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APPENDICES

1. PURPOSE

This report describes the Type B test results for the Model 702 transport package. These tests were performed in accordance with Test Plan 81 and were conducted April 9 through 15, 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 702 with these requirements is provided in the Safety Analysis Report (SAR).

2. SCOPE OF TESTING

Test Plan 81 identified three orientations that could potentially cause the most significant damage to the Model 702 transport package in the 9 meter (30 foot) drop tests. Therefore, the test plan required three test specimens. However, since the Model 702 is not portable, only one unit was preconditioned (i.e., subjected to Normal Conditions of Transport Tests) prior to the Hypothetical Accident Condition tests. Also, only one shipping cask was used (in three different cage/skid assemblies) for all tests because the number of 702 units is limited. The shipping cask was taken from the field population, and therefore represents a worse case than using a new 702 shipping cask. The tests conducted are described below.

1. Normal Conditions of Transport Tests per 10 CFR 71.71, including the following for specimen TP81(A):

   a) Compression test, with the test specimen under a load greater than or equal to five times the Model 702 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 702, the test plan specified that the decision to perform thermal testing would be based on an assessment of damage sustained by the specimen following 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 radioactive contents 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 702 transport package, the key function important to safety is the positive retention of the radioactive source in its stored position within the depleted uranium shield. Removal of the cask cover or damage to the cask or DU shield could cause radiation from the package to increase above regulatory limits. Mechanisms, which could cause these modes of failure, include:

- Failure of the Cask Cover Bolts – During the free drop or puncture tests, failure of the cask cover bolts could result in the source becoming partially or completely exposed.

- Failure of the Cask or Cover Assembly Shell – Failure (e.g., puncture) of the cask cover assembly or failure of the inner liner to outer shell weld could expose the depleted uranium (DU) shield, which could oxidize during thermal testing.

- Separation of the Cask from the Skid – If the cask to skid bolts or the tie down assembly fail during the 9 meter (30 foot) drop test, the cask may strike the impact surface. In addition, the specimen could then be further damaged in the puncture bar test when the cask impacts on the puncture bar.

- Crushing or Buckling of the Protective Cage – If there is significant deformation of the protective cage during the 1.2 meter (4 foot) drop, the distance from the source to the specimen external surface would be decreased. If there is significant deformation of the protective cage during the 9 meter (30 foot) drop, the cask may strike the impact surface.

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) drop test, the test orientation considered most likely to cause crushing or buckling of the protective cage was top, long edge down. (See Section 6 for a figure of the 1.2 meter (4 foot) drop orientation).

Three orientations were considered most likely to cause damage during the 9 meter (30 foot) drop tests. These orientations include the following:

- Horizontal, Short-Side Down – The skid is stiffer in this orientation than in the long-side down, so the maximum moment is applied to the hold down feet and the cask bolts. The impact may also cause buckling and/or brittle failure of the carbon steel protective cage structure. Detachment of the cask from the skid is possible due to thread failure of the tapped holes in the skid and brittle failure of the hold down assembly "feet" which are welded to the skid.
- Top, Long Edge Down – The impact may cause significant deformation of the carbon steel protective cage. Detachment of the cask from the skid is possible due to thread failure of the tapped holes in the skid and brittle failure of the hold down assembly "feet" which are welded to the skid.
- Vertical, Top Down – An impact in this orientation will apply the maximum tensile load to the cask cover bolts and inner liner weld. The impact may also cause buckling and/or brittle failure of the carbon steel protective cage structure. Detachment of the cask from the skid is possible due to thread failure of the tapped holes in the skid and brittle failure of the hold down assembly "feet" which are welded to the skid.

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.

The thermal test was only expected to have a significant effect on those units for which the cask or cover assembly shell failed and exposed the DU shield. The test plan required thermal tests of the test specimens only if they sustained damage that could lead to DU oxidation during the thermal test.

4. TEST UNIT DESCRIPTION

The Model 702 test specimens, identified below, were originally constructed in accordance with drawing C70290 and were prepared for testing in accordance with drawing R-TP81, Revision B. The manufacturing route cards for the units document the compliance of these units with the AEA Technology QSA QA program (see Appendix B).

Specimen	Serial Number		Total Weight
	Cask	Cage/Skid	
TP81(A)	24	24	406 lb (184 kg)
TP81(B)	24	26	402 lb (182 kg)
TP81(C)	24	23	403 lb (183 kg)

Cask Serial No. 24 was used with the cask/skid assemblies identified above for each test specimen. The only change from production units was a replacement of the tungsten "nest" that holds sources within the source cavity, with a solid tungsten plug. The weight of the plug bounds the weight of a loaded tungsten nest.

5. SUMMARY AND CONCLUSIONS

Since only one shipping cask was used for all tests, radiation profiles were only taken on the TP81(A) specimen. The test specimen met the requirements for 10CFR71 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 Puncture Test (Note 1)
	Reg. Limits	200 mR/hr	10 mR/hr	200 mR/hr	10 mR/hr	1000 mR/hr
TP81(A)	Top	20	0.5	17	0.6	1.0
	Right	37	1.0	35	0.8	1.1
S/N 24	Front	30	0.5	27	0.9	1.1
	Left	44	1.1	35	0.8	1.1
	Rear	27	0.9	22	0.8	0.8
	Bottom	3	< 0.4 (Note 2)	1.8	< 0.1	0.8 (Note 3)

Notes:

1. Radiation profile at the surface is not required for the Hypothetical Accident Condition test (see 10 CFR 71.51(a)(2)). The shipping cask had been removed from cage/skid prior to final puncture test and was profiled without the cage/skid assembly.
2. Background level is 0.3 mR/hr.
3. Activity measured at surface of shipping cask.

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
TP81(A)	Compression test	No damage
	1 meter (40 inch) penetration bar on top, center of cage	Cage perforated plate dented in and partially broken. No other damage.
	1.2 meter (4 foot) drop, top, long edge down	• Hold down ring, 30° section, and 1 bracket broken • Cage frame displaced about ¼ inch • Perforated plate buckled on sides • Skid cracked • Cask and cage still secured to skid
	Post-Drop Inspection	• Cask cover secure • No change in radiation profile
TP81(C)	9 meter (30 foot) drop, horizontal, short-side down	• Brittle fracture of both legs of skid • All 4 cask-to-skid bolts sheared off • All 4 lower brackets fractured, so cask was free within the cage • 1 of 6 cask cover bolts failed (bolt head pried off due to local buckling of cask cover) • Cask cover locally buckled near broken cover bolt • Perforated plate torn along impacted edge
	1 meter (40 inch) puncture, horizontal, short-side down (puncture bar positioned directly under tear in perforated plate)	• Broke off one leg of skid • Puncture bar tore through perforated plate • Bottom tube of cage frame broken • Slight bend on one cask fin
	Post-Drop Inspection	• Cask cover still secured by remaining 5 bolts
TP81(B)	9 meter (30 foot) drop, top, long edge down	• 3.75 inch to 4 inch deflection of cage frame • Perforated plate detached on both sides of cage • Some buckling of skid • 2 of 4 hold down ring brackets (next to impact edge) failed • 2 cage frame welds on top edge failed • Tube steel dented by impact from 2 hold down ring brackets • 2 of 4 hold down base brackets (opposite impact edge) broke

Specimen	Test Performed	Test Results
TP81(B) (con't)	1 meter (40 inch) puncture test not performed for this cage/skid because potential damage to cask was bounded by puncture tests using cask with cage/skid assemblies TP81(C) and TP81(A)	n/a
	Post-Drop Inspection	• Cask remained secured to skid via 4 cask-to-skid bolts • Cask cover remained secured
TP81(A)	9 meter (30 foot) drop, vertical, top down	• Brittle fracture of skid • Cask and square plate welded to skid tore away from rest of skid • 3 hold down ring brackets failed (4th had broken in 1.2 meter (4 foot) drop test) • Cask struck impact surface, which dented head of 1 cask cover bolt • Cask fin ends dented
	1 meter (40 inch) puncture, cask attached to portion of skid, dropped upside down, 10° to 15° off vertical onto dented cask cover bolt	Bolt was further dented, but remained secure.
	Post-Drop Inspection	• Cask remained secured (after 3rd 30 foot drop and 2 puncture tests) • Small change in radiation profile

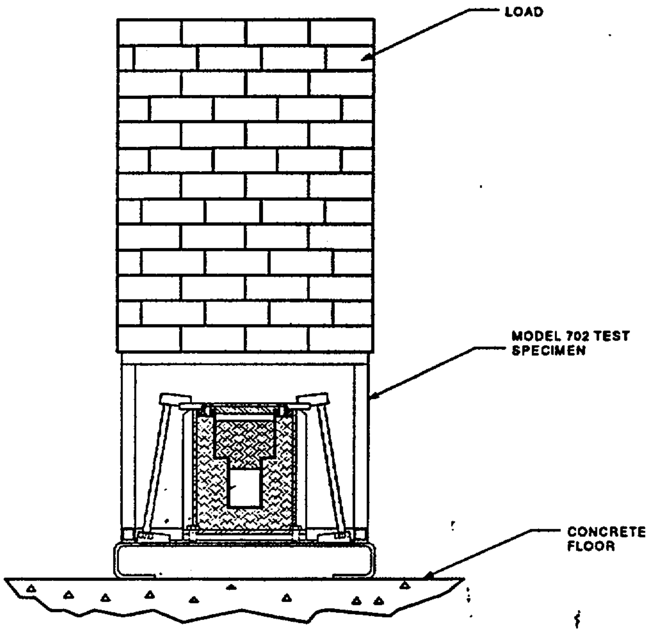
The skid, cage, and hold down assemblies of each test specimen were damaged. The only significant damage to the cask, however, was the loss of 1 of the 6 cask cover bolts during the 9 meter (30 foot) drop test of specimen TP81(C). Further testing (e.g., 2 additional 9 meter drop tests and 2 puncture tests with the same cask) added no significant damage to the cask or cask cover bolts. There were no openings in the cask cover or in the cask shell, so thermal testing was not required.

6. TP81 NORMAL TESTS

Compression Test

Test specimen TP81(A) was loaded as shown in the figure below. Lead weights were placed on a steel plate, which was positioned on top of the test specimen.

The vertical projected area of the unit is 19 inch (483 mm) x 21 inch (533 mm) or 399 square inches (2574 square centimeters), yielding a total load of 798 lb (362 kg) for an applied pressure of 2 psi. Since the maximum weight of the Model 702 transport package is 410 lb (186 kg), a load of 5 times the weight, or 2050 lb (930 kg), is more conservative. The total compressive load actually used was 2138 lb (970 kg). The test setup is shown below.



Compression Test Setup for Specimen TP81(A)

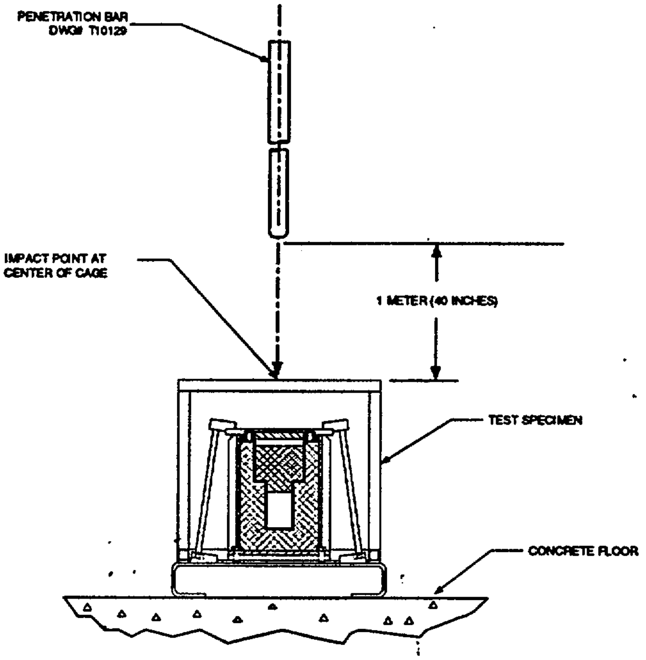
After a period of 24 hours, the weights were removed. No visible deformation or buckling occurred and no other damage was observed for any of the test specimens.

Penetration Test

Test specimen TP81(A) was subjected to the penetration test. Temperature readings taken just before the test are summarized below.

Specimen	Ambient	Cask	Skid	Cage
TP81(A)	7°C (45°F)	-72°C (-98°F)	-77°C (-107°F)	-63°C (-81°F)

The penetration bar target was the top center of the protective cage in an attempt to penetrate the perforated plate and impact the cask cover. For this test, the specimen was positioned right side up, as shown below.



Penetration Test Orientation for Specimen TP81(A)

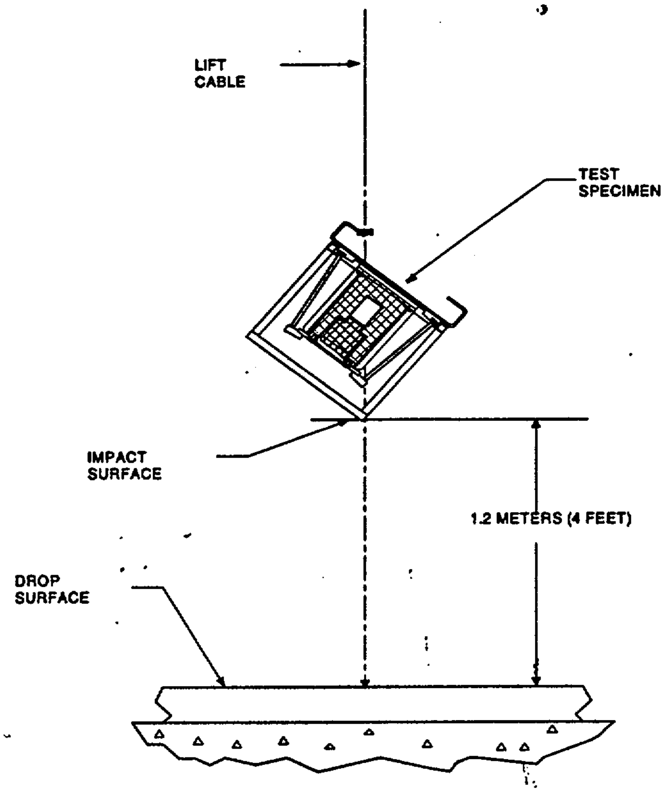
The penetration bar was dropped from a height of at least 1 meter (40 inches) above the impact point. The bar hit as intended on the specimen, and dented and partially broke the perforated plate at the point of impact.

1.2 Meter (4 Foot) Drop Test

Test specimen TP80(A) was then subjected to the 1.2 meter (4 foot) drop test. Temperature readings taken just before the test are summarized below.

Specimen	Ambient	Cask	Skid	Cage
TP81(A)	7°C (45°F)	-71°C (-96°F)	-71°C (-96°F)	-54°C (-65°F)

The drop orientation for the unit is shown below.



1.2 Meter (4 Foot) Drop Orientation for Specimen TP81(A)

The test specimen impacted as intended. The hold down ring fractured and a 30 degree section of the ring (along with one of the top brackets) broke off. The perforated plate buckled on the sides and the cage was displaced about 1/2 inch towards the shipping cask. There was some tearing of the perforated plate. The cask and cage remained secured to the skid.

Post-Test Inspection and Assessment

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

Specimen	Damage	Radiation Profile
TP81(A)	• Protective cage and perforated plate slightly damaged • One tie down bracket and 30° section of the hold down ring broken • Skid cracked • Cask and cage remain attached to skid. • Cask cover secure	• No change

7. TP81 ACCIDENT DROP TESTS – TP81(C)

Due to the damage sustained during the Normal Conditions of Transport tests, Specimen TP81(C) was dropped in the orientation defined in Test Plan 81 for TP81(A) (horizontal, short-side down).

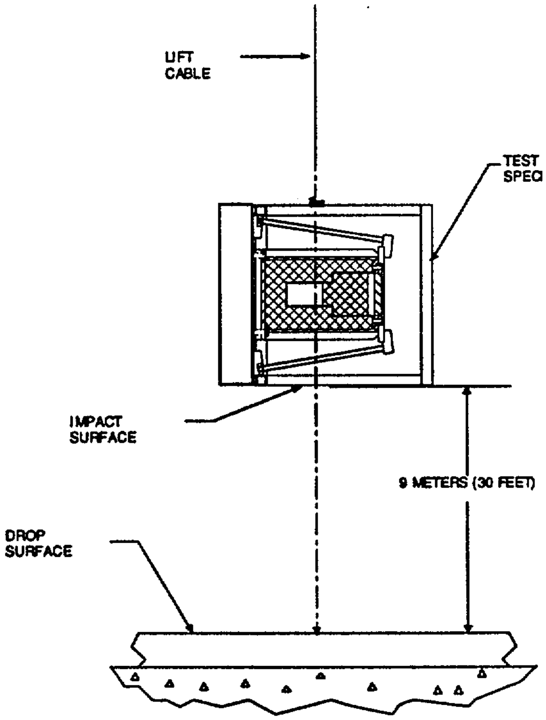
Specimen TP81(C) was subjected to both a 9 meter (30 foot) drop test and a puncture test in accordance with Test Plan 81. The results are described below.

9 Meter (30 Foot) Drop Test

Just before the drop test, thermocouple readings for Specimen TP81(C) were as follows:

Specimen	Ambient	Cask	Skid	Cage
TP81(C)	10°C (50°F)	-90°C (-130°F)	-92°C (-134°F)	-93°C (-135°F)

The orientation for Specimen TP81(C) was horizontal, short-side down as shown below. The intention was to apply the maximum moment to the hold down feet and the cask-to-skid bolts, thereby breaking the cask free from the skid.



