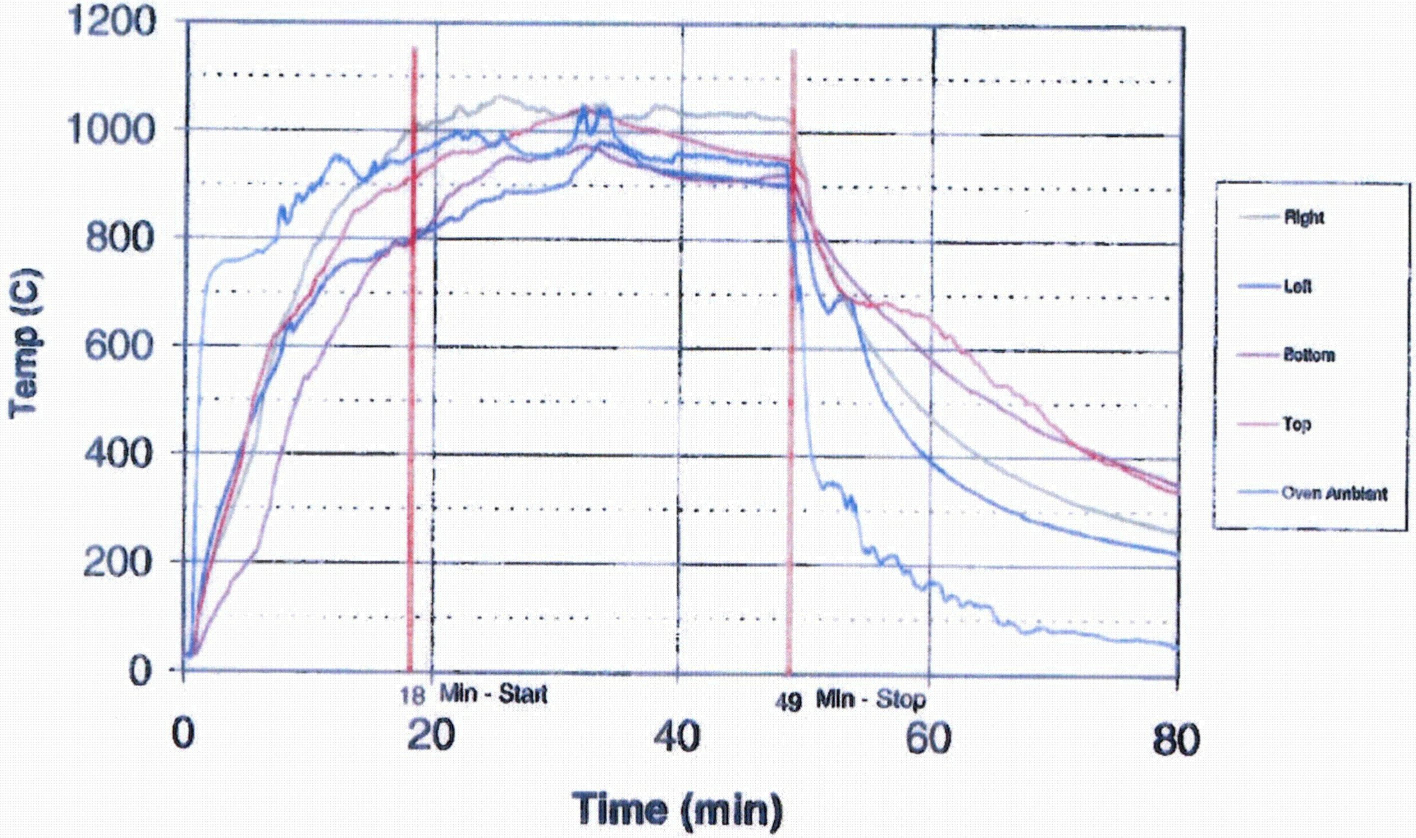
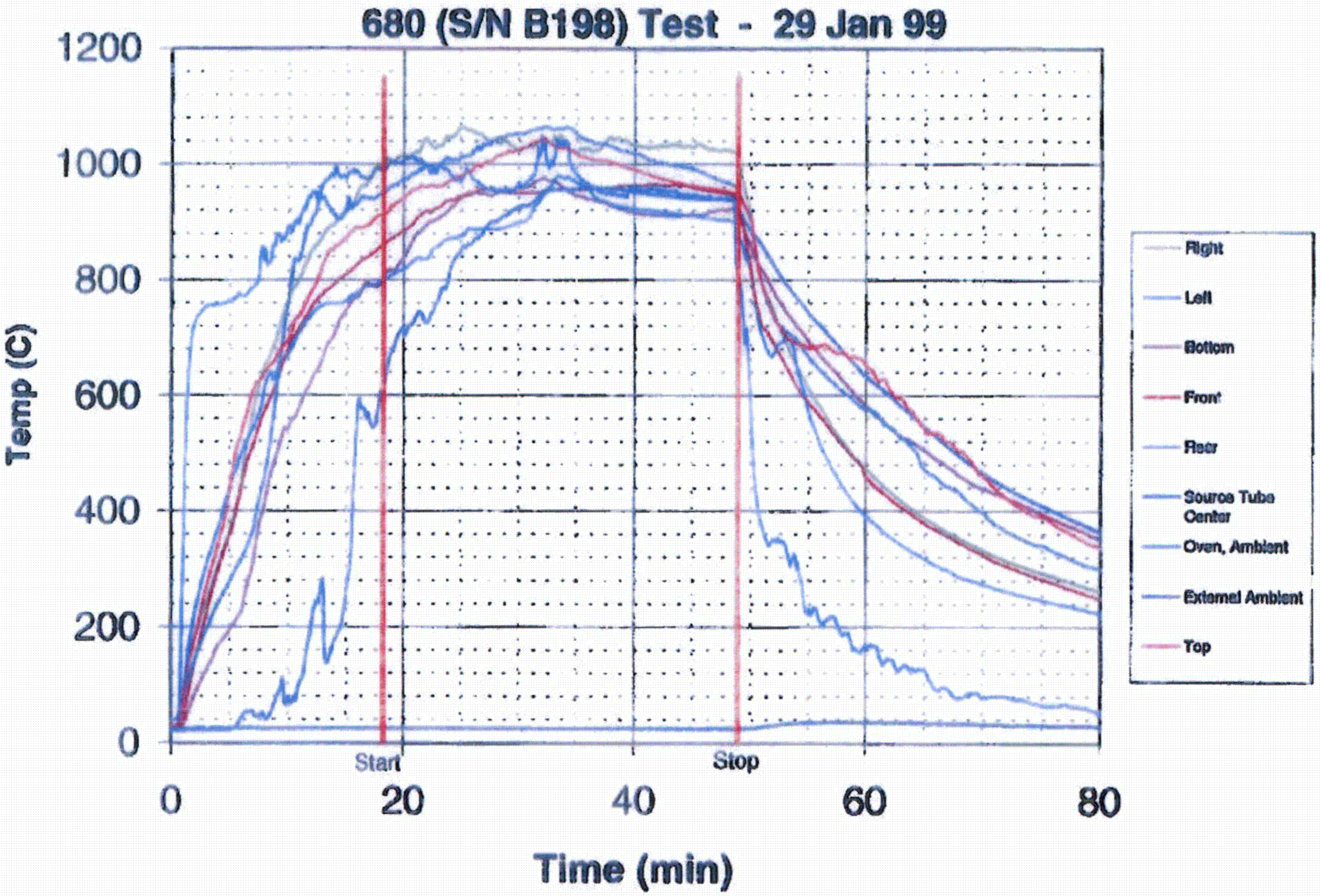
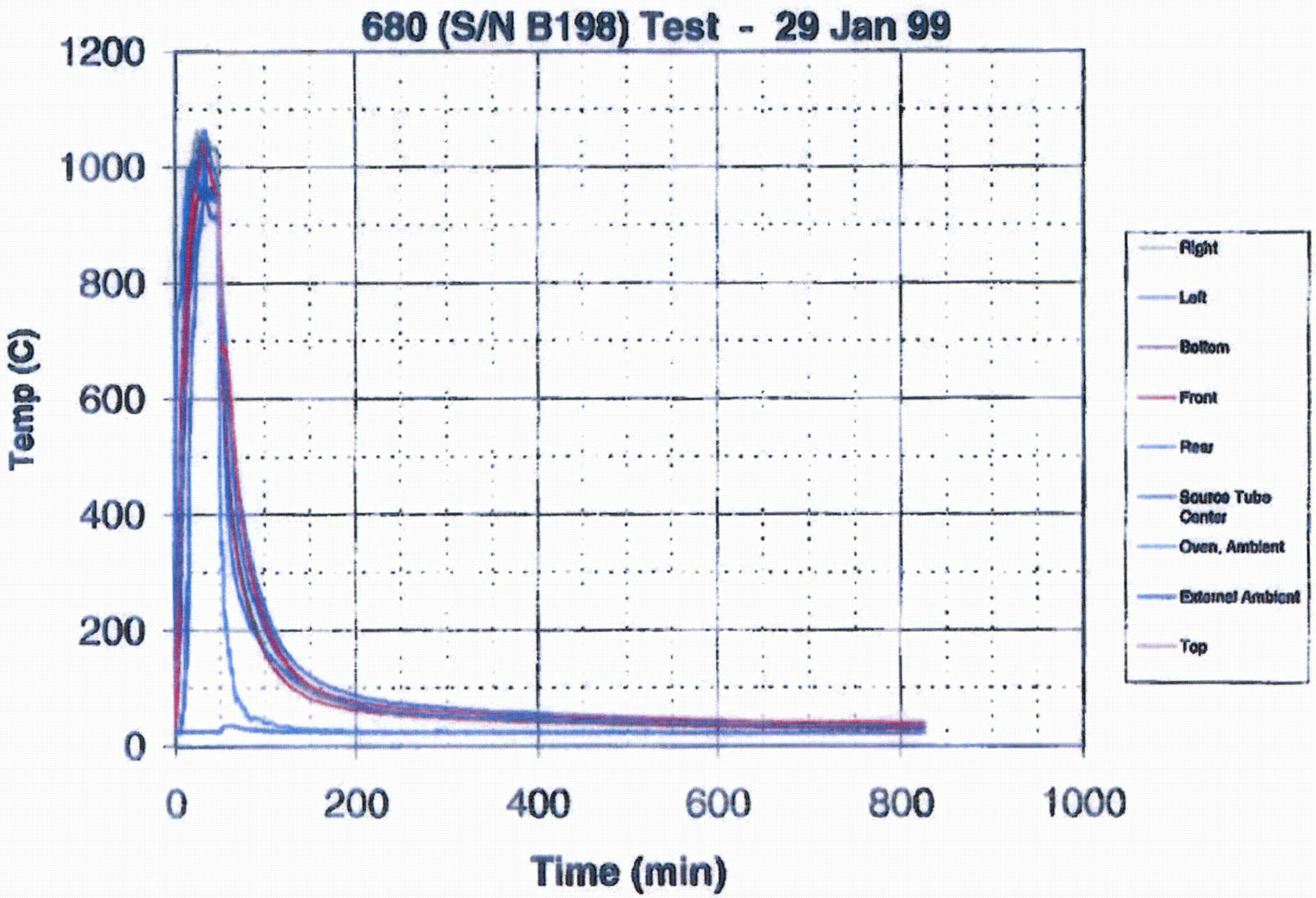
APPENDIX E
THERMAL GRAPHS

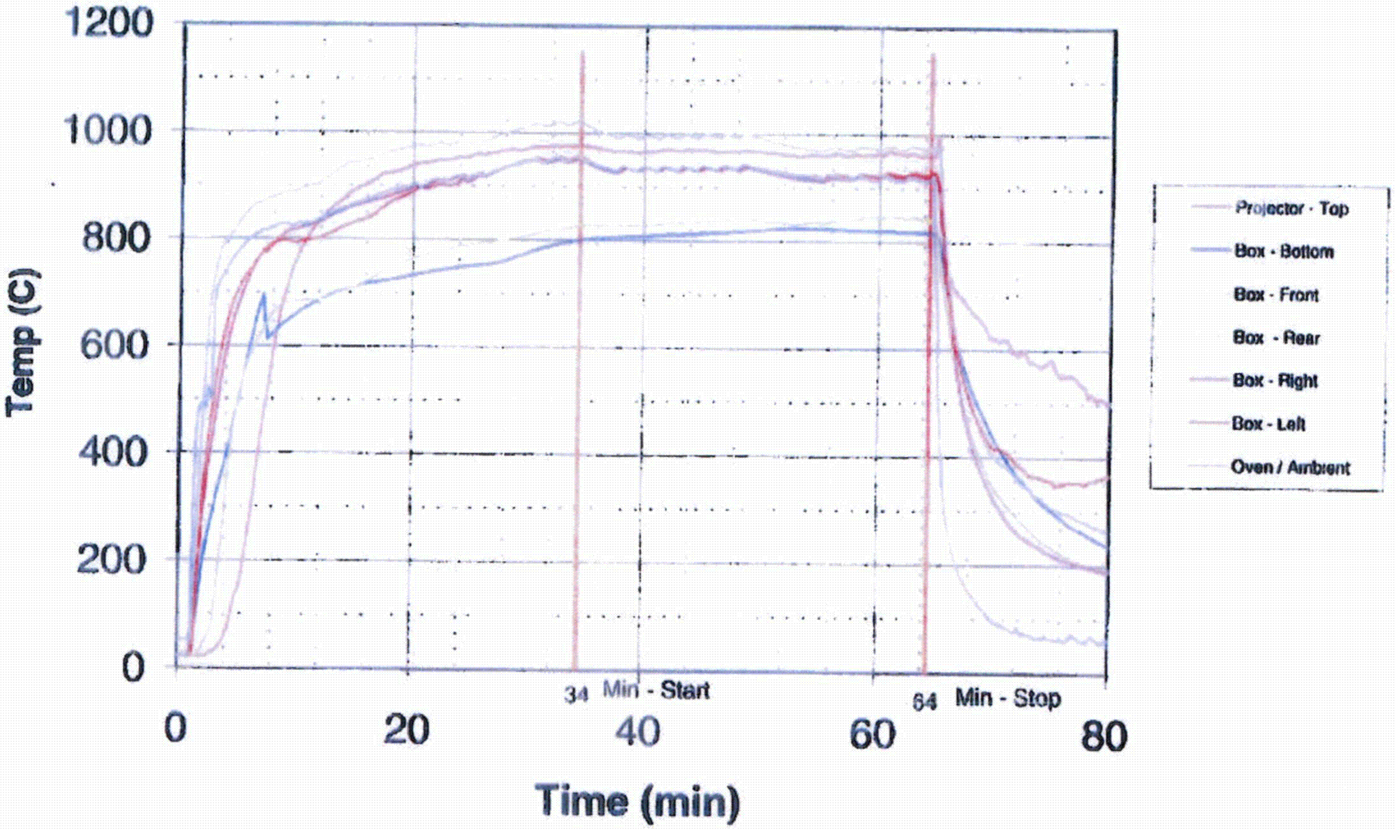
680 (S/N B198) Test - 29 Jan 99
SHELL TEMPERATURES

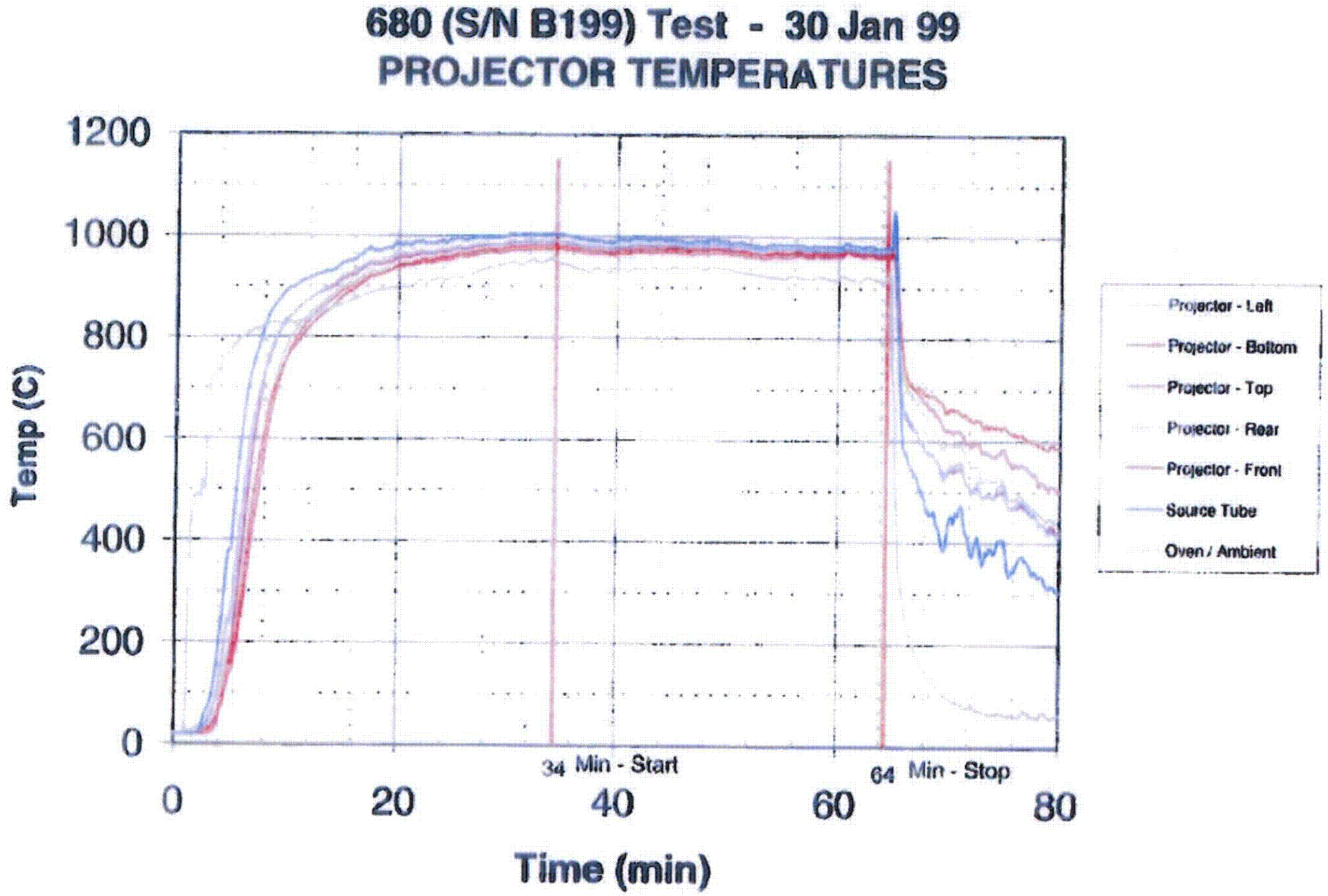



680 (S/N B198) Test - 29 Jan 99
Temp (C)
1200
1000
800
600
400
200
0
Time (min)
0
20
40
60
80
Start
Stop
Right
Left
Bottom
Front
Rear
Source Tube Center
Oven, Ambient
External Ambient
Top

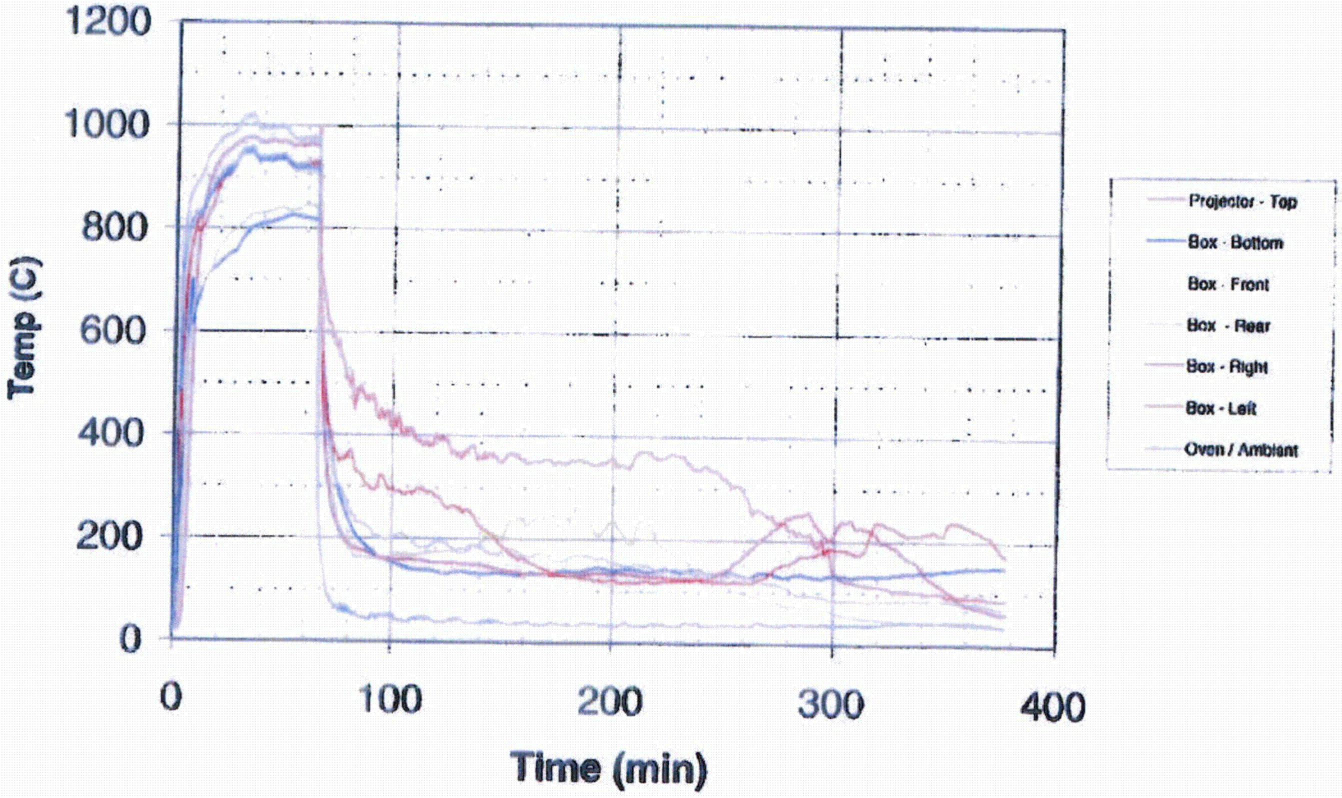

680 (S/N B198) Test - 29 Jan 99
Temp (C)
1200
1000
800
600
400
200
0
0
200
400
600
800
1000
Time (min)
Right
Left
Bottom
Front
Rear
Source Tube Center
Oven, Ambient
External Ambient
Top

680 (S/N B199) Test - 30 Jan 99
SURFACE TEMPERATURES

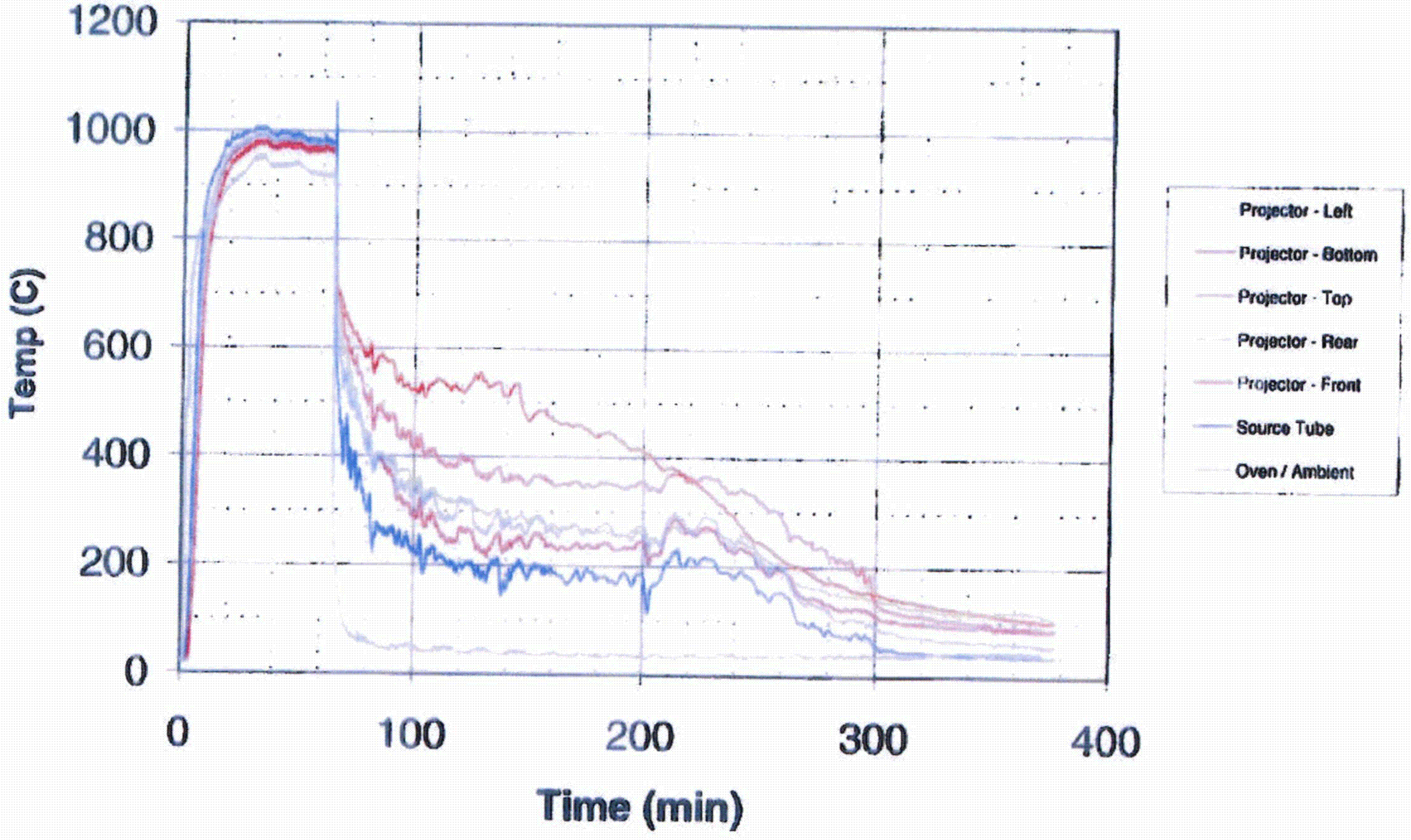



680 (S/N B199) Test - 30 Jan 99
PROJECTOR TEMPERATURES
Temp (C)
1200
1000
800
600
400
200
0
Time (min)
0
20
40
60
80
34 Min - Start
64 Min - Stop
Projector - Left
Projector - Bottom
Projector - Top
Projector - Rear
Projector - Front
Source Tube
Oven / Ambient

680 (S/N B199) Test - 30 Jan 99
SURFACE TEMPERATURES



680 (S/N B199) Test - 30 Jan 99
PROJECTOR TEMPERATURES



2.12.6 Test Plan Report 80 dated June 1999 (Minus Manufacturing Records)

AEA TECHNOLOGY

TEST PLAN NO. 80 Rev 1	
TEST PLAN COVER SHEET	
TEST TITLE: TEST PLAN 80, REVISION 1, MODEL 650L SOURCE CHANGER TYPE B TRANSPORT TESTS	
PRODUCT MODEL: 650L	
ORIGINATED BY: (MFR)	DATE: 12 MAR 99
TEST PLAN REVIEW	
ENGINEERING APPROVAL:	DATE: 12 MAR 99
QUALITY ASSURANCE APPROVAL: Dennis W. Kurtz	DATE: 12 Mar 99
REGULATORY APPROVAL:	DATE: 12 Mar 99
COMMENTS:	
TEST RESULTS REVIEW	
ENGINEERING APPROVAL:	DATE: 17 JUL 99
QUALITY ASSURANCE APPROVAL: Dennis W. Kurtz	DATE: 13 Jul 99
REGULATORY APPROVAL:	DATE: 13 Jul 99

SENTINEL

TEST PLAN 80 REPORT

MODEL 650L

June 1999

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Burlington, MA

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1. PURPOSE

This report describes the Type B test results for the Model 650L source changer. These tests were performed in accordance with Test Plan 80 and were conducted March 15 through 20, 1999. The Test Plan specified testing necessary to demonstrate compliance with the requirements in 10 CFR Part 71 and IAEA Safety Series No. 6 (1985 as amended 1990) for "Normal Conditions of Transport" and "Hypothetical Accident Conditions." Evaluation of the compliance of the Model 650L with these requirements is provided in the Safety Analysis Report (SAR).

2. SCOPE OF TESTING

Test Plan 80 identified three orientations that could potentially cause the most significant damage to the Model 650L source changer in the 9 meter (30 foot) drop tests. Therefore, the test plan required three test specimens. Each of these test specimens was subjected to the tests described below.

1. Normal Conditions of Transport Tests per 10 CFR 71.71, including the following for each test specimen:
   a) Compression test, with the test specimen under a load greater than or equal to five times the Model 650L maximum weight for at least 24 hours.
   b) Penetration test, in which a 13.4 lb (6.08 kg) penetration bar is dropped from at least 1 meter (40 inches) onto the test specimen in the most vulnerable location.
   c) 1.2 meter (4 foot) drop test, in which the test specimen is dropped in an orientation expected to cause maximum damage.

   Water spray preconditioning of the test specimens prior to testing was not required in the test plan and is evaluated separately.

2. Hypothetical Accident Condition Tests per 10 CFR 71.73, including the following for each of the test specimens:
   a) 9 meter (30 foot) drop test, in which the test specimen is dropped in an orientation expected to cause maximum damage.
   b) Puncture test, in which the test specimen is dropped from at least 1 meter (40 inches) onto a 6 inch (152.4 mm) diameter vertical bar in an orientation expected to compound damage from the 9 meter (30 foot) drop test.
   c) Thermal test, in accordance with 10 CFR71.73(c)(4), in which the test specimen is exposed for 30 minutes to an environment which provides a time-averaged environmental temperature of at least 800°C (1472°F), and an emissivity coefficient of at least 0.9. For the Model 650L, the test plan specified that the thermal test would be performed for only one of the three test specimens, unless other test units suffered significant damage in the drop and puncture tests. This requirement was based on the evaluation of the construction of the unit, and on the potential failure modes, which are discussed in the following section.

   The crush test specified in 10 CFR 71.73(c)(2) was not required because the source capsules are qualified as Special-Form radioactive material.

   The water immersion test specified in 10 CFR 71.73(c)(6) and other tests specified in 10 CFR 71 are evaluated separately.

   For all tests, sufficient margin was included in test parameters to account for measurement uncertainty. These test parameters included test specimen weight, temperature, and drop height.

3. FAILURE MODES

For the Model 650L source changer, the key function important to safety is the positive retention of the radioactive source in its stored position within the depleted uranium shield. Displacement of either the source or the shield from the design position or failure of the shield could cause radiation from the package to increase above regulatory limits. Mechanisms, which could cause these modes of failure, include:

- Oxidation of the DU Shield - During the thermal test, oxidation of the DU shield could lead to reduced shielding effectiveness and higher radiation exposure. This could occur if failure of the inner and outer shells or failure of the through-bolts during drop testing results in a large, open path to the DU shield.

- Source Pull-Out from the Shield - During drop testing or during the thermal test, source pull-out could lead to higher radiation exposure. This could occur if there is significant relative displacement between the shield and the lock assembly on the top cover plate. Such displacement could occur if the top plate is deformed outward, and the shield moves laterally or downward through the polyurethane foam.

The drop orientations for the normal and hypothetical accident tests were selected to challenge the components that are intended to prevent these failures. For the 1.2 meter (4 foot) and 9 meter (30 foot) drop tests, these orientations include the following:

- Horizontal with the long side of the unit down - This orientation could cause movement of the shield or failure of the inner and/or outer shells.
- Vertical upside down - This orientation could cause deformation of the top plate, failure of the through-bolts, or failure of the lock assembly which would all lead to source pull-out from the shield. Additionally, movement of the shield through the foam in the upper part of the unit would put a large lateral load on the upper portion of the inner shell, which is subject to brittle failure.
- Top corner down - This orientation could cause failure of the bolts holding the protective lid in place, exposing the lock assembly to damage during the puncture test. This orientation also loads the through-bolts, top plate, and inner shell similar to the vertical upside down orientation.

