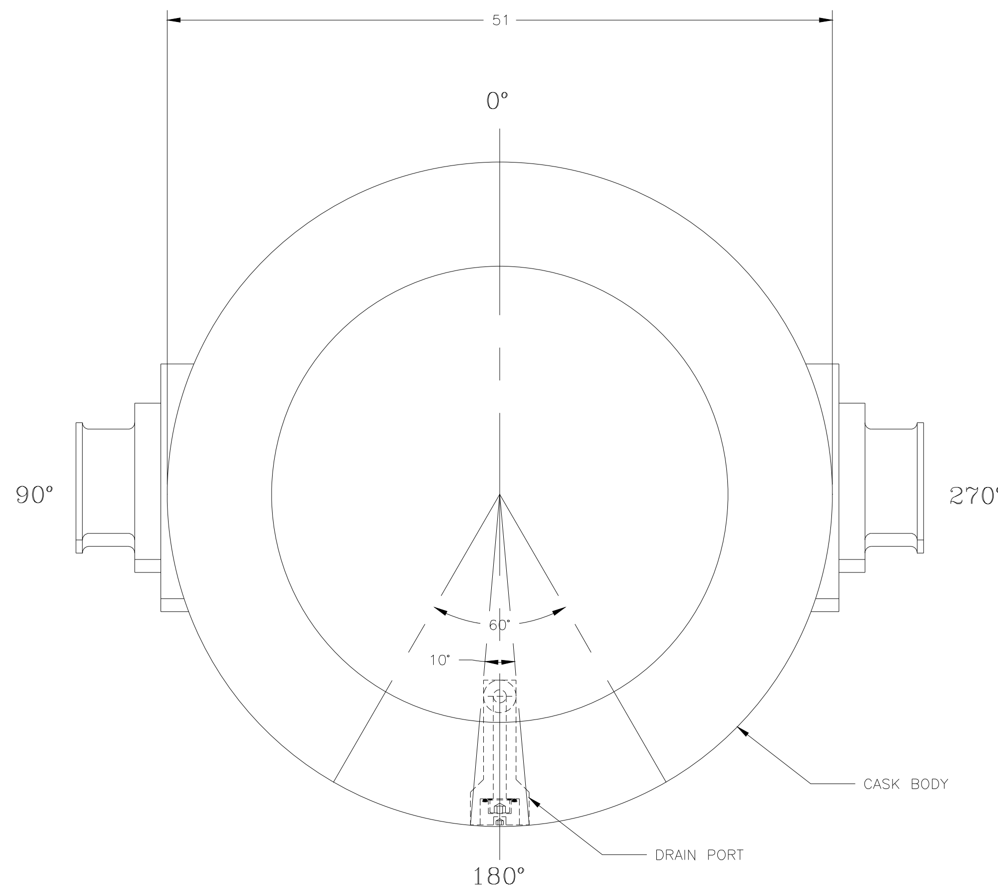


Figure – 3: 3-60B Cask – Drain Port Assembly Details