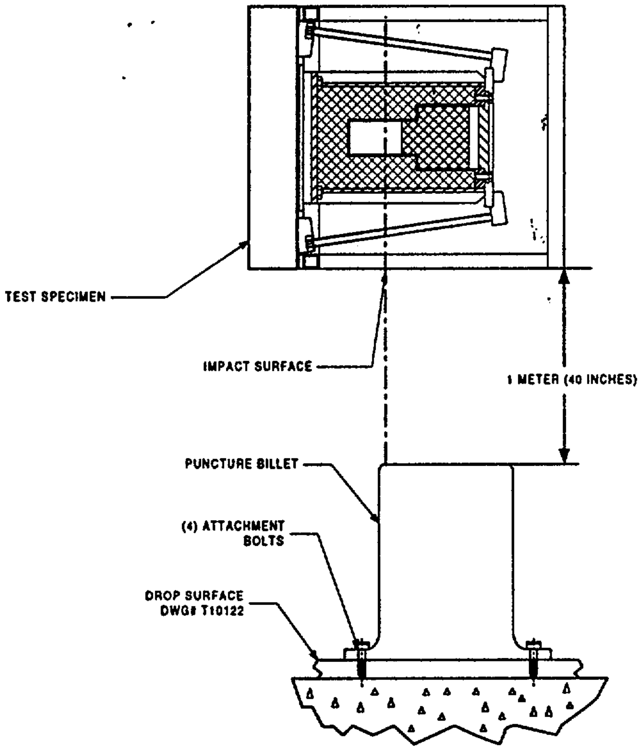
9 Meter (30 Foot) Drop Orientation for Specimen TP81(C)

The specimen impacted as intended. Both legs of the skid fractured. All four cask to skid bolts sheared off and all four lower brackets of the hold down assembly fractured, which freed the cask and allowed the hold down ring to strike the impact surface. The hold down ring transferred the side impact load into the top edge of the cask cover, which locally buckled and pried off one of the 6 cask cover bolts.

Puncture Test

For the puncture test, TP81(C) was dropped in the cage horizontal, short-side down as in the 9 meter (30 foot) drop with the puncture bar directly under the tear in the perforated plate, where the hold down ring had struck the impact surface. The puncture billet was intended to strike the cask cover through the side of the perforated plate.

Puncture Drop Orientation for Specimen TP81(C)



The unit impacted on its side and the puncture billet impacted at the tear in the perforated plate as intended. The impact caused further degradation of the skid and cage. One of the skid legs broke off, the puncture bar tore through the perforated plate at the point of impact, and the bottom tube of the cage frame broke. One of the cask cooling fins was slightly bent, but there was no additional damage to the cask or cask cover bolts.

Post-Test Inspection and Assessment

Following the test, the protective cage was removed and the unit was inspected. The cask and cask cover retained their structural integrity.

8. TP81 ACCIDENT DROP TESTS – TP81(B)

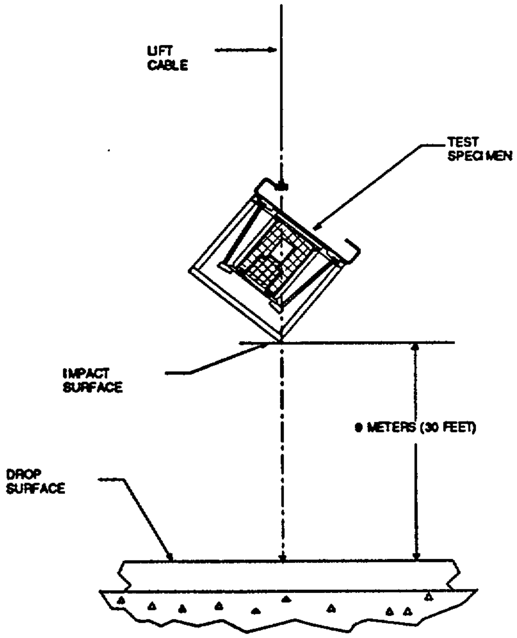
During re-assembly of Specimen TP81(B), the 5 remaining cover bolts for the cask were replaced and torqued in accordance with drawing R-TP81, Revision B. Specimen TP81(B) was then subjected to a 9 meter (30 foot) drop test in accordance with Test Plan 81. A puncture test was not performed because the 9 meter (30 foot) drop test did not result in significant damage to the shipping cask, and, therefore, the puncture test performed for TP81(C) (and later for TP81(A)) bounds any puncture tests that could have been done for TP81(B). The results of the 9 meter (30 foot) test are described below.

9 Meter (30 Foot) Drop Test

Just before the drop test, thermocouple readings for Specimen TP81(B) were as follows:

Specimen	Ambient	Cask	Skid	Cage
TP81(B)	12°C (54°F)	-54°C (-65°F)	-69°C (-92°F)	-62°C (-80°F)

The orientation for Specimen TP81(B), shown below, was the same as for the 1.2 meter (4 foot) drop. The intention was to cause significant deformation of the carbon steel protective cage.



9 Meter (30 Foot) Drop Orientation for Specimen TP81(B)

The specimen impacted as intended. The impact deflected the cage frame about 4 inches towards the shipping cask. The perforated plates on both sides of the cage detached. The skid buckled slightly. Two of the four base brackets (those opposite the impact edge) broke. Two of the four top brackets (those next to impact edge) also failed. Frame welds on the top edge failed and the tube steel dented due to the impact from the two top brackets. The cask remained secured to the skid via the four cask to skid bolts.

Puncture Test

Not performed.

Post-Test Inspection and Assessment

Since the 9 meter (30 foot) drop resulted in essentially no damage to the cask, and since only one cask was used for all tests, the final 9 meter (30 foot) drop test for Specimen TP81(A) was performed before selecting a final puncture test orientation.

9. TP81 ACCIDENT DROP TESTS – TP81(A)

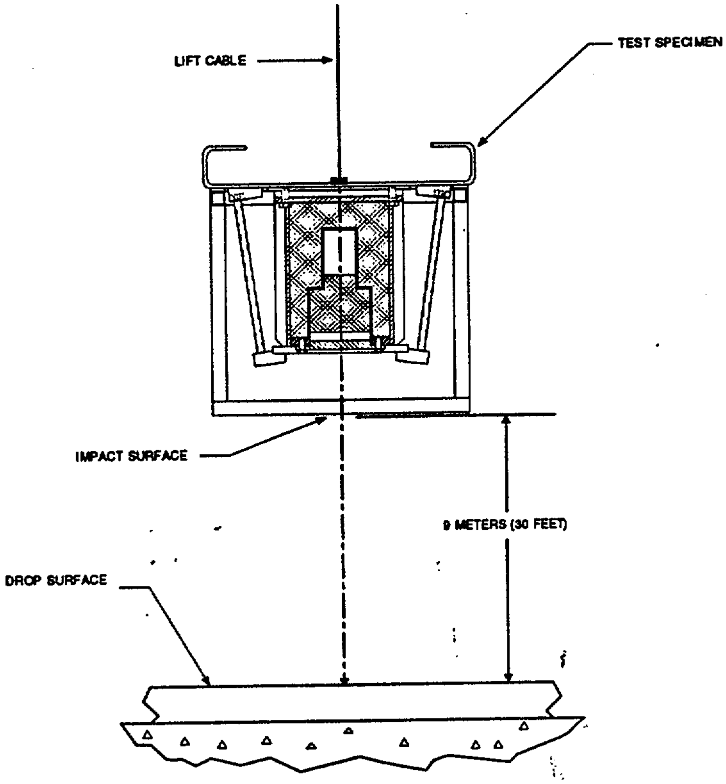
Specimen TP81(A) was subjected to the third orientation for the 9 meter (30 foot) drop test and puncture test described in Test Plan 81. The results are described below.

9 Meter (30 Foot) Drop Test

Just before the drop test, thermocouple readings for Specimen TP81(A) were as follows:

Specimen	Ambient	Cask	Skid	Cage
TP81(A)	10°C (50°F)	-45°C (-49°F)	-82°C (-116°F)	-63°C (-81°F)

The orientation for Specimen TP81(A), shown below, was vertical, top down. The intention was to apply the maximum tensile load to the cask cover bolts and inner liner weld.

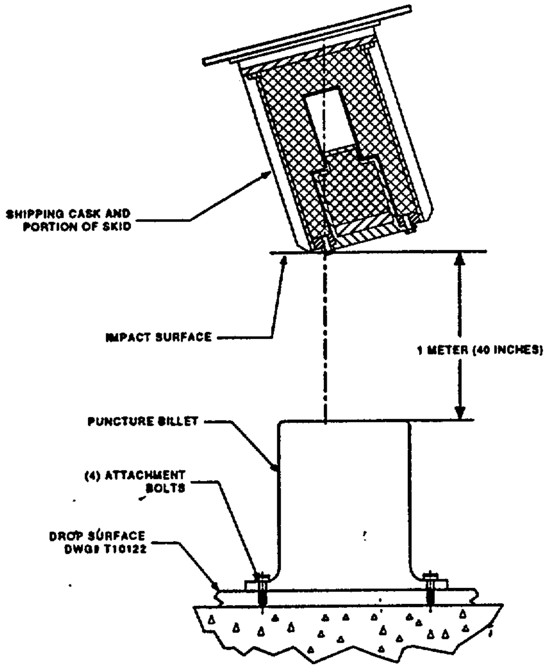


9 Meter (30 Foot) Drop Orientation for Specimen TP81(A)

The specimen impacted as intended. The skid fractured and the cask and square plate welded to the skid tore away from the rest of the skid. Three hold down ring brackets broke off (the fourth bracket was broken in the 1.2 meter drop test of specimen TP81(A)). The cask struck the impact surface, as evidenced by the dented-in head of one of the 5 remaining cask cover bolts, and by the dented ends of the cask cooling fins.

Puncture Test

For the Specimen TP81(A) puncture test, the cask bolted to the portion of the skid that remained after the 9 meter (30 foot) drop was dropped without the cage at a 15 to 20 degree angle off vertical onto the puncture bar. The targeted impact point was the bolt that had been dented during the 9 meter (30 foot) drop test.



Puncture Drop Orientation for Specimen TP81(A)

The cask struck the puncture bar on the intended bolt. The bolt was dented further, but remained secure. There was no additional damage to the cask or the other cask cover bolts.

Post-Test Inspection and Assessment

The cask and cask cover retained their structural integrity. The post-test radiation profile was performed on the cask without the cage/skid assembly, and showed only a slight change in radiation levels from the pre-test profile (see Appendices B and C). Because no damage occurred that could result in oxidation of the DU shield, the thermal test was not required (see Section 3).

SENTINEL

TEST PLAN NO. 81, Rev. 1

TEST PLAN COVER SHEET

TEST TITLE: Model 702 Transport Package Type B Transport Tests

PRODUCT MODEL: Model 702

ORIGINATED BY:	DATE: 30 MAR 99

TEST PLAN REVIEW

ENGINEERING APPROVAL:	DATE: 31 MAR 99
QUALITY ASSURANCE APPROVAL: D.W. Kurtz	DATE: 31 Mar 99
REGULATORY APPROVAL:	DATE: 31 Mar 99

COMMENTS:

TEST RESULTS REVIEW

ENGINEERING APPROVAL:	DATE: 03 NOV 99
QUALITY ASSURANCE APPROVAL:	DATE: 7 Nov 99
REGULATORY APPROVAL:	DATE: 11 NOV 99

Amersham QSA

MPR
ASSOCIATES INC.
ENGINEERS

QUALITY ASSURANCE DOCUMENT
This document has been prepared, reviewed, and approved in accordance with the Quality Assurance requirements of 10CFR50 Appendix B, as specified in the MPR Quality Assurance Manual.

Prepared by
Reviewed by
Approved by

September 8, 1999

Mr. Michael L. Tremblay
AEA Technology QSA, Inc.
40 North Avenue
Burlington, MA 01803

Subject: Final Test Plan 81 Report, Model 702, Type B(U) Transport Package

Dear Mr. Tremblay:

Three copies of the final Test Plan 81 Report, Model 702, Type B(U) Transport Package are enclosed. This version of the report incorporates the documentation missing from our May 14 draft report.

Please call me if you have comments or questions about this letter or enclosure.

Sincerely,

Caroline S. Schlaseman

Enclosure

TEST PLAN 81 REPORT

MODEL 702

September 8, 1999

Prepared By: Laura Ridzon Date: 08 SEPT 1999
Laura Ridzon, MPR Associates, Inc.

Reviewed By: Nicholas J. Marrone Date: 8 SEPT 1999
Nicholas J. Marrone, MPR Associates, Inc.

Approved By: Caroline S. Schlaseman Date: 8 SEPT 99
Caroline S. Schlaseman, MPR Associates, Inc.

AEA Technology QSA, Inc.
Burlington, MA

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APPENDICES

1. PURPOSE

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1. Normal Conditions of Transport Tests per 10 CFR 71.71, including the following for specimen TP81(A):

    a) Compression test, with the test specimen under a load greater than or equal to five times the Model 702 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:

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    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 702, the test plan specified that the decision to perform thermal testing would be based on an assessment of damage sustained by the specimen following 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.

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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 702 transport package, the key function important to safety is the positive retention of the radioactive source in its stored position within the depleted uranium shield. Removal of the cask cover or damage to the cask or DU shield could cause radiation from the package to increase above regulatory limits. Mechanisms, which could cause these modes of failure, include:

- Failure of the Cask Cover Bolts – During the free drop or puncture tests, failure of the cask cover bolts could result in the source becoming partially or completely exposed.

- Failure of the Cask or Cover Assembly Shell – Failure (e.g., puncture) of the cask cover assembly or failure of the inner liner to outer shell weld could expose the depleted uranium (DU) shield, which could oxidize during thermal testing.

- Separation of the Cask from the Skid – If the cask to skid bolts or the tie down assembly fail during the 9 meter (30 foot) drop test, the cask may strike the impact surface. In addition, the specimen could then be further damaged in the puncture bar test when the cask impacts on the puncture bar.

- Crushing or Buckling of the Protective Cage – If there is significant deformation of the protective cage during the 1.2 meter (4 foot) drop, the distance from the source to the specimen external surface would be decreased. If there is significant deformation of the protective cage during the 9 meter (30 foot) drop, the cask may strike the impact surface.

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) drop test, the test orientation considered most likely to cause crushing or buckling of the protective cage was top, long edge down. (See Section 6 for a figure of the 1.2 meter (4 foot) drop orientation).

Three orientations were considered most likely to cause damage during the 9 meter (30 foot) drop tests. These orientations include the following:

- <u>Horizontal, Short-Side Down</u> – The skid is stiffer in this orientation than in the long-side down, so the maximum moment is applied to the hold down feet and the cask bolts. The impact may also cause buckling and/or brittle failure of the carbon steel protective cage structure. Detachment of the cask from the skid is possible due to thread failure of the tapped holes in the skid and brittle failure of the hold down assembly "feet" which are welded to the skid.
- <u>Top, Long Edge Down</u> – The impact may cause significant deformation of the carbon steel protective cage. Detachment of the cask from the skid is possible due to thread failure of the tapped holes in the skid and brittle failure of the hold down assembly "feet" which are welded to the skid.
- <u>Vertical, Top Down</u> – An impact in this orientation will apply the maximum tensile load to the cask cover bolts and inner liner weld. The impact may also cause buckling and/or brittle failure of the carbon steel protective cage structure. Detachment of the cask from the skid is possible due to thread failure of the tapped holes in the skid and brittle failure of the hold down assembly "feet" which are welded to the skid.

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.

The thermal test was only expected to have a significant effect on those units for which the cask or cover assembly shell failed and exposed the DU shield. The test plan required thermal tests of the test specimens only if they sustained damage that could lead to DU oxidation during the thermal test.

4. TEST UNIT DESCRIPTION

The Model 702 test specimens, identified below, were originally constructed in accordance with drawing C70290 and were prepared for testing in accordance with drawing R-TP81, Revision B. The manufacturing route cards for the units document the compliance of these units with the AEA Technology QSA QA program (see Appendix B).

Specimen	Serial Number		Total Weight
	Cask	Cage/Skid	
TP81(A)	24	24	406 lb (184 kg)
TP81(B)	24	26	402 lb (182 kg)
TP81(C)	24	23	403 lb (183 kg)

Cask Serial No. 24 was used with the cask/skid assemblies identified above for each test specimen. The only change from production units was a replacement of the tungsten "nest" that holds sources within the source cavity, with a solid tungsten plug. The weight of the plug bounds the weight of a loaded tungsten nest.

5. SUMMARY AND CONCLUSIONS

Since only one shipping cask was used for all tests, radiation profiles were only taken on the TP81(A) specimen. The test specimen met the requirements for 10CFR71 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 Puncture Test (Note 1)
	Reg. Limits	200 mR/hr	10 mR/hr	200 mR/hr	10 mR/hr	1000 mR/hr
TP81(A)	Top	20	0.5	17	0.6	1.0
	Right	37	1.0	35	0.8	1.1
S/N 24	Front	30	0.5	27	0.9	1.1
	Left	44	1.1	35	0.8	1.1
	Rear	27	0.9	22	0.8	0.8
	Bottom	3	< 0.4 (Note 2)	1.8	< 0.1	0.8 (Note 3)

Notes:

1. Radiation profile at the surface is not required for the Hypothetical Accident Condition test (see 10 CFR 71.51(a)(2)). The shipping cask had been removed from cage/skid prior to final puncture test and was profiled without the cage/skid assembly.
2. Background level is 0.3 mR/hr.
3. Activity measured at surface of shipping cask.