Because of the potential for brittle failure of carbon steel components, all test units were packed in dry ice and cooled to less than -40°C (-40°F) (the minimum temperature required by IAEA Safety Series 6) for the penetration, 1.2 meter (4 foot) drop, 9 meter (30 foot) drop, and puncture tests.

In selecting test units for the thermal test, it was concluded that an undamaged unit would not be significantly affected by exposure to the conditions of the thermal test. In particular, for an undamaged unit, the depleted uranium shield would still be completely enclosed within the inner and outer shells and be supported by foam and a shim of either copper, steel, or lead. Under the thermal test conditions, degradation of the foam and melting of the shim, if it is lead, will allow the shield to move by a small amount. This could result in limited movement of the source relative to the shield, but not enough to significantly increase radiation levels.

Therefore, the thermal test is only expected to have a significant effect on those units which sustained damage relating to the two modes of failure described above, specifically: (1) an opening in the inner and outer shells to allow oxidation of the shield, or (2) relative displacement of the lock assembly and shield which could be compounded by shield movement during the thermal test. Since relative displacement of the lock assembly was expected in the vertical upside down drop orientation, it was planned to perform the thermal test with the unit dropped in this orientation. The test plan required thermal tests of the other test specimens only if they sustained damage that could lead to failure during the thermal test.

4. TEST UNIT DESCRIPTION

The Model 650L test specimens, identified below, were originally constructed in accordance with drawing C65009 and were prepared for testing in accordance with drawing R-TP80, Rev. E. The manufacturing route cards for the units document the compliance of these units with the ABA Technology QSA Inc. QA program (see Appendix B).

Specimen	Serial No.	Total Weight	Lead Configuration
TP80(A)	2243	80.0 lb (36.3 kg)	No lead between DU shield and long side of inner shell.
TP80(B)	182	83.6 lb (37.9 kg)	Thickest lead under DU shield (total 3/8" thick).
TP80(C)	195	89.0 lb (40.4 kg)	Any location.

Important features of the test unit construction include the following:

- The configuration of lead added to each unit for supplemental shielding was specified as shown above to provide the worst case for the each drop orientation.
- For TP80(B), the original steel shim used in the unit was replaced with a solid 3/8" thick lead shim.
- The original carbon steel through-bolts were replaced with stainless steel bolts.
- The original carbon steel lid bolts were replaced with high strength, strain hardened stainless steel bolts.
- The weights of the test specimens are representative of the heaviest 650L units in use. The range of weights of 650L units is 75 lb to 90 lb (34.0 kg to 40.8 kg).

The test specimens were radiographed to document the lead configuration and the position of the internal components. Also, the position of the "dummy" source used in the units was measured prior to testing.

5. SUMMARY AND CONCLUSIONS

All test specimens met the requirements for 10 CFR 71 Type B(U) Transport Testing, as shown in the following table of Radiation Profile results.

Specimen	Specimen Surface	At Surface, Before Test	At One Meter, Before Test	At Surface, After 4 ft Drop Test	At One Meter, After 4 ft Drop Test	At One Meter, After Final Test (Notes 1,2)
	Reg. Limits	200 mR/hr	10 mR/hr	200 mR/hr	10 mR/hr	1000 mR/hr
TP80(A) S/N 2243	Top	84	3.2	94	2.4	2.7
	Right	47	0.6	47	0.7	0.8
	Front	88	0.7	89	0.8	1.0
	Left	56	0.6	65	0.7	0.7
	Rear	74	0.7	89	0.8	0.9
	Bottom	51	0.4	94	0.7	0.6
TP80(B) S/N 182	Top	60	3.1	71	2.0	28
	Right	56	0.4	53	0.6	5.6
	Front	84	0.8	83	0.8	5.6
	Left	88	0.6	83	0.6	7.9
	Rear	79	0.8	77	0.8	7.9
	Bottom	74	0.5	83	0.7	1.1
TP80(C) S/N 195	Top	72	2.2	59	2.0	2.2
	Right	105	0.7	71	0.7	0.9
	Front	50	0.6	47	0.5	0.6
	Left	127	0.7	106	0.8	1.0
	Rear	50	0.6	53	0.6	0.6
	Bottom	61	0.6	59	0.5	0.5

Notes:

1. The final Hypothetical Accident Condition test for test specimens TP80(A) and TP80(C) was the Puncture Test. The final test for specimen TP80(B) was the Thermal Test.
2. Radiation profile at the surface is not required for the Hypothetical Accident Condition test (see 10 CFR 71.51(a)(2)).

Results of each test are summarized in the table below, in the sequence in which the tests were completed. Detailed results are provided in the following sections of this report, test data sheets are in Appendix C, and photographs are included in Appendix D.

Specimen	Test Performed	Test Results (Note 1)
TP80(A)	Compression Test	No damage
	1 meter (40 inch) penetration bar on side	Impact mark; no visible damage
	1.2 meter (4 foot) drop, horizontal on long side	○ Impact mark on edge of plates ○ Small change in radiation profile
	9 meter (30 foot) drop, horizontal on long side	Bent bottom plate flange inward
	1 meter (40 inch) puncture, horizontal on long side (dropped twice to ensure specimen temperature was below -40°C (-40°F))	Shallow dent on outer shell at impact point
	Post-Drop Inspection	○ Lid secured in place ○ Locks undamaged; source secured ○ No significant change in source position ○ Small change in radiation profile
TP80(B)	Compression Test	No damage
	1 meter (40 inch) penetration bar on side	Impact mark; no visible damage
	1.2 meter (4 foot) drop, vertical upside down	○ Impact mark on top of lid ○ Small change in radiation profile
	9 meter (30 foot) drop, vertical upside down	○ Outer shell split open from top to bottom ○ Inner shell cracked, creating a 3 inch (76.2 mm) high by 0.5 inch (12.7 mm) wide opening ○ Small upward deflection of top plate ○ Top and bottom plates remained secured by the through bolts.
	1 meter (40 inch) puncture on crack in shell	Bent shell inward slightly in area of crack

Specimen	Test Performed	Test Results (Note 1)
TP80(B) (con't)	Post-Drop Inspection	o Lid secured in place o Locks undamaged; source secured o Top plate deflection at center about 0.16 inch (4.1 mm). o No damage to through bolts o No significant change in source position. o Outer and inner shells cracked; opening about 3 inch (76.2 mm) by 0.5 inch (12.7 mm).
	Thermal test	o Some oxidation of DU shield near crack in shell o Shield moved down (as expected) o Polyurethane foam burned off, exposing the shield o Some oxidation of shield near crack in shell o Shield self-extinguished after removal from oven o Source pullout less than 0.5 inch (12.7 mm). o Max. radiation level at one meter was 28 mR/hr (which is much less than 1000mR/hr allowable)
TP80(C)	Compression Test	No damage
	1 meter (40 inch) penetration bar on side	Impact mark; no visible damage
	1.2 meter (4 foot) drop on top edge of lid	o Bent corner of lid and cracked top plate of lid (brittle failure) o Small change in radiation profile
	9 meter (30 foot) drop on top edge of lid	o Increased lid top plate crack length in vicinity of impact point o Locks still protected by lid
	1 meter (40 inch) puncture vertical upside down on lid and on underside of top plate	Broke inside of lid top plate (locks still protected)
	Post-Drop Inspection	o Locks undamaged; source secured o No significant change in source position o Small change in radiation profile

Note 1: None of the new stainless steel bolts installed in the test specimens failed.

Specimen TP80(A) was not significantly damaged in the testing. On specimen TP80(C), the top plate of the protective lid was substantially cracked and portions broke away; however, the rectangular tube section which surrounds the locks was undamaged and still attached to the lower portion which in turn was secured to the body of the changer. As such, the locks remained protected. The post-test radiation profiles showed a slight increase in radiation levels for these units, but these radiation levels were well below the allowable values.

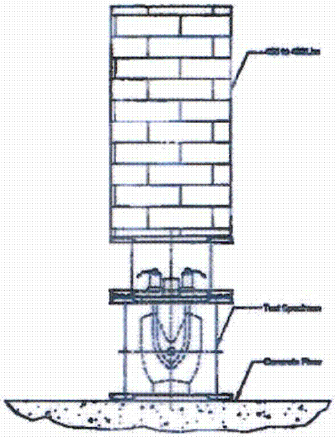
The only significant damage to any unit was the cracked shell in specimen TP80(B). Because of this crack, the depleted uranium shield was exposed to air during the thermal test, and portions of the shield near the crack opening were oxidized. In addition, after the lead shim melted, the shield was free to move downward, pulling the dummy source out of its fully inserted position in the shield. However, even with the oxidized shield and source pull-out, the post-test radiation profile showed a maximum radiation level of 28 mR/hr at one meter. This is well below the maximum allowable level of 1,000 mR/hr at one meter following the hypothetical accident conditions.

6. TP80 NORMAL TESTS

Compression Test

All three test specimens were loaded as shown in the figure below. Lead weights were placed on a steel plate, which was positioned on top of each test specimen.

The vertical projected area of the unit is 8.25 inch (209 mm) x 10 inch (254 mm) or 82.5 square inches (531 square centimeters), yielding a total load of 165 lb (74.8 kg) for an applied pressure of 2 psi. Since the maximum weight of the Model 650L source changer is 90 lb (40.8 kg), a load of 5 times the weight, or 450 lb (204 kg), is more conservative. The total compressive load actually used was 458 lb to 462 lb (208 kg to 210 kg).



Compression Test Orientation – All Specimens

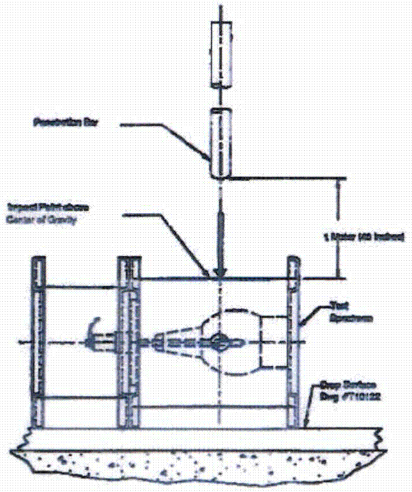
After a period of 24 hours, the weights were removed. No visible deformation or buckling occurred and no other damage was observed for any of the test specimens.

Penetration Test

The three test specimens were subjected to the penetration test. Temperature readings taken just before the test are summarized below.

Specimen	Ambient	Surface	Internal
TP80(A)	10°C (50°F)	-96°C (-141°F)	-95°C (-139°F)
TP80(B)	9°C (48°F)	-93°C (-135°F)	-83°C (-117°F)
TP80(C)	10°C (50°F)	-90°C (-130°F)	-90°C (-130°F)

The penetration bar target was the side of the unit in an attempt to damage the shell. For this test, each specimen was positioned with its horizontal long side down, as shown below.



Penetration Test Orientation – All Specimens

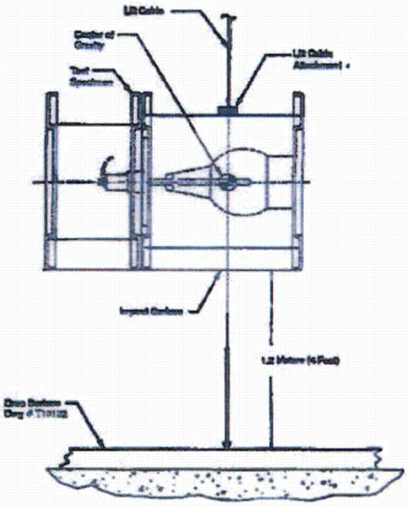
The penetration bar was dropped from a height of at least 1 meter (40 inches) above the impact point. The bar hit as intended on each package, leaving a visible impact mark, but no other damage.

1.2 Meter (4 Foot) Drop Test

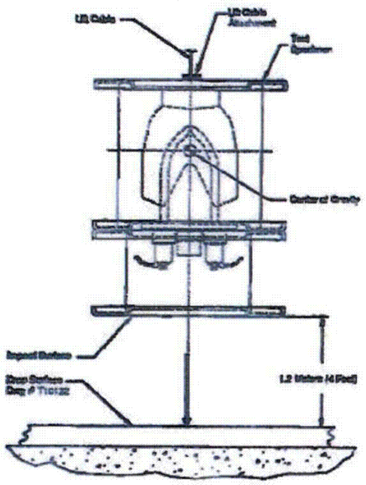
The three test specimens were then subjected to the 1.2 meter (4 foot) drop test. Temperature readings taken just before the test are summarized below.

Specimen	Ambient	Surface	Internal
TP80(A)	13°C (55°F)	-92°C (134°F)	-90°C (-130°F)
TP80(B)	13°C (55°F)	-87°C (-125°F)	-89°C (-128°F)
TP80(C)	13°C (55°F)	-95°C (-139°F)	-92°C (-134°F)

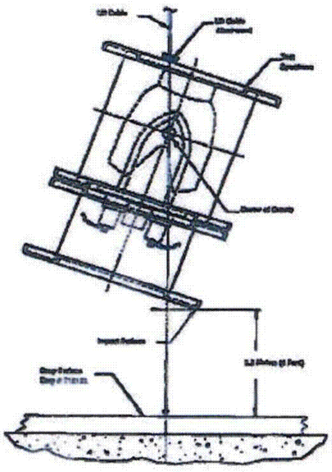
The drop orientations for each unit are shown below and on the next page. These orientations are the same as those used for each specimen in the 9 meter (30 foot) drop tests.



1.2 Meter (4 Foot) Drop Orientation for Specimen TP80(A)



1.2 Meter (4 Foot) Drop Orientation for Specimen TP80(B)



1.2 Meter (4 Foot) Drop Orientation for Specimen TP80(C)

Each test specimen impacted as intended. Visual inspections showed impact marks but no significant damage to either TP80(A) or TP80(B). For TP80(C), a 2 inch (50.8 mm) long crack in the top of the protective lid was observed, and the flange corner was bent.

Post-Test Inspection and Assessment

Results of the first intermediate inspections and assessments are summarized below. The radiation profile of each specimen was measured, and data sheets are provided in Appendices B and C.

Specimen	Damage	Source Movement	Radiation Profile (Note 1)
TP80(A)	No visible damage, locks functional	No significant change observed	Largest change at bottom surface: 51mR/hr to 94 mR/hr (Note 2)
TP80(B)	No visible damage, locks functional	No significant change observed	Largest change at top surface: 60 mR/hr to 71 mR/hr
TP80(C)	Cracked top lid, locks functional	No significant change observed	Largest change at rear surface: 50 mR/hr to 53 mR/hr

Note 1: Radiation levels at one meter were 2.4 mR/hr or less after Normal Condition Tests.

Note 2: All other surfaces measured remained essentially the same, exhibiting no corresponding shift in radiation levels. Additionally, no source movement was measured. Therefore, this change was considered insignificant.

7. TP80 ACCIDENT DROP TESTS – TP80(A)

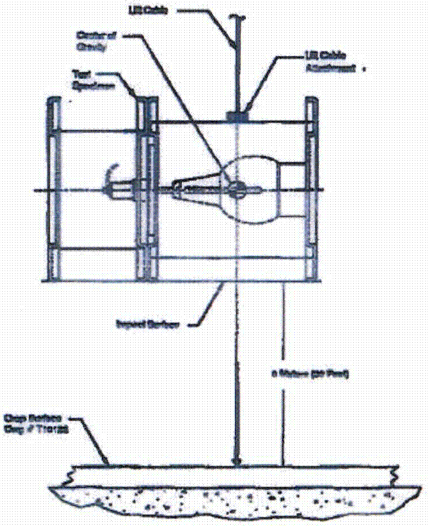
Specimen TP80(A) was subjected to a 9 meter (30 foot) drop test and a puncture test in accordance with Test Plan 80. The results are described below.

<u>9 Meter (30 Foot) Drop Test</u>

Just before the drop test, thermocouple readings for Specimen TP80(A) were as follows:

- Internal (source tube): -93°C (-135°F)
- Surface (shell): -92°C (-134°F)

The orientation for Specimen TP80(A), shown below, was the same as for the 1.2 meter (4 foot) drop. The intention was to cause the shield to move relative to the lock assembly and/or to cause failure of the inner and outer shells.

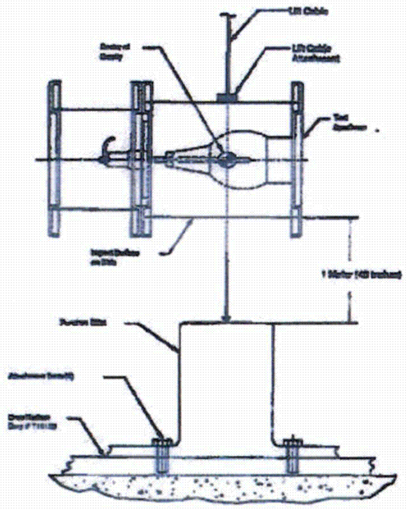


9 Meter (30 Foot) Drop Orientation for Specimen TP80(A)

The package rotated very slightly causing the edge of the bottom plate to impact first. However, the impact was sufficiently close to ideal as to impart the desired force into the package. Visual inspections showed that the edge of the bottom plate had bent inward to the point where it contacted and dented the outer shell. The edge of the top plate of the lid also bent inward slightly.

Puncture Test

For the puncture test, TP80(A) was dropped, as planned, on its side with the center of gravity over the impact area, as shown below. The intention of this orientation was to inflict further damage to the shell. The thermocouple reading on the surface of the unit before the puncture test was -69°C (-92°F) but warmed to -26°C (-15°F) just after the test due to delays in rigging the unit for the drop. Consequently, the unit was cooled again and dropped a second time. For the second test, the surface temperature was -46°C (-51°F) before the test and -42°C (-44°F) after the test.



Puncture Drop Orientation for Specimen TP80(A)

For both drops, the unit impacted on its side as intended. Each impact caused the side of the shell to deform inward slightly, but no significant damage was observed.

Post-Test Inspection and Assessment

Following the test, the protective lid was removed and the unit was inspected. No damage to the lock assembly was observed, and no significant source movement was measured. Radiographs of the unit showed no discernable change in the position of the shield. The post-test radiation profile showed no significant change in radiation levels from the pre-test profile (see Appendices B and C). Because no significant damage occurred to the unit, the thermal test was not considered necessary (see Section 3). In addition, Specimen TP80(B) was considered worst case.

8. TP80 ACCIDENT DROP TESTS – TP80(B)

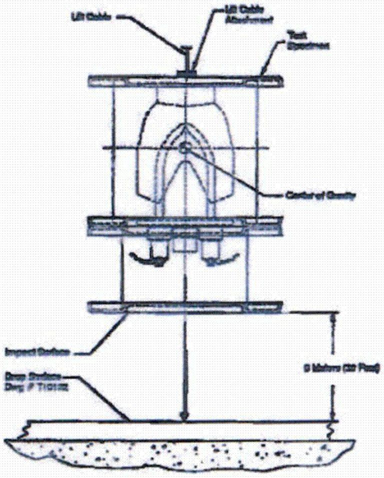
Specimen TP80(B) was subjected to a 9 meter (30 foot) drop test and a puncture test in accordance with Test Plan 80. The results are described below.

9 Meter (30 Foot) Drop Test

Just before the drop test, thermocouple readings for Specimen TP80(B) were as follows:

- Internal (source tube): -94°C (-137°F)
- Surface (shell): -93°C (-135°F)

The package orientation for Specimen TP80(B), shown below, was the same as for the 1.2 meter (4 foot) drop. The intention was to cause deformation of the top plate, failure of the through-bolts, and failure of the lock assembly, leading to source pull-out from the shield.



9 Meter (30 Foot) Drop Orientation for Specimen TP80(B)

The package impacted as intended. The impact caused the depleted uranium shield to move into the foam below the top plate, putting a large lateral load on the inner shell, and causing the shell to crack. The cracking of the inner shell resulted in a transfer of the lateral load to the outer shell, breaking the spot welds that hold the outer shell together. The outer stainless steel wrap also failed and sprung open. One of the rivnuts in the top plate broke, but its associated bolt and the all the other lid bolts were undamaged and the lid remained secured to the package.

Puncture Test

For the puncture test, the planned orientation was changed in order to inflict the greatest damage, based on the on-site assessment of Engineering, Regulatory and QA. As such, TP80(B) was dropped so that the cracked shell was aligned with the top edge of the puncture bar. The intention was to open up the crack or cause additional cracking in the damaged area. The thermocouple reading on the outside surface of the unit was -57°C (-71°F) before the puncture test and -44°C (-47°F) after the test.

The unit impacted directly on the crack. The outer shell was deformed inward at the impact area, but additional cracking was not observed.

Post-Test Inspection and Assessment

Following the test the protective lid was removed and the unit was inspected. The through-bolts were all intact. One of the locks had broken out, but the dummy source remained securely retained (i.e., the lock slide was still secure). The top plate (with the lock assembly) deflected outward by about 0.16 inch (4.1 mm). The resulting source pull-out was measured to be 0.027 inch (0.69 mm) in one side and 0.064 inch (1.6 mm) in the other side. Radiographs showed the crack in the inner shell extended from the top plate to the bottom plate.

9. TP80 ACCIDENT DROP TESTS – TP80(C)

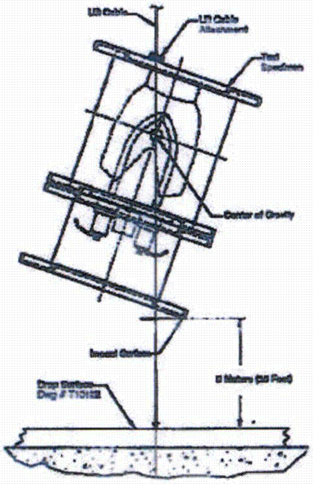
Specimen TP80(C) was subjected to a 9 meter (30 foot) drop test and a puncture test in accordance with Test Plan 80 and results are described below.

<u>9 meter (30 Foot) Drop Test</u>

Just before the drop test, thermocouple readings for Specimen TP80(C) were as follows:

- Internal (source tube): -97°C (-143°F)
- Surface (shell): -98°C (-144°F)

The package orientation for Specimen TP80(C), shown below, was the same as for the 1.2 meter (4 foot) drop. The intention was to fail the bolts holding the protective lid to the rest of the unit. This would expose the lock assembly to further damage during the puncture test.



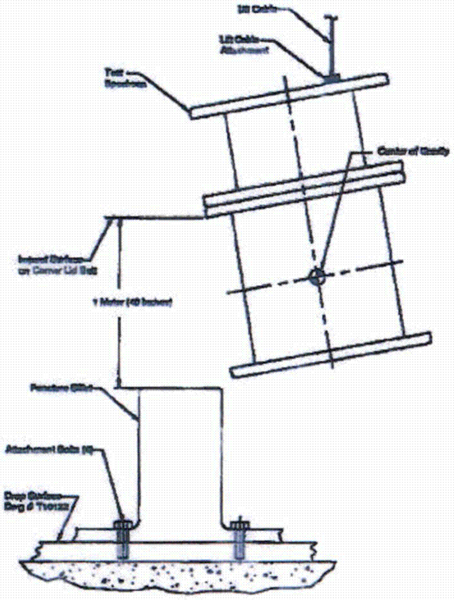
9 Meter (30 Foot) Drop Orientation for Specimen TP80(C)

The package impacted as intended. Visual inspections showed that none of the lid bolts failed, but the lid crack initiated in the 1.2 meter (4 foot) drop increased in both directions. The crack went around the top plate at its interface with the rectangular tube section that protects the locks. The crack went about halfway around the lid, and the top plate was deflected downward about 0.5 inch (13 mm). Portions of the top plate flange also broke off.

Puncture Test

Specimen TP80(C) was subjected to two puncture tests. An additional puncture drop was added as two possible orientations were deemed "worst case". In the first test, the unit was dropped vertically upside down, with the intention of breaking through the lid and damaging the locks. The thermocouple reading on the surface of the unit was -53°C (-63°F) before the puncture test and -50°C (-58°F) after the test.

For the second test, the unit was dropped such that the impact was on the underside of the top plate, as shown below. The objective of this drop was to damage the rivnuts, which hold the lid to the top plate, and to pry the top plate off of the unit by overloading the through-bolts. The initial surface temperature was -47°C (-53°F).



Second Puncture Drop Orientation for Specimen TP80(C)

The unit impacted as intended in both drops. In the first drop, the top of the lid was damaged further, however, the lid remained intact and the puncture bar did not impact the lock assembly. In the second drop, the top plate deformed slightly, but no significant damage was observed.

Post-Test Inspection and Assessment

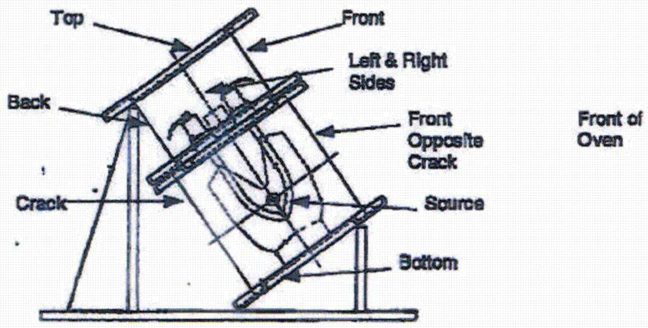
Following the test, the protective lid was removed and the unit was inspected. No damage to the locks was observed and no significant movement of the source was measured. The post-test radiation profile showed no significant change in radiation levels from the pre-test profile (see Appendix B). Because no significant damage occurred to the unit, the thermal test was not considered necessary (see Section 3). In addition, Specimen TP80(B) was considered worst case.

10. TP80 THERMAL TEST – TP80(B)

Based on the results of the drop tests, a thermal test was performed with specimen TP80(B). The damage to this unit was such that the maximum source pull-out, as well as oxidation of the depleted uranium shield, could occur during the thermal test. The thermal test was not considered necessary for the other test specimens since the results are bounded by those for TP80(B).

Orientation and Setup

Based on the damage observed in the drop tests, it was concluded that worst orientation for the thermal test was to have the unit at an angle such that the center of gravity of the shield was over the bottom corner edge of the inner shell. The cracked side of the unit was oriented downward, so that the shield would move toward the crack as the lead shim melted and the shield dropped down. The worst case angle was determined to be 53° based on the internal geometry of the unit. This would allow the maximum amount of shield movement relative to the top plate, pulling the source out of position. To hold the specimen in this orientation, a steel jig was constructed as shown below.



TP80(B) Orientation and Thermocouple Locations

Seven thermocouples were attached to the specimen on the top, bottom, and four side surfaces (two thermocouples on the front side). An eighth thermocouple was inserted into one of the source tubes to measure the internal temperature. A ninth thermocouple was used to measure the ambient oven temperature.

To allow for combustion during the thermal test, the oven door was blocked open with a gap of 1 inch (25.4 mm) at the top and bottom of the door, permitting airflow into the oven while allowing the oven to maintain its temperature. Since the oven door is 36 inches (914 mm) long, each opening was approximately 36 square inches (232 square centimeters).

Test Chronology

Temperatures were recorded from the time the specimen was inserted in the oven until after it had cooled and was moved to a temporary storage area. The total duration of this period was about 1,000 minutes (16 hours). Plots of the temperature data are included in Appendix C. The overall test chronology is as follows:

- Zero to 32 minutes – heat up of the specimen from ambient to over 810°C (1490°F). The 30 minute test started when all surfaces of the specimen exceeded 810°C (1490°F). The thermocouple on the bottom of the unit was the last to reach the target temperature, and the test was started when it reached 813°C (1495°F).

- 32 to 64 minutes – 30 minute test period, with all temperatures maintained above 810°C (1490°F). The maximum temperature was 996°C (1825°F) on the side of the unit facing the rear of the oven, while the minimum temperature was 813°C (1495°F) on the bottom of the unit. The initial and final temperatures of all thermocouples over the 30 minute period are shown below. Flames due to combustion of the foam were observed, however these diminished and stopped before the end of the 30 minute test.

Location	Initial Temp.	Final Temp.	Average Temp.
Bottom	813°C (1495°F)	861°C (1582°F)	872°C (1602°F)
Top	980°C (1796°F)	879°C (1614°F)	913°C (1675°F)
(Lid) Front Oven	934°C (1713°F)	848°C (1558°F)	879°C (1614°F)
(Lid) Back Oven	995°C (1823°F)	884°C (1623°F)	923°C (1693°F)
(Lid) Left Side	949°C (1740°F)	865°C (1589°F)	899°C (1650°F)
(Lid) Right Side	979°C (1794°F)	872°C (1602°F)	909°C (1668°F)
Side (Opposite Crack)	830°C (1526°F)	810°C (1490°F)	823°C (1513°F)
Source Tube	906°C (1663°F)	865°C (1589°F)	886°C (1627°F)
Oven/Ambient	940°C (1724°F)	839°C (1542°F)	877°C (1611°F)

- 64 minutes – removal from oven. The depleted uranium shield was visible, with a slightly red glow in areas. Some depleted uranium oxide (black power) was observed coming out of the crack and onto the surface below, indicating the shield was oxidizing.

- 64 to 700 minutes – cool down to below 100°C (212°F). During this time, the shield was allowed to self-extinguish.

During the cool down period, the unit was allowed to cool via natural convection with no additional heat input. The hypothetical accident conditions specified in the IAEA Safety Series 6 regulations include a requirement to account for heat input due to insolation during the cool down period. This heat input could reduce the cool down rate. However, the reduction was not considered to have any effect on the damage sustained by the test specimen, particularly compared with the 30 minute exposure to 810°C (1490°F) in the oven.

Post-Test Inspection and Assessment

The initial on-site assessment of the test specimen included the following observations:

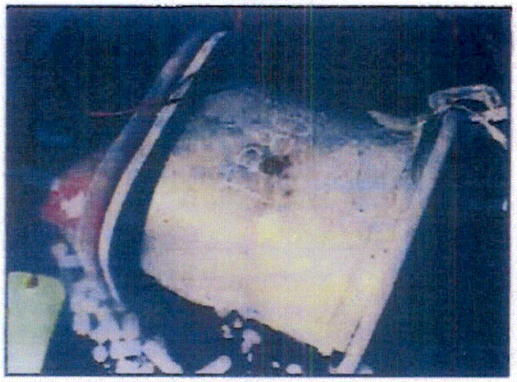
- A cracked piece of the inner shell was dislodged and had dropped out of position.
- Most paint had vaporized. Radiation labels were still legible.
- All the foam had burned off, leaving a small amount of carbon char.
- The lead shielding and shim melted and some lead had dripped out the bottom of the unit.
- Radiography showed the shield moved laterally and downward as expected. The resulting source pull-out was measured to be 0.436 inch (11.1 mm) on one side and 0.480 inch (12.2 mm) on the other side.
- The lock assemblies were functional; however, the source tubes had completely pulled out of the top plate and had shifted laterally. This caused an interference between the source wire and the top plate, and required that the top plate be machined to enlarge the holes before the unit could be profiled.

After the thermal test, visual observations indicated that the shield had come to rest on the through bolts and bottom plate. However, to securely fix the shield in position for shipping and extensive handling, holes were drilled in the shell of the unit so that foam could be poured in, and the shield was foamed in place. A radiation profile was then done on site with the source located to replicate the amount of observed source pull-out. The highest radiation measurement was 28 mR/hr at one meter (when scaled to the 240 Ci licensed capacity of the unit) at the top of the unit. The small amount of shield oxidation experienced in the test had a minimal effect on the overall effectiveness of the shielding.