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
TP81(A)	Compression test	No damage
	1 meter (40 inch) penetration bar on top, center of cage	Cage perforated plate dented in and partially broken. No other damage.
	1.2 meter (4 foot) drop, top, long edge down	• Hold down ring, 30° section, and 1 bracket broken • Cage frame displaced about ¼ inch • Perforated plate buckled on sides • Skid cracked • Cask and cage still secured to skid
	Post-Drop Inspection	• Cask cover secure • No change in radiation profile
TP81(C)	9 meter (30 foot) drop, horizontal, short-side down	• Brittle fracture of both legs of skid • All 4 cask-to-skid bolts sheared off • All 4 lower brackets fractured, so cask was free within the cage • 1 of 6 cask cover bolts failed (bolt head pried off due to local buckling of cask cover) • Cask cover locally buckled near broken cover bolt • Perforated plate torn along impacted edge
	1 meter (40 inch) puncture, horizontal, short-side down (puncture bar positioned directly under tear in perforated plate)	• Broke off one leg of skid • Puncture bar tore through perforated plate • Bottom tube of cage frame broken • Slight bend on one cask fin
	Post-Drop Inspection	• Cask cover still secured by remaining 5 bolts
TP81(B)	9 meter (30 foot) drop, top, long edge down	• 3.75 inch to 4 inch deflection of cage frame • Perforated plate detached on both sides of cage • Some buckling of skid • 2 of 4 hold down ring brackets (next to impact edge) failed • 2 cage frame welds on top edge failed • Tube steel dented by impact from 2 hold down ring brackets • 2 of 4 hold down base brackets (opposite impact edge) broke

Specimen	Test Performed	Test Results
TP81(B) (con't)	1 meter (40 inch) puncture test not performed for this cage/skid because potential damage to cask was bounded by puncture tests using cask with cage/skid assemblies TP81(C) and TP81(A)	n/a
	Post-Drop Inspection	• Cask remained secured to skid via 4 cask-to-skid bolts • Cask cover remained secured
TP81(A)	9 meter (30 foot) drop, vertical, top down	• Brittle fracture of skid • Cask and square plate welded to skid tore away from rest of skid • 3 hold down ring brackets failed (4th had broken in 1.2 meter (4 foot) drop test) • Cask struck impact surface, which dented head of 1 cask cover bolt • Cask fin ends dented
	1 meter (40 inch) puncture, cask attached to portion of skid, dropped upside down, 10° to 15° off vertical onto dented cask cover bolt	Bolt was further dented, but remained secure.
	Post-Drop Inspection	• Cask remained secured (after 3rd 30 foot drop and 2 puncture tests) • Small change in radiation profile

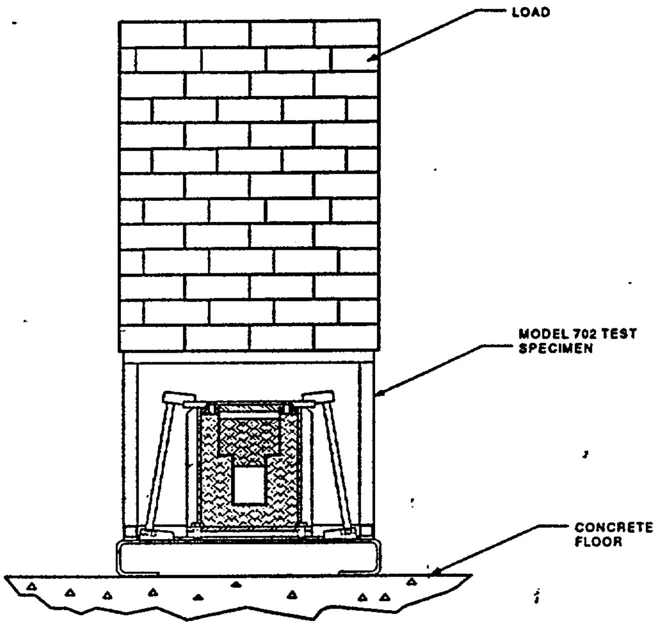
The skid, cage, and hold down assemblies of each test specimen were damaged. The only significant damage to the cask, however, was the loss of 1 of the 6 cask cover bolts during the 9 meter (30 foot) drop test of specimen TP81(C). Further testing (e.g., 2 additional 9 meter drop tests and 2 puncture tests with the same cask) added no significant damage to the cask or cask cover bolts. There were no openings in the cask cover or in the cask shell, so thermal testing was not required.

6. TP81 NORMAL TESTS

Compression Test

Test specimen TP81(A) was loaded as shown in the figure below. Lead weights were placed on a steel plate, which was positioned on top of the test specimen.

The vertical projected area of the unit is 19 inch (483 mm) x 21 inch (533 mm) or 399 square inches (2574 square centimeters), yielding a total load of 798 lb (362 kg) for an applied pressure of 2 psi. Since the maximum weight of the Model 702 transport package is 410 lb (186 kg), a load of 5 times the weight, or 2050 lb (930 kg), is more conservative. The total compressive load actually used was 2138 lb (970 kg). The test setup is shown below.



Compression Test Setup for Specimen TP81(A)

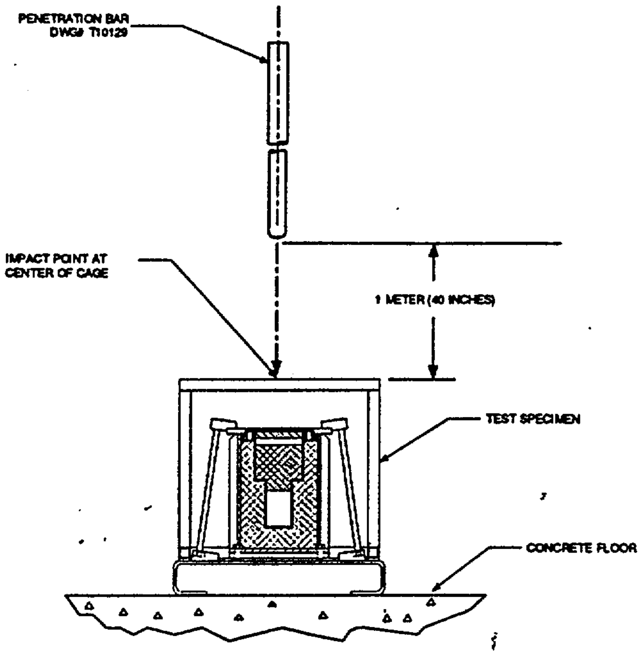
After a period of 24 hours, the weights were removed. No visible deformation or buckling occurred and no other damage was observed for any of the test specimens.

Penetration Test

Test specimen TP81(A) was subjected to the penetration test. Temperature readings taken just before the test are summarized below.

Specimen	Ambient	Cask	Skid	Cage
TP81(A)	7°C (45°F)	-72°C (-98°F)	-77°C (-107°F)	-63°C (-81°F)

The penetration bar target was the top center of the protective cage in an attempt to penetrate the perforated plate and impact the cask cover. For this test, the specimen was positioned right side up, as shown below.



Penetration Test Orientation for Specimen TP81(A)

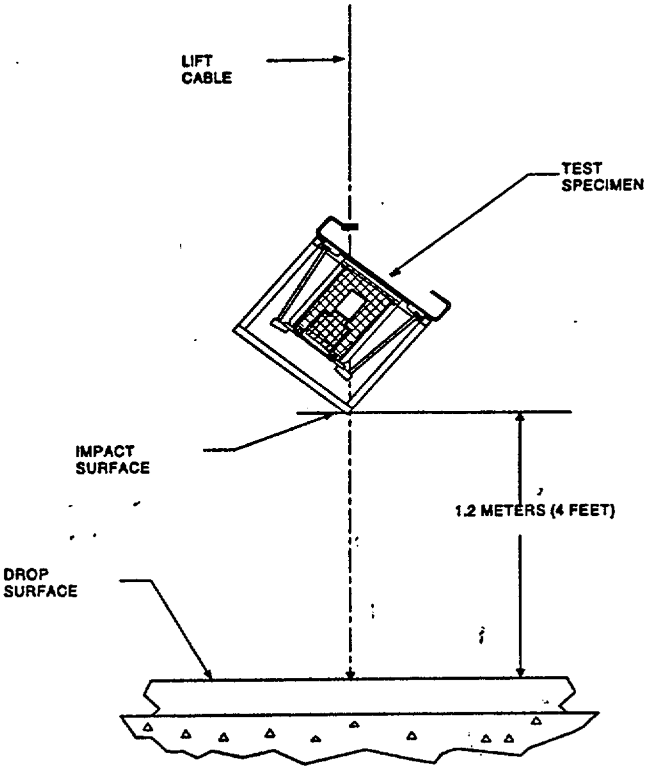
The penetration bar was dropped from a height of at least 1 meter (40 inches) above the impact point. The bar hit as intended on the specimen, and dented and partially broke the perforated plate at the point of impact.

1.2 Meter (4 Foot) Drop Test

Test specimen TP80(A) was then subjected to the 1.2 meter (4 foot) drop test. Temperature readings taken just before the test are summarized below.

Specimen	Ambient	Cask	Skid	Cage
TP81(A)	7°C (45°F)	-71°C (-96°F)	-71°C (-96°F)	-54°C (-65°F)

The drop orientation for the unit is shown below.



1.2 Meter (4 Foot) Drop Orientation for Specimen TP81(A)

The test specimen impacted as intended. The hold down ring fractured and a 30 degree section of the ring (along with one of the top brackets) broke off. The perforated plate buckled on the sides and the cage was displaced about 1/2 inch towards the shipping cask. There was some tearing of the perforated plate. The cask and cage remained secured to the skid.

Post-Test Inspection and Assessment

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

Specimen	Damage	Radiation Profile
TP81(A)	• Protective cage and perforated plate slightly damaged • One tie down bracket and 30° section of the hold down ring broken • Skid cracked • Cask and cage remain attached to skid. • Cask cover secure	• No change

7. TP81 ACCIDENT DROP TESTS – TP81(C)

Due to the damage sustained during the Normal Conditions of Transport tests, Specimen TP81(C) was dropped in the orientation defined in Test Plan 81 for TP81(A) (horizontal, short-side down).

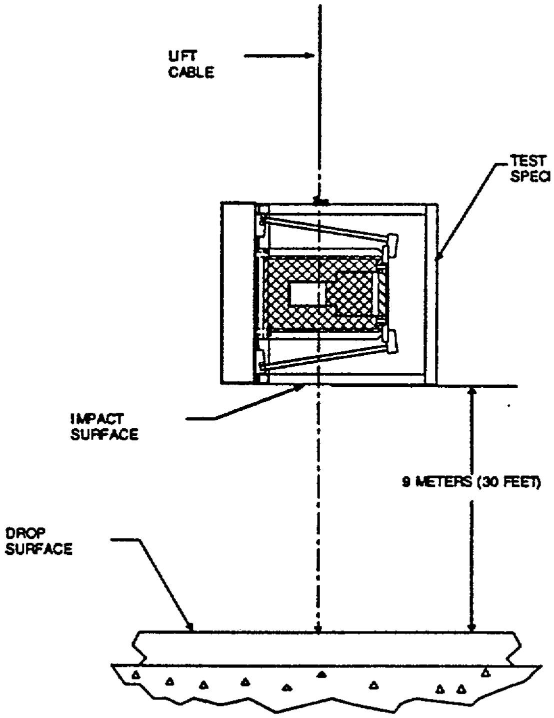
Specimen TP81(C) was subjected to both a 9 meter (30 foot) drop test and a puncture test in accordance with Test Plan 81. The results are described below.

9 Meter (30 Foot) Drop Test

Just before the drop test, thermocouple readings for Specimen TP81(C) were as follows:

Specimen	Ambient	Cask	Skid	Cage
TP81(C)	10°C (50°F)	-90°C (-130°F)	-92°C (-134°F)	-93°C (-135°F)

The orientation for Specimen TP81(C) was horizontal, short-side down as shown below. The intention was to apply the maximum moment to the hold down feet and the cask-to-skid bolts, thereby breaking the cask free from the skid.



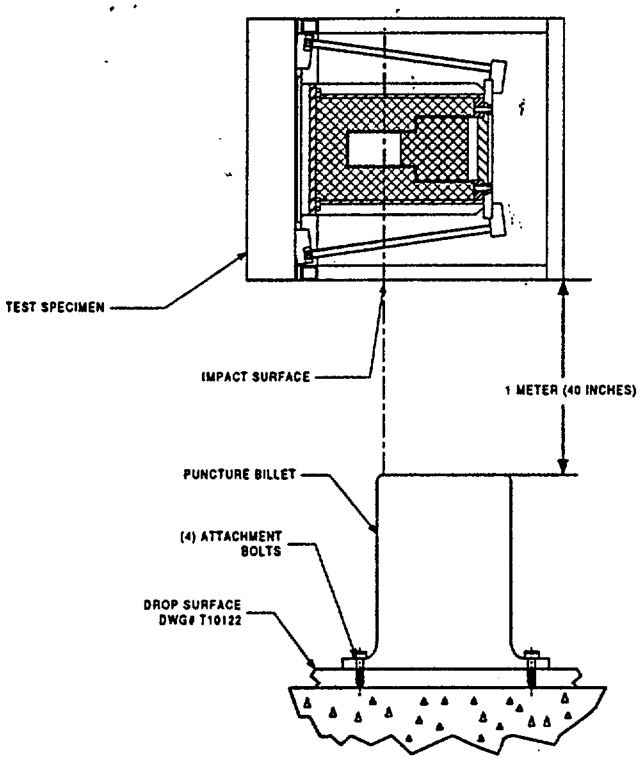
9 Meter (30 Foot) Drop Orientation for Specimen TP81(C)

The specimen impacted as intended. Both legs of the skid fractured. All four cask to skid bolts sheared off and all four lower brackets of the hold down assembly fractured, which freed the cask and allowed the hold down ring to strike the impact surface. The hold down ring transferred the side impact load into the top edge of the cask cover, which locally buckled and pried off one of the 6 cask cover bolts.

Puncture Test

For the puncture test, TP81(C) was dropped in the cage horizontal, short-side down as in the 9 meter (30 foot) drop with the puncture bar directly under the tear in the perforated plate, where the hold down ring had struck the impact surface. The puncture billet was intended to strike the cask cover through the side of the perforated plate.

Puncture Drop Orientation for Specimen TP81(C)



The unit impacted on its side and the puncture billet impacted at the tear in the perforated plate as intended. The impact caused further degradation of the skid and cage. One of the skid legs broke off, the puncture bar tore through the perforated plate at the point of impact, and the bottom tube of the cage frame broke. One of the cask cooling fins was slightly bent, but there was no additional damage to the cask or cask cover bolts.

Post-Test Inspection and Assessment

Following the test, the protective cage was removed and the unit was inspected. The cask and cask cover retained their structural integrity.

8. TP81 ACCIDENT DROP TESTS – TP81(B)

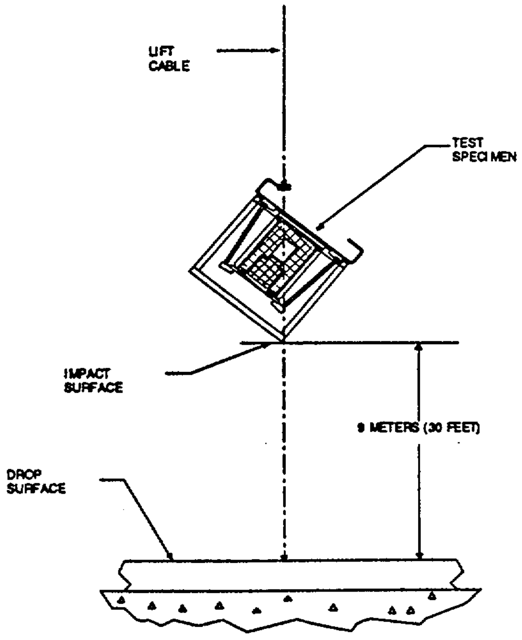
During re-assembly of Specimen TP81(B), the 5 remaining cover bolts for the cask were replaced and torqued in accordance with drawing R-TP81, Revision B. Specimen TP81(B) was then subjected to a 9 meter (30 foot) drop test in accordance with Test Plan 81. A puncture test was not performed because the 9 meter (30 foot) drop test did not result in significant damage to the shipping cask, and, therefore, the puncture test performed for TP81(C) (and later for TP81(A)) bounds any puncture tests that could have been done for TP81(B). The results of the 9 meter (30 foot) test are described below.

9 Meter (30 Foot) Drop Test

Just before the drop test, thermocouple readings for Specimen TP81(B) were as follows:

Specimen	Ambient	Cask	Skid	Cage
TP81(B)	12°C (54°F)	-54°C (-65°F)	-69°C (-92°F)	-62°C (-80°F)

The orientation for Specimen TP81(B), shown below, was the same as for the 1.2 meter (4 foot) drop. The intention was to cause significant deformation of the carbon steel protective cage.



9 Meter (30 Foot) Drop Orientation for Specimen TP81(B)

The specimen impacted as intended. The impact deflected the cage frame about 4 inches towards the shipping cask. The perforated plates on both sides of the cage detached. The skid buckled slightly. Two of the four base brackets (those opposite the impact edge) broke. Two of the four top brackets (those next to impact edge) also failed. Frame welds on the top edge failed and the tube steel dented due to the impact from the two top brackets. The cask remained secured to the skid via the four cask to skid bolts.

Puncture Test

Not performed.

Post-Test Inspection and Assessment

Since the 9 meter (30 foot) drop resulted in essentially no damage to the cask, and since only one cask was used for all tests, the final 9 meter (30 foot) drop test for Specimen TP81(A) was performed before selecting a final puncture test orientation.

9. TP81 ACCIDENT DROP TESTS – TP81(A)

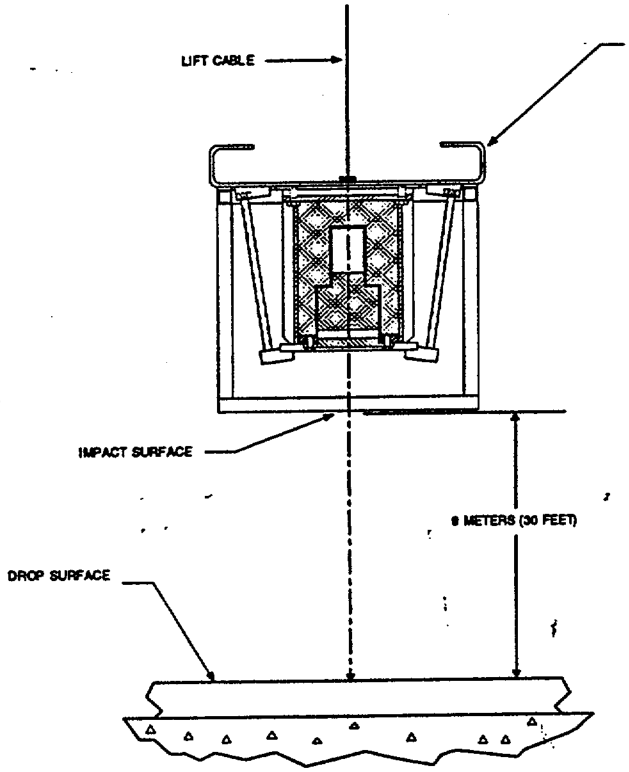
Specimen TP81(A) was subjected to the third orientation for the 9 meter (30 foot) drop test and puncture test described in Test Plan 81. The results are described below.

9 Meter (30 Foot) Drop Test

Just before the drop test, thermocouple readings for Specimen TP81(A) were as follows:

Specimen	Ambient	Cask	Skid	Cage
TP81(A)	10°C (50°F)	-45°C (-49°F)	-82°C (-116°F)	-63°C (-81°F)

The orientation for Specimen TP81(A), shown below, was vertical, top down. The intention was to apply the maximum tensile load to the cask cover bolts and inner liner weld.

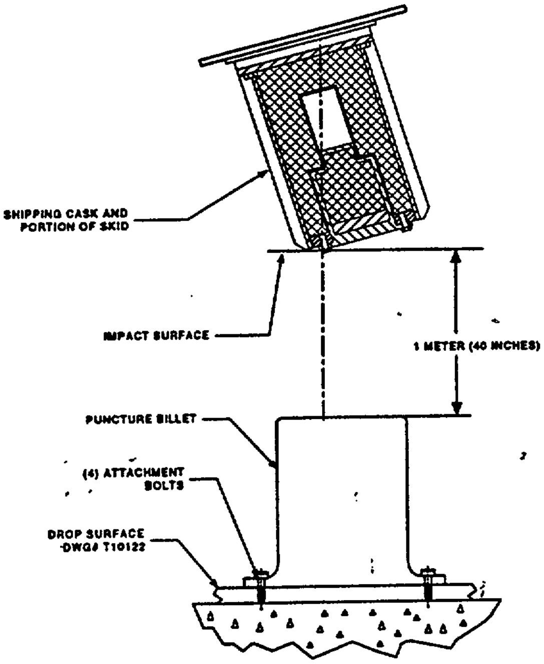


9 Meter (30 Foot) Drop Orientation for Specimen TP81(A)

The specimen impacted as intended. The skid fractured and the cask and square plate welded to the skid tore away from the rest of the skid. Three hold down ring brackets broke off (the fourth bracket was broken in the 1.2 meter drop test of specimen TP81(A)). The cask struck the impact surface, as evidenced by the dented-in head of one of the 5 remaining cask cover bolts, and by the dented ends of the cask cooling fins.

Puncture Test

For the Specimen TP81(A) puncture test, the cask bolted to the portion of the skid that remained after the 9 meter (30 foot) drop was dropped without the cage at a 15 to 20 degree angle off vertical onto the puncture bar. The targeted impact point was the bolt that had been dented during the 9 meter (30 foot) drop test.



Puncture Drop Orientation for Specimen TP81(A)

The cask struck the puncture bar on the intended bolt. The bolt was dented further, but remained secure. There was no additional damage to the cask or the other cask cover bolts.

Post-Test Inspection and Assessment

The cask and cask cover retained their structural integrity. The post-test radiation profile was performed on the cask without the cage/skid assembly, and showed only a slight change in radiation levels from the pre-test profile (see Appendices B and C). Because no damage occurred that could result in oxidation of the DU shield, the thermal test was not required (see Section 3).

APPENDIX A

CALIBRATION RECORDS

METTLER TOLEDO

SCALE CALIBRATION RECORD

Date: 11-16-98

SCALE LOCATION Shipping + Rec.
MANUFACTURER FAIRBANKS
MODEL NUMBER Port Beam
CAPACITY 2000 X 1/2
TEST PROCEDURE HB44

TAG NO. ASSY II
SERIAL NUMBER L482397
DIVISIONS 4000
CSWA#

TEST PROCEDURE REFERENCE: METTLER TOLEDO MANUAL FOR CALIBRATIONS SERVICES, HANDBOOK 44 FIELD MANUAL

Shift Test	Weights Applied	Scale Reading	Error (+/-)	Scale Reading After Adjustment		
Position 1	500 lb	501 lb	+1 lb		[✓ Acc.]	Rej.
Position 2	500	500	0		[✓ Acc.]	Rej.
Position 3	500	500 1/2	+1/2		[✓ Acc.]	Rej.
Position 4	500	500 1/2	+1/2		[✓ Acc.]	Rej.

Test Load	Weights Applied	Scale Reading	Error (+/-)	Scale Reading After Adjustment		
Zero Balance	0 lb	0 lb	0 lb		[✓ Acc.]	Rej.
	500	500 1/2	+1/2		[✓ Acc.]	Rej.
	1000	999 1/2	-1/2		[✓ Acc.]	Rej.
	1500	1501	+1		[✓ Acc.]	Rej.
Maximum Test Load	2000	1998	-2		[✓ Acc.]	Rej.
					Acc.	Rej.
	1000		-1/2		[✓ Acc.]	Rej.
					Acc.	Rej.
Zero Balance	0		0		[✓ Acc.]	Rej.

TEST WEIGHT ID NUMBERS: 01 thru 28

COMMENTS/ACTIONS:

CUSTOMERS SIGNATURE (FOR OFF TOLERANCE):

TECHNICIANS SIGNATURE: J. Draper + B. Clarke

METTLER TOLEDO

SCALE CALIBRATION RECORD

Date: 11/16/98

SCALE LOCATION Shipping / Rec

MANUFACTURER Flex Weigh

MODEL NUMBER DWM II

CAPACITY 5000 X 1

TEST PROCEDURE HB 44

TAG NO. N/A

SERIAL NUMBER F16383

DIVISIONS 5000

CSWA#

TEST PROCEDURE REFERENCE: METTLER TOLEDO MANUAL FOR CALIBRATIONS SERVICES, HANDBOOK 44 FIELD MANUAL

Shift Test	Weights Applied	Scale Reading	Error (+/-)	Scale Reading After Adjustment		
Position 1	1000 lb	1000 lb	0 lb		[✓ Acc.]	Rej.
Position 2	1000	1000	0		[✓ Acc.]	Rej.
Position 3	1000	1001	+1		[✓ Acc.]	Rej.
Position 4	1000	1001	+1		[✓ Acc.]	Rej.

Test Load	Weights Applied	Scale Reading	Error (+/-)	Scale Reading After Adjustment		
Zero Balance	0 lb	0 lb	0 lb	0	[✓ Acc.]	Rej.
	1000	1001	+1	1000	[✓ Acc.]	Rej.
	2000	2002	+2	2001	[✓ Acc.]	Rej.
	4000	4004	+4	3999	[✓ Acc.]	Rej.
Maximum Test Load	5000	5006	+6	5001	[✓ Acc.]	Rej.
	4000			3999	[✓ Acc.]	Rej.
	2000			2001	[✓ Acc.]	Rej.
	1000			1001	[✓ Acc.]	Rej.
Zero Balance	0			0	[✓ Acc.]	Rej.

TEST WEIGHT ID NUMBERS: 01 thru 28

COMMENTS/ACTIONS:

CUSTOMERS SIGNATURE (FOR OFF TOLERANCE):

TECHNICIANS SIGNATURE: J. Draper + B Clarke

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Customer: AEA TECHNOLOGY
                                                                P.O. No.: 3753
                                                               Date Cal: 04/01/99
      ID.No.: 140                Manufacturer: DELTRONIC       Date Due: 04/01/00
    2 ID.No.:                      Serial No.: 140            Technician: PR
  Department:                       Model No.:              Cal. Proc. No: 20
 Deviation u.:                   Standard No.: 006      Cal.: 02/10/99   Due: 08/31/99
    Accuracy: +/-0.000 04"       Standard No.: 021      Cal.: 02/10/99   Due: 08/31/99
    Accuracy:                    Standard No.:          Cal.:            Due:
                                 Standard No.:          Cal.:            Due:
   Gage Type: PLAIN PLUG - X CLASS
            :    END A          END B
   Required. .   0.2801"        0.2801"
   Deviation: :  +0.000 01"     0.000 00"
   Measured: :   0.28011"       0.28000"
             ------------    ------------------------------------------------

    Customer: AEA TECHNOLOGY                                    P.O. No.: 3753
                                                               Date Cal: 04/01/99
      ID.No.: 142                Manufacturer: STARRETT        Date Due: 04/01/00
    2 ID.No.:                      Serial No.:                Technician: PR
  Department: QC                    Model No.: 4R           Cal. Proc. No: 37
 Deviation u.:                   Standard No.: 027      Cal.: 02/10/99   Due: 08/31/99
    Accuracy: +/-0.0010"         Standard No.: 101      Cal.: 02/10/99   Due: 08/31/99
    Accuracy:                    Standard No.: 051      Cal.: 01/15/99   Due: 01/15/00
                                 Standard No.:          Cal.:            Due:
   Gage Type: 24.0" RULER
            :     STRAIGHT WITHIN .0001"
   Required: ·   6.0"     12.0"     18.0"     22.0"
   Deviation: :   0        0         0         0       SQUARE HEAD WITHIN 0.0001"
   Measured: :  6.000"  12.000"   18.000"   22.000"      INCREMENTS CORRECT
            :----------------------------   ----------------------------

    Customer: AEA TECHNOLOGY                                    P.O. No.: 3753
                                                               Date Cal: 04/01/99
      ID.No.: 143                Manufacturer: DELTRONIC       Date Due: 04/01/00
    2 ID.No.:                      Serial No.: 143            Technician: PR
  Department:                       Model No.:              Cal. Proc. No: 20
 Deviation u.:                   Standard No.: 006      Cal.: 02/10/99   Due: 08/31/99
    Accuracy: +/-0.000 04"       Standard No.: 021      Cal.: 02/10/99   Due: 08/31/99
    Accuracy:                    Standard No.:          Cal.:            Due:
                                 Standard No.:          Cal.:            Due:
   Gage Type: PLAIN PLUG - X CLASS
            :    END A          END B
   Required: :   0.4527"        0.4527"
   Deviation: :  -0.000 04"     -0.000 03"
   Measured: :   0.45266"       0.45267"
            :--------------------------------------------    ------------