Test Plan 80 Photographs

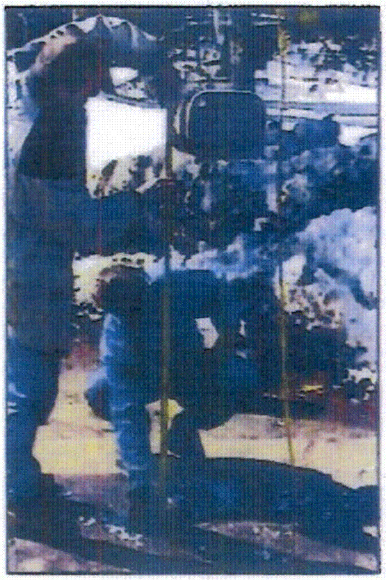
Compression Test

Typical Penetration Test Setup

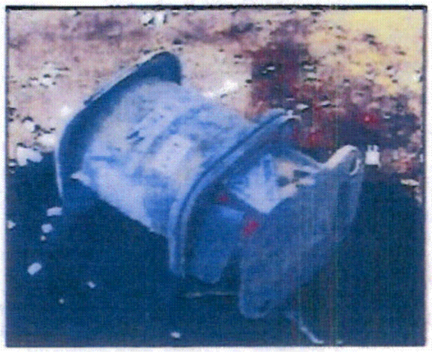


Typical Penetration Impact

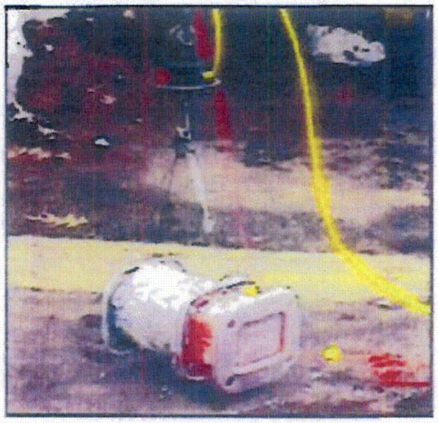
Test Plan 80 Photographs



TP80(A) 4 Foot Drop Setup



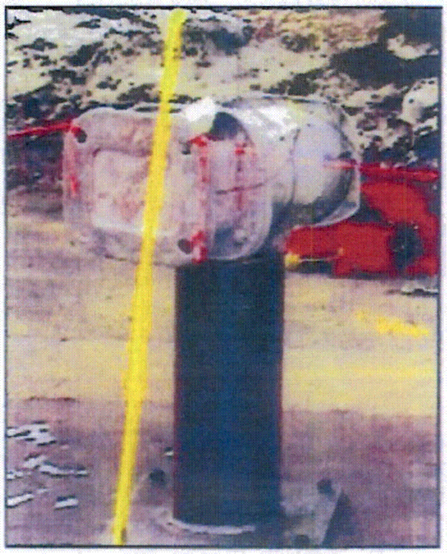
TP80(A) 4 Foot Drop Results



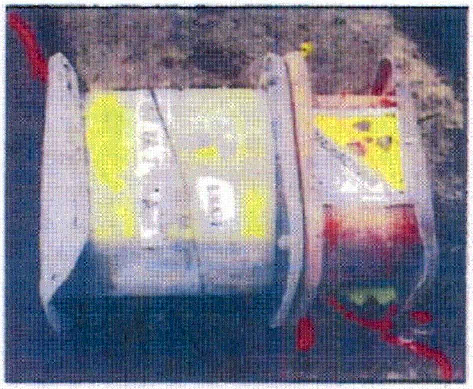
TP80(A) 30 Foot Drop Setup

TP80(A) 30 Foot Drop Results

Test Plan 80 Photographs



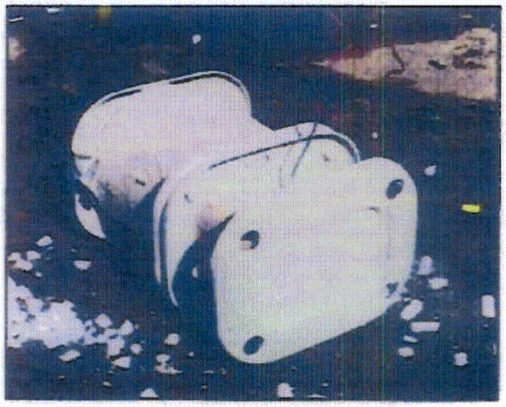
TP80(A) Puncture Test Setup



TP80(A) Puncture Test Results

Test Plan 80 Photographs

TP80(B) 4 Foot Drop Setup

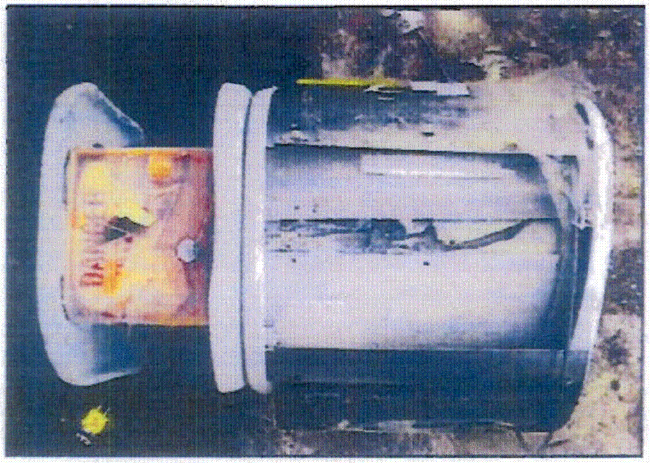


TP80(B) 4 Foot Drop Test Results

Test Plan 80 Photographs

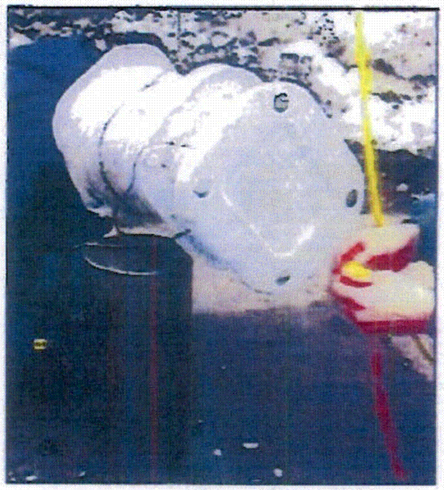
TP80(B) 30 Foot Drop Setup

TP80(B) 30 Foot Drop Results

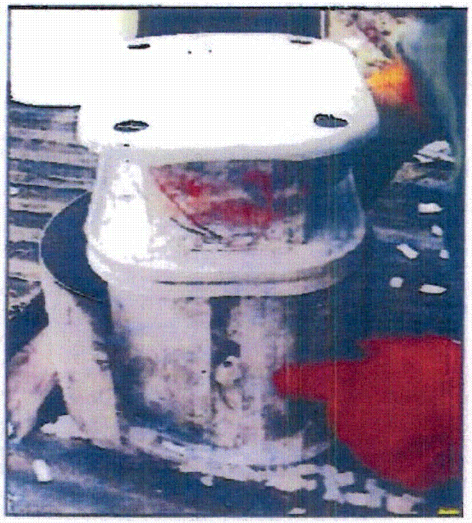


TP80(B) 30 Foot Drop Results

Test Plan 80 Photographs

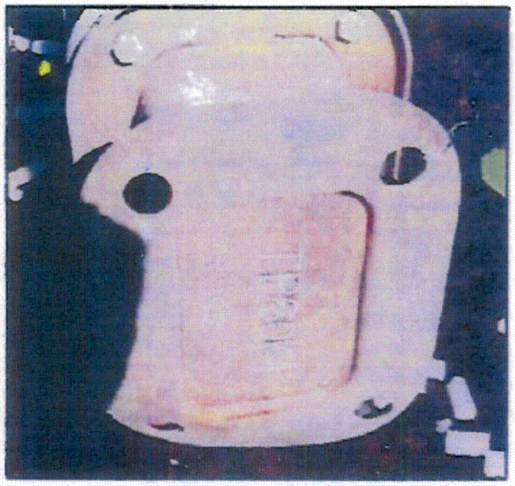


TP80(B) Puncture Test Setup



TP80(B) Puncture Test Results

Test Plan 80 Photographs



TP80(C) 4 Foot Drop Test Results

TP80(C) 30 Foot Drop Setup

TP80(C) 30 Foot Drop Results

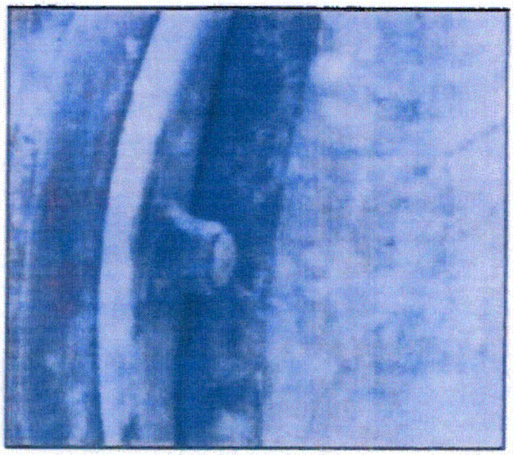
TP80(C) 30 Foot Drop Results

Test Plan 80 Photographs

TP80(C) Puncture Drop 1 Setup

TP80(C) Puncture Drop 1 Results

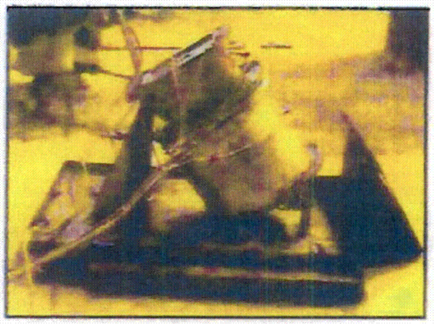
TP80(C) Puncture Drop 2 Setup



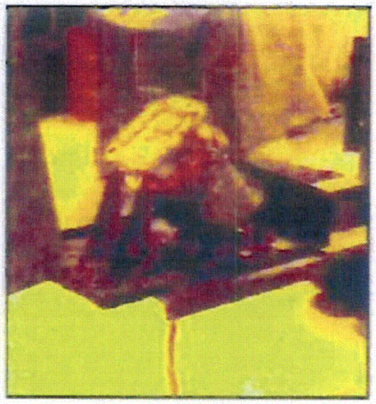
TP80(C) Puncture Drop 2 Results
Showing Closeup of Rivnut

Test Plan 80 Photographs

TP80(B) Thermal Test Setup



TP80(B) Thermal Test Setup



TP80(B) Thermal Test
After Removal From Oven

TP80(B) Thermal Test After
Removal From Oven

Test Plan 80 Photographs

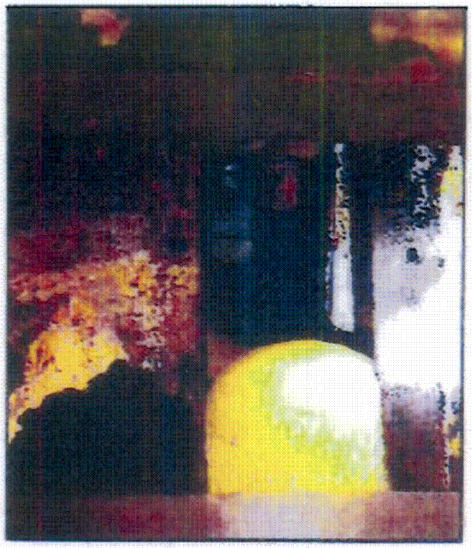
TP80(B) Thermal Test After Removal From Oven

TP80(B) Detail of Cracked Shell

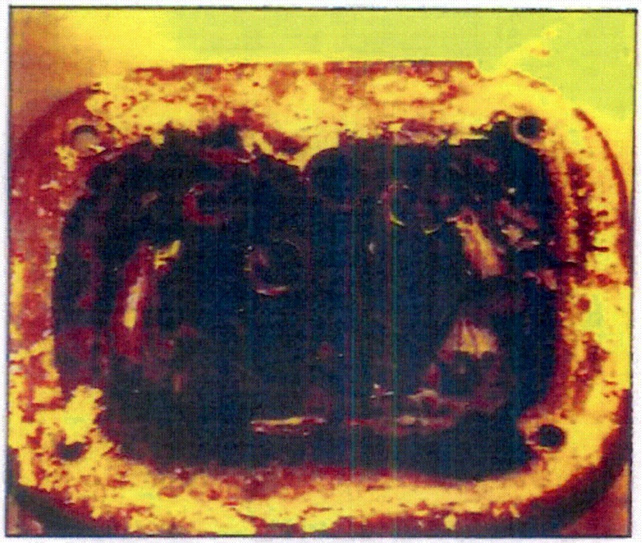
TP80(B) Detail of Uranium Oxide Residue

TP80(B) Detail of Uranium Oxide Residue

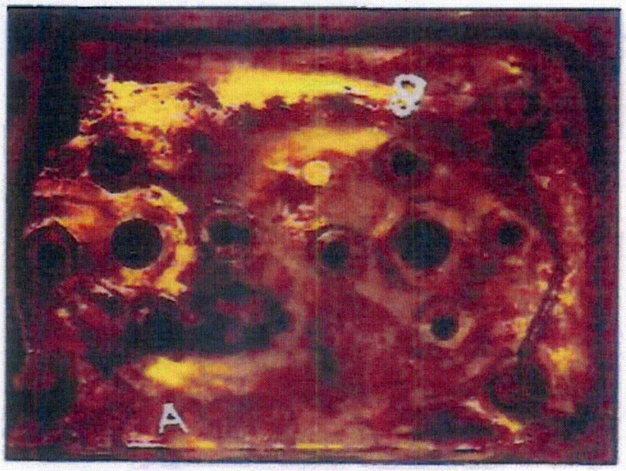
Test Plan 80 Photographs



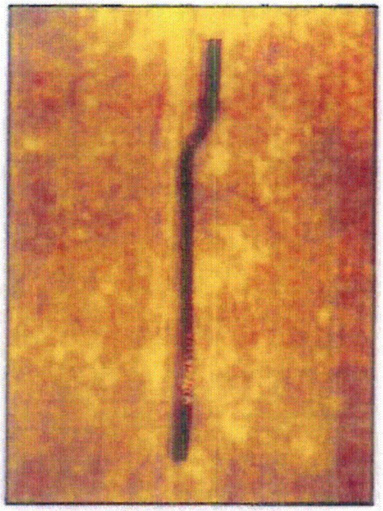
TP80(B) Thermal Test After Removal From Oven--Detail of Crack After Foaming to Stabilize Shield



TP80(B) Thermal Test After Removal From Oven—Lid Removed



TP80(B) Thermal Test After Removal From Oven--Detail of Source Tube Displacement After Removal of Lock Assemblies



TP80(B) Thermal Test After Removal From Oven--Dummy Source Wire--White Mark Shows Top of Source Tube Position

Appendix D: Multiple Wire Locking Assembly

D.1 Background

Currently the Model 650L source changer is equipped with the standard locking assembly. It is the intention of AEAT to modify all 650L source changers to the multiple wire lock assembly during the currently planned modification cycle (i.e., replacement of the through and cover bolts).

The Type B(U) Testing documented in Appendix C was performed with source changers equipped with the standard locking assemblies. Qualification of the source changer when equipped with the standard locking assemblies is addressed in the body of this document.

In this appendix, the Model 650L source changer, equipped with multiple wire locking assemblies, is evaluated with respect to the requirements for Type B(U) Transport packages contained in 10CFR71. This evaluation is performed by reviewing the 10CFR71 requirements that are potentially affected by the design of the locking assemblies, and assessing the effect of the differences between the standard and multiple wire designs.

D.2 Design Description

The standard and multiple wire locking assembly designs are described in the following sections.

D.2.1 Standard Locking Assembly Design

The main components of the standard locking assembly are the base plate, lock slide, key lock, and hold down cap, as shown in the drawings in Appendix A. With the exception of the key lock subassembly, all components are stainless steel. The key lock is a standard, commercially available part. The standard locking assembly is secured to the source changer top plate with four 1/4-20 stainless steel screws. These screws are arranged in a rectangular pattern (1.25 inch x 1.124 inch) around the source hold down cap.

When the assembly is in the locked position, the source can not be withdrawn from its shielded position because the source wire is captured by tines on the end of the lock slide. The lock slide is prevented from disengaging from the source wire by a lock bolt that projects down from the key lock cylinder and captures the slide. The standard lock assembly is designed to accommodate sources using teleflex wires.

D.2.2 Multiple Wire Locking Assembly Design

The main components of the multiple wire locking assembly are the base plate, base plate adjustment shims, lock slide, key lock, and hold down cap, as shown in the drawings at the end of this appendix. All components are stainless steel, except for the brass key lock and guiding insert.

The multiple wire locking assembly can accommodate source wires with lengths that differ by as much as 1/2 inch. To allow the capture of the different length source wires, the lock base plate and lock slide are thicker than in the standard design. Additionally, there are spacers of varying heights (0 to 0.25 in) between the top plate and bottom of the lock base plate to provide a tightly controlled distance between the bottom of the source tube and the locking assembly. These dimensional changes result in a slight weight increase for the multiple wire locking assembly of approximately 1 lb (0.45 kg) per source changer (with 2 locking assemblies). Additionally, the overall height of the multiple wire locking assembly is 2.8 to 3.0 inches at the hold down cap, versus 2.3 inches for the standard design. The method of attachment of the lock assemblies to the source changer top plate is the same as for the standard lock assembly, i.e., 1/4-20 screws threaded into the same holes in the top plate.

When the multiple wire locking assembly is in its locked position, the source wire can not be removed from the source changer. The stop ball on the source wire is contained within the 1/2 inch vertical cavity in the lock slide by the slots in the top and bottom of the slide. The spring-loaded pin within the hold down cap keeps the source wire fully inserted in the DU shield.

D.3 Effect of Multiple Wire Locking Assembly Design on Type B(U) Transport Requirements

The characteristics of the multiple wire locking assembly that could have an effect on Type B(U) Transport requirements, as defined in 10CFR71, are compared with those of the standard locking assembly in the following sections.

D.3.1 Weight and Center of Gravity

The source changer weighs up to 90 lb (41 kg), including the DU shield, which weighs approximately 42 lb (19 kg). The weight difference between the standard and multiple wire locking assemblies is 1 lb (0.45 kg) for two assemblies. This increase of 1% for total package weight is considered negligible.

D.3.2 Positive Closure

The multiple wire locking assembly, which secures the source assembly in the shielded position and assures positive closure, cannot be exposed without first removing the top lid of the source changer. After removal of the seal-wired lid, the hold down cap must be removed, the key lock unlocked, and the lock slide moved to the unlocked position before the source wire can be removed from the source changer. When the lock slide is in the locked position, the stop ball on the source wire is contained within the 1/2 inch vertical cavity in the lock slide by the slots in the top and bottom of the slide.

One other change in the design of the multiple wire locking assembly is the use of a brass key lock. This lock is used by AEA Technology QSA Inc. in all of the Posilock© devices. It has proven safe and effective without failure through extensive field use and Type B testing, whether in or outside of an overpack. Additionally, brass does not undergo a ductile to brittle transition at low temperatures like cast zinc and carbon steel. The brass lock, therefore, is not susceptible to the lock cylinder damage that occurred at low temperatures during the 650L experimental and Type B drop tests. As a result, the key lock is considered capable of ensuring that the lock slide remains in the locked position under both the normal and hypothetical accident conditions.

Based on this evaluation, the multiple wire lock assembly meets the requirements for positive closure.

D.3.3 Normal Conditions of Transport Tests

The use of multiple wire locking assemblies would have no impact on the results of the Normal Conditions of Transport Tests discussed in the body of this report, and in Appendix C. Specifically, as shown in the Test Report (Appendix C), there was no damage to the source changer that could have been affected by the lock assembly design. For Specimens TP80(A) and TP80(B), damage was limited to impact witness markings on the top and bottom plates and the lid. For Specimen TP80(C), the 1.2 meter (4 foot) drop initiated a crack in the top of the lid. No damage was observed for either the locking assemblies or source changer top plates.

The multiple wire lock assembly has the same basic dimensions, materials, and attachment to the source changer top plate, as the standard lock assembly. Therefore, it is concluded that these lock assemblies would not be damaged by the Normal Conditions of Transport Tests.

D.3.4 Hypothetical Accident Condition Tests

The Hypothetical Accident Condition Tests reported in Appendix C identified three potential damage mechanisms that could be affected by the change in the design of the lock assembly. These potential damage mechanisms include the following:

1. Large Deflection of Source Changer Top Plate (Resulting in Source Tube Pullout and Failure of Lock Assembly Attachment Screws)

2. Failure of Lid (Resulting in Failure of Lock Assemblies)

3. Shock of Impact (Resulting in Failure of Lock Assemblies)

These potential damage mechanisms are discussed below.

Large Deflection of Source Changer Top Plate—In the vertical upside down 9 meter (30 foot) drop test of TP80(B), the top plate was deflected upward about 0.16 inch (4.1 mm) in the center of the plate. The top plate, which is 10 gage (~1/8 inch) thick, is less stiff than the standard locking assembly. Therefore, the area of the top plate bounded by the rectangles formed by the lock screws stayed in plane (flat). The distances between the screws (1.124 inch x 1.250 inch) are the same for both designs, and the multiple wire lock assembly is at least as stiff as the standard design. Therefore, the top plate deformation (and potential source tube pullout) would be unaffected by use of the multiple wire locking assembly. Note that although the footprint of the multiple wire locking assembly is slightly different than that of the standard design, the differences are in the key lock end of the assembly, which cantilevers above the top plate when the plate deflects upward. The extra weight (1 lb) of the multiple wire locking assembly would have a negligible effect on the deflection of the top plate, which is driven by the weight of the DU shield (approximately 42 lb).

Failure of Lid—In the top corner down 9 meter (30 foot) drop test of TP80(C), the source changer lid partially failed due to the brittle condition of the carbon steel. Specifically, the lid cracked and its top plate deflected inward about 1/2 inch along one edge. The subsequent puncture test increased the lid damage slightly. The normal height of the lid (4 1/2 inches) is sufficient to allow such a deflection and still protect the multiple wire locking assembly, which is about 3 inches high at the cap. Therefore, it is concluded that the source changer lid would protect the multiple wire lock assembly during Hypothetical Accident Condition Testing.

Shock of Impact—The standard locking assembly was dropped three times from 9 meters (30 feet). The assemblies stayed in the locked position for all three tests. The multiple wire lock assembly has the same basic dimensions, materials, and attachment to the source changer top plate, as the standard lock assembly. Therefore, it is concluded that these lock assemblies would remain in the locked position during the Hypothetical Accident Conditions of Transport Tests.

D.4 Conclusion

The Model 650L source changer, when equipped with the multiple wire locking assembly, satisfies the requirements for Type B(U) Transport packages by comparison to the standard locking assembly.

2.12.7 USDOT Special Form Certificate USA/0377/S-96 Rev 8

U.S. Department
of Transportation
**Pipeline and
Hazardous Materials
Safety Administration**

**East Building, PHH-23
1200 New Jersey Avenue Southeast
Washington, D.C. 20590**

**IAEA CERTIFICATE OF COMPETENT AUTHORITY
SPECIAL FORM RADIOACTIVE MATERIALS
CERTIFICATE USA/0377/S-96, REVISION 8**

This certifies that the sources described have been demonstrated to meet the regulatory requirements for special form radioactive material as prescribed in the regulations of the International Atomic Energy Agency[1] and the United States of America[2] for the transport of radioactive material.

1. <u>Source Identification</u> - QSA Global, Inc. Models 60011, 60012, and 60013.

2. <u>Source Description</u> - Cylindrical double encapsulations made of Type 304 or 304L stainless steel and seal welded. Approximate outer dimensions are 6.35 mm (0.25 in.) in diameter and 24.3 mm (0.96 in.) in length (Model 60011); 8.89 mm (0.35 in.) in diameter and 32.5 mm (1.28 in.) in length (Model 60012); and 12.1 mm (0.48 in.) in diameter and 40.3 mm (1.59 in.) in length (Model 60013). Inner capsules are made of stainless steel or titanium, secured by stainless steel, titanium, or aluminum spacer disks and springs. Construction shall be in accordance with attached Tech/Ops Drawing No. 60060, Rev. B.

3. <u>Radioactive Contents</u> - No more than 8.14 TBq (220.0 Ci) of Cobalt-60 for the Model 60011. No more than 25.9 TBq (700.0 Ci) of Cobalt-60 for the Model 60012. No more than 44.4 TBq (1,200.0 Ci) of Cobalt-60 for the Model 60013. The Co-60 is in solid metallic form.

4. <u>Quality Assurance</u> - Records of Quality Assurance activities required by Paragraph 310 of the IAEA regulations[1] shall be maintained and made available to the authorized officials for at least three years after the last shipment authorized by this certificate. Consignors in the United States exporting shipments under this certificate shall satisfy the applicable requirements of Subpart H of 10 CFR 71.

5. <u>Expiration Date</u> - This certificate expires on February 28, 2016.

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[1] "Regulations for the Safe Transport of Radioactive Material, 1996 Edition (Revised), No. TS-R-1 (ST-1, Revised)," published by the International Atomic Energy Agency(IAEA), Vienna, Austria.

[2] Title 49, Code of Federal Regulations, Parts 100-199, United States of America.

CERTIFICATE USA/0377/S-96, REVISION 8

This certificate is issued in accordance with paragraph 804 of the IAEA Regulations and Section 173.476 of Title 49 of the Code of Federal Regulations, in response to the February 10, 2011 petition by QSA Global, Inc., Burlington, MA, and in consideration of other information on file in this Office.

Certified By:

Feb 18 2011
(DATE)

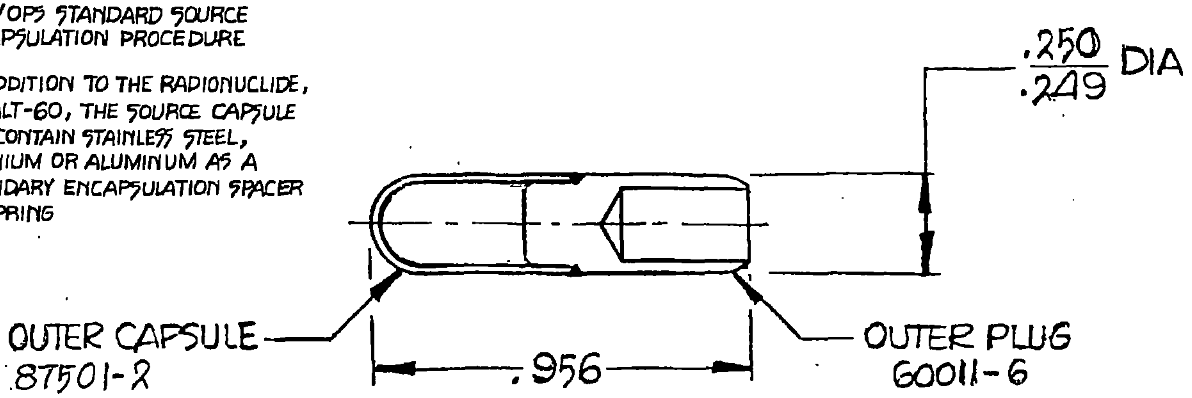
for Dr. Magdy El-Sibaie
Associate Administrator for Hazardous Materials Safety

Revision 8 - Issued to extend the expiration date.

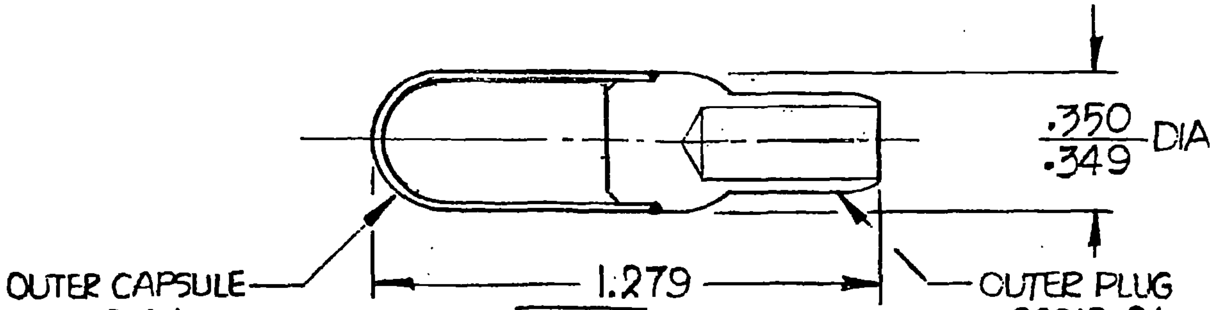
REV.	DATE	DESCRIPTION
A	25 SEP 85	SEE HT 1 F/G
B	1 MAY 86	NOTES ADDED TO DESCRIBE ADDITIONAL CONTENTS F/

NOTES:

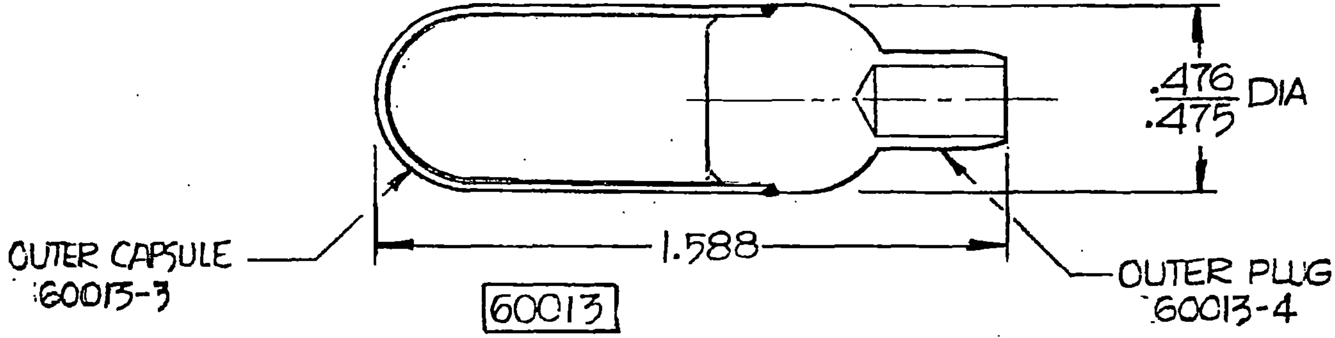
1. EACH SOURCE CAPSULE IS SEAL WELDED IN ACCORDANCE WITH TECH/OPS STANDARD SOURCE ENCAPSULATION PROCEDURE
2. IN ADDITION TO THE RADIONUCLIDE, COBALT-60, THE SOURCE CAPSULE MAY CONTAIN STAINLESS STEEL, TITANIUM OR ALUMINUM AS A SECONDARY ENCAPSULATION SPACER OR SPRING



60011



60012



60013

MATERIALS	
FINISH	
DRAWN BY 23 JUL. 79	UNLESS OTHERWISE SPECIFIED TOLERANCES ARE
	.X ±
CHECKED BY	.XX ±
	.XXX ±
APPROVED BY	ANGLES ±
	FRACTIONS ±

Tech/Ops

TECH/OPS, INC.
RADIATION PRODUCTS DIVISION
BURLINGTON, MA 01803

DWG TITLE

COBALT ^{60} SOURCE REFERENCE

CLASSIFICATION	SIZE	DWG. NO.	REV.
	A	60060	B

SCALE 2:1

SHEET 2 OF 3

2.12.8 Test Plan 79 Report dated 22 October 1998

SENTINEL

TEST PLAN NO. 79

TEST PLAN COVER SHEET

TEST TITLE: VULTAFOAM COMPRESSION TEST	
PRODUCT MODEL: 650 AND 680	
ORIGINATED BY:	DATE: 8 OCT 98

TEST PLAN REVIEW

ENGINEERING APPROVAL:	DATE: 8 OCT 98
QUALITY ASSURANCE APPROVAL:	DATE: 9 Oct 98
REGULATORY APPROVAL:	DATE: 9 Oct 98

COMMENTS:

TEST RESULTS REVIEW

ENGINEERING APPROVAL:	DATE: 16 OCT 98
QUALITY ASSURANCE APPROVAL: Nicholas J Marro	DATE: 20 Oct 98
REGULATORY APPROVAL:	DATE: 22 Oct 98

Amersham QSA

PURPOSE

This test plan describes an experiment to determine the typical compression and energy absorption characteristics of the foam material used in the Sentinel radiography device and transport packages. The foam is Vultafoam, part number 16-L-708 and 16-L-720, manufactured by General Latex and Chemical Corp. The tests involve dropping a steel bar onto foam samples and measuring the depth of compression. Tests will be done at various temperatures.

MEASURING AND TEST EQUIPMENT

Required measuring and test equipment includes:

1. Steel bar and guide tube
2. Scale (calibrated)
3. Thermocouples and thermocouple reader (calibrated)
4. Ruler, one meter long, OR tape measure
5. Graduated cylinder (1 ml accuracy)
6. Caliper (0.001 inch accuracy)
7. Oven
8. Freezer or cooler with dry ice

TEST SPECIMEN PREPARATION

A total of 12 test specimens (identified in Table 1) are to be made using this test plan and work instruction WI-AS40. All the test specimens are to be contained in a ½ pint tin can. Test specimen foam mixtures are determined in Table 4 to simulate representative volumes of the model 650 and model 680 in the ½ pint cans.