    Customer: AEA TECHNOLOGY                                    P.O. No.: 3753
                                                               Date Cal: 04/01/99
      ID.No.: 144                Manufacturer: DELTRONIC       Date Due: 04/01/00
    2 ID.No.:                      Serial No.: 144            Technician: PR
  Department:                       Model No.:              Cal. Proc. No: 20
 Deviation u.:                   Standard No.: 006      Cal.: 02/10/99   Due: 08/31/99
    Accuracy: +/-0.000 04"       Standard No.: 021      Cal.: 02/10/99   Due: 08/31/99
    Accuracy:                    Standard No.:          Cal.:            Due:
                                 Standard No.:          Cal.:            Due:
   Gage Type: PLAIN PLUG - X CLASS
            :    END A          END B
   Required: :   0.4534"        0.4534"
   Deviation: :  0.000 00"      0.000 00"
   Measured: :   0.45340"       0.45340"
            :-- ---------------------------------------------------------
```

METTLER TOLEDO

SCALE CALIBRATION RECORD

Date: 11-16-98

SCALE LOCATION Shipping + Rec
MANUFACTURER Pelouze
MODEL NUMBER 4010
CAPACITY 125 X .2
TEST PROCEDURE HB44

TAG NO. D14
SERIAL NUMBER 1126131
DIVISIONS 625
CSWA#

TEST PROCEDURE REFERENCE: METTLER TOLEDO MANUAL FOR CALIBRATIONS SERVICES, HANDBOO
44 FIELD MANUAL

Shift Test	Weights Applied	Scale Reading	Error (+/-)	Scale Reading After Adjustment		
Position 1	50 lb	50.2 lb	+.2 lb		[✓ Acc.]	Rej.
Position 2	50	50.0	0		[✓ Acc.]	Rej.
Position 3	50	49.8	-.2		[✓ Acc.]	Rej.
Position 4	50	50.0	0		[✓ Acc.]	Rej.

Test Load	Weights Applied	Scale Reading	Error (+/-)	Scale Reading After Adjustment		
Zero Balance	0 lb	0 lb	0 lb		[✓ Acc.]	Rej.
	25	25.0	0		[✓ Acc.]	Rej.
	50	50.0	0		[✓ Acc.]	Rej.
	75	75.0	0		[✓ Acc.]	Rej.
Maximum Test Load	125	125.0	0		[✓ Acc.]	Rej.
	75	75.0	0		[✓ Acc.]	Rej.
	50	50.0	0		[✓ Acc.]	Rej.
	25	25.0	0		[✓ Acc.]	Rej.
Zero Balance	0	0	0		[✓ Acc.]	Rej.

TEST WEIGHT ID NUMBERS:

COMMENTS/ACTIONS:

CUSTOMERS SIGNATURE (FOR OFF TOLERANCE):

TECHNICIANS SIGNATURE: J. Draper + B. Clarke unt Metrology Service, Inc. Data Sheet HMSCC: 01843 PAGE 1

ustpmer: AEA TECHNOLOGY QSA

P.O.No.: P3236

Date Cal: 11/10/98

Date Due: 11/10/99

Technician: DD

Cal. Proc. No.: 23

ID.No.: 279 (1)

2 ID.No.:

Department: Q.C.

eviation u.:

Accuracy: +/-4%

Accuracy:

Manufacturer: CRAFTSMAN

Serial No.: 5970355413

Model No.:

Standard No.: 158 Cal.: 07/06/98 Due: 07/06/99

Standard No.: 161 Cal.: 07/06/98 Due: 07/06/99

Standard No.: Cal.: Due:

Gage Type: 20-150 ft/lb TORQUEWRENCH (PART 1 of 2)

:			CW		
Required: :	40	60	80	120	140 lb
Deviation: :	+0.77	+1.70	+2.40	+4.00	+2.07
Measured: :	40.77	61.70	82.40	124.00	142.07 lb

---

ustomer: AEA TECHNOLOGY QSA

P.O.No.: P3236

Date Cal: 11/10/98

Date Due: 11/10/99

Technician: DD

Cal. Proc. No.: 23

ID.No.: 279 (2)

2 ID.No.:

Department: Q.C.

eviation u.:

Accuracy: +/-4%

Accuracy:

Manufacturer: CRAFTSMAN

Serial No.: 5970355413

Model No.:

Standard No.: 158 Cal.: 07/06/98 Due: 07/06/99

Standard No.: 161 Cal.: 07/06/98 Due: 07/06/99

Standard No.: Cal.: Due:

Gage Type: 20-150 ft/lb TORQUEWRENCH (PART 2 of 2)

:			CCW		
Required: :	40	60	80	120	140 lb
Deviation: :	+1.60	+0.19	+1.34	+3.60	+2.37
Measured: :	41.60	60.19	81.34	123.60	142.37 lb

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

Do 8 OCT 98

CALIBRATION REPORT

NQA ISO9002 REGISTERED COMPANY ANSI-RAB Certificate No. 10154
NQA ISO9002 REGISTERED COMPANY BS EN ISO 9002 Certificate No. 8229

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
23.00C	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

CALIBRATION CHECKED TO MANUFACTURER'S SPECIFICATIONS ADJUSTED TO MANUFACTURER'S SPECIFICATIONS

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

TEKSERV CERTIFIES THAT ALL CALIBRATION EQUIPMENT USED IN THE TEST IS TRACEABLE TO N.I.S.T. AND THE TEST WAS PERFORMED IN ACCORDANCE WITH MIL-STD-45662A, ISO9002, ISO-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	"

INSPECTION INSTRUCTION AND RECORD

PART/DWG. NO. T10129

REV. B

VENDOR: PERIODIC MAINTENANCE

Page 1 of 1

DESCRIPTION: PENETRATION TEST BAR

CM - NA

CHARACTERISTICS	TOLERANCE	AQL	1	2	3	4	5	6	7	8	9	10	11	12
GENERAL VISUAL	N/A	C/100%	0/1	0/1										
VERIFY WEIGHT	13/13.5 lbs	C/100%	0/1	0/1										

ORIGINATOR DATE 2 SEPT 97	~~P.O. / W.O.~~ FREQ. DAYS	365												
ENGINEERING APPROVAL DATE N/A	~~RECEIVING RECORD #~~ DUE DATE	2 Sep 98	2 Sep 99											
REGULATORY APPROVAL DATE N/A	LOT / SERIAL NO.	01	01											
Q A APPROVAL DATE 3 Sep 97	LOT QTY.	1	1											
COMMENTS:	QTY REJ / NCR NO.	0 / NA	0 / NA											
	QTY ACC.	1	1											
	INSP / DATE	Dw / 2 Sep 97	Da / 2 Sep 98											

INSPECTION INSTRUCTION AND RECORD

PART/DWG. NO. T10122

REV. B

VENDOR: PERIODIC MAINTENANCE

Page 1 of 1

DESCRIPTION: DROP TEST SURFACE

CM - NA

CHARACTERISTICS	TOLERANCE	AQL	1	2	3	4	5	6	7	8	9	10	11	12
GENERAL VISUAL SURFACE SECURE & NOT DAMAGED	N/A	C/100%	0 / 1											
REMOVE 4 ½-13 SCREWS LUBRICATE AND REINSTALL	N/A	C/100%	0 / 1											

		1	2	3	4	5	6	7	8	9	10	11	12
ORIGINATOR Dave Annis **DATE** 29 SEPT 97	~~P.O. / W.O.~~ DAYS, FREQ	365											
ENGINEERING APPROVAL N/A **DATE**	~~RECEIVING RECORD #~~ DATE DUE	25 SEPT 98											
REGULATORY APPROVAL N/A **DATE**	LOT / SERIAL NO.	01											
Q A APPROVAL **DATE** 29 Sep 97	LOT QTY.	1											
COMMENTS:	QTY REJ / NCR NO.	0 / N/A											
	QTY ACC.	1											
	INSP / DATE	DW / 25 SEPT											

Simpson Gumpertz & Heger Inc.

Consulting Engineers
Arlington, MA
San Francisco, CA

297 Broadway
Arlington, MA
02174-5310

Telephone:
617 643 2000
Fax:
617 643 2009

9 June 1997

Sentinel Amersham Corporation
40 North Avenue
Burlington, Massachusetts 01803

Attention: Steven J. Grenier

Tel: 617-272-2000
Fax: 617-273-2216

Comm. 97276 – Test Foundation Study, Sentinel Amersham Test Site, Groveland, MA

Gentlemen:

At your request we studied a test foundation located on the property of Valley Tree Service, Inc. at 1210 Salem Street, Groveland, Massachusetts. The purpose of our study was to determine if the test foundation provides an essentially unyielding horizontal surface for purposes of a drop test.

Scope

The scope of our study included: visiting the site to examine the foundation; reviewing documents provided by you that describe the construction of the foundation; reviewing drawings describing the housing of your Model 676 Projector; and computing the performance characteristics of the foundation in a drop test of the Model 676 Projector.

Background and Information From Others

We understand from our discussions with Sentinel Amersham representatives that the test foundation is used as a reaction support in a drop test for the Model 676 Projector. The projector is dropped from a height of 30 ft onto the center portion of the foundation. The drawings for the Model 676 Projector show that the weight is 625 lbs, and the end plates are fabricated from 1 in. thick steel plate.

We understand from discussions with Sentinel Amersham representatives and from construction records that the test foundation was built in 1982. The delivery tickets show that 2-1/2 cubic yards of 3,000 psi concrete were utilized. We were also told that a 1 in. thick steel plate is embedded in the top surface of the foundation and welded to reinforcing steel in the foundation.

Observations

On 5 June 1997, Joseph J. Zona of Simpson Gumpertz & Heger Inc. visited the test facility and observed the following:

- The test foundation is 7 ft 4 in. x 7 ft 5 in.
- A steel plate is embedded in the top of the foundation so that the top of the plate is approximately flush with the top of the concrete. The plate is 47 in. x 48 in. At one

side of the plate, the concrete is chipped away exposing part of the plate edge. The bottom of the plate is not visible, but 7/8 in. of plate is exposed to view.

- The top surface of the steel plate is approximately horizontal. The plate slopes a maximum of 1/8 in. per 2 ft.
- The top surface of the concrete is weathered, but sound.
- Four cracks are visible in the foundation, each emanating from a corner of the steel plate. The cracks appear stable and show no signs of recent movement.
- The concrete is flush with the adjoining bituminous pavement. There is no evidence of settlement or heaving of the foundation.
- The exposed soil in the vicinity of the foundation is firm and sandy.

Results of Analysis

We estimated the depth of the foundation as 15 in. based on the measured plan dimensions and the reported volume of concrete delivered. We characterized the supporting soil as medium dense coarse grained material.

We used simple analytical models to estimate the response of the foundation in a drop test. A conservation of momentum approach that models the test as a plastic impact provides an upper bound estimate of the kinetic energy taken by the foundation. This approach predicts that 6 percent of the kinetic energy of the Model 676 Projector is taken by the foundation upon impact.

Arya et al present a relevant method of analysis in "Design of Structures & Foundations For Vibrating Machines." The approach accounts for the participation of an effective soil mass in resisting a dynamic loading. This method predicts less than 1 percent of the kinetic energy is taken by the foundation. Arya el al also present a method of estimating the foundation deflection. We computed a deflection upon impact of 0.014 in.

We estimated the flexibility of the concrete foundation as a plate on an elastic foundation using a method presented in "Theory of Plates and Shells" by Timoshenko & Woinowsky-Krieger. This approach shows that the foundation is rigid relative to the soil, and virtually all of the foundation deflection is the result of soil response.

Discussion

The plastic impact approach provides an upper bound estimate of the energy transmitted to the foundation. In an actual test, energy is absorbed in the device being tested in both plastic deformation and rebound energy that is not accounted for in this analysis.

The Arya approach is fully applicable to foundations that support vibrating equipment. This approach may somewhat overstate the participation of the soil in a single impact loading. However, we expect the influence of the participating soil mass will be significant and, therefore, we expect the percent of kinetic energy taken by the foundation is closer to 1 percent than 6 percent.

The four cracks near the corners of the foundation intersect corners of the embedded steel plate. This suggests that the plate restrained the free shrinkage of the foundation and caused these cracks. The cracks are obviously old, yet they remain tight and there is no sign of recent movement at the cracks. This strongly indicates that the cracks have not compromised the monolithic behavior of the foundation. Any loss of stiffness in the foundation related to these cracks is insignificant within the limits of our simple analytical models.

Conclusion

Based on the study described above, we conclude that the existing test foundation absorbs between 1 and 6 percent of the kinetic energy at impact during a 30-ft drop test of a Model 676 Projector. In our opinion the foundation provides an essentially unyielding horizontal surface for the purpose of this test. For items of lesser mass, the foundation also provides an essentially unyielding horiozntal surface.

Sincerely yours,

Joseph J. Zona, P.E.
Principal
JJZ32-97.ras

Atis A. Liepins, P.E.
Senior Associate

OMEGA
ENGINEERING, INC.
An OMEGA Technologies Company

Certificate of Conformance

for

AEA TECHNOLOGY
40 NORTH AVE
BURLINGTON MA 01803

Cust. P.O. #: 3291 **OMEGA W.O. #** 812995304

CAL-1

OMEGA Engineering, Inc. certifies that the items comprising the above order have been manufactured in accordance with all applicable instructions and specifications as published in the OMEGA TEMPERATURE MEASUREMENT HANDBOOK AND ENCYCLOPEDIA®. OMEGA Engineering Inc. further certifies that all thermocouple base and noble metal materials conform to ANSI Limits of Error (ANSI Standard MC96.1)

Certified by: Stephen Cardone Date: 12-04-98
Quality Assurance Inspector

Omega Engineering, Inc., One Omega Drive, Box 4047, Stamford, CT 06907
Telephone: (203) 359-1660 · FAX: (203) 359-7811
Internet Address: http://www.omega.com E-Mail: info@omega.com

Cal1Temp

OMEGA ENGINEERING, INC.
An OMEGA Technologies Company

Certificate of Conformance

for

AEA TECHNOLOGY
40 NORTH AVE
BURLINGTON MA 01803

Cust. P.O. #: 3226 **OMEGA W.O. #** 811973359

CAL-1

OMEGA Engineering, Inc. certifies that the items comprising the above order have been manufactured in accordance with all applicable instructions and specifications as published in the OMEGA TEMPERATURE MEASUREMENT HANDBOOK AND ENCYCLOPEDIA®. OMEGA Engineering Inc. further certifies that all thermocouple base and noble metal materials conform to **ANSI Limits of Error** (ANSI Standard MC96.1)

Certified by: Stephen Cardone **Date:** 11-04-98
Quality Assurance Inspector

Omega Engineering, Inc., One Omega Drive, Box 4047, Stamford, CT 06907
Telephone: (203) 359-1660 · FAX: (203) 359-7811
Internet Address: http://www.omega.com E-Mail: info@omega.com

Cal1Temp

INSPECTION INSTRUCTION AND RECORD

T10119

C

PERIODIC MAINTENANCE

Page 1 of 1

DESCRIPTION: PUNCTURE TEST BILLET

CM - NA

CHARACTERISTICS	TOLERANCE	AQL	1	2	3	4	5	6	7	8	9	10	11	12
GENERAL VISUAL	N/A	C/100%	0 / 1	0 / 1										

ORIGINATOR **DATE** 3 SEPT 97

ENGINEERING APPROVAL **DATE** N/A

REGULATORY APPROVAL **DATE** N/A

Q A APPROVAL **DATE** 3Sep97

COMMENTS:

	1	2	3	4	5	6	7	8	9	10	11	12
~~P.O. / W.O.~~ FREQ. DAYS	365 →											
~~RECEIVING RECORD #~~ DUE DATE	3 SEPT 98	3 Sep 99										
LOT / SERIAL NO.	01	01										
LOT QTY.	1	1										
QTY REJ / NCR NO.	0 / N/A	0 / NA										
QTY ACC.	1	1										
INSP / DATE	DW / 3 SEPT 97	DW / 3 Sep 97										

APPENDIX B

MANUFACTURING ROUTE CARDS AND PRE-TEST RADIATION PROFILE DATA SHEET

Page 1 of 3

ROUTE CARD

CASK for all Specimens
CAGE/SKID for TP81(A)

SERIAL NUMBER 24

AMERSHAM
CORPORATION

N/A COMPLETE LOT
N/A SPLIT LOT

TOTAL WO QTY: 11
RTE. CD. QTY: 1

LOT NO: N/A
SUB-LOT NO: N/A

CM-A

PART NUMBER	DESCRIPTION	DRAWING NUMBER	REV	WORK ORDER
70206	Uranium Shield Shipping Container General Assembly	D 70206	~~F~~ G MB3 4-28-93	MD52630

OPER SEQ	DEPT	OPERATION DESCRIPTION	BY	DATE	STATUS	REFERENCE	COMMENTS
A	–	Cover Assy	P/N	70203		Rev D	
1	MS	Install Spacers	DRB	4-12-93	–	B70203	Less item 9 spacer
2	QC	In. Process Insp	MB3	4-12-93	Acc	B70203	Spacer verification, less item 9
3	MS	.010 Max Gap and Weld Prep	DRB	4-12-93	–	B70203.	SOP-W003 & SOP-W011 Machine, if necessary
4	QC	Weld Fit-Up Inspection	MB3	4-12-93	Acc	B70203.	SOP-W003, Verify .010 Max Gap
5	MS	Assemble & Weld	DRB	4-12-93	–	B70203.	SOP-W003
6a	QC	Assembly Insp	MB3	4-23-93	Acc	SOP-Q015	Verify S/N 24.
6b	QC	Weld Visual Insp	MB3	4-23-93	Acc	B70203.	SOP-W011
6c	QC	Liq. Pen. Insp.	MB3	4-23-93	Acc	B70203.	SOP-W012

CHECKLIST			CHECKLIST			CHECKLIST		
INITIALS	DESCRIPTION	SOP-STEP	INITIALS	DESCRIPTION	SOP-STEP	INITIALS	DESCRIPTION	SOP-STEP
DRB	Stamp S/N	–						
DRB	Configure Shield Lot#/Heat#	–						

ENGINEERING: 11 JAN 93

REGULATORY: 11 Jan 93

MATERIALS: 11 JAN 93

PRODUCTION: 11 Jan 93

QUALITY ASSURANCE: 11 Jan 93

ISSUE NUMBER: 1

REVISION 1

ROUTE CARD

SERIAL NUMBER: 24

AMERSHAM
CORPORATION

N/A COMPLETE LOT
N/A SPLIT LOT

TOTAL WO QTY: 1
RTE. CO. QTY: 1

LOT NO: N/A
SUB-LOT NO: N/A

CM-A

PART NUMBER	DESCRIPTION	DRAWING NUMBER	REV	WORK ORDER
70206	Uranium Shield Shipping Container General Assembly	D70206	F	M052630

MRB 4-28-93

OPER SEQ	DEPT	OPERATION DESCRIPTION	BY	DATE	STATUS	REFERENCE	COMMENTS
B	–	Shipping Container Assy				PN 70202	Rev L
		93-014 Lot #28					
7	MS	Weld Prep & Spacer Installation MRB	MM	4-15	–	D70202.	SOP-W003, SOP-W011 Install Items 6&8 Only
							ITEMS 6 + 8 VERIFIED CF 4/15/93
8	QC	Weld Fit-Up Inspection	MRB	4-15-93	ACC	D70202.	SOP-W003 Verify Items 6&8
9	MS	Assemble & Weld	MM	4-15	–	D70202.	SOP-W003
10a	QC	Assembly Insp	MRB	4-23-93	ACC	SOP-Q015	Verify S/N 24
10b	QC	Weld Visual Insp	MRB	4-23-93	ACC	D70202.	SOP-W011
10c	QC	Liq Pen Insp	MRB	4-23-93	ACC	D70202.	SOP-W012

CHECKLIST

INITIALS	DESCRIPTION	SOP-STEP
MM	Install Items 7,9,10,11 & 12 (See DWG. 70202)	–
MM	Stamp S/N	–
MM	Configure Shield – Lot#/Heat#	

CHECKLIST

INITIALS	DESCRIPTION	SOP-STEP

CHECKLIST

INITIALS	DESCRIPTION	SOP-STEP

ENGINEERING: 11 Jun 93
REGULATORY: 11 Jun 93
MATERIALS: R Moran 11 Jun 93
PRODUCTION: Richard W 11 Jun 93
QUALITY ASSURANCE: 11 Jun 93
ISSUE NUMBER: 1

REVISION 1

Pg 3 of 3

ROUTE CARD

SERIAL NUMBER 24

AMERSHAM
CORPORATION
CM-A

N/A COMPLETE LOT
N/A SPLIT LOT

TOTAL WO QTY: 1
RTE. CD. QTY: 1

LOT NO: N/A
SUB-LOT NO: N/A

PART NUMBER	DESCRIPTION	DRAWING NUMBER	REV	WORK ORDER
70206	Uranium Shielding Shipping Container General Assembly	D70206	~~F~~ MD3 4-28-93	M052630

OPER SEQ	DEPT	OPERATION DESCRIPTION	BY	DATE	STATUS	REFERENCE	COMMENTS
C	–	General Assembly	MM	4-26	PN	70206	Rev ~~F~~ G MD3 4-28-93
11	MS	Final Assembly	MM	4-26	–	D70206	Weight: 410 lb
12	QC	Final Inspection	CF	4-29-93	AEC	SOP-Q003	
13	QA	Review	YM	26ap93	=	SOP-Q025	
14	IC	Stock Room Processing		4-30-93	–	SOP-M002	

CHECKLIST

INITIALS	DESCRIPTION	SOP-STEP
MM	Engrave Nameplate	–
MM	Stamp S/N	–

CHECKLIST

INITIALS	DESCRIPTION	SOP-STEP

CHECKLIST

INITIALS	DESCRIPTION	SOP-STEP

ENGINEERING: 11 JAN 93

REGULATORY: Cathleen Lorry 11 Jan 93

MATERIALS: 11 JAN 93

PRODUCTION: Richard W 11 Jan 93

QUALITY ASSURANCE: 11 Jan 93

ISSUE NUMBER: 1

REVISION 1

INSPECTION INSTRUCTION AND RECORD

PART/DWG. NO. D 70206

REV G CF 1-18-93 PER ECO # 1220

VENDOR: ASSEMBLY / MS

Page 1 of 1

DESCRIPTION: URANIUM SHIELD SHIPPING CONTAINER GENERAL ASSEMBLY

CM - A

CHARACTERISTICS	TOLERANCE	AQL	1	2	3	4	5	6	7	8	9	10	11	12
GENERAL VISUAL	—	100%	0 / 5	PR 2-4 0 / 1	R. 5	MRB 4-28-93 / 6								
PROPER LABELS + NAMEPLATES PRESENT	—	100%	0 / 5	0 PR 2-4 / 1	R. 5	MRB 4-28-93 / 6								
PROPER HARDWARE + FASTENERS INSTALLED	—	100%	0 / 5	PR 2-4 0 / 1	R. 5	MRB 4-28-93 / 6								
COVER GASKET PRESENT (70203-10) + PROPERLY INSTALLED	—	100%	0 / 5	0 PR 2-4 / 1	R. 5	MRB 4-28-93 / 6								
VERIFY S/N MARKED ON COVER ASSEMBLY, SKID AND CONTAINER ASSEMBLY	—	100%	0 / 5	0 PR 2-4 / 1	R. 5	MRB 4-28-93 / 6								
PROFILE	—	100%	0 / 5	0 & / 1	5 CF	— / [illegible]								
						MRB 4-28-93								

USE NEW I.Q.

ORIGINATOR C Ferrera **DATE** 12 JAN 93

ENGINEERING APPROVAL **DATE** 12 JAN 93

REGULATORY APPROVAL **DATE** 12 Jan 93

Q A APPROVAL **DATE** 12 Jan 93

COMMENTS: SOP-Q003

	1	2	3	4	5	6	7	8	9	10	11	12
P.O. / W.O.	50500	50670	52630	52630								
RECEIVING RECORD #	N/A	N/A	N/A	N/A								
~~LOT~~ / SERIAL NO. CF 1-18-93	12 - 16	17	18 thru 22	23 Thru 28								
LOT QTY.	5	1	5	6								
QTY REJ / NCR NO.	0 / –	0 / –	0 / –	0 / –								
QTY ACC.	5	1	5	6								
INSP / DATE	CF / 1-18-93	PR/CF / 2-5-[illegible]	PR/CF / 2-25-93	CF/MRB / [illegible]-93								

Amersham Corporation
40 North Avenue
Burlington, MA 01803

SHIELDING PROFILE AND INSPECTION FORM

Model No.: 702 Serial No.: 24 Radionuclide IR192 Max. Capacity 10,000 Ci

INCOMING SHIELD INSPECTION

Shield I.D. No. Lot# 2B (93-014) Lot# 1 (92-188) Source Tube Clear of Obstructions N/A

Mass of Shield 97 (2-10-93) 20.5 (1-12-93) Hot Top Dimension Measured ( ) N/A

Visual Inspection MRB Tube Cut in Fixture N/A

Inspector Signature MBoyd Date 4-28-93 NCR No. 3199 & 3138

SHIELDING EFFICIENCY TEST
INCOMING SHIELD ASSEMBLY

Source Model No.:_____ Source Serial No.:_____ Activity_____

Survey Instrument:_____ Serial No.:_____ Date Cal._____ Due_____

N/A

OBSERVED INTENSITY mR/hr

	AT SURFACE	SURFACE CORRECTION FACTOR
TOP		
RIGHT		
FRONT		
LEFT		
REAR		
BOTTOM		

CAPACITY CORRECTION FACTOR

ADJUSTED INTENSITY mR/hr

	AT SURFACE
TOP	
RIGHT	
FRONT	
LEFT	
REAR	
BOTTOM	

Inspector's Signature _____ Date_____ NCR NO._____

SENTINEL

AMERSHAM CORPORATION

FIRST ARTICLE REPORT

DATE:	SUPPLIER:	PART NO:	REV:	P.O./W.O.	QTY.
25 FEB 99	MACHINE SHOP	T10287	A	INDIRECT	1

DESCRIPTION: TEST PLAN INSERT 702 CONTAINER

INSPECTED BY: Dave

DRAWING DIMENSION	ACTUAL DIMENSION	MTE USED	SN. / CAL DATE DUE
GENERAL VISUAL	ACCEPTABLE	N/A	N/A -
2.200 ⌀	2.200 ⌀	DIGITAL CALIPER	#180 1 APR 99
3 1/8"	3.123	" "	#180 1 APR 99
WT. 8lbs ± .2 lbs	7.6 lbs *	SCALE	#268 16 MAY 99
TUNGSTEN	ACCEPTABLE	N A	N A

COMMENTS:

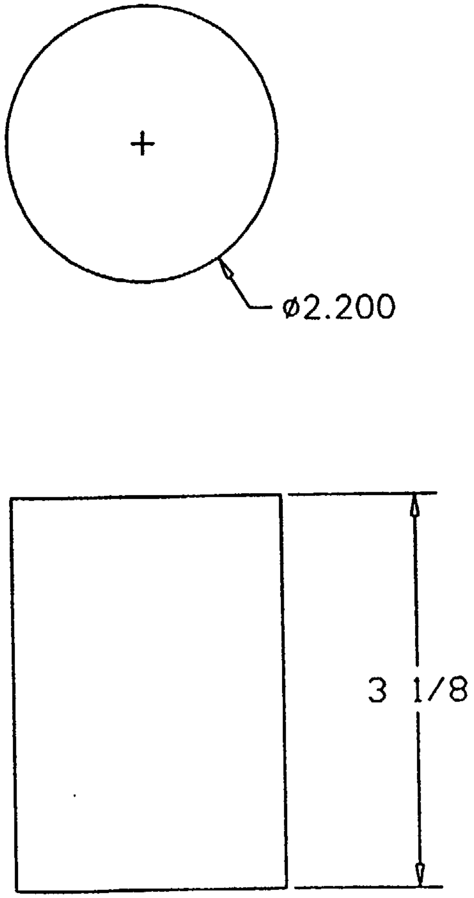
* - Use as is - will not effect form, fit or function 25FEB99

QP15-2/1

Amersham QSA

REVISIONS

REV.	ECO/TCR #	DESCRIPTION	APPROVALS	DATE
A	310	INITIAL RELEASE	SEE TITLE	BLOCK



NOTE:
1. WEIGHT 8.0 ± .2 LBS.

MATERIALS: TUNGSTEN
PROTECTIVE FINISH: NA

UNLESS OTHERWISE SPECIFIED;
1. DIMENSIONS ARE IN INCHES.
2. MIN SURFACE TEXTURE: 125
3. TOLERANCES APPLY AFTER PLATING.
4. REMOVE BURRS AND SHARP EDGES.
5. DO NOT SCALE DRAWING.
6. TOLERANCES: .X ± 0.1
FRACTIONS ± 1/64 .XX ± 0.01
MACHINED ANGLES ± 1° .XXX ± 0.005

USED ON: NA

DRAWN		22FEB99
CHECKED	NA	
APPR.	S. Gr	24FEB99

THIRD ANGLE PROJECTION
SAFETY CLASS NA

AEA TECHNOLOGY
QSA
40 NORTH AVE, BURLINGTON, MA 01803

TITLE: TEST PLAN INSERT FOR 702 CONTAINER
SIZE B
DWG. NO. T10287
REV A
SCALE: 1:1
SHEET 1 OF 1

SENTINEL

Sheet 1 of 1

INSPECTION INSTRUCTION AND RECORD

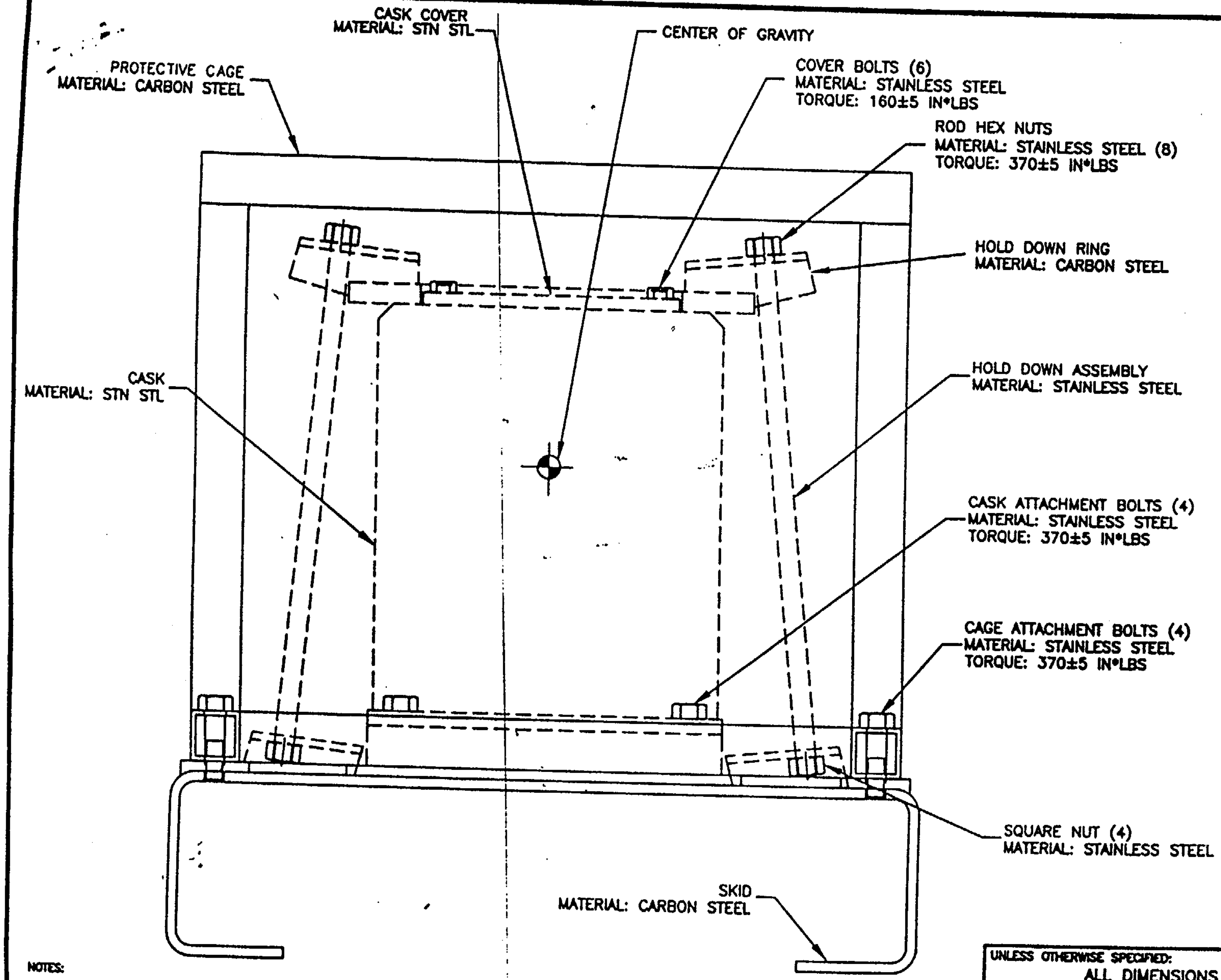
DWG 9 APR99

ORIGINATOR / DATE 9 APR 99	REV ~~A~~B	PART NO. R-TP81	SUPPLIER TEST SPECIMEN TP81	
QA APPROVAL / DATE 9 APR 99	CM A	PIL NA	DESCRIPTION MODEL 702 TEST SPECIMEN	

CHARACTERISTICS	TOLERANCE	MTE / SN.	AQL	1	2	3	4	5	6	7	8	9	10
General Visual	N/A	N/A	C/100%	0 1									
VERIFY ALL ITEMS PRESENT	N/A	N/A		0 1									
VERIFY PROPER HARDWARE	N/A	N/A		0 1									
VERIFY NOTES #1 - #4	N/A	N/A		0 1									
VERIFY ALL TORQUES PER DWG	PER DWG	# TORQUE WRENCH 279		0 1									

COMMENTS:

	1	2	3	4	5	6	7	8	9	10
PO/WO #	N/A									
TRAVELER / QCL #	N A									
LOT / SERIAL #	CAGE 24 SKID CAST 24									
LOT QTY.	1									
QTY. REJ / NCR #	0 NA									
QTY. ACC.	1									
INSP / DATE	DWG 9 APR 99									



NOTES:

1. EXCEPT AS SHOWN, MANUFACTURED PER AEAT DRAWING# D70206, REV J AND AEAT QA PROGRAM.
   (a) INSTALL IN CASK CAVITY TUNGSTEN PLUG T10287
2. MATERIALS INDICATED REPRESENT WORST CASE TRANSPORT SPECIMEN.
3. ORIENTATION AND HOLDING ATTACHMENT POINTS TO BE DETERMINED. THESE SHALL NOT INTERFERE WITH THE CENTER OF GRAVITY LOCATION OR ACT AS IMPACT LIMITERS. DOCUMENT SIZE AND LOCATION OF ATTACHMENT POINTS.
4. TOTAL WEIGHT IS 400 TO 410 LBS.

DDCO 35 ADD TORQUE SPECS	LR /	3/31/99	B
DESCRIPTION	APPROVALS	DATE	LTR

REVISIONS

UNLESS OTHERWISE SPECIFIED:
ALL DIMENSIONS ARE INCHES AND REFERENCE

AEA TECHNOLOGY
QSA