Table 1. Foam Specimens

Set No.	Number of Specimens	Foam Part No.	Can Top Open or Closed
1	3	16-L-708	Open
2	3	16-L-708	Closed
3	3	16-L-720	Open
4	3	16-L-720	Closed

Can Preparation

1. Identify each can with its set number and specimen number 1 through 3.
2. For Sets 2 and 4, drill a small hole (about ½ inch diameter) in the top of the can lid.
3. Weigh each tin can and record the weight before adding the Vultafoam. Record the weight in attached foam compression test data sheets.
4. Measure the volume of a can without the top on and a can with the top on. Note: Based on previous observations the volume of a can without a top on is typically 257 ± 2 mL. Measure the volume by filling the can with water and measuring the water volume with the graduated cylinder. Record the volume for each can in the attached foam compression test data sheets.

Foam Component Density

Determine the density of Vultafoam components. For each component (16-L-708 and 16-L-1720) perform the following steps:

- a) Weigh the graduated cylinder when empty and dry.
- b) Fill the graduated cylinder with the component and record the volume in Table 2.
- c) Weigh the cylinder to determine the weight of the component and record in Table 2.
- d) Repeat this procedure for the other component.
- e) Calculate the density of the component in Table 2

Foam Mass Required

Determine the mass of mixture used in the Vultafoam work instruction (WI-AS40-01) for Model 650 and 680 using Table 3.

Foam Mixture Required for Test Can

Determine the mass of mixture to use in the test sets by completing Table 4.

Test Set Preparation

1. For Test Set 1, mix Vultafoam components A and B in the volume ratio specified in the WI for the model 650 or 680 as appropriate. Record the volume of each component in test date sheet (mix enough foam to prepare the number of cans which can be foamed in about 3 minutes). Mix the Vultafoam parts using a pistol drill with a stirrer for approximately five seconds.
2. Place the test can on the scale and zero the scale. Pour the required mixture weight (as determined in Table 4) into the test can. Record the weight in the attached data sheets. Remove the can from the scale.
3. For test sets 2 and 4 place the lid on the can and tap edges with a rubber mallet to ensure the lid is tight.
4. Repeat steps 1 through 3 for the remaining test set cans.
5. After the foam has cured, remove the top of the can for Sets 2 and 4. For Sets 1 and 3, cut the top of the foam flush with the top of the can. Record the cure time in the attached data sheets.
6. Weigh each can and record value in the attached data sheets.
7. Calculate the effective density in the attached data sheets.
8. Cut approximately ¼" off the top and bottom of the can to obtain a level surface for the drop test.
9. Record the foam height of the test specimen.
10. Drill a small hole in the center of the side of the test can shell approximately 1 inch deep for the thermocouple.

TEST INSTRUCTIONS

Document completion of these test instructions on the attached data sheet.

Test Preparation:

1. Verify all measuring and test equipment is in calibration.
2. Fabricate and measure specimens as described above.
3. Insert the thermocouple into the foam approximately in the center of the can.
4. Place one of each type of specimen in oven set to a temperature of at least 100°F for at least one hour.
5. Place one of each type of specimen in a freezer set to –40°F or lower or in a cooler with dry ice for at least one hour.
6. Allow one of each type of specimen to remain at room temperature for testing.

7. Mount the guide tube over a clean, flat surface such that the tube is vertical (see Figure 2). Make sure the guide tube is mounted such that the drop height of the steel bar can be accurately measured and both ends of the tube will be unobstructed during the test (i.e., make sure that air can easily escape the tube as the bar is dropped).

Compression Test:

1. Position the steel bar in the guide tube and measure the drop height.
2. Record the temperature of the test specimen as it is removed from the oven/freezer.
3. Place the specimen on the test surface and secure in place. Immediately drop the bar onto the specimen.
4. Measure the depth of compression.
5. Record any observations regarding damage to the specimen.

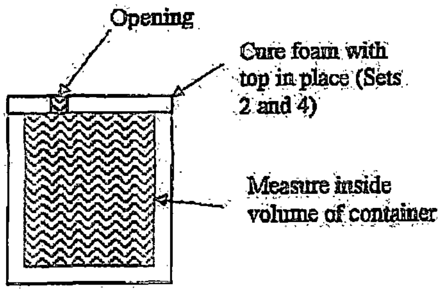


Figure 1. Foam Container

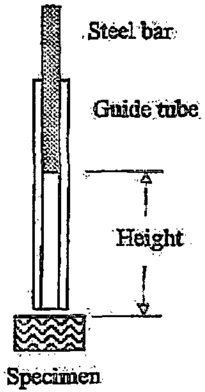


Figure 2. Test Set Up

Table 2. Vultafoam Component Density

Set No.	Part	Empty Cylinder Wgt. (A) (lbs)	Volume of Component (B) (mL)	Wgt of Cylinder w/Comp (C) (lbs)	Calculated Density (C-A)/(B/29.575) (lbs/oz)
16-L-1708	A				
	B				
16-L-1720	A				
	B				

Note: Volume conversion: 1 oz. = 29.575 ml

Completed by: ____________________ Date: ____________________

Check by: ____________________ Date: ____________________

Table 3. Vultafoam Mixture Weight Used in Model 650 and 680

Model	Foam Type	Part A			Part B			Total Mass of Mixture used in device $(m_A + m_B)$
		Vol_A * (oz)	ρ_A (From Table 2)	m_A $(Vol_A)(\rho_A)$	Vol_B * (oz)	ρ_B (From Table 2)	m_B $(Vol_B)(\rho_B)$	
650	16-L-708	24			30			
680	16-L-720	225			281			

* Volumes of A and B from WIAS40

Completed by: ____________________ Date: ____________________

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Table 4. Vultafoam Mixture Required for Test Cans

Test Sets	Foam Type	Total Mass of Mixture in Device (From Table 3) (A)	Volume Ratio Vol_{Can} / Vol_{Device} * (B)	Mass of Vultafoam Added to Test Can (lbs) (A*B)
1,2	16-L-708		0.057	
3,4	16-L-720		0.010	

* Based on scoping estimates (Attachment A and B)

Completed by: ____________________ Date: ____________________

Check by: ____________________ Date: ____________________

Foam Compression Test Data Sheet

Equipment

Description	Model/Serial Number(s)	Calibration Date(s)
Steel bar #1		N/A
Steel bar #2		N/A
Thermocouple/thermometer		
Scale #1		
Scale #2		
Height Gage		
Oven		N/A
Additional Equipment:		
Graduated Cylinder		N/A
Ruler/tape measure		N/A

Completed by: ____________________ Date: ____________________

Check by: ____________________ Date: ____________________

Foam Compression Test Data Sheet
- 16-L-708 (8 pcf Density) Foam
- Free Rise

Set 1 – Free Rise Specimens	Specimen 1-1	Specimen 1-2	Specimen 1-3
1. Can empty weight (lbs)			
2. Can volume (mL)			
3. Volume of Component A / B in mixture (ml)			
4. Weight of Vultafoam added to can (lbs)			
5. Cure time (min)			
6. Filled weight (lbs)			
7. Foam height, Pre-drop (in)			
8. Heating/cooling time (min)			
9. Specimen temperature (°F)			
10. Drop Bar Used			
11. Bar drop height (in)			
12. Foam height, Post-drop (in)			

Completed by: ____________________ Date: ____________________

Check by: ____________________ Date: ____________________

Foam Compression Test Data Sheet
- 16-L-708 (8 pcf density) Foam
- Contained Specimens

Set 2 – Contained Specimens	Specimen 2-1	Specimen 2-2	Specimen 2-3
13. Can empty weight (lbs)			
14. Can volume (mL)			
15. Volume of Component A / B in mixture (ml)			
16. Weight of Vultafoam added to can (lbs)			
17. Cure time (min)			
18. Filled weight (lbs)			
19. Foam height, Pre-drop (in)			
20. Heating/cooling time (min)			
21. Specimen temperature (°F)			
22. Drop Bar Used			
23. Bar drop height (in)			
24. Foam height, Post-drop (in)			

Completed by: ____________________ Date: ____________________

Check by: ____________________ Date: ____________________

Foam Compression Test Data Sheet
- 16-L-720 (20 pcf Density) Foam
- Free Rise

Set 3 – Free Rise Specimens	Specimen 3-1	Specimen 3-2	Specimen 3-3
25. Can empty weight (lbs)			
26. Can volume (mL)			
27. Volume of Component A / B in mixture (ml)			
28. Weight of Vultafoam added to can (lbs)			
29. Cure time (min)			
30. Filled weight (lbs)			
31. Foam height, Pre-drop (in)			
32. Heating/cooling time (min)			
33. Specimen temperature (°F)			
34. Drop Bar Used			
35. Bar drop height (in)			
36. Foam height, Post-drop (in)			

Completed by: ____________________ Date: ____________________

Check by: ____________________ Date: ____________________

Foam Compression Test Data Sheet
- 16-L-720 (20 pcf Density) Foam
- Contained Specimen

Set 4 – Contained Specimens	Specimen 4-1	Specimen 4-2	Specimen 4-3
37. Can empty weight (lbs)			
38. Can volume (mL)			
39. Volume of Component A / B in mixture (ml)			
40. Weight of Vultafoam added to can (lbs)			
41. Cure time (min)			
42. Filled weight (lbs)			
43. Foam height, Pre-drop (in)			
44. Heating/cooling time (min)			
45. Specimen temperature (°F)			
46. Drop Bar Used			
47. Bar drop height (in)			
48. Foam height, Post-drop (in)			

Completed by: ____________________ Date: ____________________

Check by: ____________________ Date: ____________________

SENTINEL
AEA Technology QSA, Inc.
Burlington, Massachusetts

Test Report No. 79
October 16, 1998
Page 1 of 10

VULTAFOAM IMPACT TEST RESULTS

PURPOSE

To document the results of impact testing conducted on Vultafoam 16-L-708 and 16-L-720 test specimens at AEA Technology.

SUMMARY

Vultafoam 16-L-708 and 16-L-720 specimens were produced in ½ pint (8 fluid ounce) cans to simulate the typical foam formed in Sentinel Model 650 and 680 radiography devices during manufacturing. The samples were then tested to determine the effects of temperature and foam density on the compression characteristics of the foam at various impact energies by dropping a 1-inch diameter steel bar from various heights. Test results are summarized below in Table 1 and detailed results are in Tables 2 through 5. Test data sheets and equipment calibration records can be found in Attachment A and Attachment B respectively.

Table 1. Test Summary

Set No.	Foam Part No.	Open / Closed	Specimen No.	Effective Density (lb/ft^3)	Test Temp (F)	Drop Height (in)	Drop Energy (ft-lbs)	Foam Compression (in)	Foam Strain
1	16-L-708	Open	1	10.4	-54	48.75	17.875	.359	.134
			2	10.1	71	40.13	14.713	.374	.135
			3	10.2	105	40.13	14.713	.352	.132
2	16-L-708	Closed	1	12.7	-45	48.75	45.906	.864	.320
			2	13.0	70	40.18	14.733	.214	.083
			3	12.8	120	56.75	20.808	.189	.071
3	16-L-720	Open	1	24.3	-50	99.00	93.225	.321	.116
			2	24.1	70	67.63	63.685	.255	.090
			3	24.5	134	99.00	93.225	.262	.098
4	16-L-720	Closed	1	25.7	-63	99.13	93.347	.410	.152
			2	26.1	70	84.25	79.335	.296	.109
			3	28.7	117	99.00	93.225	.265	.097
5	16-L-708	Open	1	10.3	71	56.75	20.808	.466	.176
			2	10.3	71	48.88	46.029	1.060	.400
6	16-L-708	Closed	1	12.6	70	48.88	46.024	.856	.318
			2	12.7	71	56.75	53.440	.810	.299
7	16-L-720	Open	1	23.8	70	98.75	92.990	.349	.124
			2	24.8	70	98.88	93.112	.383	.136
8	16-L-720	Closed	1	28.8	70	99.00	93.225	.265	.097
			2	28.9	70	99.13	93.343	.289	.107

TEST DESCRIPTION

The impact testing discussed below was conducted in accordance with AEA Test Plan 79. Vultafoam test specimens were prepared in ½ pint tin cans to simulate representative volumes of the Sentinel Model 650 and 680 radiography devices. The amount of foam required in the test containers was determined experimentally. The foam for the specimens was then mixed following the guidelines in AEA Work Instruction WI-AS40. After the samples were allowed to cure, they were either cooled in dry ice, left at room temperature, or heated in an oven for approximately one hour. The test specimens were then impacted with 1-inch diameter steel bars (either 4.4 lb or 11.3 lb) and the depth of foam compression was measured. The method of determining the foam required in the test containers, the preparation of the test specimens, the impact test method, and the test equipment are described below.

Determination of Foam Required in Test Containers

The amount of Vultafoam required in the test container to simulate representative volumes of the Sentinel Model 650 and 680 was determined experimentally. First, the densities of the Vultafoam parts (A and B) for each foam type (708 and 720) were determined by weighing a known volume of each foam part. The foam density was then multiplied by the volume called for in the foam work instruction and the ratio of the device volume to the test container volume to determine the mass of Vultafoam required in each test container. These calculations are included in the test data sheets (Attachment B). The calculation to determine the volume ratio of each device to the test container is included in Attachment C.

Preparation of Test Specimens

A total of 20 foam test specimens were prepared in ½ pint tin cans. Twelve foam specimens were prepared as specified in the test plan. Four additional test sets, with two specimens each, were also produced and left at room temperature to provide additional data points. The tops of test cans for test sets 1, 3, 5, and 7 were left open. The lids for test sets 2, 4, 6, and 8 were drilled with a small hole (Figure 1) and placed on the cans after the foam was poured. This was intended to be representative of the opening used to fill the actual devices.

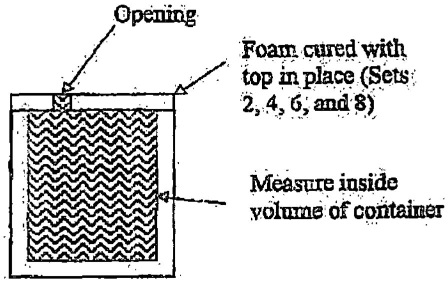


Figure 1. Test Container

The empty volume and weight of the test specimens were determined before the foam was poured so that the density of the foam could be determined after it cured. The volume of a can with the lid off and with the lid in place was verified by filling the can with water and measuring the volume of the water with a graduated cylinder. Each can was then weighed and the data was recorded in the test plan data sheets.

The foam was mixed and poured in accordance with AEA Work Instruction WI-AS40. Batches of the foam mixture were prepared in a sufficient quantity to fill two or three specimens at a time. After the samples were allowed to cure for at least 2 hours, the overflow foam was trimmed and the lids on the contained test cans were removed. The test specimens were then weighed to determine effective density of the foam. The foam density calculations are provided in Attachment D. The top and bottom of the test specimen can was then trimmed with the lathe to provide a flat and level impact surface and a thermocouple hole was drilled in the side of the can. Foam height for each test specimen was then recorded. Finally, the test specimens were either cooled in dry ice, left at room temperature, or heated in an oven.

Impact Test Method

To test the compression characteristics of the foam, a 1-inch diameter steel impact bar was dropped from various heights. A guide tube was used to ensure the bar impacted the foam squarely (Figure 2). The foam specimens were placed on a solid steel impact surface and clamped horizontally in place to ensure the samples would not move sideways during impact.

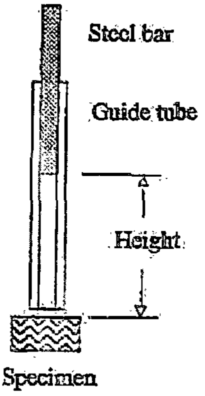


Figure 2. Test Set Up

TEST RESULTS

Detailed test results are shown in Tables 2 through 5. Observations for each test are described in the notes of the Table 2. Note, for the majority of 20 PCF specimens the steel bar was observed rebounding after the initial impact.

Table 2. Test Details 16-L-708 (8 PCF) Free Rise Specimens

	Specimen number									
	1-1		1-2		1-3		5-1		5-2	
Container empty weight (lbs)	0.108		0.099		0.098		0.098		0.108	
Container volume (mL)	258		258		258		258		258	
Mixture Volume A & B (mL)	133	150	133	150	133	150	133	150	133	150
Mixture Weight A & B (lbs)	0.354	0.354	0.354	0.354	0.354	0.354	0.354	0.354	0.354	0.354
Vultafoam added to Can - Weight (lbs)	0.230		0.242		0.226		0.230		0.170	
Cure time (min)	175		175		175		135		135	
Filled Weight (excess removed) (lbs)	0.203		0.191		0.191		0.192		0.202	
Effective density (lbs/ft^3)	10.4		10.1		10.2		10.3		10.3	
Specimen temperature (F)	-54		71		105		71		71	
Vultafoam height, pre-drop (in)	2.683		2.763		2.657		2.642		2.647	
Bar weight (lbs)	4.4		4.4		4.4		4.4		11.3	
Bar drop height (in)	48.75		40.13		40.13		56.75		48.88	
Bar area (in2)	0.75		0.75		0.75		0.75		0.79	
Vultafoam height, post-drop (in)	2.324		2.389		2.315		2.176		1.587	
Calculated compression (in)	0.359		0.374		0.352		0.466		1.060	
Strain	0.134		0.135		0.132		0.176		0.400	
Kinetic Energy at Impact (ft-lbs)	17.875		14.713		14.713		20.808		45.029	
Observations (See Notes)	1		1		1		1		1	

1 - Steel bar did not bounce at impact
2 - Steel bar bounced < 1/8" above foam surface
3 - Steel bar bounced < 1/2" above foam surface
4 - Radial Crack in Foam from Impact
5 - Steel bar impacted foam at small angle <5 deg
6 - Steel bar impacted foam at small angle <10 deg
7 - Rebound impression in Foam

Table 3. Test Details 16-L-708 (8 PCF) Contained Specimens

	Specimen number									
	2-1		2-2		2-3		6-1		6-2	
Container empty weight (lbs)	0.109		0.109		0.109		0.099		0.098	
Container volume (mL)	257		257		257		257		257	
Mixture Volume A & B (mL)	141	159	141	159	141	155	134	150	134	150
Mixture Weight A & B (lbs)	0.375	0.375	0.375	0.375	0.375	0.375	0.355	0.356	0.356	0.356
Vultafoam added to Can - Weight (lbs)	0.220		0.224		0.220		0.252		0.226	
Cure time (min)	160		160		160		155		155	
Filled Weight (excess removed) (lbs)	0.224		0.227		0.225		0.213		0.213	
Effective density (lbs/ft^3)	12.7		13.0		12.8		12.6		12.7	
Specimen temperature (F)	-45		70		120		70		71	
Vultafoam height, pre-drop (in)	2.700		2.582		2.667		2.694		2.706	
Bar weight (lbs)	11.3		4.4		4.4		11.3		11.3	
Bar drop height (in)	48.75		40.18		56.75		48.88		56.75	
Bar area (in2)	0.79		0.75		0.75		0.79		0.79	
Vultafoam height, post-drop (in)	1.836		2.368		2.478		1.838		1.896	
Calculated compression (in)	0.864		0.214		0.189		0.856		0.810	
Strain	0.320		0.083		0.071		0.318		0.299	
Kinetic Energy at Impact (ft-lbs)	45.906		14.733		20.808		46.024		53.440	
Observations (See Notes)	1,4		2		2		1		1	

Table 4. Test Details 16-L-720 (20 PCF) Free Rise Specimens

	Specimen number									
	3-1		3-2		3-3		7-1		7-2	
Container empty weight (lbs)	0.108		0.109		0.098		0.098		0.098	
Container volume (mL)	258		258		258		258		258	
Mixture Volume A & B (mL)	219	249	219	249	219	249	189	214	189	214
Mixture Weight A & B (lbs)	0.580	0.580	0.580	0.580	0.580	0.580	0.500	0.500	0.500	0.500
Vultafoam added to Can - Weight (lbs)	0.372		0.372		0.346		0.374		0.370	
Cure time (min)	140		140		140		135		135	
Filled Weight (excess removed) (lbs)	0.329		0.329		0.321		0.315		0.324	
Effective density (lbs/ft^3)	24.3		24.1		24.5		23.8		24.8	
Specimen temperature (F)	-50		70		134		70		70	
Vultafoam height, pre-drop (in)	2.76		2.831		2.678		2.812		2.813	
Bar weight (lbs)	11.3		11.3		11.3		11.3		11.3	
Bar drop height (in)	99.00		67.63		99.00		98.75		98.88	
Bar area (in2)	0.79		0.79		0.79		0.79		0.79	
Vultafoam height, post-drop (in)	2.439		2.576		2.416		2.463		2.430	
Calculated compression (in)	0.321		0.255		0.262		0.349		0.383	
Strain	0.116		0.090		0.098		0.124		0.136	
Kinetic Energy at Impact (ft-lbs)	93.225		63.685		93.225		92.990		93.112	
Observations (See Notes)	1,4		2		2,6		3,4		1	

Table 5. Test Details 16-L-720 (20 PCF) Contained Specimens

	Specimen number									
	4-1		4-2		4-3		8-1		8-2	
Container empty weight (lbs)	0.098		0.099		0.099		0.098		0.098	
Container volume (mL)	257		257		257		257		257	
Mixture Volume A & B (mL)	227	258	227	258	227	258	189	215	189	215
Mixture Weight A & B (lbs)	0.601	0.601	0.601	0.601	0.601	0.601	0.501	0.501	0.501	0.501
Vultafoam added to Can - Weight (lbs)	0.376		0.376		0.372		0.376		0.376	
Cure time (min)	130		130		130		125		125	
Filled Weight (excess removed) (lbs)	0.331		0.336		0.359		0.359		0.360	
Effective density (lbs/ft^3)	25.7		26.1		28.7		28.8		28.9	
Specimen temperature (F)	-63		70		117		70		70	
Vultafoam height, pre-drop (in)	2.706		2.708		2.725		2.719		2.709	
Bar weight (lbs)	11.3		11.3		11.3		11.3		11.3	
Bar drop height (in)	99.13		84.25		99.00		99.00		99.13	
Bar area (in2)	0.79		0.79		0.79		0.79		0.79	
Vultafoam height, post-drop (in)	2.296		2.412		2.460		2.454		2.420	
Calculated compression (in)	0.410		0.296		0.265		0.265		0.289	
Strain	0.152		0.109		0.097		0.097		0.107	
Kinetic Energy at Impact (ft-lbs)	93.347		79.335		93.225		93.225		93.343	
Observations (See Notes)	1,4		3,5		2,6		3,5,7		3,5	

ATTACHMENT A – TEST DATA SHEETS

Table 2. Vultafoam Component Density

Set No. 15oct98	Part	Empty Cylinder Wgt. (A) (lbs) #S1	Volume of Component (B) (mL)	Wgt of Cylinder w/Comp (C) (lbs) #S1	Calculated Density (C-A)/(B/29.575) (lbs/oz)
16-L-~~1~~708	A	.2768	50	.4094	.0784
15oct98	B	.2739	50	.3922	.0700
16-L-~~1~~720	A	.2771	50	.4093	.0782
	B	.2756	50	.3922	.0690

T= 69.9°F
using 6-6-12
6-6-11

Note: Volume conversion: 1 oz. = 29.575 ml

Completed by: S. Gr Date: 15 OCT 98

witnessed ~~Check~~ by: Date: 15 OCT 98
7 15 OCT 98

CHECKED BY: 15 OCT 98

#S1 DENOTES SCALE USED WAS SCALE #1

#S2 DENOTES SCALE USED WAS SCALE #2

SENTINEL
AEA Technology QSA, Inc.
Burlington, Massachusetts

Test Plan 79
October 8, 1998

Foam Compression Test Data Sheet

Equipment

Description	Model/Serial Number(s)	Calibration Date(s)
Steel bar #1	T10236 / SN01	N/A
Steel bar #2	T10248 / SN01	N/A
Thermocouple/thermometer T	ENG-11, ENG-12	SERVICED 8-OCT-98 DUE 8-OCT-99
Scale #1 #S1	8200 / SR87840011	SERVICED 8-MAY-98 DUE 8-NOV-98
Scale #2 (High Precision) #S2	500C / 834468	SERVICED 8-MAY-98 DUE 8-NOV-98
Height Gage HG	MITUTOYO / 027	SERVICED 8-JUN-98 DUE 8-JUN-99
Oven	THERMOLYNE 1300	N/A
Additional Equipment:		
Graduated Cylinder GC	PYREX 100 ML	N/A
Ruler/tape measure TM		N/A

Completed by: ______ Date: 15 OCT 98

Check by: ______ Date: 15 Oct 98

Foam Compression Test Data Sheet
- 16-L-708 (8 pcf Density) Foam
- Free Rise

	Set 1 – Free Rise Specimens	Specimen 1-1	Specimen 1-2	Specimen 1-3
#S1	1. Can empty weight (lbs)	.108	.099	.098
GC	2. Can volume (mL)	258	258	258
①	3. Volume of Component A / B in mixture (ml)	133 / 150 (.354 / .354 LBS)	→	→
#S2	4. Weight of Vultafoam added to can (lbs)	.230	.242	.226
	5. Cure time (min)	175	175	175
#S1	6. Filled weight (lbs)	.203	.191	.191
HG	7. Foam height, Pre-drop (in)	2.683	2.763	2.667
	8. Heating/cooling time (min)	60	NA	60
T	9. Specimen temperature (°F)	-54	71	105
	10. Drop Bar Used	#1 (44 LBS)	#1	#1
TM	11. Bar drop height (in)	48.75	40.13	40.13
HG	12. Foam height, Post-drop (in)	2.324	2.389	2.315
	OBSERVATIONS	②	②	②

Completed by: S. G Date: 15 OCT 98

Check by: MBoyd Date: 15 Oct 98

NOTES:

① MEASURING SMALL QUANTITIES OF COMPONENTS BY VOLUME PROVED TO BE DIFFICULT AND INACCURATE DURING TRIAL RUNS. SINCE THE WORK INSTRUCTION ALLOWS MIXING COMPONENTS IN A 1:1 RATIO BY WEIGHT, THE COMPONENT VOLUMES WERE CALCULATED USING (COMPONENT WEIGHT MEASUREMENTS) AND DENSITY FACTORS FROM TABLE 2.

② DROP BAR DID NOT BOUNCE.

③ DROP BAR BOUNCED LESS THAN 1/8 INCH.

④ DROP BAR BOUNCED LESS THAN 1/2 INCH.

⑤ RADIAL CRACKS PRODUCED BY IMPACT.

⑥ IMPACT SURFACE AT LESS THAN 5° ANGLE.

⑦ IMPACT SURFACE AT LESS THAN 10° ANGLE.

#S1 USED SCALE #1

#S2 USED SCALE #2

Foam Compression Test Data Sheet
- 16-L-708 (8 pcf density) Foam
- Contained Specimens

	Set 2 – Contained Specimens	Specimen 2-1	Specimen 2-2	Specimen 2-3
#S1	13. Can empty weight (lbs)	.109	.109	.109
GC	14. Can volume (mL)	257	257	257
①	15. Volume of Component A / B in mixture (ml)	141 / 159 (.375 / .375 LBS)	→ →	→ →
#S2	16. Weight of Vultafoam added to can (lbs)	.220	.224	.220
	17. Cure time (min)	160	160	160
#S1	18. Filled weight (lbs)	.224	.227	.225
HG	19. Foam height, Pre-drop (in)	2.700	2.582	2.695
	20. Heating/cooling time (min)	60	NA	60
T	21. Specimen temperature (°F)	-45	70	120
	22. Drop Bar Used	#2 (11.3 LBS)	#1 (4.4 LBS)	#1
TM	23. Bar drop height (in)	48.75	40.18	56.75
HG	24. Foam height, Post-drop (in)	1.836	2.368	2.478
	OBSERVATIONS	② ⑤	③	③

Completed by: S. G____ Date: 15 OCT 98

Check by: M Boyd Date: 15 Oct 98

Foam Compression Test Data Sheet
- 16-L-720 (20 pcf Density) Foam
- Free Rise

	Set 3 -- Free Rise Specimens	Specimen 3-1	Specimen 3-2	Specimen 3-3
#S1	25. Can empty weight (lbs)	.108	.109	.098
GC	26. Can volume (mL)	258	258	258
T	27. Volume of Component A / B in mixture (ml)	219 / 249 (.580 / .580 LBS)	→ →	→ →
#S2	28. Weight of Vultafoam added to can (lbs)	.372	.372	.346
	29. Cure time (min)	140	140	140
#S1	30. Filled weight (lbs)	.329	.329	.321
HG	31. Foam height, Pre-drop (in)	2.760	2.831	2.678
	32. Heating/cooling time (min)	60	NA	60
T	33. Specimen temperature (°F)	-50	70	134
	34. Drop Bar Used	#2 (11.3 LBS)	#2	#2
TM	35. Bar drop height (in)	99.00	67.63	99.00
HG	36. Foam height, Post-drop (in)	2.439	2.576	2.416
	OBSERVATIONS	② ⑤	③	③ ⑦

Completed by: S. Gen Date: 15OCT98

Check by: MBoyd Date: 15Oct98

Foam Compression Test Data Sheet
- 16-L-720 (20 pcf Density) Foam
- Contained Specimen

	Set 4 – Contained Specimens	Specimen 4-1	Specimen 4-2	Specimen 4-3
(#S1)	37. Can empty weight (lbs)	.098	.099	.099
(GC)	38. Can volume (mL)	257	257	257
(L)	39. Volume of Component A/B in mixture (ml)	227/258 (.600/.602 LBS)	→	→
(#S2)	40. Weight of Vultafoam added to can (lbs)	.376	.376	.372
	41. Cure time (min)	130	130	130
(#S1)	42. Filled weight (lbs)	.331	.336	.359
(HG)	43. Foam height, Pre-drop (in)	2.706	2.708	2.725
	44. Heating/cooling time (min)	60	NA	60
(T)	45. Specimen temperature (°F)	-63	70	117
	46. Drop Bar Used	#2 (11.3 LBS)	#2	#2
(TM)	47. Bar drop height (in)	99.13	84.25	99.00
(HG)	48. Foam height, Post-drop (in)	2.296	2.412	2.460
	OBSERVATIONS	② ⑤	④ ⑥	④ ⑥

Completed by: S. G Date: 15 OCT 98

Check by: Date: 15 Oct 98

SENTINEL
AEA Technology QSA, Inc.
Burlington, Massachusetts

Test Plan 79
October 8, 1998
Page 9 of 12

Foam Compression Test Data Sheet
- 16-L-708 (8 pcf Density) Foam
- Free Rise

	Set 1 – Free Rise Specimens	Specimen ~~1-1~~ S-1	Specimen ~~1-2~~ S-2	~~Specimen 1-3~~
#S1	1. Can empty weight (lbs)	.098	.108	
GC	2. Can volume (mL)	258	258	
1	3. Volume of Component A / B in mixture (ml)	133 / 150 (.354 / .354 LBS)	→	
#S2	4. Weight of Vultafoam added to can (lbs)	.230	.170	
	5. Cure time (min)	135	135	
#S1	6. Filled weight (lbs)	.192	.202	
HG	7. Foam height, Pre-drop (in)	2.642	2.647	
	8. Heating/cooling time (min)	NA	NA	
T	9. Specimen temperature (°F)	71	71	
	10. Drop Bar Used	#1 (4.4 LBS)	#2 (11.3 LBS)	
TM	11. Bar drop height (in)	56.75	48.88	
HG	12. Foam height, Post-drop (in)	2.176	1.587	

OBSERVATIONS ② ②

Completed by: 9. G

Date: 15 OCT 98

Check by: MBoyd

Date: 15 Oct 98

Foam Compression Test Data Sheet
- 16-L-708 (8 pcf density) Foam
- Contained Specimens

	Set 2 – Contained Specimens	Specimen ~~2-1~~ 6-1	Specimen ~~2-2~~ 6-2	~~Specimen 2-3~~
#S1	13. Can empty weight (lbs)	.099	.098	
GC	14. Can volume (mL)	257	257	
①	15. Volume of Component A / B in mixture (ml)	134 / 150 (.354 / .358 LBS)	→ →	
#S2	16. Weight of Vultafoam added to can (lbs)	.252	.226	
	17. Cure time (min)	155	155	
#S1	18. Filled weight (lbs)	.213	.213	
HG	19. Foam height, Pre-drop (in)	2.694	2.706	
	20. Heating/cooling time (min)	NA	NA	
T	21. Specimen temperature (°F)	70	71	
	22. Drop Bar Used	#2 (11.3 LBS)	#2	
TM	23. Bar drop height (in)	48.88	56.75	
HG	24. Foam height, Post-drop (in)	1.838	1.896	
	OBSERVATIONS	②	②	

Completed by: S. G Date: 15OCT98

Check by: Date: 15Oct98

Foam Compression Test Data Sheet
- 16-L-720 (20 pcf Density) Foam
- Free Rise

	Set 3 – Free Rise Specimens	Specimen ~~3-1~~ 7-1	Specimen ~~3-2~~ 7-2	~~Specimen 3-3~~
#S1	25. Can empty weight (lbs)	.098	.098	
GC	26. Can volume (mL)	252	258	
1	27. Volume of Component A/B in mixture (ml)	189 / 214 → (.500 / .500 LBS) →		
#S2	28. Weight of Vultafoam added to can (lbs)	.374	.370	
	29. Cure time (min)	135	135	
#S1	30. Filled weight (lbs)	.315	.324	
HG	31. Foam height, Pre-drop (in)	2.812	2.813	
	32. Heating/cooling time (min)	NA	NA	
T	33. Specimen temperature (°F)	70	70	
	34. Drop Bar Used	#2 (11.3 LBS)	#2	
TM	35. Bar drop height (in)	98.75	98.88	
HG	36. Foam height, Post-drop (in)	2.463	2.430	
	OBSERVATIONS	④ ⑤	②	

Completed by: ________ Date: 15 OCT 98

Check by: ________ Date: 15Oct98

Foam Compression Test Data Sheet
- 16-L-720 (20 pcf Density) Foam
- Contained Specimen

	Set 4 – Contained Specimens	~~Specimen 4-1~~ 8-1	~~Specimen 4-2~~ 8-2	~~Specimen 4-3~~
#51	37. Can empty weight (lbs)	.098	.098	
GC	38. Can volume (mL)	257	257	
①	39. Volume of Component A/B in mixture (ml)	189 / 215 → (.500 / .502 LBS) →		
#52	40. Weight of Vultafoam added to can (lbs)	.376	.376	
	41. Cure time (min)	125	125	
#51	42. Filled weight (lbs)	.359	.360	
HG	43. Foam height, Pre-drop (in)	2.719	2.709	
	44. Heating/cooling time (min)	NA	NA	
T	45. Specimen temperature (°F)	70	70	
	46. Drop Bar Used	#2 (11.3 LBS)	#2	
TM	47. Bar drop height (in)	99.00	99.13	
HG	48. Foam height, Post-drop (in)	2.454	2.420	

OBSERVATIONS ④ ⑥ ④ ⑥

Completed by: S. G Date: 15 OCT 98

Check by: MRBoyd Date: 15 Oct 98

TEST PLAN #79
S. G[illegible] 15OCT98

VOLUME OF COMPONENT A/B IN MIXTURE (mL)

#LBS.

16-L-708 A (.4094 - .2768) = .1326 PER 50 mL
B (.3922 - .2739) = .1183 PER 50 mL

16-L-720 A (.4093 - .2771) = .1322 PER 50 mL
B (.3922 - .2756) = .1166 PER 50 mL

SPECIMEN 1-1 → 1-3 BATCH (wgt_A = .354 LBS, wgt_B = .354 LBS)

16-L-708 A (.354 / .1326) * 50 = 133 mL
B (.354 / .1183) * 50 = 150 mL

SPECIMEN 2-1 → 2-3 BATCH (wgt_A = .375 LBS, wgt_B = .375 LBS)

16-L-708 A (.375 / .1326) * 50 = 141 mL
B (.375 / .1183) * 50 = 159 mL

SPECIMEN 3-1 → 3-3 BATCH (wgt_A = .580 LBS, wgt_B = .580 LBS)

16-L-720 A (.580 / .1322) * 50 = 219 mL
B (.580 / .1166) * 50 = 249 mL

SPECIMEN 4-1 → 4-3 BATCH (wgt_A = .601 LBS, wgt_B = .601 LBS)

16-L-730 A (.601 / .1322) * 50 = 227 mL
B (.601 / .1166) * 50 = 258 mL

5-1 + 5-2
(wgt = .354 LBS)
133 mL
150 mL

6-1 + 6-2
(wgt = .356 LBS)
134 mL
150 mL

7-1 + 7-2
(wgt = .500 LBS)
189 mL
214 mL

8-1 + 8-2
(wgt = .501 LBS)
189 mL
~~258 mL~~
215 mL

SG
15OCT98

Effective Foam Density

Wgt of Foam = .203 - .108 = .095 LBS.

VOL OF CAN = 258 mL × 3.53×10^{-6} FT^3 = .009112 FT^3

1 mL = .00000353 FT^3

Density = .095 / .009112 = 10.43 LB/FT^3

ATTACHMENT B – EQUIPMENT CALIBRATION RECORDS

TEKSERV

27 Riverneck Road
helmsford, MA 01824
elephone: 978 - 459-9480
AX 978 - 453-6336
ITE: http://www.tekserv.com

CALIBRATION REPORT

SERVICE NUMBER:	SN-0226212
CONTRACT NUMBER:	SENTINEL

A59848

EA TECHNOLOGIES
O NORTH AVENUE

URLINGTON MA 01803

DATE RECEIVED	CUSTOMER P.O.	ASSET NUMBER
10/08/98	2887	ENG - 11

MANUFACTURER	
OMEGA	
MODEL	**SERIAL NUMBER**
TYPE K	NONE
DESCRIPTION	
THERMOCOUPLE	

TEMP.	HUMIDITY	PRIOR CAL	CAL CYCLE	DATE OF TEST	NEXT TEST DUE
23.00 C	50.00 %		12 MO	10/08/98	10/08/99

WORK REQUESTED	SERVICES RENDERED	REMARKS
ALIBRATE/CERTIFY	CALIBRATED/CERTIFIED	READINGS AS RECEIVED

PROCEDURE USED	N.I.S.T. TEST NUMBER	TECHNICIAN
MANUFACTURER'S	413348-433349-259071-LRAN	POULIN

LIBRATION CHECKED TO: MANUFACTURER'S SPECIFICATIONS ADJUSTED TO: MANUFACTURER'S SPECIFICATIONS

IANUFACTURER	MODEL	SERIAL	ACCURACY	DATE CALIBRATED
UILDLINE	9540	52-310	MFG.	2/24/98

KSERV CERTIFIES THAT ALL CALIBRATION EQUIPMENT USED IN THE TEST IS TRACEABLE TO N.I.S.T. AND THE TEST WAS
RFORMED IN ACCORDANCE WITH MIL-STD-45662A, ISO9002,
)-10012-1, ANSI/NCSL-Z540-1-1994.

CERTIFIED BY

READINGS AS RECEIVED

TEKSERV
CALIBRATION DATA

Manufacturer: OMEGA

Serial Number : —

Date of Test : 10-8-98

Technician: m.P.

Prior cal: 6-25-97

Model : TYPE K

DATA AS RECEIVED ✓

Asset Number: ENG-11

THERMOCOUPLE 6 POINT CALIBRATION

T/C TYPE K

Standard	Measured value	Tolerance
-60.00	-56.3	A5-15
-40.00	-37.6	
0.00	0.6	
50.00	49.7	
100.00	99.9	
200.00	201.9	

See attached CALIBRATION REPORT for traceability information

tc.6pt

TEKSERV

127 Riverneck Road
Chelmsford, MA 01824
Telephone: 978 - 459-9480
FAX # 978 - 453-6336
W SITE: http://www.tekserv.com

CALIBRATION REPORT

ISO9002 REGISTERED COMPANY ANSI-RAB
Certificate No. 10154

ISO9002 REGISTERED COMPANY
EN ISO 9002 Certificate No. [illegible]

SERVICE NUMBER:	SN-0226210
CONTRACT NUMBER:	SENTINEL

A59847

AEA TECHNOLOGIES
40 NORTH AVENUE

BURLINGTON MA 01803

DATE RECEIVED	CUSTOMER P.O.	ASSET NUMBER
10/08/98	2887	ENG-12

MANUFACTURER
OMEGA

MODEL	SERIAL NUMBER
HH-21	T-179139

DESCRIPTION
THERMOMETER

TEMP.	HUMIDITY	PRIOR CAL	CAL CYCLE	DATE OF TEST	NEXT TEST DUE
23.00 C	30.00 %	9/25/97	12 MO	10/08/98	10/08/99

WORK REQUESTED	SERVICES RENDERED	REMARKS
CALIBRATE/CERTIFY	CALIBRATED/CERTIFIED	IN TOLERANCE AS RCV'D

PROCEDURE USED	N.I.S.T. TEST NUMBER	TECHNICIAN
MANUFACTURER'S	413348-433349-259071-LRAN	POULIN

ALIBRATION CHECKED TO: MANUFACTURER'S SPECIFICATIONS

ADJUSTED TO: MANUFACTURER'S SPECIFICATIONS

MANUFACTURER	MODEL	SERIAL	ACCURACY	DATE CALIBRATED
ANALOGIC	AN6520	8904010	MFG.	7/03/98

KSERV CERTIFIES THAT ALL CALIBRATION EQUIPMENT USED IN THE TEST IS TRACEABLE TO N.I.S.T. AND THE TEST WAS
ERFORMED IN ACCORDANCE WITH MIL-STD-45662A, ISO9002,
D-10012-1, ANSI/NCSL-Z540-1-1994.

CERTIFIED BY

IN TOLERANCE AS RECEIVED

TEKSERV
CALIBRATION DATA

OMEGA Model HH-21
Serial Number: T 179139
Date of test: 10-8-98
Prior Cal: 9-25-97
Technician: M.P.

Data as Received ✓
Data After Adjustment
Data After Repair
Asset Number: ENG-12

Range	Reading	Specification
Deg.C Type J		
- 100.0	-99.6	+/-{0.1%rdg+0.5°C}
0.0	0.3	"
100.0	100.3	"
500.0	500.0	"
Deg.F Type J		
- 100.0	-99.3	+/-{0.1%rdg+1.0°F}
32.0	32.6	"
200.0	200.5	"
650.0	650.4	"
1200.0	1199.9	"
Deg.C Type K		
- 100.0	-99.5	+/-{0.1%RDG+0.5°C}
0.0	0.4	"
100.0	100.4	"
600.0	599.9	"
1000.0	1000.2	"
Deg.F Type K		
- 100.0	-99.1	+/-{0.1%rdg+1.0°F}
32.0	32.9	"
200.0	200.7	"
600.0	600.4	"
1600.0	1600.5	"
Deg.C Type T		
- 100.0	-99.5	+/-{0.1%rdg+0.5°C}
0.0	0.3	"
100.0	100.2	"
350.0	350.1	"
Deg.F Type T		
- 100.0	-99.4	+/-{0.1%rdg+1.0°F}
32.0	32.5	"
100.0	100.3	"
500.0	500.3	"

Mettler-Toledo, Inc.
Scales & Systems

METTLER TOLEDO

CERTIFICATE OF CALIBRATION No.:01492-97

This is to certify that the below listed weighing equipment was tested and found to be within the NIST tolerances according to the requirements listed in NIST Handbook 44 for weighing devices and in accordance with MIL-STD 45662A. See the Test Record and Service Report for details on errors found and corrections made.

Model #	Serial #	ID	Location	Capacity	Inspector	Next Date Due
10100	242		SHIPPING	100 LB	LEO A.	11/98
DWM-IV	F16383		SHIPPING	5000 LB	"	11/98
DS10	35014		QC	110 LB	"	11/98
4010	1126131		QC	125 LB	"	11/98
8920	267		QC	200 LB	"	11/98
DYNO	D3500		QC	500 LB	"	11/98
8582	2642125		STK RM	10 LB	"	11/98
8200	SR81840011		STK RM	10 LB	"	11/98
500C	834468		STK RM	500 GR	"	11/98
2K BEAM	L482397		ASSEMBLY	2000 LB	"	11/98

Date Test Performed: 5/6/98

Purchase Order No.:
Note: This document may be reproduced and a copy placed at each device if required.

METTLER TOLEDO INC. ______________________
(Service Manager)

Date: 10/9/98

Due Date

METTLER TOLEDO INC.
TEST RECORD AND SERVICE REPORT

PAGE 1 OF 1

CUSTOMER: Amersham Corp

STREET ADDRESS: 40 North AVE

CITY & STATE: BURLington MA

CUSTOMER CONTACT: DAVE ANNIS

DUE DATE 11-8-98 DATE SERVICE RENDERED: 5-8-98

	SCALE IDENTIFICATION				CHART/INDIC.		LOCATION OF SCALE	TEST LOAD APPLIED / ERROR IN GRADUATIONS					CORR		SERVICES RENDERED; PARTS
	MODEL	SERIAL #	MAKE	I.D. #	CAP.	GRAD.							Y	N	
1	DIAM III	F16383	Flex Weigh	F16383	5K lb	1 lb	Shipping	0 0	100 0	200 0	300 0	500 0		✓	CAL OK
2	DSC4848	12486		1"	5K lb	BASE		550 0	550 0	550 0	550 0	—		✓	Shift good.
3	10100	242	Pelouze	242	100 lb	4 oz		0 ±6	25 +1	50 0	75 0	100 0	✓		NOTES
4								—	—	—	—	—			
5	4010	1126131	Pelouze	1126131	125 lb	.2 lb	QC	~~25~~0 0	25 0	50 0	75 0	100 +1		✓	CAL OK
6	D510	35014	OHAUS	3501	110 lb	.05 lb		0 0	25 -4	50 -8	75 -11	100 -13	✓		Recalibrated
7	8920	267	HANSON	267	200 lb	1 lb		0 0	50 0	100 0	150 0	200 0		✓	CAL OK
8	DYNO	D3500	Dillion	D3500	500 lb	2 lb		0 0	100 +1	200 +1	300 0	500 +1		✓	CAL IN SPEC
9								—	—	—	—	—			
10	8200	SR8724001	NCI	269	10 lb	.002 lb	STOCK RM	0 0	2.5 0	5.0 0	7.5 0	10.0 +1		✓	CAL OK
11	500C	834468	Setra	834468	500 g	.001 g		0	100 +5	200 0	300 +4	500 -2	✓		Recalibrated.
12	8582	2642125	Toledo	268	10 lb	.001 lb		0 0	2.5 0	5.0 0	7.5 0	10.0 -1		✓	CAL OK
13								—	—	—	—	—			
14	2KBeam	L482397	NES	L482397	2K lb	.5 lb	Assembly	0 +3	100 0	200 0	300 0	500 0	✓		REZERO
15								—	—	—	—	—			Checked all Counter Weights

REMARKS: 3) Rubbing on plastic LENS, Caved in, Removed Popped out and Reinstalled

Al

TECHNICIAN:

CUSTOMER SIGNATURE: Dave 8 MAY 98

TRACEABILITY #:

PROCEDURE #: Q032-07

Established in 1972

HUNT METROLOGY SERVICE, INC.
175 Jackson St. Methuen, MA 01844-5042
Phone: (978) 688-7278 Fax: (978) 794-4632

CALIBRATION CERTIFICATE

Company Name: AEA TECHNOLOGY
Address: 40 NORTH AVENUE
BURLINGTON, MA. 01803

Calibration No: HMSCC-09028
Dated: AUG 3-7, 1998
Pages: 62

Department:

Phone No.: (781) 272-2000 Ext:

Fax No.: (781) 273-2216

Attention: DAVE ANNIS
P.O. No.: 2603
Technician: DAVID DICKINSON

The calibration performed on the following measuring and test equipment (M&TE) of this document are traceable to the National Institute of Standards and Technology (N.I.S.T.) through N.I.S.T. test number 821/256504-96; Dated February 26, 1997 for dimensional calibration, and/or through N.I.S.T. test number 822/254480 dated February 26, 1997 for mass calibration.

The M&TE have been cleaned and lubricated, as needed. Our technician(s) have calibrated, adjusted and/or reset the M&TE, affixed a calibration label to the M&TE, updated the corresponding record(s), and provided this calibration certificate.

The standard(s) utilized to perform the calibration have been calibrated, certified and maintained in our laboratory which sustains a temperature of 68 degrees (+/- 2 degrees F.) and less than 50% relative humidity. All records pertaining to our standards, and the masters utilized to calibrate them, are kept on file in our laboratory for a period of no less than 3 years.

The services provided, traceability to the N.I.S.T., and Hunt Metrology Service's calibration system comply with the requirements of ANSI/NCSL Z540-1-1994 and ISO 10012-1:1994(E).

The reported value is both "as found" and "as left" data, unless otherwise specified. A calibration uncertainty ratio of at least 4:1 is maintained unless otherwise stated.

This calibration certificate cannot, in any way, be reproduced, except in full, without prior written consent from a representative of Hunt Metrology Service, Inc.

Keith R. Young
Technical Manager

Hunt Metrology Service, Inc. Data Sheet HMSCC: 09028 Page 1

Customer: AEA TECHNOLOGY P.O. No.: 2603

Date Cal: 08/06/98

ID.No.: 027 (A) Manufacturer: MITUTOYO Date Due: 08/06/99

2 ID.No.: Serial No.: 701046 Technician: DD

Department: QC Model No.: 543-425-1 Cal. Proc. No: 30

Deviation u.: Standard No.: 012 Cal.: 04/08/98 Due: 10/30/98

Accuracy: +/-0.000 10" Standard No.: Cal.: Due:

Accuracy: Standard No.: Cal.: Due:

Standard No.: Cal.: Due:

Gage Type: 0-2.0" DIGITAL INDICATOR (PART 1 OF 2)

Required:	0	0.010"	0.025"	0.050"	0.100"	0.250"	0.500"	0.750"
Deviation:	REF	0	0	0	0	0	0	-.0001
Measured:	REF	0.010"	0.025"	0.050"	0.100"	0.250"	0.500"	0.7499"

Customer: AEA TECHNOLOGY P.O. No.: 2603

Date Cal: 08/06/98

ID.No.: 027 (B) Manufacturer: MITUTOYO Date Due: 08/06/99

2 ID.No.: Serial No.: 701046 Technician: DD

Department: QC Model No.: 543-425-1 Cal. Proc. No: 30

Deviation u.: Standard No.: 012 Cal.: 04/08/98 Due: 10/30/98

Accuracy: +/-0.000 10" Standard No.: Cal.: Due:

Accuracy: Standard No.: Cal.: Due:

Standard No.: Cal.: Due:

Gage Type: 0-2.0" DIGITAL INDICATOR (PART 2 OF 2)

Required:	1.0	1.25	1.50	1.75	2.00
Deviation:	0	0	+.00010"	0	0
Measured:					

ATTACHMENT C – CALCULATION OF VOLUME RATIOS

Values are estimates of true device volume based on design drawings and engineering judgement

Model 680 Projector

Shell volume (internal):
$L \times W \times H = 13.88 \times 13.63 \times 9.94 = 1880.5 \text{ in}^3$

Shield volume:
Weight /Density = 292 lbs./0.683 lbs./in^3 = 427.5 in^3

Void volume:
Shell volume – Shield volume = 1880.5 – 427.5 = 1453 in^3

Proportion
$14.44 \text{ in}^3 / 1453 \text{ in}^3 = 0.01 = 1\%$

Model 650 Projector

Shell volume (internal):
$V = \pi(3.719)^2(8.25 - 2(0.5)) = 315 \text{ in}^3$

Shield volume:
Weight /Density = 42 lbs./0.683 lbs./in^3 = 61.5 in^3

Void volume:
Shell volume – Shield volume = 315 – 61.5 = 253.5 in^3

Volume Ratio

$14.44 \text{ in}^3 / 253.5 \text{ in}^3 = 0.057 = 5.7\%$

ATTACHMENT D – EFFECTIVE DENSITY CALCULATIONS

Table 1. Calculation Table

Set No.	Specimen No.	Container Empty Weight (lbs) (A)	Container Volume (mL) (B)	Container Filled Weight (lbs) (C)	Effective Density* (lb/ft^3) (C-A)/B * 28321
1	1	.108	258	.203	10.4
	2	.099	258	.191	10.1
	3	.098	258	.191	10.2
2	1	.109	257	.224	12.7
	2	.109	257	.227	13.0
	3	.109	257	.225	12.8
3	1	.108	258	.329	24.3
	2	.109	258	.329	24.1
	3	.098	258	.321	24.5
4	1	.098	257	.331	25.7
	2	.099	257	.336	26.1
	3	.099	257	.359	28.7
5	1	.098	258	.192	10.3
	2	.108	258	.202	10.3
6	1	.099	257	.213	12.6
	2	.098	257	.213	12.7
7	1	.098	258	.315	23.8
	2	.098	258	.324	24.8
8	1	.098	257	.359	28.8
	2	.098	257	.360	28.9

* 28,321 mL = 1 ft^3

2.12.9 Technical Report 171 Sentry Transport Package Lifting Analysis dated 30 Jun 2010

QSA GLOBAL

Technical Report No. 171

QSA GLOBAL, Inc.

Engineering Department

Technical Report

SENTRY Transport Package Lifting Analysis

Prepared by: ______________________ **Date:** 24 Jun 2010

Checked by: ______________________ **Date:** 24 JUN 2010

Regulatory Approval: ______________________ **Date:** 30 Jun 2010

Engineering Approval: ______________________ **Date:** 24 Jun 2010

1.0 Purpose:

This report documents an analysis performed on the SENTRY transport package to the lifting requirements of 10 CFR Part 71.45 (a).

2.0 SENTRY Transport Package Lifting Provisions:

The SENTRY transport package in the Standard configuration is equipped with four identical, multi-purpose Lifting/Tie-Down provisions symmetrically located around the package. Half of each lifting provision is attached to the upper portion of the cylindrically shaped welded body by three high strength bolts, two on the top flat surface and one on the curved side surface of the body. The other half of the provision is attached to the body in the same manner, but with two bolts attached to the bottom and one attached to the side of the body. See Figure 1.

The two halves of the provision are connected together by a link plate attached to each half by a load pin. The strength of the two load pins is only needed when the package is lifted using the link plate. Lifting the package with the link plate is not recommended, but this part of the provision still needs to meet the lifting requirement of 10 CFR part 71.45 (a). The recommended lifting method is to lift the package by looping high capacity straps or chains with or without a pivoting shackle through the large hole in the upper lifting provision.

The bottom end also includes a very large hex nut and bolt for added strength in emergency situations. The large hex nut and bolt will recruit the lower half of the provision if a rapid, high loading (snatch) condition occurs.

The SENTRY transport package in the Basic configuration has an array of Rivnuts for attaching a properly rated hoist ring for lifting. See Figure 10 & 11.

The center of gravity (CG) of the 780 pound (maximum) package is located approximately at its geometric center.

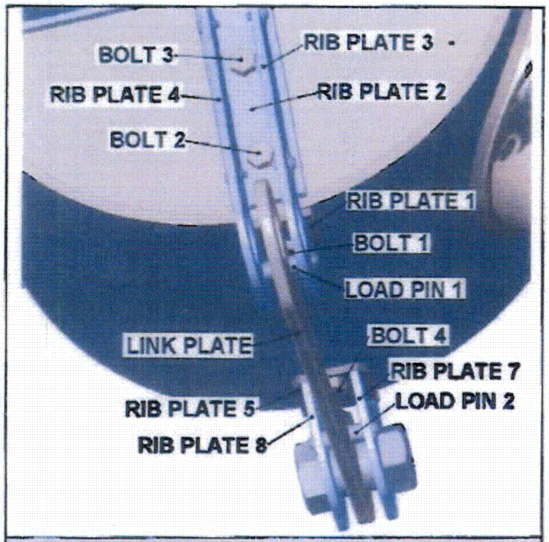


Figure 1 SENTRY Lifting Provision (1 of 4) Standard Configuration

Table 1 Lifting/Tie-Down Provision Materials List

Component Name	Material	Condition	ASTM Spec	Minimum Yield Strength, psi
Rib Plate 1 thru 8	17-4 PH STN STL	H1025	A693	145,000
Link Plate	17-4 PH STN STL	H900	A693	170,000
Bolts 1 thru 8	17-4 PH STN STL	AH	F593	105,000
Load Pin 1 & 2	17-4 PH STN STL	H900	A693	170,000
Rivnuts 1 thru 8	316 STN STL	CW	A276	93,694

3.0 Transport Lifting Requirement:

10 CFR Part 71.45 (a): Any lifting attachment that is a structural part of a package must be designed with a **minimum safety factor of three against yielding** when used to lift the package in the intended manner, and it must be designed so that **failure** of any lifting device under excessive load **would not impair the ability of the package to meet other requirements** of this subpart. Any other structural part of the package that could be used to lift the package must be capable of being rendered inoperable for lifting the package during transport, or must be designed with strength equivalent to that required for lifting attachments.

4.0 Assumptions:

1. Temperature range equal to -40 to +130 F.
2. No corrosion exists on the rib assembly and fastener components.
3. Only one lifting provision carries the load in the lifting analysis.

5.0 Analysis – Rib Assembly Lifting:

The SENTRY lifting provision or rib assembly is a structural part of the package. However, it is designed to be intentionally removed without affecting the ability of the package to meet other requirements of 10 CFR Part 71.

Lifting the transport package by only one lifting provision (rib assembly) can be considered the worst case for lifting the package. The maximum tensile load applied to the single lifting provision is equal to the maximum weight of the package or 780 lbs. See figure 2 through 4.

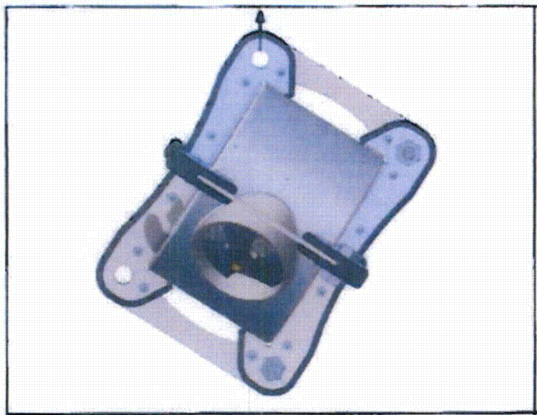


Figure 2 SENTRY Lifting from a Single Rib Assembly

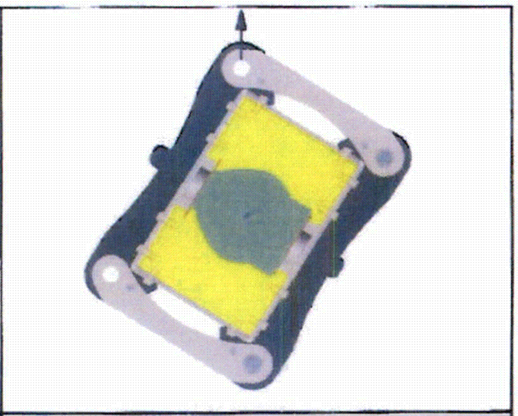


Figure 3 SENTRY Lifting from a Single Rib Assembly – Section View

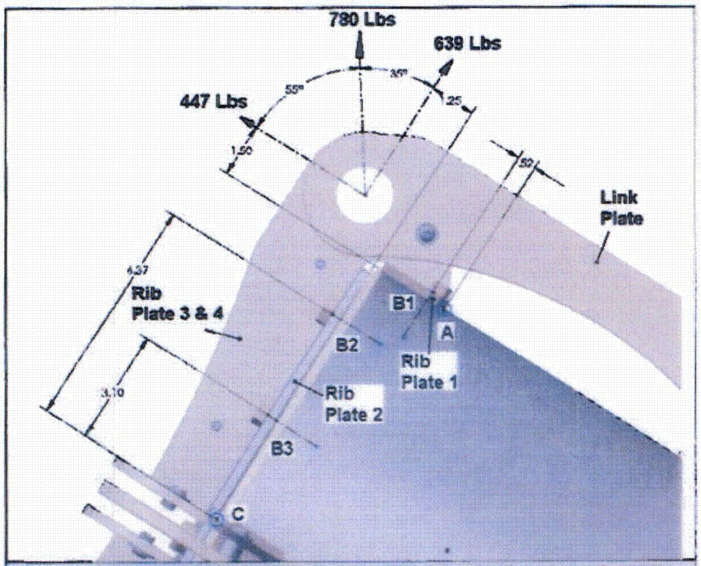


Figure 4 SENTRY Lifting from a Single Rib Assembly (Rib Plate 4 not shown) – Close-up View

The rib assembly consists of two vertical parallel plates welded to a flat horizontal plate with two mounting holes and one perpendicular plate with one mounting hole. The vertical plates are separated by a gap to allow three hex bolts to be inserted between them. The bolts pass through the mounting holes and mate into the Rivnuts. The Rivnuts are riveted into the cylindrical welded body of the transport package.

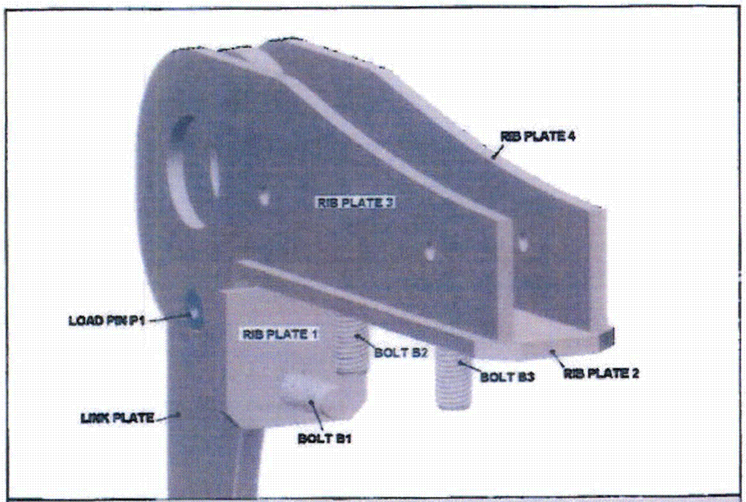


Figure 5 SENTRY Rib Assembly Close-up

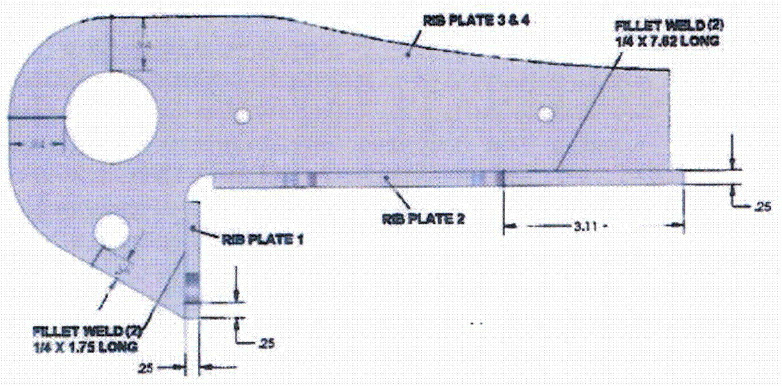


Figure 6 SENTRY Rib Assembly showing relevant dimensions

6.0 Results – Rib Assembly Lifting:

Table 2 is a summary comparing calculated factor of safeties against the required factor of safety, 3, when lifting the package by only one rib assembly as shown in Figure 4. See Appendix A for the detailed calculations. Table 2 reveals "Bolt B1 Tensile or Shear" is the worst case loading condition resulting in a calculated factor of safety equal to 8. This is over 2 times the required factor of safety of 3.

Table 2 Summary of SENTRY Lifting **by Rib Analysis per 10 CFR Part** 71.45(a)

Failure Mode	Calculated Factor of Safety	Required Factor of Safety	Pass/Fail
Rib Plates 3 & 4 Shear Tear-out	87	3	Pass
Rib Plate 1 Shear Tear-out	20		Pass
Rib Plate 1 Bearing Failure	34		Pass
Rib Plate 1 Tensile Failure	139		Pass
Rivnut 1,2,&3 Thread Shear Strip	85		Pass
Rib Plate 2 Shear Tear-out	176		Pass
Rib Plate 2 Bearing Failure	24		Pass
Rib Plate 2 Tensile Failure	98		Pass
Bolt B1 Tensile Failure	8		Pass
Bolt B1 Shear Failure	8		Pass
Bolt B1 Thread Bearing Stress	75		Pass
Bolt B1 Thread Shear Strip	34		Pass
Bolt B2 Tensile Failure	79		Pass
Bolt B2 Shear Failure	49		Pass
Bolts B2 & B3 Thread Bearing Stress	320		Pass
Bolts B2 & B3 Thread Shear Strip	145		Pass
Rib Plate Weld – 639 Lbs Direction	306		Pass
Rib Plate Weld – 447 Lbs Direction	100		Pass

See Appendix A - Lifting by **Rib Assembly Calculations**

7.0 Analysis – Link Plate Lifting:

The link plate is not recommended to be used as a lifting provision. However, if the package is lifted by the link plate, then it shall also meet the lifting requirements of 10 CFR Part 71.45(a).