40 NORTH AVE, BURLINGTON, MA 01803

DESCRIPTIVE
DRAWING

TITLE MODEL 702 TEST SPECIMEN

SIZE A
DWG. NO. R–TP81
REV P
SCALE: NONE
SHEET 1 OF 1

SENTINEL PRE-TEST

SHIELDING PROFILE AND INSPECTION FORM

odel: 702 Serial Number: 24 Radionuclide: Ir-192 Max.Capacity: 10,000 Ci

Shield Data

Shield Heat#: Mass of Shield: Lbs. Lot #:

Initial Profile

Source Model: Source SN: Activity: Ci

Survey Inst.: SN: Date Cal.: Date Due:

Surface	Observed Intensity mR/hr	Surface Correction Factor		Adjusted Intensity mR/hr
Top			N/A Capacity Correction Factor:	
Right				
Front				
Left				
Rear				
Bottom				

Inspector: Date: NCR #:

Final Profile

Source Model: * N/A Source SN: * N/A Activity: 7898 Ci Mass of Device: 406 Lbs.

Survey Inst.: AN/PDR27T SN: SM392402 Date Cal.: 8Oct98 Date Due: 8Oct99

	Observed Intensity mR/hr				Adjusted Intensity mR/hr	
Surface	At Surface	Surface Corr. Factor	At One Meter		At Surface	At One Meter
Top	15	1.08	.4	Capacity Correction Factor: 1.26	20	.5
Right	27	1.09	.8		37	1.0
Front	22	1.08	.4		30	.5
Left	32	1.09	.9		44	1.1
Rear	20	1.08	.7		27	.9
Bottom	2.2	1.07	<.3 ⊛		3	<.4 ⊛

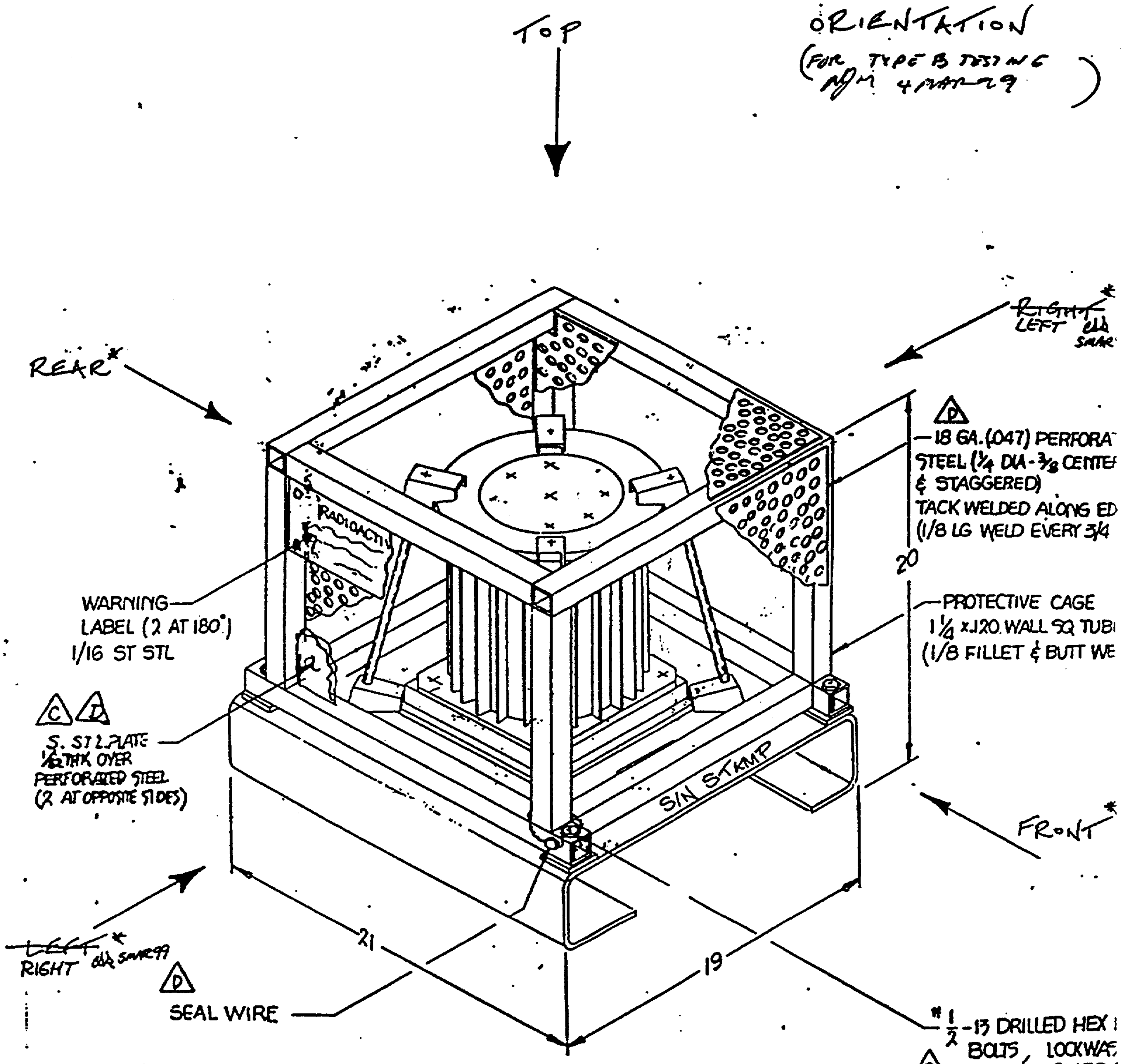
Inspector: MRBoyd Date: 10 Mar 99 NCR #: N/A

QI6-1/1

omments: * Bulk Iridium
⊛ Background Level = .3

Amersham QSA

PROFILE
ORIENTATION
(FOR TYPE B TESTING
AJM 4MAR99)



MODEL 702 PACKAGE
GENERAL ARRANGEMENT

* PLEASE CLEARLY IDENTIFY ON CAGE AND CASK

APPENDIX C

TEST CHECKLISTS AND DATA SHEETS

Specimen Preparation List

Step	TP81(A)	TP81(B)	TP81(C)
1. Serial Number:	SN 24	CASK # 24 CAGE # 26	CASK # 24 CAGE # 23
2. Weight of tungsten plug (lb):	7.6 lbs.	7.6 lbs	7.6 lbs
3. Weight of cask (lb):	269 lbs.	269 lbs	269 lbs
~~4. Weight of skid (lb):~~ 08APR99	N/A ~~486 lbs.~~ 8APR99	78 lbs	79 lbs
~~5. Weight of cage (lb):~~ 08APR99	N/A	55 lbs.	55 lbs
6. Total weight of package (lb):	406 lbs	402 lbs	403 lbs
7. Attach thermocouples to the cask, the skid, and the protective cage.	Yes	yes DW	yes DW
8. All fabrication and inspection records documented in accordance with the AEAT QA Program?	Yes	yes DW	yes DW
9. Does the unit comply with the requirements of Drawing R-TP81, Revision B?	NOTES 1&2 - 14 APR 99 Yes	NOTE 1 Yes	yes DW 13 APR 99
10. Has the radiation profile been recorded in accordance with AEAT QSA Work Instruments WI-Q09?	Yes	N/A	N/A
11. Is the package prepared for transport?	Yes	Yes	yes DW 13 APR 99

For TP81(A)

Verified by:	Print Name:	Signature:	Date:
Engineering	MICHAEL L TREMBLAY		08 APR 99
Regulatory Affairs	MARC S. NADEAU		9-APR-99
Quality Assurance	DANIEL W. KURTZ	Daniel W. Kurtz	9 APR 99

for TP81(B) & (C)

ENGINEERING	MICHAEL L TREMBLAY		~~14APR99~~ 14 APR 99 ~~14APR99~~
REGULATORY AFFAIRS	MARC S. NADEAU		~~15~~ 14 APR 99 N 14APR99
QUALITY ASSURANCE	DANIEL W. KURTZ	D.W. Kurtz	14 APR 99

NOTE 1: CASK WAS DAMAGED DURING PRIOR 30' DROP TEST — ONLY 5 OF 6 CASK COVER BOLTS ARE SECURED PER DWG. R-TP81, REV. B. N

NOTE 2: HOLD-DOWN RING FRACTURED (PIECE MISSING AT ONE TIE-DOWN BRACKET) DURING 1.2M (4 FOOT) DROP. ALSO, SKID WAS CRACKED DURING 1.2M (4 FOOT) DROP. N

SENTINEL

SHIELDING PROFILE AND INSPECTION FORM

Model: 7D2 Serial Number: 24 Radionuclide: Ir 192 Max.Capacity: 10,000 Ci

Shield Data

Shield Heat#: Mass of Shield: Lbs. Lot #:

Initial Profile

Source Model: Source SN: Activity: Ci

Survey Inst.: SN: Date Cal.: Date Due:

Surface	Observed Intensity mR/hr	Surface Correction Factor		Adjusted Intensity mR/hr
Top			N/A Capacity Correction Factor:	
Right				
Front				
Left				
Rear				
Bottom				

Inspector: Date: NCR #:

Final Profile

Source Model: * N/A Source SN: * N/A Activity: 7898 Ci Mass of Device: 406 Lbs.

Survey Inst.: AN/PDR27T SN: SM392402 Date Cal.: 8Oct98 Date Due: 8Oct99

	Observed Intensity mR/hr				Adjusted Intensity mR/hr	
Surface	At Surface	Surface Corr. Factor	At One Meter		At Surface	At One Meter
Top	15	1.08	.4	Capacity Correction Factor: 1.26	20	.5
Right	27	1.09	.8		37	1.0
Front	22	1.08	.4		30	.5
Left	32	1.09	.9		44	1.1
Rear	20	1.08	.7		27	.9
Bottom	2.2	1.07	< .3 ⊛		3	< .4 ⊛

Inspector: MRBoyd Date: 10 Mar99 NCR #: N/A

Q16-1/1

Comments: * Bulk Iridium
⊛ Background Level = .3

Amersham QSA

Equipment List 1: Compression Test

Description	Enter the Model and Serial Number	Attach Inspection Report or Calibration Certificate
Weight Scale	Port Beam ASSY 11	due 16 MAY 99
Record any additional tools used to facilitate the test and attach the appropriate inspection report or calibration certificate.		
FLOOR SCALE - Shipping	F16383	16 MAY 99
Combination Square	ID 142	01 APR 00
Weight Scale	4010 1126131	16 MAY99
Thermometer	ENG-12	08OCT99

	Print Name:	Signature:	Date:
Completed by:	DAVE ANNIS		09 APR 99
Verified by:	MICHAEL L TREMBLAY		09 APR 99

Torque wrench 5970355413 See Appendix A

Checklist 1: Compression Test

Step	TP81(A)
1. Position the specimen on concrete surface, per the appropriate drawing.	Figure 3
2. Measure the ambient temperature.	70.6°F
Note the instrument used:	ENG-12
3. Apply a uniformly distributed weight of at least 2080 pounds on the top of the protective cage for a period of 24 hours.	
Record the actual weight:	2138 lbs
Note the instrument used:	Floor scale - shipping
Record start time and date:	11APR99@1700
4. After 24 hours, remove the weight.	
Record end time and date:	12APR99 @ 1350
5. Measure the ambient temperature.	71.9°F
Note the instrument used:	ENG-12
6. Photograph the test specimen and record any damage on Data Sheet 1.	
7. Engineering, Regulatory Affairs and Quality Assurance make a preliminary assessment, per Section 8.5.2. Record the assessment on Data Sheet 1. Determine what changes are necessary in package orientation for the penetration test to achieve maximum damage.	

Verified by:	Print Name:	Signature:	Date:
Engineering	MICHAEL L TREMBLAY		12 APR 99
Regulatory Affairs	Marc S. [illegible]		12 APR 99
Quality Assurance	DANIEL W. KURTZ	D.W. Kurtz	12 APR 99

Data Sheet 1: Compression Test

Test Unit Model and Serial Number: SN24

Test Specimen: TP81 (A)

Test Date: 09APR99

Test Time:

Test Plan 81 Step No.: 8.5

Describe test orientation and setup:

on concrete floor
plate c̄ lead ingots

to floor from plate bottom

corner #	1	2	3	4
	20 9/16	20 5/8	20 7/8	20 9/16

Describe on-site inspection (damage, broken parts, etc.):

NONE

On-site assessment:

NO DAMAGE
no change

post test corner	1	2	3	4
	20 9/16	20 5/8	20 7/8	20 9/16

Engineering:

Regulatory:

QA: D.W. Kurtz

Describe any post-test disassembly and inspection:

NONE

Describe any change in source position: NOT APPLICABLE

Completed by:

Date: 12 APR 99

Equipment List 2: Penetration Test

Description	Enter the Model and Serial Number	Attach Inspection Report or Calibration Certificate
Penetration Bar	Drawing BT10129, Rev. B	SEE APPENDIX "A"
Drop Surface	Drawing AT10122, Rev. B	
Thermometer	OMEGA HH-21 FN6-12	
Thermocouple CASK	OMEGA #WTK-10-36-SMP-M	
Thermocouple CAGE	OMEGA #WTK-10-36-SMP-M	
Thermocouple SKID	OMEGA #WTK-10-36-SMP-M	
Record any additional tools used to facilitate the test and attach the appropriate inspection report or calibration certificate.		
Torque wrench	5970355413	

	Print Name:	Signature:	Date:
Completed by:	DAVE ANNIS	Dave Annis	13 APR 98
Verified by:		MICHAEL L TREAHAN	13 APR 99

Checklist 2: Penetration Test

Step	TP81(A)
1. Immerse specimen in dry ice or cool in freezer to bring carbon steel portions of the specimen below –40°C.	
2. Position the package as shown in the referenced figure.	Figure 4
3. Begin video recording of the test.	
4. Inspect the orientation setup and verify the bar height.	
5. Photograph the set-up in at least two perpendicular planes.	
6. Measure the ambient temperature and the specimen temperatures. Ensure that the specimen is at the specified temperature. Note the instrument used:	7°C ENG-12
Record the ambient temperature:	7°C
Record the cask temperature:	BEFORE –72°C / –71°C AFTER
Record the skid temperature:	–77°C / –71°C
Record the protective cage temperature:	–63°C / –54°C
7. Drop the penetration bar.	
8. Check to ensure that penetration bar hit the specified area.	
9. Measure the specimen's surface temp. Ensure that specimen is at specified temp.	–54°C
Note the instrument used:	ENG-12
10. Photograph the test specimen and record any damage on Data Sheet 2.	
11. **Engineering, Regulatory Affairs and Quality Assurance** make a preliminary assessment, per Section 8.6.3. Record the assessment on Data Sheet 2. Determine what changes are necessary in package orientation for the 1.2 meter (4 foot) free drop to achieve maximum damage.	

Verified by:	Print Name:	Signature:	Date:
Engineering	MICHAEL L TREMBLAY		13 APR 99
Regulatory Affairs	MARC S. NASON		13 APR 99
Quality Assurance	DANIEL W. KUETZ	D.W. Kurtz	13 APR 99

Data Sheet 2: Penetration Test

Test Unit Model and Serial Number: 702 SN 24

Test Specimen: TP81 (A)

Test Date: 13 APR 99

Test Time: 10:00 am

Test Plan 81 Step No.: 8.6

Describe test orientation and setup:
SEE FIGURE 4, SECTION 8.6.2

Describe impact (location, rotation, etc.):
PENETRATION BAR STRUCK TOP, CENTER OF CAGE, AS PRESCRIBED.

Describe on-site inspection (damage, broken parts, etc.):
PERF. PLATE DENTED IN AND PARTIALLY BROKEN THROUGH AT LOCATION OF PENETRATION BAR IMPACT. NO OTHER DAMAGE TO SPECIMEN.

On-site assessment:
DAMAGE TO PERFORATED PLATE ON TOP OF CAGE IS NOT SIGNIFICANT. CONTINUE WITH NEXT TEST (1.2M (4 FT.) FREE DROP) AS PLANNED.

Engineering:

Regulatory:

QA: D.W. Kurtz

Describe any post-test disassembly and inspection:
N/A

Describe any change in source position: NOT APPLICABLE

Describe results of any pre- or post-test radiography:
N/A

Completed by:

Date: 13 APR 99

Equipment List 3: 1.2 Meter (4 Foot) Free Drop

Description	Enter the Model and Serial Number	Attach Inspection Report or Calibration Certificate
Drop Surface	Drawing AT10122, Rev. B	SEE APPENDIX "A"
Thermometer	OMEGA ENG-12 HH-21	
Thermocouple CASK	OMEGA # WTK-10-36-SMP-M	
Thermocouple CAGE	OMEGA # WTK-10-36-SMP-M	
Thermocouple SKID	OMEGA # WTK-10-36-SMP-M	
Record any additional tools used to facilitate the test and attach the appropriate inspection report or calibration certificate.		
torque wrench	5970355413	

	Print Name:	Signature:	Date:
Completed by:	DAVE ANNIS	Dave Annis	13 APR 99
Verified by:		MICHAEL L TREMBLAY	15 APR 99

Checklist 3: 1.2 Meter (4 Foot) Free Drop

Step	TP81(A)
1. Immerse specimen in dry ice or cool in freezer to bring carbon steel portions of the specimen below -40°C.	
2. Measure the ambient temperature.	7°C
Note the instrument used:	ENG-12
3. Attach the test specimen to the release mechanism.	
4. Begin video recording of the test.	
5. Measure specimen temperatures. Ensure specimen is at specified temperature. Note the instrument used:	ENG-12
Record the cask temperature:	-71°C
Record the skid temperature:	-71°C
Record the protective cage temperature:	-54°C
6. Lift and orient the test specimen as shown in the specified referenced figure.	Figure 5
7. Inspect the orientation setup and verify drop height.	
8. Photograph the set-up in at least two perpendicular planes.	
9. Release the test specimen.	
10. Measure specimen temperatures. Ensure specimen is at specified temperature. Note the instrument used:	ENG-12
Record the cask temperature:	-69°C
Record the skid temperature:	-53°C
Record the protective cage temperature:	-15°C (damaged TC
11. Photograph the test specimen and record any damage on Data Sheet 3.	