Figures 7 through 9 show the transport package lifted by the link plate.

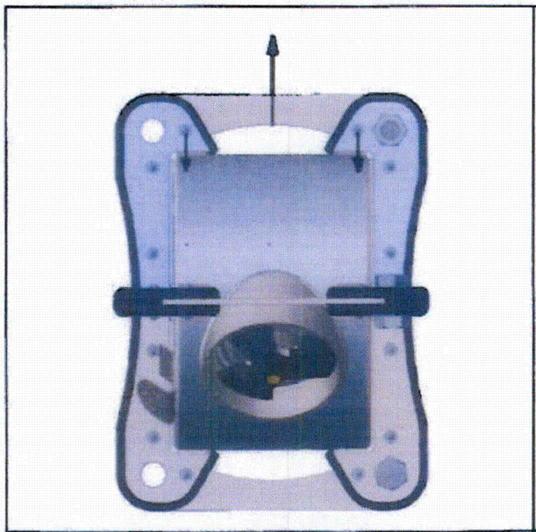


Figure 7 SENTRY Lifting from a Single Link Plate

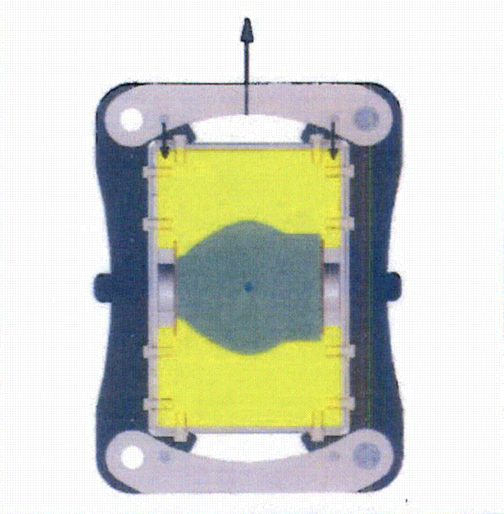


Figure 8 SENTRY Lifting from a Single Link Plate – Section View

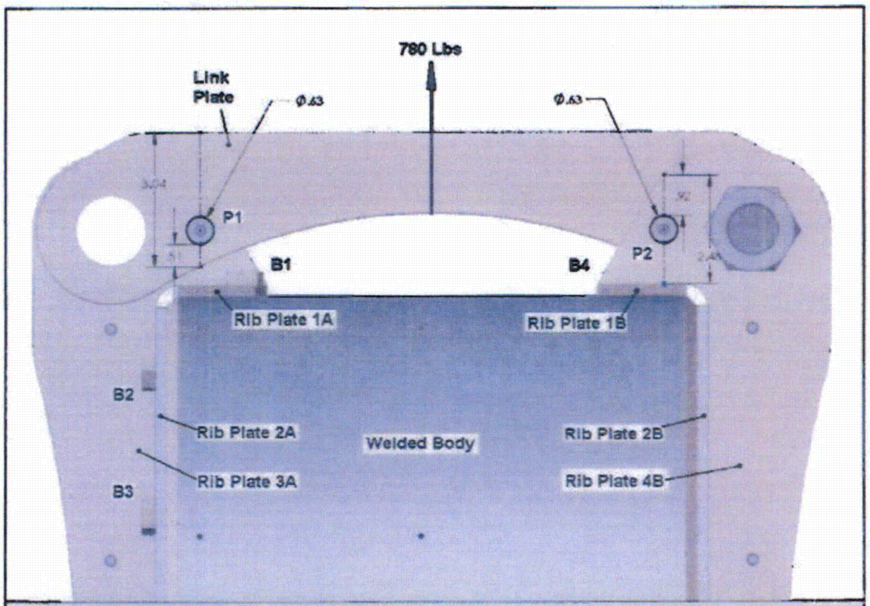


Figure 9 SENTRY Lifting from a Link Plate – Close-up Section View

8.0 Results – Link Plate Lifting:

Table 3 is a summary comparing calculated factor of safeties against the required factor of safety, 3, when lifting the package by only one link plate as shown in Figure 9. See Appendix B for the detailed calculations. Table 3 reveals "Bolt B1 or B4 Tensile Failure" is the worst case loading condition resulting in a calculated factor of safety equal to 38. This is over 12 times the required factor of safety of 3. The calculation for this loading condition is conservative since it did not take into consideration the load sharing provided by bolts B2, B3, B5 & B6 in the load direction.

Table 3 Summary of SENTRY Lifting by Link Analysis per 10 CFR Part 71.45(a)

Failure Mode	Calculated Factor of Safety	Required Factor of Safety	Pass/Fail
Link Plate Tensile Failure - Midsection	151	3	Pass
Link Plate Shear Tear-out	84		Pass
Link Plate Bearing Failure	96		Pass
Link Plate Tensile Failure	399		Pass
Load Pin P1 or P2 Double Shear	230		Pass
Rib Plate 2 Shear Tear-out Failure	289		Pass
Rib Plate 2 Bearing Failure	39		Pass
Rib Plate 2 Tensile Failure	160		Pass
Bolt B1 or B4 Tensile Failure	38		Pass
Rib Plate 3 & 4 Shear Tear-out Failure	171		Pass
Rib Plate 3 & 4 Bearing Failure	108		Pass
Rib Plate 3 & 4 Tensile Failure	345		Pass
Rib Plate Weld – Lift Direction	501		Pass

See Appendix B - Lifting by Link Plate Calculations

9.0 Analysis – Rivnut Lifting:

The Rivnut can be used for lifting the package in the basic configuration. Lifting the package by one Rivnut is the worst case lifting condition for this configuration. See Figures 10 & 11.

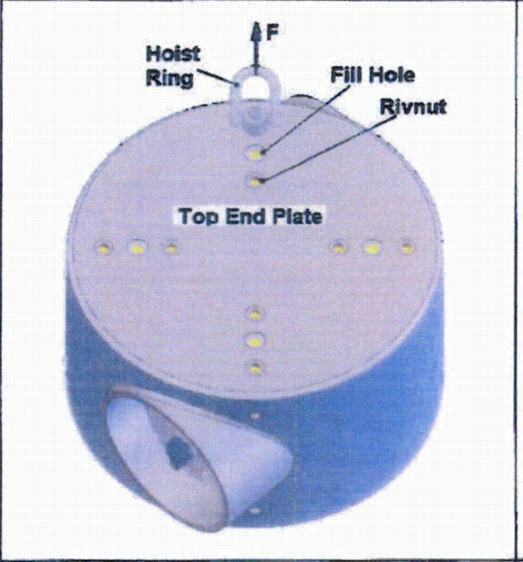


Figure 10 SENTRY Lifted by a Single Rivnut

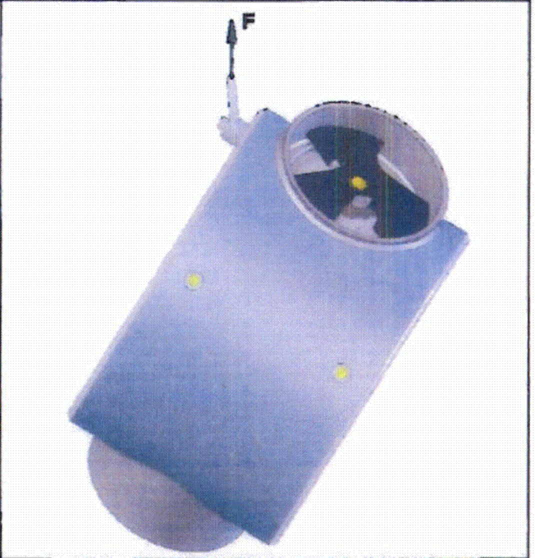


Figure 11 SENTRY Lifted by a Single Rivnut –Side View

10.0 Results – Rivnut Lifting:

Table 4 is a summary comparing calculated factor of safeties against the required factor of safety, 3, when lifting the package by only one link plate as shown in Figures 10 & 11. See Appendix C for the detailed calculations. Table 4 reveals "Rivnut 1 Shear Failure" is the worst case loading condition resulting in a calculated factor of safety equal to 7. This is over 2 times the required factor of safety of 3.

Table 4 Summary of SENTRY Lifting Rivnut Analysis per 10 CFR Part 71.45(a)

Failure Mode	Calculated Factor of Safety	Required Factor of Safety	Pass/Fail
Rivnut 1 Shear Failure	7	3	Pass
Rivnut 1 Thread Shear Strip	33		Pass

See Appendix C - Lifting by Rivnut Calculations

11.0 Final Assessment:

The SENTRY transport package in the Standard Configuration lifted by either the rib assembly or the link plate and the package in Basic configuration lifted by one Rivnut meets the lifting requirements of 10 CFR Part 71.45 (a). No failure mode was found to be less than 3 against yielding when lifting the package by a rib assembly, link plate or Rivnut.

If the lifting provision were to fail due to excessive loading, the package is designed so that the failed provision would not impair the ability of the package to meet the other requirements of 10 CFR Part 71.

Appendix A - Lifting by Rib Assembly Calculations

Determine Rib Plates 3&4 Shear Tearout Failure

Rtfs = 830 psi = Tensile Stress = Fn/(2*L*t)

F = 780 Lbf = Max Package Weight (Std Config)

Fn = 390 Lbf = Load shared by plates 3 & 4 = F/2

t = 0.25 in = Plate thickness

L = 0.94 in = Distance from hole to plate edge

Ysr = *145000* psi = Allowable Yield Strength

Ssr = 72500 psi = Allowable Shear Strength = Ysr/2

Fs = 87 = Factor of Safety = Ssr/Rtfs

Determine Rib Plate 1 Shear Tearout Failure

Rsts = 3576 psi = Calc Shear Stress = Fd/(2*L*t)

F = 780 Lbf = Max Package Weight (Std Config)

Fd = 447 Lbf = Load Normal to Rib Plate 2

t = 0.25 in = Plate thickness

L = 0.25 in = Distance from hole to Rib 1 edge

Ysr = *145000* psi = Allowable Yield Strength

Ssr = 72500 psi = Allowable Shear Strength = Ysr/2

Fs = 20 = Factor of Safety = Ssr/Rsts

Determine Rib Plate 1 Bearing Failure

Rbfs = 4237 psi = Calc Bearing Stress = Fd/(d*t)

F = 780 Lbf = Max Package Weight (Std Config)

Fd = 447 Lbf = Load Normal to Rib Plate 2

t = 0.25 in = Plate thickness

d = 0.42 in = Bolt minor diameter

Ysr = *145000* psi = Allowable Yield Strength

Fs = 34 = Factor of Safety = Ysr/Rbfs

Determine Rib Plate 1 Tensile Failure

Rtfs = 1040 psi = Tensile Stress = Fd/((w-d)*t)

F = 780 Lbf = Max Package Weight (Std Config)

Fd = 447 Lbf = Load Normal to Rib Plate 2

t = 0.25 in = Plate thickness

d = 0.53 in = Hole diameter

w = 2.25 in = Plate width

Ysr = *145000* psi = Allowable Yield Strength

Fs = 139 = Factor of Safety = Ysr/Rtfs

Determine Rivnut 1,2&3 Thread Shear Strip

Nts = 534 psi = Calc Shear Stress = Fn/(Pi*dn*(h/2))

F = 780 Lbf = Max Package Weight (Std Config)

Fn = 260 Lbf = Load shared by 3 Rivnuts = F/3

dn = 0.50 in = Nut root diameter

Pi = 3.14 in = Constant

h = 0.62 in = Nut engagement

Ysn = 90435 psi = Allowable Yield Strength

Ssn = 45217 psi = Allowable Shear Strength = Ysn/2

Fs = 85 = Factor of Safety = Ssn/Nts

Determine Rib Plate 2 Shear Tearout Failure

Rsts = 411 psi = Calc Shear Stress = Fd/(2*L*t)

F = 780 Lbf = Max Package Weight (Std Config)

Fd = 639 Lbf = Load Normal to Rib Plate 1

t = 0.25 in = Plate thickness

L = 3.11 in = Distance from hole to Rib 2 edge

Ysr = 145000 psi = Allowable Yield Strength

Ssr = 72500 psi = Allowable Shear Strength = Ysr/2

Fs = 176 = Factor of Safety = Ssr/Rsts

Determine Rib Plate 2 Bearing Failure

Rbfs = 6057 psi = Calc Bearing Stress = Fd/(d*t)

F = 780 Lbf = Max Package Weight (Std Config)

Fd = 639 Lbf = Load Normal to Rib Plate 1

t = 0.25 in = Plate thickness

d = 0.42 in = Bolt minor diameter

Ysr = 145000 psi = Allowable Yield Strength

Fs = 24 = Factor of Safety = Ysr/Rbfs

Determine Rib Plate 2 Tensile Failure

Rtfs = 1486 psi = Tensile Stress = Fd/[(w-d)*t)

F = 780 Lbf = Max Package Weight (Std Config)

Fd = 639 Lbf = Load Normal to Rib Plate 1

t = 0.25 in = Plate thickness

d = 0.53 in = Hole diameter

w = 2.25 in = Plate width

Ysr = 145000 psi = Allowable Yield Strength

Fs = 98 = Factor of Safety = Ysr/Rtfs

Determine Bolt 1 Tensile Failure (Combined Stress)

B1ms= 13161 psi =Max Tensile Stress on Bolt 1
= B1st/(Sqrt((B1st/2)^2 + Bss^2))

B1st = 12990 psi = Calc Tensile Stress = Fp/A

Fd = 639 Lbf = Load Normal to Rib Plate 1

Fp = 1843 Lbf = Moment Load on Bolt 1 = M*Lx

A = 0.14 in^2 = Bolt Stress Area

M = 959 in-Lb = Moment = Fd*Lm

Lm = 1.50 in = Moment Arm

Lx = 0.52 in = Bolt Distance to pivot point (A)

Ysb = 105000 psi = Allowable Yield Strength

Fs = 8 = Factor of Safety = Ysb/B1ms

Determine Bolt 1 Shear Failure (Combined Stress)

B1ss= 6666 psi = Max Shear Stress on Bolt 1
= Sqrt ((B1st/2)^2 + Bss^2)

Bss = 1501 psi = Calc Tensile Stress = Fn/A

Fd = 639 Lbf = Load Normal to Rib Plate 1

Fn = 213 Lbf = Load shared by 3 bolts = F/3

A = 0.14 in^2 = Bolt Stress Area

Ysb = 105000 psi = Allowable Yield Strength

Ssb = 52500 psi = Allowable Shear Strength = Ysb/2

Fs = 8 = Factor of Safety = Ssb/B1ss

Determine Bolt 1 Thread Bearing Stress

Btbs = 1405 psi = Thread Bearing Stress
= Fd/ ((Pi/4)*(d^2-dr^2)*(h/p))

Fd = 639 Lbf = Load applied in Rib Plate 2 direction

dr = 0.42 in = Bolt root diameter

d = 0.50 in = Bolt outer diameter

Pi = 3.14 in = Constant

h = 0.62 in = Nut engagement

p = 0.08 in = Thread pitch = 1/13

Ysb = 105000 psi = Allowable Yield Strength

Fs = 75 = Factor of Safety = Ysb/Btbs

Determine Bolts 1 Thread Shear Strip

Bts = 1555 psi = Calc Shear Stress = Fd/(Pi*dr*(h/2))

Fd = 639 Lbf = Load applied in Rib Plate 2 direction

dr = 0.42 in = Bolt root diameter

Pi = 3.14 in = Constant

h = 0.62 in = Nut engagement

Ysr = 105000 psi = Allowable Yield Strength

Ssr = 52500 psi = Allowable Shear Strength = Ysb/2

Fs = 34 = Factor of Safety = Ssb/Bts

Determine Bolt 2 Tensile Failure (Combined Stress)

B2ms=	1329	psi	=Max Tensile Stress on Bolt 2 = B2st/(Sqrt($(B2st/2)^2 + Bss^2$))
B2st =	500	psi	= Calc Tensile Stress = Fp/A
Fd =	447	Lbf	= Load Normal to Rib Plate 2
Fp =	71	Lbf	= Proportion of load on Bolt2 = M*L2/SLx
A =	0.14	in^2	= Bolt Stress Area
M =	559	in-Lt	= Moment = F*Lm
Lm =	1.25	in	= Moment Arm
SLx =	50.19	in^2	= Bolt Distances Sumed $(L2^2)+(L3^2)$
Ysb =	*105000*	psi	= Allowable Yield Strength
Fs =	79		= Factor of Safety = Ysb/B2ms

Determine Bolt 2 Shear Failure (Combined Stress)

B2ss=	1079	psi	= Max Shear Stress on Bolt 2 = Sqrt ($(B2st/2)^2 + Bss^2$)
Bss =	1050	psi	= Calc Tensile Stress = Fn/A
Fd =	447	Lbf	= Load Normal to Rib Plate 2
Fn =	149	Lbf	= Load shared by 3 bolts = F/3
A =	0.14	in^2	= Bolt Stress Area
Ysb =	*105000*	psi	= Allowable Yield Strength
Ssb =	52500	psi	= Allowable Shear Strength = Ysb/2
Fs =	49		= Factor of Safety = Ssb/B2ss

Determine Bolt 2 & 3 Thread Bearing Stress

Btbs =	328	psi	= Thread Bearing Stress = Fn/ ((PI/4)*(d^2-dr^2)*(h/p))
Fd =	447	Lbf	= Load applied in Rib Plate 1 direction
Fn =	149	Lbf	= Load shared by 3 bolts = Fd/3
dr =	0.42	in	= Bolt root diameter
d =	0.50	in	= Bolt outer diameter
Pi =	3.14	in	= Constant
h =	0.62	in	= Nut engagement
p =	0.08	in	= Thread pitch = 1/13
Ysb =	*105000*	psi	= Allowable Yield Strength
Fs =	320		= Factor of Safety = Ysb/Btbs

Determine Bolts 2 & 3 Thread Shear Strip

Bts =	363	psi	= Calc Shear Stress = Fn/(PI*dr*(h/2))
Fd =	447	Lbf	= Load applied in Rib Plate 1 direction
Fn =	149	Lbf	= Load shared by 3 bolts = Fd/3
dr =	0.42	in	= Bolt root diameter
Pi =	3.14	in	= Constant
h =	0.62	in	= Nut engagement
Ysb =	*105000*	psi	= Allowable Yield Strength
Ssb =	52500	psi	= Allowable Shear Strength = Ysb/2
Fs =	145		= Factor of Safety = Ssb/Bts

Determine Rib Plate Weld Shear Failure - 639 Lbs Direction			
Rws =	237	psi	= Tensile Stress = Fn/(Lw*Tw)
F =	639	Lbf	= Applied Load
Fn =	320	Lbf	= Load shared by 2 weld lengths = F/2
hs =	0.25	in	= Weld Size
Lw =	7.62	in	= Total Weld Length - 639 Lbs Direction
Tw =	0.18	in	= Weld Throat Dimension = .7071*hs
Ysr =	145000	psi	= Allowable Yield Strength
Ssr =	72500	psi	= Allowable Shear Strength = Ysr/2
Fs =	306		= Factor of Safety = Ssr/Rws

Determine Rib Plates Weld Shear Failure - 447 Lbs Direction			
Rws =	722	psi	= Tensile Stress = Fn/(Lw*Tw)
F =	447	Lbf	= Applied Load
Fn =	224	Lbf	= Load shared by 2 weld lengths = F/2
hs =	0.25	in	= Weld Size
Lw =	1.75	in	= Total Weld Length - 447 Lbs Direction
Tw =	0.18	in	= Weld Throat Dimension = .7071*hs
Ysr =	145000	psi	= Allowable Yield Strength
Ssr =	72500	psi	= Allowable Shear Strength = Ysr/2
Fs =	100		= Factor of Safety = Ssr/Rws

Appendix B - Lifting by Link Plate Calculations

Determine Link Plate Tensile Failure at Midsection

Lts = 1128 psi = Calc Tensile Stress = F/A

F = 780 Lbf = Max Package Weight (Std Config)

X = 1.82 in = Min Link Length

t = 0.38 in = Link Plate thickness

A = 0.69 in^2 = Min Plate Stress Area = X*t

Ysl = 170000 psi = Allowable Yield Strength

Fs = 151 = Factor of Safety = Ysl/Lts

Determine Link Plate Shear Tearout Failure

Lsts = 1006 psi = Calc Shear Stress = Fn/(2*w*t)

F = 780 Lbf = Max Package Weight (Std Config)

Fn = 390 Lbf = Load shared by 2 ends = F/2

t = 0.38 in = Link Plate thickness

w = 0.51 in = Distance from hole to edge

Ysl = 170000 psi = Allowable Yield Strength

Ssl = 85000 psi = Allowable Shear Strength = Ysl/2

Fs = 84 = Factor of Safety = Ssl/Lsts

Determine Link Plate Bearing Failure

Lbfs = 1770 psi = Calc Bearing Stress = Fn/(dp*t)

F = 780 Lbf = Max Package Weight (Std Config)

Fn = 390 Lbf = Load shared by 2 ends = F/2

dp = 0.58 in = Pin diameter

t = 0.38 in = Link Plate thickness

Ysl = 170000 psi = Allowable Yield Strength

Fs = 96 = Factor of Safety = Ysl/Lbfs

Determine Link Plate Tensile Failure

Ltfs = 426 psi = Tensile Stress = Fn/[(w-d)*t]

F = 780 Lbf = Max Package Weight (Std Config)

Fn = 390 Lbf = Load shared by 2 ends = F/2

d = 0.63 in = Hole diameter

t = 0.38 in = Link Plate thickness

w = 3.04 in = Link Plate width

Ysl = 170000 psi = Allowable Yield Strength

Fs = 399 = Factor of Safety = Ysl/Ltfs

Determine Load Pin Double Shear Failure

Pdss = 738 psi = Calc Tensile Stress = Fn/(A*2)

F = 780 Lbf = Max Package Weight (Std Config)

Fn = 390 Lbf = Load shared by 2 pins = F/2

d = 0.58 in = Pin diameter

A = 0.264 in^2 = Pin Area = Pi*d^2/4

Pi = 3.142 in = Constant

Ysp = 170000 psi = Allowable Yield Strength

Fs = 230 = Factor of Safety = Ysp/Pdss

Determine Rib Plate 2 Shear Tearout Failure

Rsts = 251 psi = Calc Shear Stress = Fn/(2*L*t)

F = 780 Lbf = Max Package Weight (Std Config)

Fn = 390 Lbf = Load shared by 2 plates = F/2

t = 0.25 in = Rib Plate thickness

w = 3.11 in = Distance from hole to edge

Ysr = *145000* psi = Allowable Yield Strength

Ssr = 72500 psi = Allowable Shear Strength = Ysr/2

Fs = 289 = Factor of Safety = Ssr/Rsts

Determine Rib Plate 2 Bearing Failure

Rbfs = 3697 psi = Calc Bearing Stress = Fn/(dp*t)

F = 780 Lbf = Max Package Weight (Std Config)

Fn = 390 Lbf = Load shared by 2 plates = F/2

dp = 0.42 in = Bolt minor diameter

t = 0.25 in = Rib Plate thickness

Ysr = *145000* psi = Allowable Yield Strength

Fs = 39 = Factor of Safety = Ysr/Rbfs

Determine Rib Plate 2 Tensile Failure

Rtfs = 907 psi = Tensile Stress = Fn/((w-d)*t)

F = 780 Lbf = Max Package Weight (Std Config)

Fn = 390 Lbf = Load shared by 2 plates = F/2

d = 0.53 in = Hole diameter

t = 0.25 in = Rib Plate thickness

w = 2.25 in = Rib Plate width

Ysr = *145000* psi = Allowable Yield Strength

Fs = 160 = Factor of Safety = Ysr/Rtfs

Determine Bolt 1 Tensile Failure

B1ms= 2748 psi =Max Tensile Stress on Bolt 1 = Fn/A

F = 780 Lbf = Max Package Weight (Std Config)

Fn = 390 Lbf = Load shared by 2 Bolts = F/2

A = 0.14 in^2 = Bolt Stress Area

Ysb = *105000* psi = Allowable Yield Strength

Fs = 38 = Factor of Safety = Ysb/B2ms

Determine Rib Plate 3 & 4 Shear Tearout Failure

Rsts = 424 psi = Calc Shear Stress = Fn/(2*L*t)

F = 780 Lbf = Max Package Weight (Std Config)

Fn = 195 Lbf = Load shared by 4 plates = F/4

t = 0.25 in = Rib Plate thickness

L = 0.92 in = Distance from hole to edge

Ysr = *145000* psi = Allowable Yield Strength

Ssr = 72500 psi = Allowable Shear Strength = Ysr/2

Fs = 171 = Factor of Safety = Ssr/Rsts

Determine Rib Plates 3 & 4 Bearing Failure

Rbfs = 1345 psi = Calc Bearing Stress = Fn/(dp*t)

F = 780 Lbf = Max Package Weight (Std Config)

Fn = 195 Lbf = Load shared by 4 plates = F/4

dp = 0.58 in = Pin diameter

t = 0.25 in = Rib Plate thickness

Ysr = *145000* psi = Allowable Yield Strength

Fs = 108 = Factor of Safety = Ysr/Rbfs

Determine Rib Plate 3 & 4 Tensile Failure

Rtfs = 420 psi = Tensile Stress = Fn/((w-d)*t)

F = 780 Lbf = Max Package Weight (Std Config)

Fn = 195 Lbf = Load shared by 4 plates = F/4

d = 0.625 in = Hole diameter

t = 0.25 in = Rib Plate thickness

w = 2.48 in = Rib Plate width

Ysr = *145000* psi = Allowable Yield Strength

Fs = 345 = Factor of Safety = Ysr/Rtfs

Determine Rib Plate Weld Shear Failure - Lift Direction

Rws = 145 psi = Tensile Stress = F/(Lw*Tw)

F = 780 Lbf = Max Package Weight (Std Config)

hs = 0.25 in = Weld Size

Lw = 30.48 in = Total Weld Length - Lift Direction

Tw = 0.18 in = Weld Throat Dimension = .7071*hs

Ysr = 145000 psi = Allowable Yield Strength

Ssr = 72500 psi = Allowable Shear Strength = Ysr/2

Fs = 501 = Factor of Safety = Ssr/Rws

Appendix C - Lifting by Single Rivnut Calculations

Determine Rivnut 1 Shear Failure

Nss = 6306 psi = Calc Tensile Stress = F/A

F = 700 Lbf = Max Package Weight (Basic Config)

A = 0.11 in^2 = Nut Stress Area

dr = 0.50 in = Nut root diameter

d = 0.63 in = Nut Outer Diameter

Ysn = *93694* psi = Allowable Yield Strength

Ssn = 46847 psi = Allowable Shear Strength = Ysn/2

Fs = 7 = Factor of Safety = Ssn/Nss

Determine Rivnut 1 Thread Shear Strip

Nts = 1438 psi = Calc Shear Stress = F/(Pi*dr*(h/2))

F = 700 Lbf = Max Package Weight (Basic Config)

dr = 0.50 in = Nut root diameter

PI = 3.14 in = Constant

h = 0.62 in = Nut engagement

Ysn = *93694* psi = Allowable Yield Strength

Ssn = 46847 psi = Allowable Shear Strength = Ysn/2

Fs = 33 = Factor of Safety = Ssn/Nts

2.12.10 Technical Report 172 Sentry Transport Package Tie-Down Analysis dated 21 Jul 2010

Technical Report No. 172

QSA GLOBAL, Inc.

Engineering Department

Technical Report

SENTRY Transport Package Tie-Down Analysis

Prepared by: S. Gomi Date: 15 JUL 10
Checked by: Date: 15 JUL 10
Regulatory Approval: Date: [illegible]
Engineering Approval: Date: 19 Jul 10

1.0 Purpose:

This report documents an analysis performed on the SENTRY transport package to the tie-down requirements of 10 CFR Part 71.45 (b).

2.0 SENTRY Transport Package Tie-Down Provisions:

The SENTRY transport package is equipped with four identical, multi-purpose Lifting/Tie-Down provisions located symmetrically around the package. The center of gravity (CG) is located approximately at the geometric center of the 780 pound maximum weight package.

The SENTRY tie-down provisions are a structural part of the package. However, they are designed to be intentionally removed without affecting the ability of the package to meet other requirements of 10 CFR Part 71.

Half of each tie-down provision is attached to the upper portion of the cylindrically shaped welded body by three high strength bolts, two on the top flat surface and one on the curved side surface of the body. The other half of the provision is attached to the body in the same manner, but with two bolts attached to the bottom and one attached to the side of the body. Refer to Figure 2.3. Materials used in construction of the tie-down provisions are shown in Table 2.1.

The upper and lower provision halves are connected together by a link plate attached to each half by a load pin. The two load pins are recruited when the package is tied-down using the link plate. It is not recommended to tie-down the package using the link plate, but this method still needs to meet the tie-down requirement of 10 CFR Part 71.45 (b).

The recommended tie-down method is to secure the package by looping high capacity straps or chains with or without a shackle through the large holes in the upper provisions and then staking the straps or chains to the vehicle down at about 45 degrees from horizontal.

There are two specific tie-down arrangements which will be analyzed separately. The first arrangement has the package oriented as shown in Figure 2.1. In this arrangement, the applied load, established by the requirements of 10 CFR Part 71, is taken by only one provision in the direction of vehicle travel. Another provision, 90 degrees from the vehicle direction, takes the load in the lateral direction. All four provisions share the load in the vertical direction.

The second arrangement has the package oriented as shown in Figure 2.2. In this arrangement, two provisions share the applied load in the direction of the vehicle. Two other provisions react to the load in the lateral direction, but one of these two provisions reacts to both the lateral and vehicle direction loads. All four provisions share the load in the vertical direction.

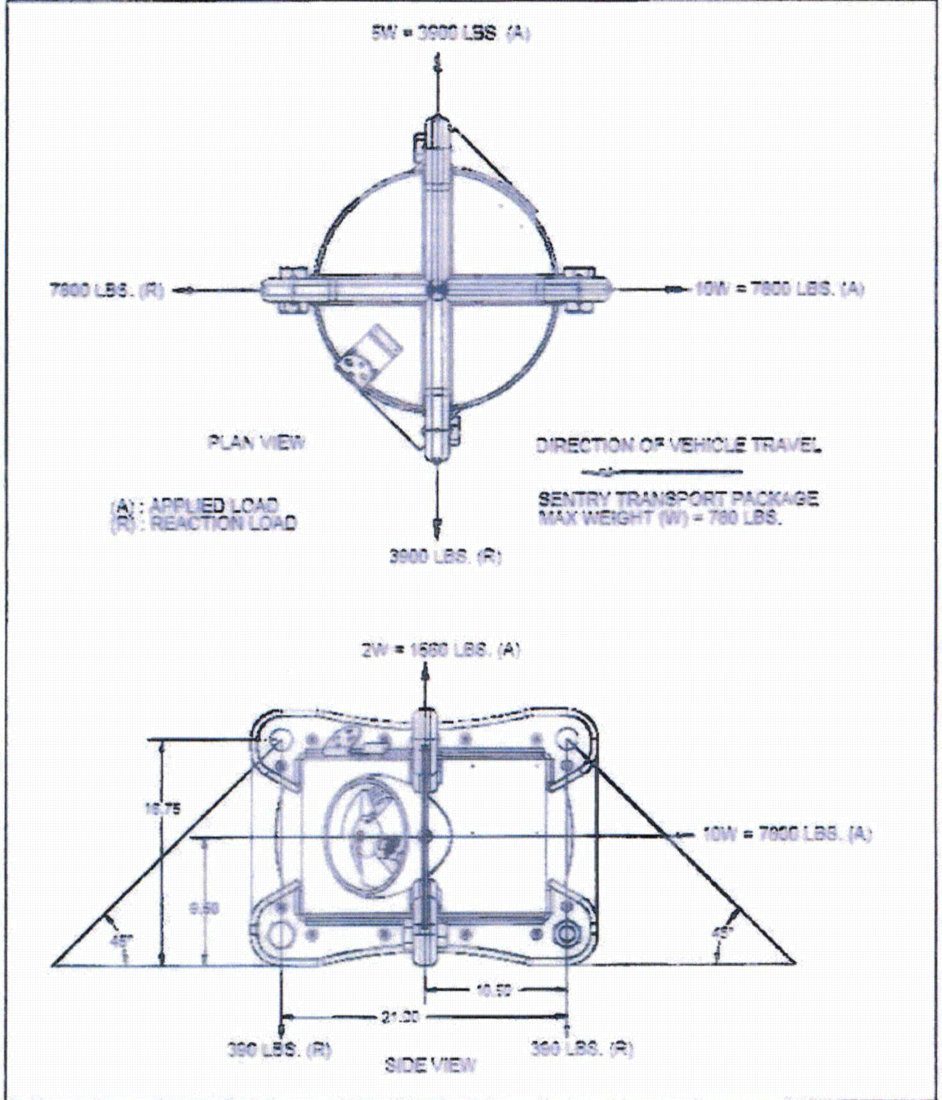


Figure 2.1. Single Provision Arrangement.

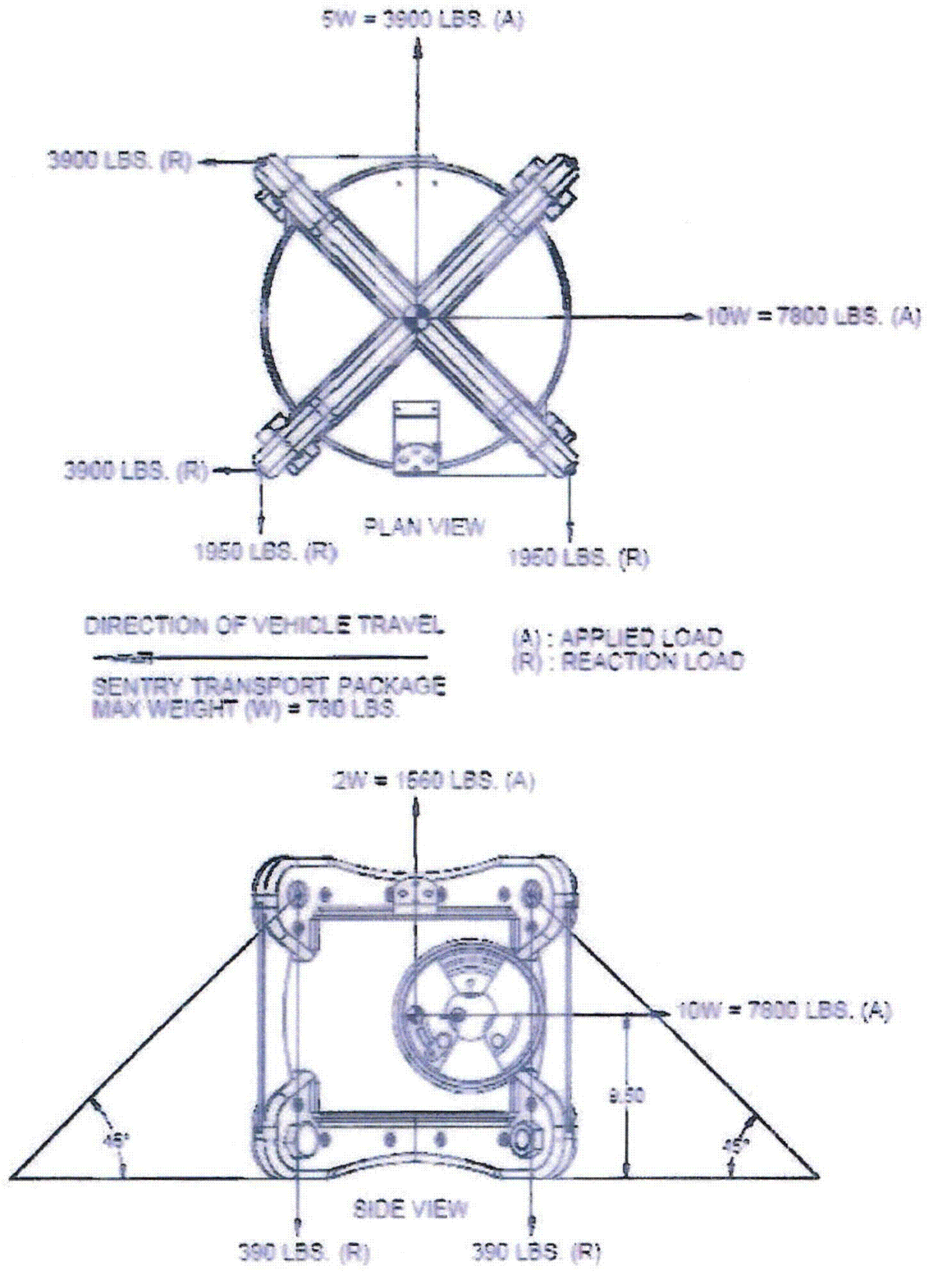


Figure 2.2. Shared Provision Arrangement.

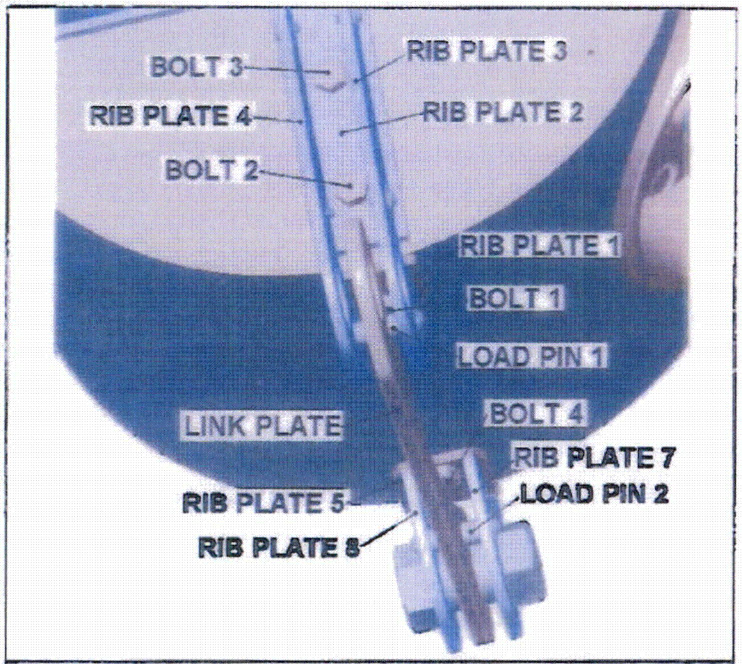


Figure 2.3. One of Four SENTRY Lifting & Tie-down Provisions

Table 2.1. Tie-Down Provision Materials List

Component Name	Material	Condition	ASTM Spec	Minimum Yield Strength, psi
Rib Plate 1 thru 8	17-4 PH STN STL	H1025	A693	145,000
Link Plate	17-4 PH STN STL	H900	A693	170,000
Bolts 1 thru 8	17-4 PH STN STL	AH	F593	105,000
Load Pin 1 & 2	17-4 PH STN STL	H900	A693	170,000
Rivnuts 1 thru 8	316 STN STL	CW	A276	93,694

The rib assembly consists of two vertical parallel plates welded to a flat horizontal plate with two mounting holes and one perpendicular plate with one mounting hole. The vertical plates are separated by a gap to allow three hex bolts to be assembled between them attaching the rib assembly to the package. See Figures 2.4 & 2.5. The bolts pass through the mounting holes and mate into Rivnuts riveted into the cylindrical welded body of the transport package.

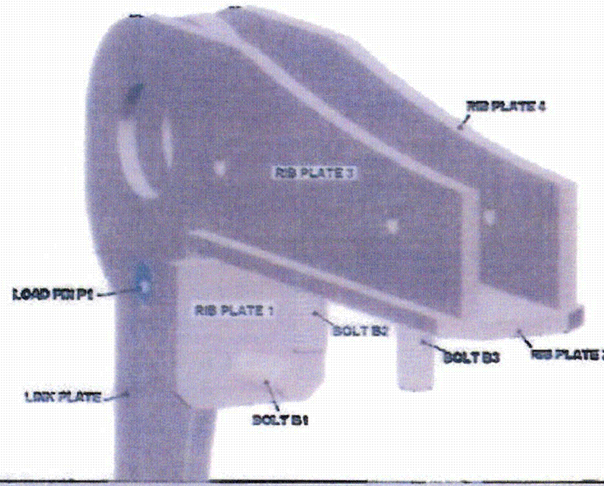


Figure 2.4. Tie-Down Rib Assembly Identification

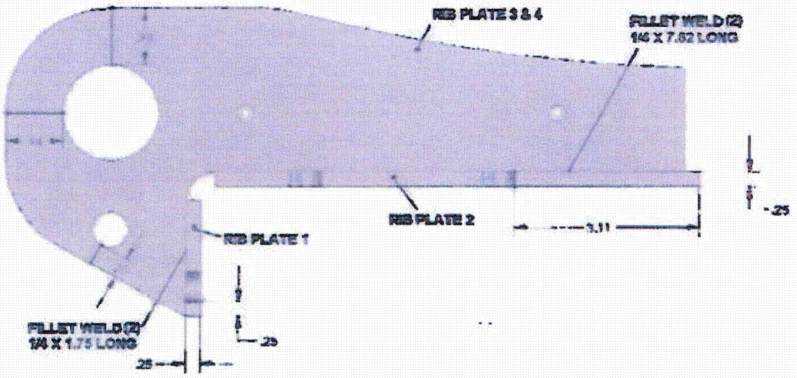


Figure 2.5. Tie-Down Rib Assembly Dimensions

3.0 Transport Tie-Down Requirement:

10 CFR Part 71.45 (b) Tie-down devices:

(1) If there is a system of tie-down devices that is a structural part of the package, the system must be capable of withstanding, without generating stress in any material of the package in excess of its yield strength, a static force applied to the center of gravity of the package having a vertical component of 2 times the weight of the package with its contents, a horizontal component along the direction in which the vehicle travels of 10 times the weight of the package with its contents, and a horizontal component in the transverse direction of 5 times the weight of the package with its contents.

(2) Any other structural part of the package that could be used to tie down the package must be capable of being rendered inoperable for tying down the package during transport, or must be designed with strength equivalent to that required for tie-down devices.

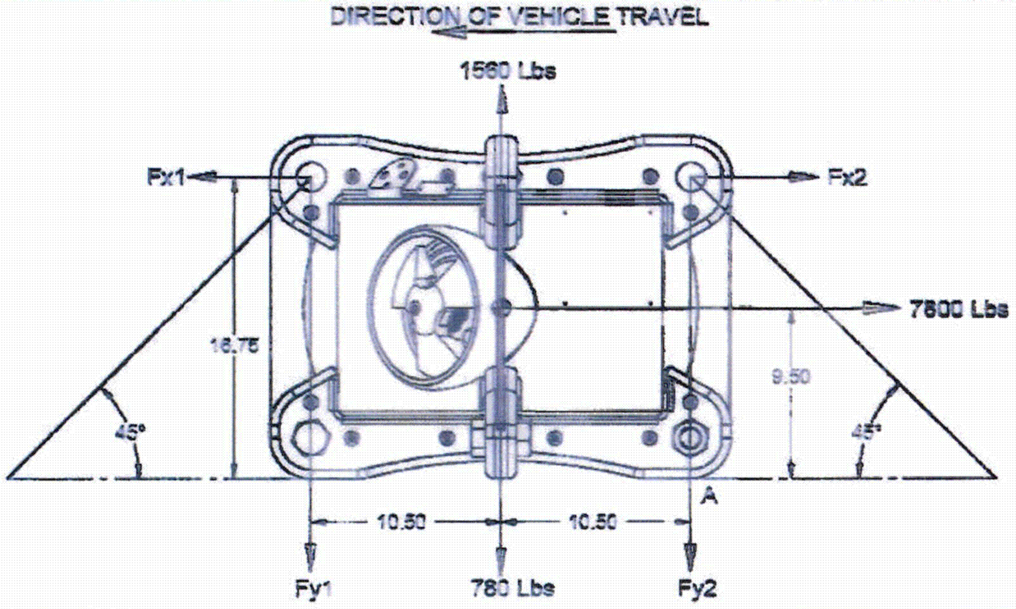
(3) Each tie-down device that is a structural part of a package must be designed so that failure of the device under excessive load would not impair the ability of the package to meet other requirements of this part.

4.0 General Assumptions:

1.0 Temperature range equal to -40 to +130 F.
2.0 No corrosion exists on the rib assembly and fastener components.
3.0 All 4 provisions are used in the tie-down analysis.

5.0 Analysis – Single Provision Tie-down by Rib Assembly:

Figure 5.1 Resolves the reaction forces in the upper tie-down provisions for a single provision arrangement with the load requirements applied per 10 CFR Part 71. Since the lateral direction loading (3900 Lbs) is less than the direction of vehicle loading (7800 Lbs), the worst case vehicle load value of 7800 lbs shall be used to determine the maximum reaction forces in the package.



$F_{X2} = 0$

+CCW $\Sigma M_A = 0 = 9.5(-7800) + 10.5(780) + 21(-F_{Y1}) + 16.75(F_{X1}) + 10.5(-1560)$: $F_{Y1} = -2303$

+ UP $\Sigma F_Y = 0 = 1560 - F_{Y1} - F_{Y2} - 780$: $F_{Y2} = +1523$

+ LEFT $\Sigma F_X = 0 = F_{X1} - 7800$: $F_{X1} = +7800$

Figure 5.1. Single Provision Force Diagram

The recommended tie-down angle for fixing the package to the bed of the vehicle is 45°. The largest reaction force found in Figure 5.1 is 7,800 Lbs in the horizontal direction. This force shall be used to determine the maximum tension force in the cable or chain from the upper provision to the vehicle bed at 45 degrees. Figure 5.2 shows the maximum tension force to be 11,031 lbs. The 11,031 tension force shall be used for the structural analysis shown in Figure 5.3.

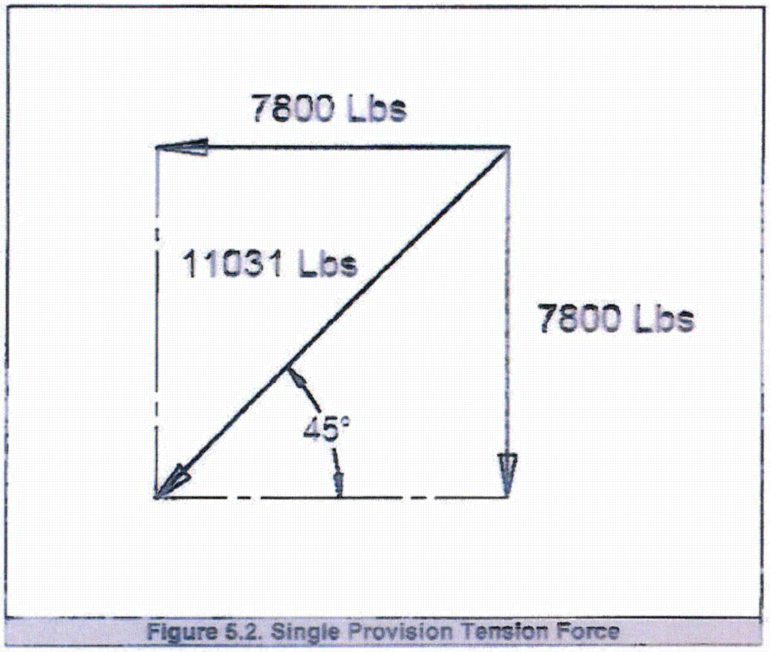


Figure 5.2. Single Provision Tension Force

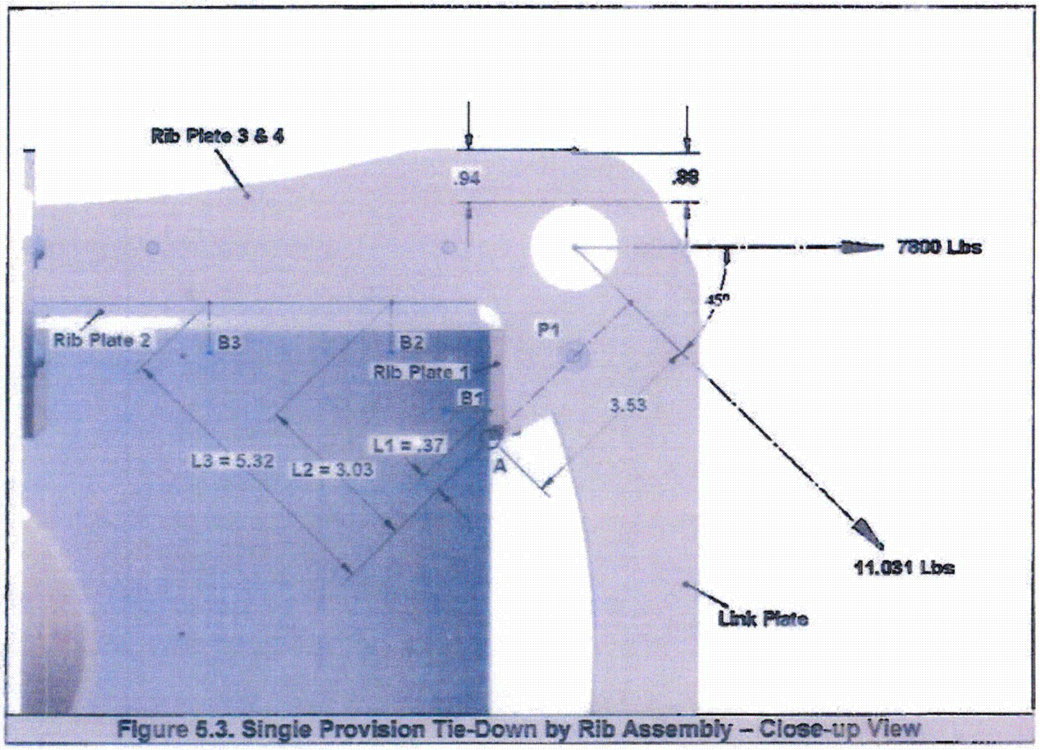


Figure 5.3. Single Provision Tie-Down by Rib Assembly – Close-up View

6.0 Results – Single Provision Tie-down by Rib Assembly:

Table 6.1 is a summary of the results of the tie-down analysis when securing the package by the rib assembly in the single provision arrangement. The table shows the calculated factor of safety for the "Bolt B3 Shear" failure is the worst case with a calculated factor of safety equal to 1. This is equal to the required factor of safety of 1. See Appendix A for the single provision tie-down by rib assembly calculations per failure mode.

Table 6.1. Summary of Single Tie-Down by Rib Analysis

Failure Mode	Calculated Factor of Safety	Required Factor of Safety	**Pass/Fail**
Rib Plates 3 & 4 Shear Tear-cut	4	1	Pass
Rib Plate 2 Shear Tear-out	14		Pass
Rib Plate 2 Bearing Failure	2		Pass
Rib Plate 2 Tensile Failure	8		Pass
Bolt B3 Tensile Failure	2		Pass
Bolt B3 Shear Failure	1		Pass
Bolt B1 Thread Bearing **Strip**	4		Pass
Bolt B1 Thread Shear Strip	2		Pass
Rivnut at **B1** Thread Shear Strip	2		Pass
Rib Plate Weld Shear – Horizontal	18		Pass
Rib Plate Weld Shear - Vertical	4		Pass

See Appendix A – Single Provision Tie-down by Rib Assembly Calculations

7.0 Analysis – Single Provision Tie-Down by Link Plate:

The link plate is not recommended to be used as a tie-down provision. However, if the package is secured by the link plate, then it shall also meet the tie-down requirements of 10 CFR Part 71.45(b). Figure 7.1 shows the transport package secured by the link plate.

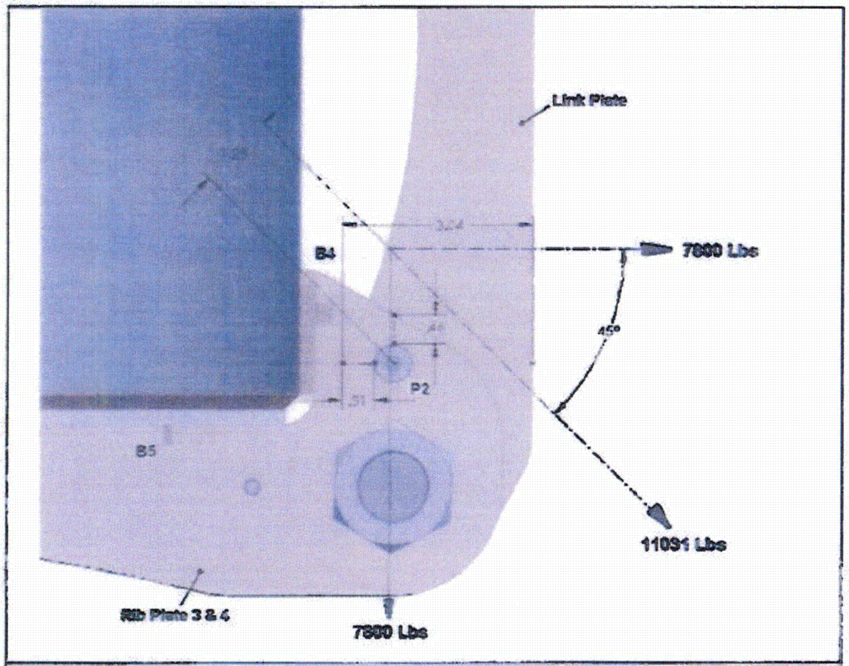


Figure 7.1. Single Provision Tie-Down by Link Plate – Close up

8.0 Results – Single Provision Tie-Down by Link Plate:

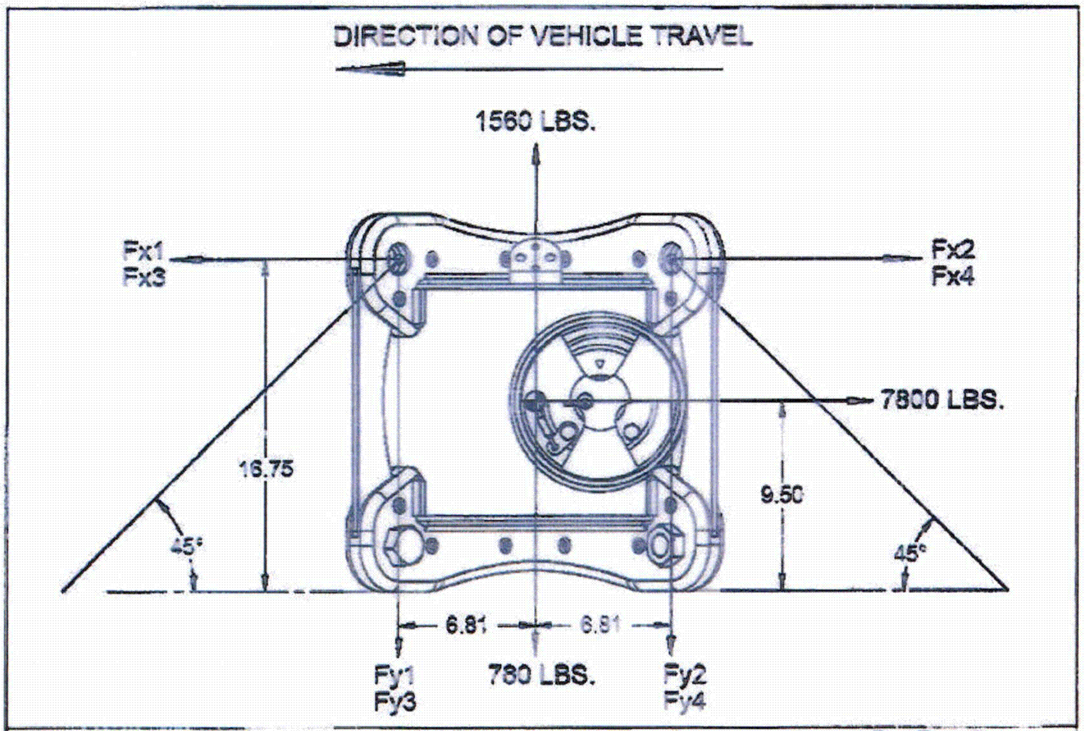
Table 8.1 is a summary of the results of the tie-down analysis when securing the package by the link plate in the single provision arrangement. The table shows the calculated factor of safety for the "Rib Plates 3 & 4 Bearing" failure mode is worst case with a calculated factor of safety equal to 3. This is 3 times the required factor of safety of 1. See Appendix B for the single provision tie-down by link plate calculations per failure mode.

Table 8.1. Summary of Single Provision Tie-Down by Link Plate Analysis

Failure Mode	Calculated Factor of Safety	Required Factor of Safety	Pass/Fail
Link Plate Tensile Failure - Midsection	15	1	Pass
Link Plate Shear Tear-out	6		Pass
Link Plate Bearing Failure	7		Pass
Link Plate Tensile Failure	28		Pass
Load Pin P1 or P2 Double Shear	12		Pass
Rib Plates 3 & 4 Shear Tear-out	3		Pass
Rib Plates 3 & 4 Bearing Failure	4		Pass
Rib Plates 3 & 4 Tensile Failure	15		Pass
See Appendix B – Single Provision Tie-down by Link Plate Calculations			

9.0 Analysis – Shared Provision Tie-Down by Rib Assembly:

Figure 9.1 Resolves the reaction forces in the upper tie-down provisions for the shared provision arrangement with the load requirements applied per 10 CFR Part 71. Since the lateral direction loading (3900 Lbs) is less than the direction of vehicle loading (7800 Lbs), the worst case vehicle load value of 7800 lbs shall be used to determine the maximum reaction forces in the package. The calculated force for Fx1 is half the value shown since it is shared with Fx3. Similarly, the calculated forces for Fy1 and Fy2 are half the value shown since they are shared with Fy3 and Fy4 respectively.



$:F_{X2}, F_{X4} = 0$

$+\text{CCW}\quad \Sigma M_A = 0 = 9.5(-7800) + 10.5(780) + 21(-F_{Y1}) + 16.75(F_{X1}) + 10.5(-1560)$ $:F_{Y1} = -2303/2$

$:F_{Y1}, F_{Y3} = -1152$

$+\text{UP}\quad \Sigma F_Y = 0 = 1560 - F_{Y2} - F_{Y1} - 780$ $:F_{Y2} = +1523/2$

$:F_{Y2}, F_{Y4} = +762$

$+\text{LEFT}\quad \Sigma F_X = 0 = F_{X1} - 7800$ $:F_{X1} = +7800/2$

$:F_{X1}, F_{X3} = +3900$

Figure 9.1. Shared Provision Force Diagram

The recommended tie-down angle for fixing the package to the bed of the vehicle is 45°. The largest reaction force found in Figure 9.1 is 3,900 Lbs in the horizontal direction. This force shall be used to determine the maximum tension force in the cable or chain from the upper provision to the vehicle bed. Figure 9.2 shows the maximum tension force to be 5515 lbs. The 5515 tension force shall be used for the structural analysis shown in Figure 9.3.

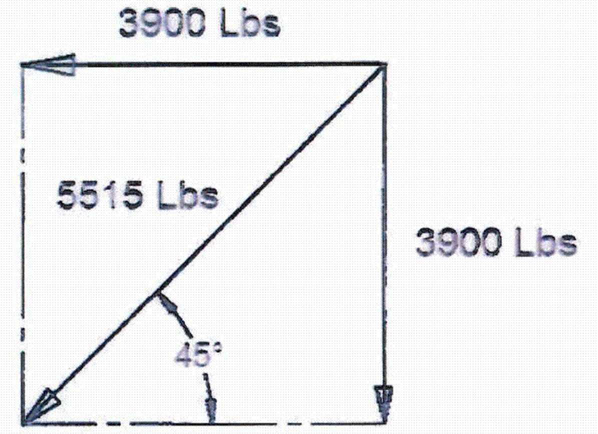


Figure 9.2. Shared Provision Tension Force

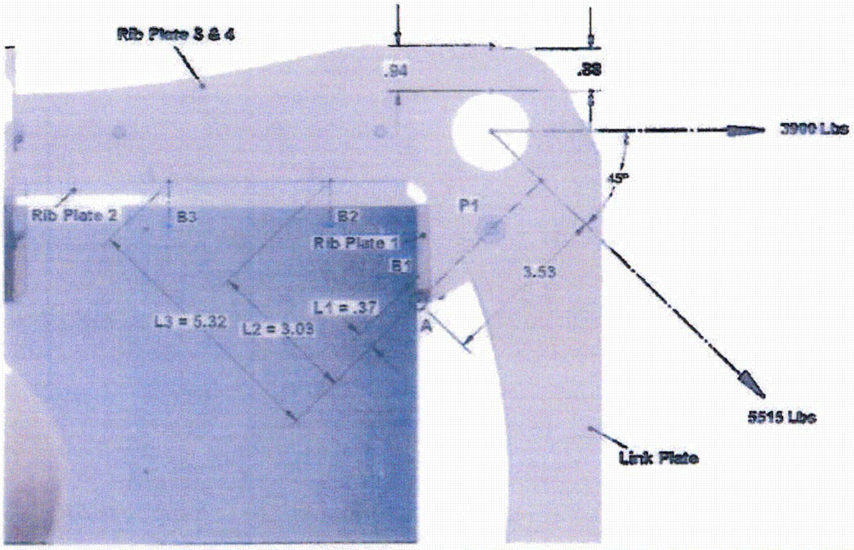


Figure 9.3. Shared Provision Tie-Down by Rib Assembly – Close-up View

10.0 Results – Shared Provision Tie-Down by Rib Assembly:

Table 10.1 is a summary of the results of the tie-down analysis when securing the package by the rib assembly in the shared provision arrangement. The table shows the calculated factor of safety for the "Bolt B3 Shear" failure is the worst case with a calculated factor of safety equal to 2. This is over 2 times the required factor of safety of 1. See Appendix C for the shared provision tie-down by rib assembly calculations per failure mode.

Table 10.1. Summary of Shared Provision Tie-Down by Rib Analysis

Failure Mode	Calculated Factor of Safety	Required Factor of Safety	Pass/Fail
Rib Plates 3 & 4 Shear Tear-out	9	1	Pass
Rib Plate 2 Shear Tear-out	29		Pass
Rib Plate 2 Bearing Failure	4		Pass
Rib Plate 2 Tensile Failure	16		Pass
Bolt B3 Tensile Failure	3		Pass
Bolt B3 Shear Failure	2		Pass
Bolt B1 Thread Bearing Strip	9		Pass
Bolt B1 Thread Shear Strip	4		Pass
Rivnut at B1 Thread Shear Strip	4		Pass
Rib Plate Weld Shear – Horizontal	35		Pass
Rib Plate Weld Shear - Vertical	8		Pass

See Appendix C – Shared Provision Tie-down by Rib Assembly Calculations

11.0 Analysis – Shared Provision Tie-Down by Link Plate:

The link plate is not recommended to be used as a tie-down provision. However, if the package is secured by the link plate, then it shall also meet the tie-down requirements of 10 CFR Part 71.45(b). Figure 11.1 shows the transport package secured by the link plate.

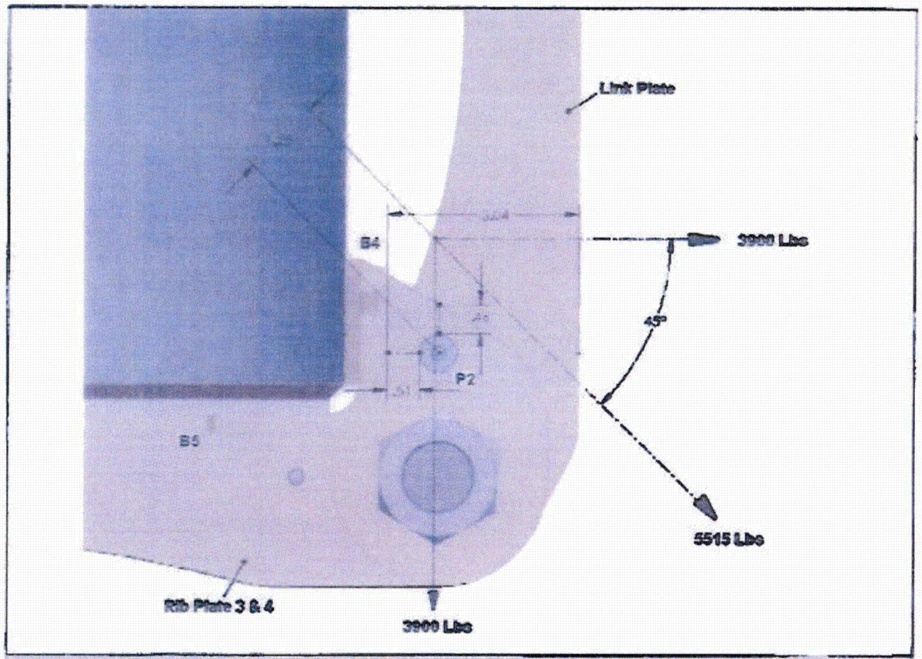


Figure 11.1. Shared Tie-Down by Link Plate – Close up

12.0 Results – Shared Provision Tie-Down by Link Plate:

Table 12.1 is a summary of the results of the tie-down analysis when securing the package by the link plate in the shared provision arrangement. The table shows the calculated factor of safety for the "Rib Plates 3 & 4 Bearing" failure mode is worst case with a calculated factor of safety equal to 6. This is 6 times the required factor of safety of 1. See Appendix D for the shared provision tie-down by link plate calculations per failure mode.

Table 12.1. Summary of Shared Provision Tie-Down by Link Plate Analysis

Failure Mode	Calculated Factor of Safety	Required Factor of Safety	Pass/Fail
Link Plate Tensile Failure - Midsection	30	1	Pass
Link Plate Shear Tear-out	12		Pass
Link Plate Bearing Failure	14		Pass
Link Plate Tensile Failure	56		Pass
Load Pin P1 or P2 Double Shear	23		Pass
Rib Plates 3 & 4 Shear Tear-out	6		Pass
Rib Plates 3 & 4 Bearing Failure	8		Pass
Rib Plates 3 & 4 Tensile Failure	30		Pass

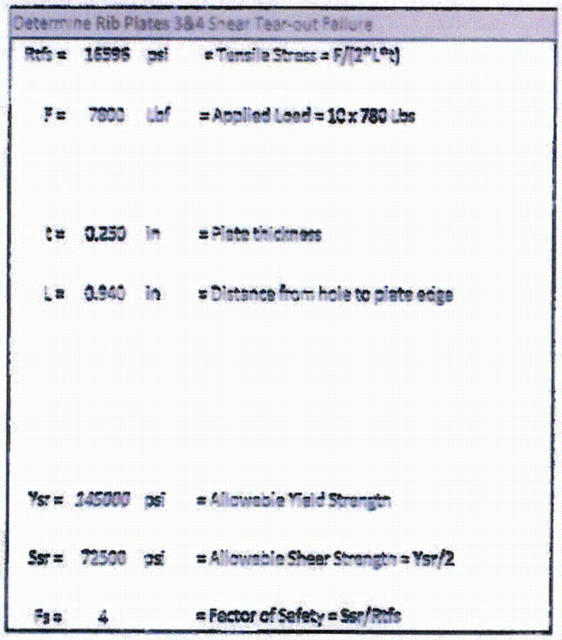
See Appendix D – Shared Provision Tie-down by Link Plate Calculations

13.0 Final Assessment:

The SENTRY transport package tied-down by either the rib assembly or the link plate meets the tie-down requirements of 10 CFR Part 71.45 (b). No failure mode was found to be less than 1 against yielding when securing the package by either one rib assembly or link plate.

If the tie-down provision were to fail due to excessive loading, the package is designed so that the failed provision would not impair the ability of the package to meet the other requirements of 10 CFR Part 71.

Appendix A – Single Provision Tie-Down by Rib Assembly Calculations



Determine Rib Plates 3&4 Shear Tear-out Failure

Rtfs = 16596 psi = Tensile Stress = F/(2*L*t)

F = 7800 Lbf = Applied Load = 10 x 780 Lbs

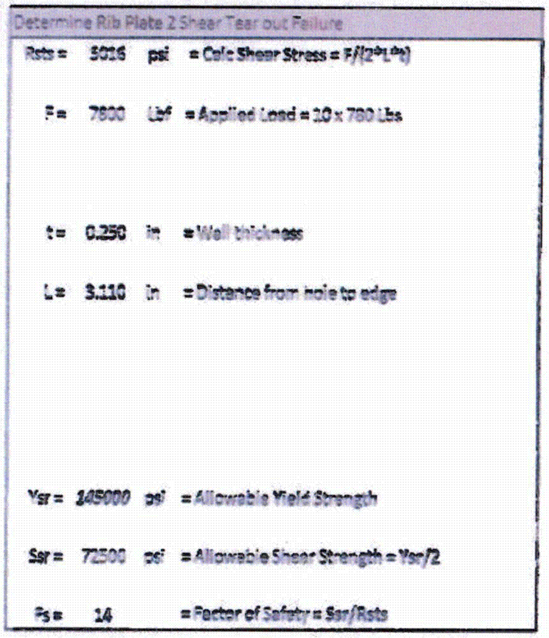
t = 0.250 in = Plate thickness

L = 0.940 in = Distance from hole to plate edge

Ysr = 145000 psi = Allowable Yield Strength

Ssr = 72500 psi = Allowable Shear Strength = Ysr/2

Fs = 4 = Factor of Safety = Ssr/Rtfs



Determine Rib Plate 2 Shear Tear out Failure

Rsts = 5016 psi = Calc Shear Stress = F/(2*L*t)

F = 7800 Lbf = Applied Load = 10 x 780 Lbs

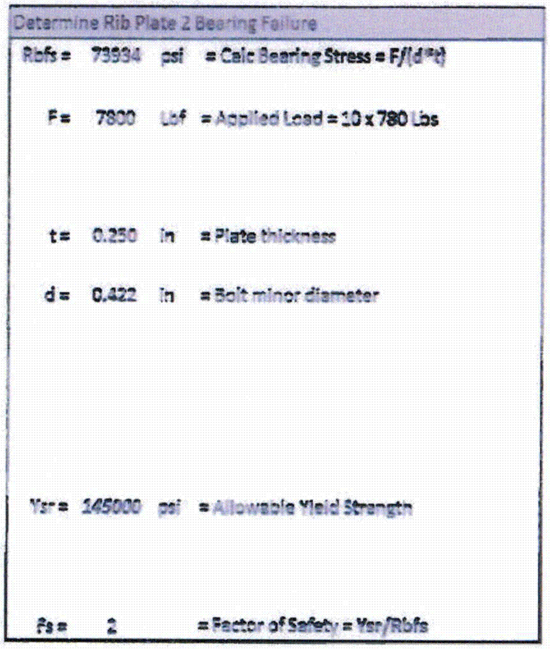
t = 0.250 in = Wall thickness

L = 3.110 in = Distance from hole to edge

Ysr = 145000 psi = Allowable Yield Strength

Ssr = 72500 psi = Allowable Shear Strength = Ysr/2

Fs = 14 = Factor of Safety = Ssr/Rsts



Determine Rib Plate 2 Bearing Failure

Rbfs = 73934 psi = Calc Bearing Stress = F/(d*t)

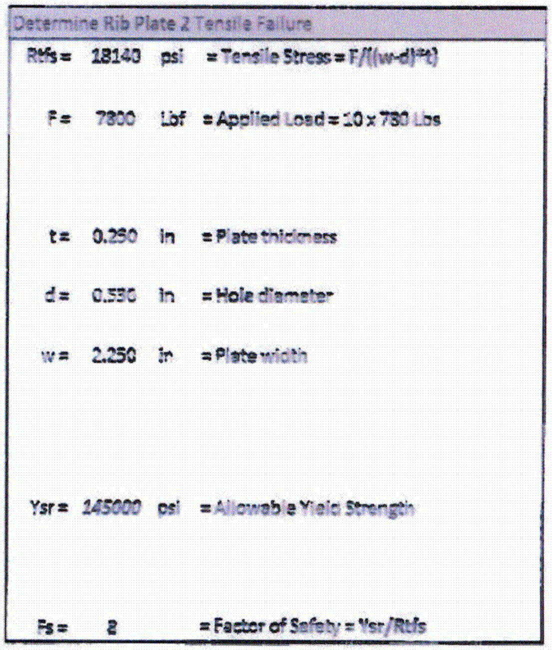
F = 7800 Lbf = Applied Load = 10 x 780 Lbs

t = 0.250 in = Plate thickness

d = 0.422 in = Bolt minor diameter

Ysr = 145000 psi = Allowable Yield Strength

Fs = 2 = Factor of Safety = Ysr/Rbfs



Determine Rib Plate 2 Tensile Failure

Rtfs = 18140 psi = Tensile Stress = F/((w-d)*t)

F = 7800 Lbf = Applied Load = 10 x 780 Lbs

t = 0.250 in = Plate thickness

d = 0.530 in = Hole diameter

w = 2.250 in = Plate width

Ysr = 145000 psi = Allowable Yield Strength

Fs = 8 = Factor of Safety = Ysr/Rtfs

Determine Bolt B3 Tensile Failure (Combined Stress)

B3ms=	62846	psi	=Max Tensile Stress on Bolt B3 = B3st/2 + Sqrt((B3st/2)^2 + Bss^2)
B3st =	36806	psi	= Calc Tensile Stress = Fp/A
F =	11031	Lbf	= Applied Load = 7800/ (sin45°)
Fp =	5506.6	Lbf	= Proportion of load on Bolt B3 = M*L3/SLx
A =	0.1419	in^2	= Bolt Stress Area
M =	38939	in-Lbf	= Moment = F*Lm
Lm =	3.530	in	= Moment Arm at point A
SLx =	37.620	in^2	= Bolt Distances Sumed (L1^2)+(L2^2)+(L3^2)
L3 =	5.320	in	= Bolt B3 Distance to Pivot Point A (See Figure 4 for L1, L2, & L3)
Ysb =	105000	psi	= Allowable Yield Strength
Fs =	2		= Factor of Safety = Ysb/B3ms

Determine Bolt B3 Shear Failure (Combined Stress)

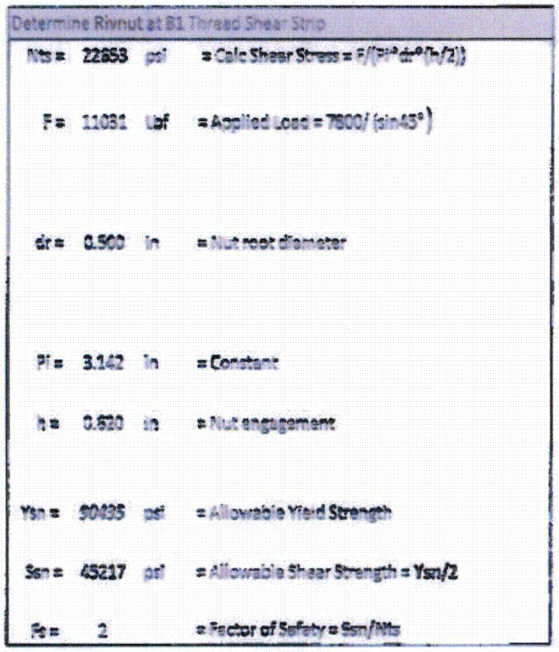
B3ss=	43443	psi	= Max Shear Stress on Bolt B3 = Sqrt [(B3st/2)^2 + Bss^2)
Bss =	38869	psi	= Calc Tensile Stress = Fn/A
F =	11031	Lbf	= Applied Load = 7800/ (sin45°)
Fn =	5516	Lbf	= Load shared by bolts B2 & B3 = F/2
A =	0.1419	in^2	= Bolt Stress Area
Ysb =	105000	psi	= Allowable Yield Strength
Ssb =	52500	psi	= Allowable Shear Strength = Ysb/2
Fs =	1		= Factor of Safety = Ssb/B3ss

Determine Bolt B1 Thread Bearing Failure

Btbs =	24255	psi	= Thread Bearing Stress = F/((PI/4)*(d^2-dr^2)*(h/p))
F =	11031	Lbf	= Applied Load = 7800/ (sin45°)
p =	0.077	in	= Thread pitch = 1/13
dr =	0.422	in	= Bolt root diameter
d =	0.500	in	= Bolt outer diameter
PI =	3.142	in	= Constant
h =	0.620	in	= Nut engagement
Ysb =	105000	psi	= Allowable Yield Strength
Fs =	4		= Factor of Safety = Ssb/Btbs

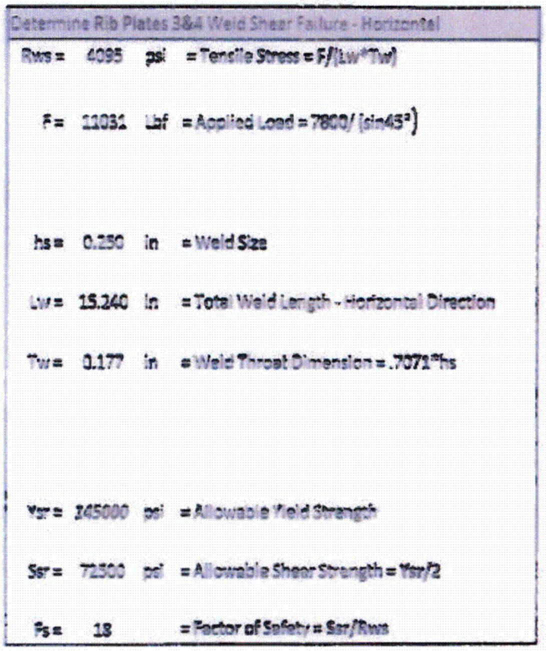
Determine Bolt B1 Thread Shear Strip

Bts =	26841	psi	= Calc Shear Stress = F/(PI*dr*(h/2))
F =	11031	Lbf	= Applied Load = 7800/ (sin45°)
dr =	0.422	in	= Bolt root diameter
PI =	3.142	in	= Constant
h =	0.620	in	= Nut engagement
Ysb =	105000	psi	= Allowable Yield Strength
Ssb =	52500	psi	= Allowable Shear Strength = Ysb/2
Fs =	2		= Factor of Safety = Ssb/Bts



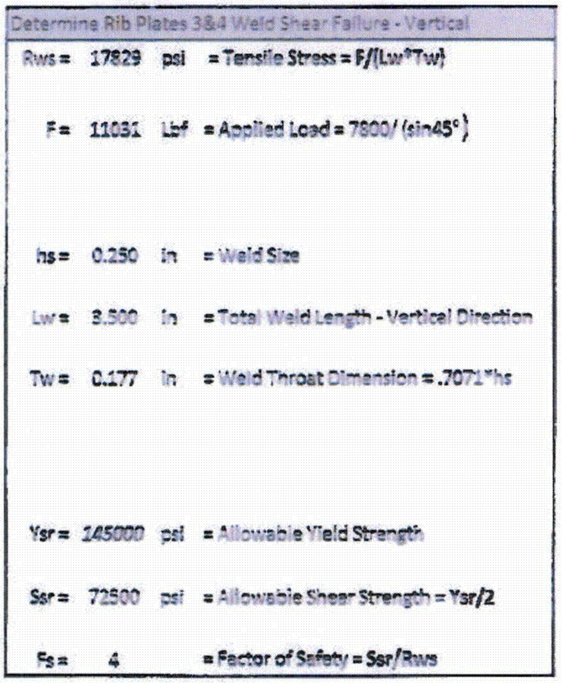
Determine Rivnut at B1 Thread Shear Strip

Nts =	22653	psi	= Calc Shear Stress = F/(PI*dr*(h/2))
F =	11031	Lbf	= Applied Load = 7800/ (sin45°)
dr =	0.500	in	= Nut root diameter
Pi =	3.142	in	= Constant
h =	0.620	in	= Nut engagement
Ysn =	90435	psi	= Allowable Yield Strength
Ssn =	45217	psi	= Allowable Shear Strength = Ysn/2
Fs =	2		= Factor of Safety = Ssn/Nts



Determine Rib Plates 3&4 Weld Shear Failure - Horizontal

Rws =	4095	psi	= Tensile Stress = F/(Lw*Tw)
F =	11031	Lbf	= Applied Load = 7800/ (sin45°)
hs =	0.250	in	= Weld Size
Lw =	15.240	in	= Total Weld Length - Horizontal Direction
Tw =	0.177	in	= Weld Throat Dimension = .7071*hs
Ysr =	145000	psi	= Allowable Yield Strength
Ssr =	72500	psi	= Allowable Shear Strength = Ysr/2
Fs =	18		= Factor of Safety = Ssr/Rws



Determine Rib Plates 3&4 Weld Shear Failure - Vertical

Rws =	17829	psi	= Tensile Stress = F/(Lw*Tw)
F =	11031	Lbf	= Applied Load = 7800/ (sin45°)
hs =	0.250	in	= Weld Size
Lw =	3.500	in	= Total Weld Length - Vertical Direction
Tw =	0.177	in	= Weld Throat Dimension = .7071*hs
Ysr =	145000	psi	= Allowable Yield Strength
Ssr =	72500	psi	= Allowable Shear Strength = Ysr/2
Fs =	4		= Factor of Safety = Ssr/Rws

Appendix B – Single Provision Tie-Down by Link Plate Calculations

Determine Link Plate Tensile Failure at Midsection

Lts = 11278 psi = Calc Tensile Stress = F/A

F = 7800 Lbf = Applied load

X = 1.820 in = Min Link Length

t = 0.380 in = Link Plate thickness

A = 0.692 in^2 = Min Plate Stress Area = X*t

Ysl = *170000* psi = Allowable Yield Strength

Fs = 15 = Factor of Safety = Ysl/Lts

Determine Link Plate Shear Tearout Failure

Lsts = 14230 psi = Calc Shear Stress = Fn/(2*L*t)

F = 11031 Lbf = Applied Load = 7800/(sin45°)

Fn = 5515.5 Lbf = Load Shared by 2 ends = F/2

t = 0.380 in = Link Plate thickness

L = 0.510 in = Distance from hole to edge

Ysl = *170000* psi = Allowable Yield Strength

Ssl = 85000 psi = Allowable Shear Strength = Ysl/2

Fs = 6 = Factor of Safety = Ssl/Lsts

Determine Link Plate Bearing Failure

Lbfs = 25025 psi = Calc Bearing Stress = Fn/(dp*t)

F = 11031 Lbf = Applied Load = 7800/(sin45°)

Fn = 5515.5 Lbf = Load Shared by 2 ends = F/2

dp = 0.580 in = Pin diameter

t = 0.380 in = Link Plate thickness

Ysl = *170000* psi = Allowable Yield Strength

Fs = 7 = Factor of Safety = Ysl/Lbfs

Determine Link Plate Tensile Failure

Ltfs = 6023 psi = Tensile Stress = Fn/((w-d)*t)

F = 11031 Lbf = Applied Load = 7800/(sin45°)

Fn = 5515.5 Lbf = Load Shared by 2 ends = F/2

d= 0.630 in = Hole diameter

t = 0.380 in = Link Plate thickness

w = 3.040 in = Link Plate width

Ysl = *170000* psi = Allowable Yield Strength

Fs = 28 = Factor of Safety = Ysl/Ltfs

Determine Load Pin #1 Double Shear Failure

Pdss =	7381	psi	= Calc Tensile Stress = Fn/(A*2)
F =	7800	Lbf	= Applied load
Fn =	3900	Lbf	= Load Shared by 2 Pins = F/2
dp =	0.580	in	= Pin diameter
A =	0.264	in^2	= Pin Area = Pi*(dp/2)^2
Pi =	3.142	in	= Constant
Ysp =	*170000*	psi	= Allowable Yield Strength
Ssp =	85000	psi	= Allowable Shear Strength = Ysp/2
Fs =	12		= Factor of Safety = Ssp/Pdss

Determine Rib Plates 3 & 4 Shear Tearout Failure

Rsts =	23980	psi	= Calc Shear Stress = Fn/(2*L*t)
F =	11031	Lbf	= Applied Load = 7800/(sin45°)
Fn =	5515.5	Lbf	= Load Shared by 2 plates = F/2
t =	0.250	in	= Rib Plate thickness
L =	0.460	in	= Distance from hole to edge
Ysr =	*145000*	psi	= Allowable Yield Strength
Ssr =	72500	psi	= Allowable Shear Strength = Ysr/2
Fs =	3		= Factor of Safety = Ssr/Rsts

Determine Rib Plates 3 & 4 Bearing Failure

Rbfs =	38038	psi	= Calc Bearing Stress = Fn/(dp*t)
F =	11031	Lbf	= Applied Load = 7800/(sin45°)
Fn =	5515.5	Lbf	= Load Shared by 2 plates = F/2
dp =	0.580	in	= Pin diameter
t =	0.250	in	= Rib Plate thickness
Ysr =	*145000*	psi	= Allowable Yield Strength
Fs =	4		= Factor of Safety = Ysr/Rbfs

Determine Rib Plates 3 & 4 Tensile Failure

Rtfs =	9698	psi	= Tensile Stress = Fn/((w-(dp+dl))*t)
F =	11031	Lbf	= Applied Load = 7800/(sin45°)
Fn =	5515.5	Lbf	= Load Shared by 2 plates = F/2
dp =	0.630	in	= Pin hole diameter
t =	0.250	in	= Rib Plate thickness
w =	4.530	in	= Rib Plate width
dl =	1.625	in	= Large hole diameter
Ysr =	*145000*	psi	= Allowable Yield Strength
Fs =	15		= Factor of Safety = Ysr/Rtfs

Appendix C – Shared Provision Tie-Down by Rib Assembly Calculations

Determine Rib Plates 3&4 Shear Tear-out Failure

Rtfs = 8298 psi = Tensile Stress = F/(2*L*t)

F = 3900 Lbf = Applied Load = (10 x 780 Lbs)/2

t = 0.250 in = Plate thickness

L = 0.940 in = Distance from hole to plate edge

Ysr = 145000 psi = Allowable Yield Strength

Ssr = 72500 psi = Allowable Shear Strength = Ysr/2

Fs = 9 = Factor of Safety = Ssr/Rtfs

Determine Rib Plate 2 Shear Tear out Failure

Rsts = 2508 psi = Calc Shear Stress = F/(2*L*t)

F = 3900 Lbf = Applied Load = (10 x 780 Lbs)/2

t = 0.250 in = Wall thickness

L = 3.110 in = Distance from hole to edge

Ysr = 145000 psi = Allowable Yield Strength

Ssr = 72500 psi = Allowable Shear Strength = Ysr/2

Fs = 29 = Factor of Safety = Ssr/Rsts

Determine Rib Plate 2 Bearing Failure

Rbfs = 36967 psi = Calc Bearing Stress = F/(d*t)

F = 3900 Lbf = Applied Load = (10 x 780 Lbs)/2

t = 0.250 in = Plate thickness

d = 0.422 in = Bolt minor diameter

Ysr = 145000 psi = Allowable Yield Strength

Fs = 4 = Factor of Safety = Ysr/Rbfs

Determine Rib Plate 2 Tensile Failure

Rtfs = 9070 psi = Tensile Stress = F/((w-d)*t)

F = 3900 Lbf = Applied Load = (10 x 780 Lbs)/2

t = 0.250 in = Plate thickness

d = 0.530 in = Hole diameter

w = 2.250 in = Plate width

Ysr = 145000 psi = Allowable Yield Strength

Fs = 16 = Factor of Safety = Ysr/Rtfs

Determine Bolt B3 Tensile Failure (Combined Stress)

B3ms =	31420	psi	= Max Tensile Stress on Bolt B3 = B3st/2 + Sqrt[$(B3st/2)^2 + Bss^2$]
B3st =	19401	psi	= Calc Tensile Stress = Fp/A
F =	5515	Lbf	= Applied Load = 3900/ (sin45°)
Fp =	2753.0	Lbf	= Proportion of load on Bolt B3 = M*L3/SLx
A =	0.1419	in^2	= Bolt Stress Area
M =	19468	in Lbf	= Moment = F*Lm
Lm =	3.530	in	= Moment Arm at point A
SLx =	37.620	in^2	= Bolt Distances Sumed $(L1^2)+(L2^2)+(L3^2)$
L3 =	5.320	in	= Bolt B3 Distance to Pivot Point A (See Figure 4 for L1, L2, & L3)
Ysb =	*105000*	psi	= Allowable Yield Strength
Fs =	3		= Factor of Safety = Ysb/B3ms

Determine Bolt B3 Shear Failure (Combined Stress)

B3ss =	21719	psi	= Max Shear Stress on Bolt B3 = Sqrt ($(B3st/2)^2 + Bss^2$)
Bss =	19435	psi	= Calc Tensile Stress = Fn/A
F =	5515	Lbf	= Applied Load = 3900/ (sin45°)
Fn =	2758	Lbf	= Load shared by bolts B2 & B3 = F/2
A =	0.1419	in^2	= Bolt Stress Area
Ysb =	*105000*	psi	= Allowable Yield Strength
Ssb =	52500	psi	= Allowable Shear Strength = Ysb/2
Fs =	2		= Factor of Safety = Ssb/B3ss

Determine Bolt B1 Thread Bearing Failure

Btbs =	12126	psi	= Thread Bearing Stress = $F/[(PI/4)*(d^2-dr^2)*(h/p)]$
F =	5515	Lbf	= Applied Load = 3900/ (sin45°)
p =	0.077	in	= Thread pitch = 1/13
dr =	0.422	in	= Bolt root diameter
d =	0.500	in	= Bolt outer diameter
PI =	3.142	in	= Constant
h =	0.620	in	= Nut engagement
Ysb =	*105000*	psi	= Allowable Yield Strength
Fs =	9		= Factor of Safety = Ssb/Btbs

Determine Bolt B1 Thread Shear Strip

Bts =	13419	psi	= Calc Shear Stress = F/(PI*dr*(h/2))
F =	5515	Lbf	= Applied Load = 3900/ (sin45°)
dr =	0.422	in	= Bolt root diameter
PI =	3.142	in	= Constant
h =	0.620	in	= Nut engagement
Ysb =	*105000*	psi	= Allowable Yield Strength
Ssb =	52500	psi	= Allowable Shear Strength = Ysb/2
Fs =	4		= Factor of Safety = Ssb/Bts

Determine Rivnut at 81 Thread Shear Strip

Nts = 11326 psi = Calc Shear Stress = F/(PI*dr*(h/2))

F = 5515 Lbf = Applied Load = 3900/ (sin45°)

dr = 0.500 in = Nut root diameter

PI = 3.142 in = Constant

h = 0.620 in = Nut engagement

Ysn = 90435 psi = Allowable Yield Strength

Ssn = 45217 psi = Allowable Shear Strength = Ysn/2

Fs = 4 = Factor of Safety = Ssn/Nts

Determine Rib Plates 3&4 Weld Shear Failure - Horizontal

Rws = 2047 psi = Tensile Stress = F/(Lw*Tw)

F = 3515 Lbf = Applied Load = 3900/ (sin45°)

hs = 0.250 in = Weld Size

Lw = 15.240 in = Total Weld Length - Horizontal Direction

Tw = 0.177 in = Weld Throat Dimension = .7071*hs

Ysr = 145000 psi = Allowable Yield Strength

Ssr = 72500 psi = Allowable Shear Strength = Ysr/2

Fs = 35 = Factor of Safety = Ssr/Rws

Determine Rib Plates 3&4 Weld Shear Failure - Vertical

Rws = 8914 psi = Tensile Stress = F/(Lw*Tw)

F = 5515 Lbf = Applied Load = 3900/ (sin45°)

hs = 0.250 in = Weld Size

Lw = 3.500 in = Total Weld Length - Vertical Direction

Tw = 0.177 in = Weld Throat Dimension = .7071*hs

Ysr = 145000 psi = Allowable Yield Strength

Ssr = 72500 psi = Allowable Shear Strength = Ysr/2

Fs = 8 = Factor of Safety = Ssr/Rws

Appendix D – Shared Provision Tie-Down by Link Plate Calculations

Determine Link Plate Tensile Failure at Midsection

Lts = 5639 psi = Calc Tensile Stress = F/A

F = 3900 Lbf = Applied load

X = 1.820 in = Min Link Length

t = 0.380 in = Link Plate thickness

A = 0.692 in^2 = Min Plate Stress Area = X*t

Ysl = *170000* psi = Allowable Yield Strength

Fs = 30 = Factor of Safety = Ysl/Lts

Determine Link Plate Shear Tearout Failure

Lsts = 7114 psi = Calc Shear Stress = Fn/(2*L*t)

F = 5515 Lbf = Applied Load = 3900/ (sin45°)

Fn = 2757.5 Lbf = Load Shared by 2 ends = F/2

t = 0.380 in = Link Plate thickness

L = 0.510 in = Distance from hole to edge

Ysl = *170000* psi = Allowable Yield Strength

Ssl = 85000 psi = Allowable Shear Strength = Ysl/2

Fs = 12 = Factor of Safety = Ssl/Lsts

Determine Link Plate Bearing Failure

Lbfs = 12511 psi = Calc Bearing Stress = Fn/(dp*t)

F = 5515 Lbf = Applied Load = 3900/ (sin45°)

Fn = 2757.5 Lbf = Load Shared by 2 ends = F/2

dp = 0.580 in = Pin diameter

t = 0.380 in = Link Plate thickness

Ysl = *170000* psi = Allowable Yield Strength

Fs = 14 = Factor of Safety = Ysl/Lbfs

Determine Link Plate Tensile Failure

Ltfs = 3011 psi = Tensile Stress = Fn/((w-d)*t)

F = 5515 Lbf = Applied Load = 3900/ (sin45°)

Fn = 2757.5 Lbf = Load Shared by 2 ends = F/2

d = 0.630 in = Hole diameter

t = 0.380 in = Link Plate thickness

w = 3.040 in = Link Plate width

Ysl = *170000* psi = Allowable Yield Strength

Fs = 56 = Factor of Safety = Ysl/Ltfs

Determine Load Pin #1 Double Shear Failure

Pdss = 3690 psi = Calc Tensile Stress = Fn/(A*2)

F = 3900 Lbf = Applied load

Fn = 1950 Lbf = Load Shared by 2 Pins = F/2

dp = 0.580 in = Pin diameter

A = 0.264 in^2 = Pin Area = PI*(dp/2)^2

PI = 3.142 in = Constant

Ysp = *170000* psi = Allowable Yield Strength

Ssp = 85000 psi = Allowable Shear Strength = **Ysp/2**

Fs = 23 = Factor of Safety = **Ssp/Pdss**

Determine Rib Plates 3 & 4 Shear Tearout Failure

Rsts = 11989 psi = Calc Shear Stress = Fn/(2*L*t)

F = 5515 Lbf = Applied Load = 3900/ (sin45°)

Fn = 2757.5 Lbf = Load Shared by 2 plates = **F/2**

t = 0.250 in = Rib Plate thickness

L = 0.460 in = Distance from hole to edge

Ysr = *145000* psi = Allowable Yield Strength

Ssr = 72500 psi = Allowable Shear Strength = **Ysr/2**

Fs = 6 = Factor of Safety = **Ssr/Rsts**

Determine Rib Plates 3 & 4 Bearing Failure

Rbfs = 19017 psi = Calc Bearing Stress = Fn/(dp*t)

F = 5515 Lbf = Applied Load = 3900/ (sin45°)

Fn = 2757.5 Lbf = Load Shared by 2 plates = **F/2**

dp = 0.580 in = Pin diameter

t = 0.250 in = Rib Plate thickness

Ysr = *145000* psi = Allowable Yield Strength

Fs = 8 = Factor of Safety = **Ysr/Rbfs**

Determine Rib Plates 3 & 4 Tensile Failure

Rtfs = 4848 psi = Tensile Stress = Fn/((w-(dp+dl))*t)

F = 5515 Lbf = Applied Load = 3900/ (sin45°)

Fn = 2757.5 Lbf = Load Shared by 2 plates = **F/2**

dp = 0.630 in = Pin hole diameter

t = 0.250 in = Rib Plate thickness

w = 4.530 in = Rib Plate width

dl = 1.625 in = Large hole diameter

Ysr = *145000* psi = Allowable Yield Strength

Fs = 30 = Factor of Safety = **Ysr/Rtfs**