12. Measure and record a radiation profile of the test specimen in accordance with AEAT/QSA Work Instruction WI-Q09.	No damage
13. **Engineering, Regulatory Affairs and Quality Assurance** make a preliminary assessment, per Section 8.7.3. Record assessment on Data Sheet 3. Determine what changes are necessary in package orientation for the 9 meter (30 foot) free drop to achieve maximum damage.	

Verified by:	Print Name:	Signature:	Date:
Engineering	MICHAEL L TREMBLAY		13 APR 99
Regulatory Affairs	MARC S. NADEAU		13 APR 99
Quality Assurance	DANIEL W. KURTZ.	D.N. Kurtz	13 APR 99

Data Sheet 3: 1.2 Meter (4 Foot) Free Drop

Test Unit Model and Serial Number: 702 SU 24

Test Specimen: TP81 (A)

Test Date: 13 APR 99

Test Time: 10:15

Test Plan 81 Step No.: 8.7

Describe drop orientation and drop height:
see figure 5. section 8.7.2

Describe impact (location, rotation, etc.):
Hit as prescribed - fell to side

Describe on-site inspection (damage, broken parts, etc.):
retaining ring broken ~ 30° section broken out
minimal damage to cage - perf. plate bulked on sides

On-site assessment:
Cask still secure to skid
cage still secure to skid
ring broken - retaining rods loose

cage out of square 1/8 → 1/2 along edge of impact (see drop test figure)
Slight tear in perf plate at edge near skid
tack welds on perf plate detached 90° to edge of impact

Engineering:

Regulatory:

QA: D.W. Kurtz

Describe any post-test disassembly and inspection:
SKID CRACKED AS SHOWN ON TEST PLAN FIG. 5 MARK-UP (ATTACHED).

Describe any change in source position: NOT APPLICABLE

Describe results of any pre- or post-test radiography:
N/A

Completed by:

Date: 13 APR 99

8.7.2 1.2 Meter (4 Foot) Free Drop Test Orientation, Specimen TP81(A)

The impact surface of Specimen TP81(A) is the top, long edge of the protective cage as shown below.

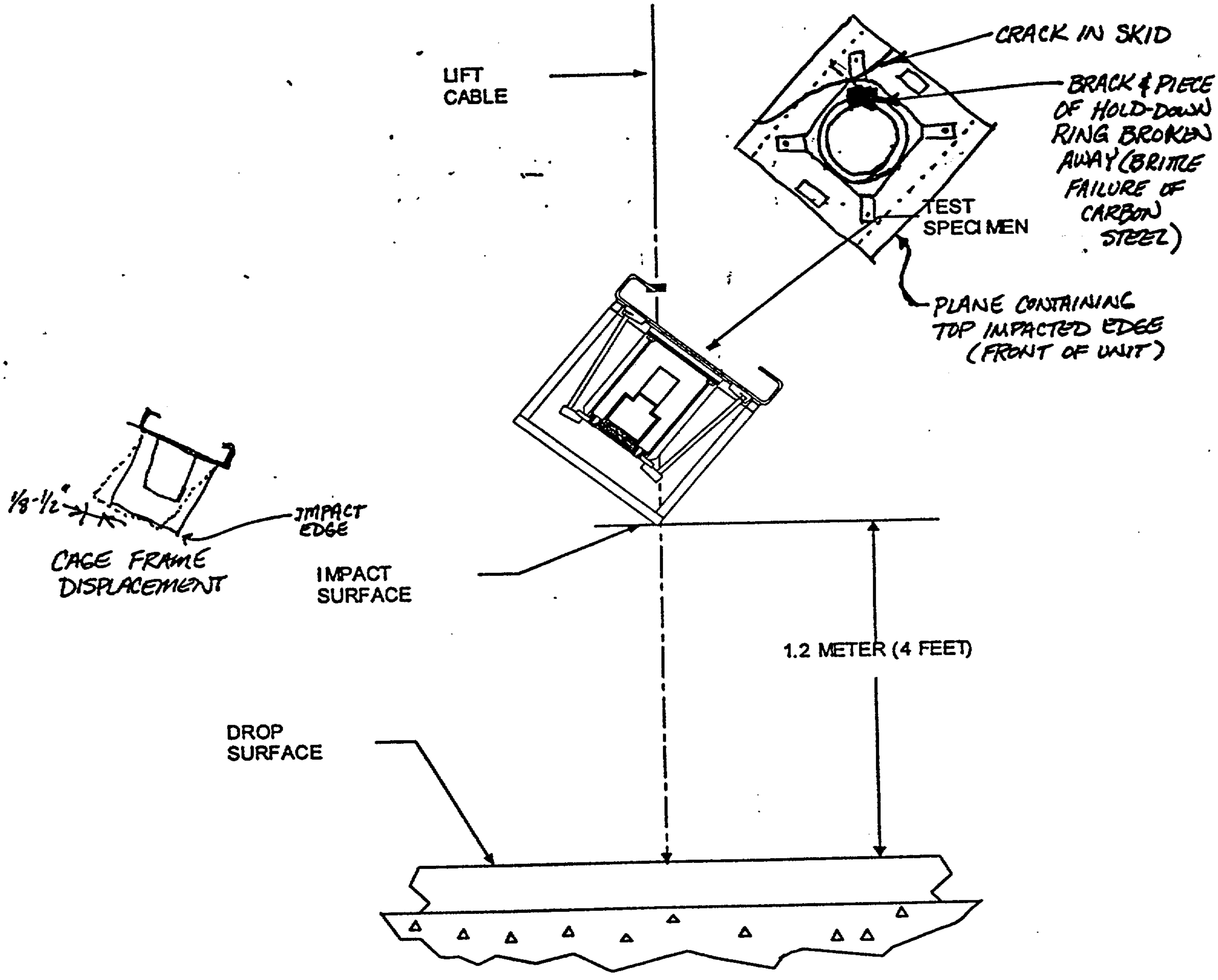


Figure 5. 1.2 Meter (4 Foot) Free Drop Test Orientation, Specimen TP81(A)

SENTINEL TP81(A) – AFTER 1.2M (4 FOOT) DROP TEST

DROP TEST UNIT

COPY

SHIELDING PROFILE AND INSPECTION FORM

Model: 702 Serial Number: 24 Radionuclide: Ir 192 Max.Capacity: 10,000 Ci

Shield Data

Shield Heat#: ⊛ Mass of Shield: ⊛ Lbs. Lot #: ⊛

Initial Profile

Source Model: Source SN: Activity: Ci

Survey Inst.: SN: Date Cal.: Date Due:

Surface	Observed Intensity mR/hr	Surface Correction Factor		Adjusted Intensity mR/hr
Top			N/A Capacity Correction Factor:	
Right				
Front				
Left				
Rear				
Bottom				

Inspector: Date: NCR #:

Final Profile

Source Model: Bulk IR192 Source SN: N/A Activity: 8761.2 Ci Mass of Device: ⊛ N/A Lbs.

Survey Inst.: AN/PDR27T SN: SM392402 Date Cal.: 8Oct99 Date Due: 8Oct99

	Observed Intensity mR/hr				Adjusted Intensity mR/hr	
Surface	At Surface	Surface Corr. Factor	At One Meter		At Surface	At One Meter
Top	14	1.08	.5	Capacity Correction Factor: 1.14	17	.6
Right	28	1.09	.7		35	.8
Front	22	1.08	.8		27	.9
Left	28	1.09	.7		35	.8
Rear	18	1.08	.7		22	.8
Bottom	1.5	1.07	<.1		1.8	<.1

Inspector: Michael R Boyd Date: 13 April 99 NCR #: N/A

Q16-1/1

Comments: ~~* Information Only~~ MRB 13 April 99

⊛ Reference Previous Documentation

Amersham QSA

Equipment List 4: 9 Meter (30 Foot) Free Drop

Description	Enter the Model and Serial Number	Attach Inspection Report or Calibration Certificate
Drop Surface	Drawing AT10122, Rev. B	SEE APPENDIX "A"
Thermometer	OMEGA HH-21 ENG-12	
Thermocouple CASK	OMEGA # WTK-10-36-SMP M	
Thermocouple CAGE	OMEGA # WTK-10-36-SMP-M	
Thermocouple SKID	OMEGA # WTK-10-36-SMP-M	
Record any additional tools used to facilitate the test and attach the appropriate inspection report or calibration certificate.		
Torque wrench	5970355413	

	Print Name:	Signature:	Date:
Completed by:	DAVE ANNIS		14 Apr 99
Verified by:	DANIEL H. KURTZ	D.H. Kurtz	14 APR 99

Checklist 4: 9 Meter (30 Foot) Free Drop

Step	TP81(A)	TP81(B)	TP81(C)
1. Immerse specimen in dry ice or cool in freezer to bring carbon steel portions of the specimen below –40°C.			
2. Measure the ambient temperature.	10°C	12°C	30°F 10°C
Note the instrument used:	ENG-12	ENG-12	ENG-12
3. Attach the test specimen to the release mechanism.	CAA	CAA	
4. Begin Video Recording of the test..	CAA	CAA	
5. Measure specimen temperatures. Ensure specimen is at specified temperature. Note the instrument used:	ENG-12	ENG-12	ENG-12
Record the cask temperature:	-45°C	-54°C	-90°C
Record the skid temperature:	-82°C	-69°C	-92°C
Record the protective cage temperature:	-63°C	-62°C	-93°C
6. Lift and orient the test specimen as shown in the specified referenced figure.	Figure ~~6~~ 8	Figure 7	Figure ~~8~~ 6
7. Inspect the orientation setup and verify drop height.	15 APR 99 C.SCHLOSSMAN CAA	CAA	
8. Photograph the setup in at least two perpendicular planes.	CAA	CAA	
9. Release the test specimen.	CAA	CAA	
10. Measure specimen temperatures. Ensure specimen is at specified temperature. Note the instrument used:	ENG-12	ENG-12	ENG-12
Record the cask temperature:	NOTE 1 CAA	-50°C	-75°C
Record the skid temperature:	-85°C	-56°C	-74°C
Record the protective cage temperature:	-35°C	-32°C	-48°C
11. Photograph the test specimen and record any damage on Data Sheet 4.	CAA	CAA	
12. **Engineering, Regulatory Affairs and Quality Assurance** make a preliminary assessment, per Section 8.9.5. Record assessment on Data Sheet 4. Determine what changes are necessary in package orientation for the puncture test to achieve maximum damage.	CAA	CAA	

Verified by:	Print Name:	Signature:	Date:
Engineering	MICHAEL L TREMBLAY		15 APR 99
Regulatory Affairs	Marc S. Nadeau		15 APR 99
Quality Assurance	DANIEL W. KURTZ	D.W. Kurtz	15 APR 99

NOTE 1: TC LOST DURING IMPACT ∴ NO READING.

Data Sheet 4: 9 Meter (30 Foot) Free Drop

Test Unit Model and Serial Number: 702 SN 23

Test Specimen: TP81(C)

Test Date: 14APR99

Test Time: 10:30 AM

Test Plan 81 Step No.: 8.9

Describe drop orientation and drop height:
DROPPED AS SHOWN IN FIG. 6.

Describe impact (location, rotation, etc.):
IMPACTED EDGE OF SKID, AS PRESCRIBED.

Describe on-site inspection (damage, broken parts, etc.):
Brittle Fracture both legs of skid. All 4 Cask to ~~Shield~~ SKID 14APR99 Bolts sheared off. ~~Top upper 3~~ All 4 DWK 14APR99 Lower Brackets Fractured. Cask Cover Bolts - 1 of 6 Failed. Perforated Plate torn in a few places on impacted edge. Cask Cover Buckled near Broken Cover Bolt.

On-site assessment:
PERFORM PUNCTURE TEST TO INCREASE DAMAGE TO CASK COVER. USE SAME UNIT ORIENTATION, WITH PUNCTURE BAR UNDER TEAR IN PERF PLATE AT TOP OF CASK. SPECIMEN WILL POSITIONED SO THAT PUNCTURE BAR WILL MISS THE TOP TUBE OF THE CAGE (WHICH WOULD PROTECT THE CASK). SINCE PERF. PLATE IS TOO THIN FOR BRITTLE FAILURE, ONLY CASK TEMP. NEEDS TO BE LESS THAN -40°C, TO ASSURE THAT CARBON STEEL HOLD-DOWN RING IS <-40°C.

Engineering: Regulatory: QA: D.W. Kurtz

Describe any post-test disassembly and inspection:
NO FURTHER INSPECTION PRIOR TO PUNCTURE TEST.

Describe any change in source position: NOT APPLICABLE

Describe results of any pre- or post-test radiography: N/A

Completed by:

Date: 14APR99

8.9.2 9 Meter (30 Foot) Free Drop Test Orientation, Specimen TP81(~~A~~ C)

13APR99
csl

The impact surface of Specimen TP81(~~A~~ C) is the short side of the protective cage as shown below.

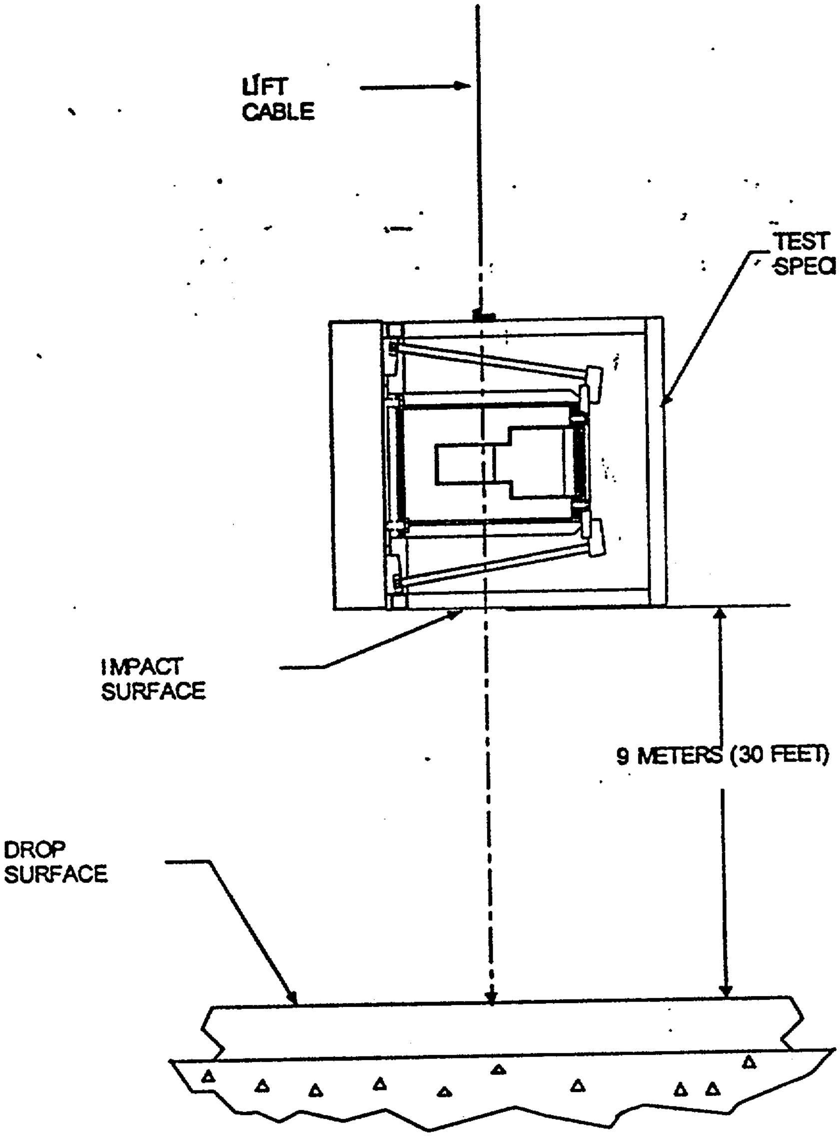


Figure 6: 9 Meter (30 Foot) Free Drop Orientation, Specimen TP81(~~A~~ C)

13 APR 99
csl

Data Sheet 4: 9 Meter (30 Foot) Free Drop

Test Unit Model and Serial Number: 702 SN 26

Test Specimen: TP81(B)

Test Date: 14APR99

Test Time: 3:45pm

Test Plan 81 Step No.: 8.9

Describe drop orientation and drop height: DROPPED AS SHOWN IN FIG. 7.

Describe impact (location, rotation, etc.): IMPACTED TOP EDGE OF FRAME (CAGE), AS PRESCRIBED.

Describe on-site inspection (damage, broken parts, etc.): SIGNIFICANT (~~2 or 3"~~ 3¾"-4". CAA 14APR99) DEFLECTION OF CAGE FRAME IN DIR. OF IMPACT. PERF. PLATE DETACHED ON BOTH SIDES. SOME BUCKLING OF SKID. 2 OF 4 HOLD DOWN BASE BRACKETS (THOSE OPPOSITE IMPACT EDGE) BROKE (BRITTLE FAILURE). HOLD DOWN RING BRACKETS (2 OF 4 - NEXT TO IMPACT EDGE) ALSO FAILED (BRITTLE), BUT CASK REMAINED SECURED TO SKID (VIA 4 CASK TO SKID BOLTS).

2 FRAME WELDS
TOP EDGE FAILE
TUBE STEEL DENT
BY IMPACT FROM T
HOLD-DOWN RING
BRACE

On-site assessment: THIS DROP RESULTED IN ESSENTIALLY NO DAMAGE TO THE CASK BECAUSE ALL THE IMPACT ENERGY WENT INTO DEFORMING THE CAGE AND BREAKING THE HOLD-DOWN ASSEMBLY. PERFORM FINAL 30ft (9m) DROP BEFORE SELECTING A FINAL PUNCTURE TEST ORIENTATION.

Engineering:

Regulatory:

QA: D.H. Kurtz

Describe any post-test disassembly and inspection: NO FURTHER INSPECTION PRIOR TO NEXT 9m (30ft) DROP OF SAME CASK (w/DIFFERENT CAGE/SKID).

Describe any change in source position: **NOT APPLICABLE**

Describe results of any pre- or post-test radiography: N/A

Completed by:

Date: 14 APR 99

8.9.3 9 Meter (30 Foot) Free Drop Test Orientation, Specimen TP81(B)

The impact surface of Specimen TP81(B) is the top long edge of the protective cage as shown below.

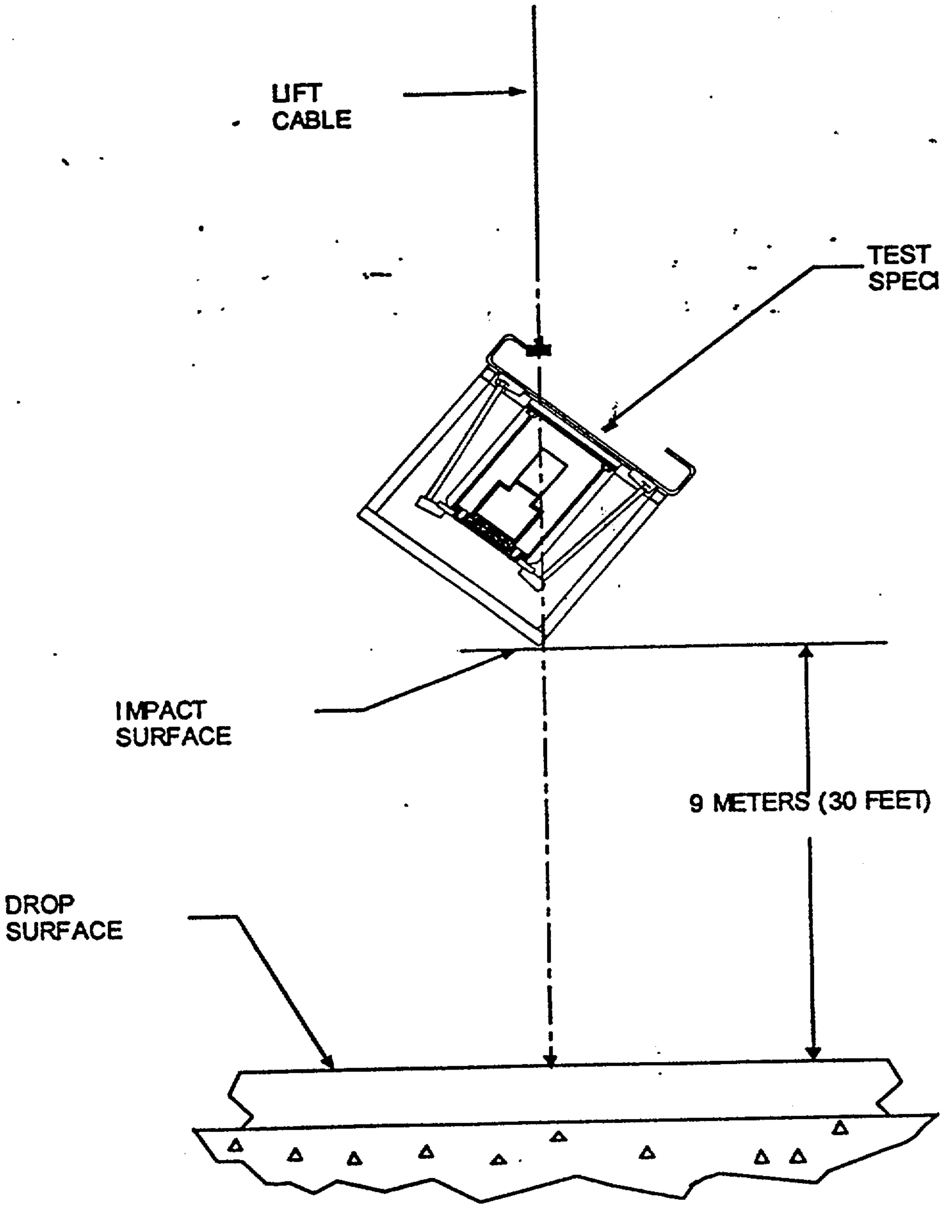


Figure 7: 9 Meter (30 Foot) Free Drop Orientation, Specimen TP81(B)

Data Sheet 4: 9 Meter (30 Foot) Free Drop

Test Unit Model and Serial Number: 702 SN 24

Test Specimen: TP81(A)

Test Date: 14 APR 99

Test Time: 5:20 pm

Test Plan 81 Step No.: 8.9

Describe drop orientation and drop height: DROPPED AS SHOWN IN FIGURE 8.

Describe impact (location, rotation, etc.): IMPACTED TOP OF CAGE, AS PRESCRIBED

Describe on-site inspection (damage, broken parts, etc.): BRITTLE FRACTURE OF SKID: CASK w/SQUARE WELDED SKID PLATE TORE AWAY FROM REST OF SKID. 2 BRACKETS AT TOP RING BROKE OFF, AS DID 3RD TIE DOWN (4th WAS BROKEN IN PRIOR 4ft (1.2 m) DROP) CASK STRUCK IMPACT SURFACE, AS EVIDENCED BY DENTED-IN HEAD OF ONE OF THE 5 CASK COVER BOLTS (6th BOLT HAD BROKEN IN PRIOR 30 ft (9 m) DROP), AND BY DENTED ENDS OF FINS AT 2 CIRCUMFERENTIAL LOCATIONS.

On-site assessment: REMOVE CASK, AND PORTION OF SKID STILL BOLTED TO CASK, FROM THE CAGE AND DROP w/o CAGE ON PUNCTURE BAR. DROP AT AN ANGLE SLIGHTLY OFF VERTICAL, ONTO THE DENTED CASK COVER BOLT, TO TRY TO BREAK OFF THIS BOLT.

Engineering:

Regulatory:

QA: D.W. Kurtz

Describe any post-test disassembly and inspection: NO FURTHER INSPECTION PRIOR TO PUNCTURE TEST.

Describe any change in source position: **NOT APPLICABLE**

Describe results of any pre- or post-test radiography: N/A

Completed by:

Date: 14 APR 99

8.9.4 9 Meter (30 Foot) Free Drop Test Orientation, Specimen TP81(~~C~~) A

13APR99

The impact surface of Specimen TP81(~~C~~) A is the top of the protective cage as shown below.

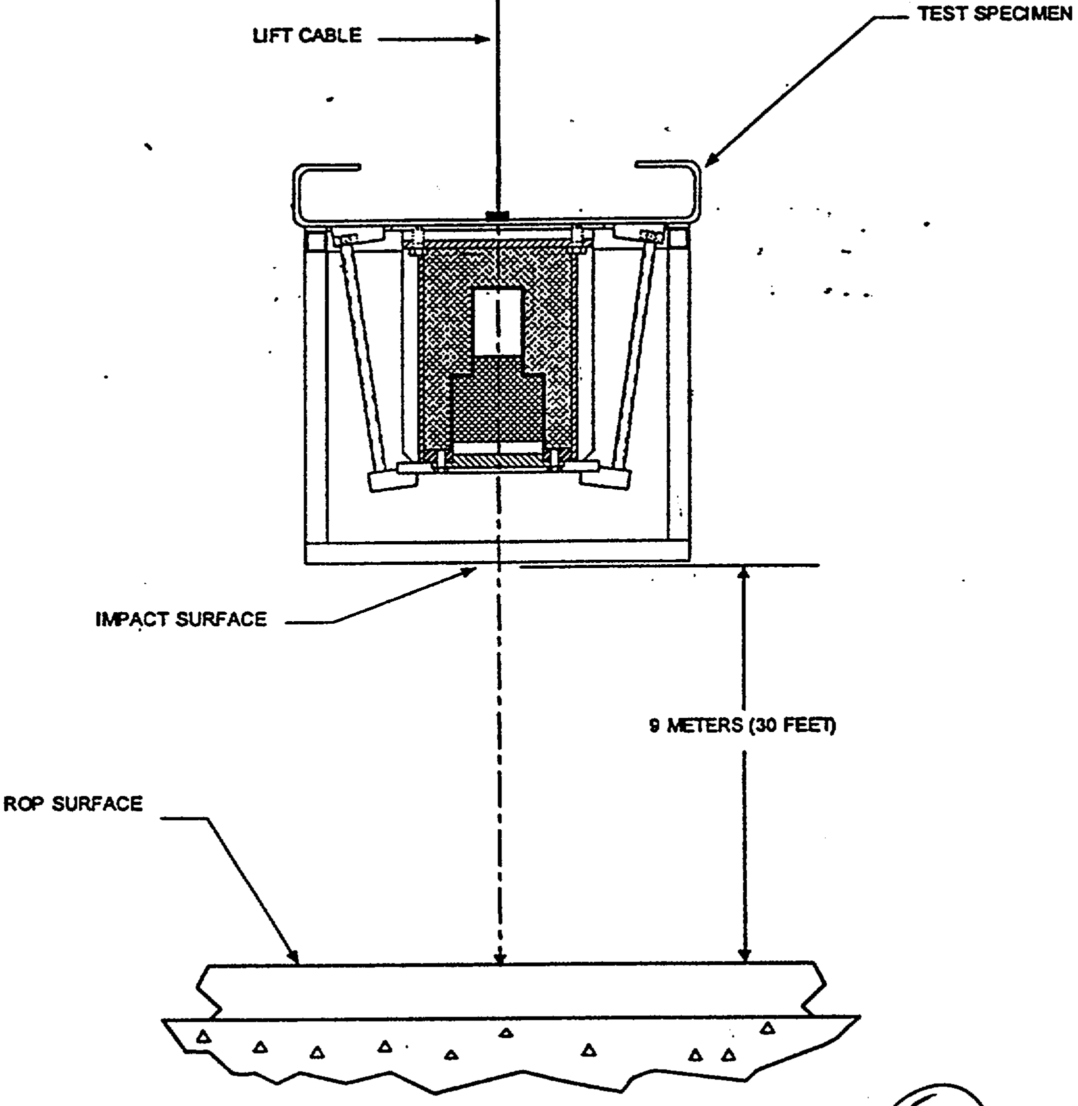


Figure 8. 9 Meter (30 Foot) Free Drop Orientation, Specimen TP81(~~C~~) A 13APR99

Equipment List 5: Puncture Test

Description	Enter the Model and Serial Number	Attach Inspection Report or Calibration Certificate
Drop Surface	Drawing AT10122, Rev. B	SEE APPENDIX "A"
Puncture Billet	Drawing CT10119, Rev. C	
Thermometer	OMEGA HH-21 ENG-12	
Thermocouple CASK	OMEGA #WTK-10-36-SMP-M	
Thermocouple CAGE	OMEGA #WTK-10-36-SMP-M	
Thermocouple SKID	OMEGA #WTK-10-36-SMP-M	
Record any additional tools used to facilitate the test and attach the appropriate inspection report or calibration certificate.		

	Print Name:	Signature:	Date:
Completed by:	DAVE ANNIS	Dave Annis	14 Apr 99
Verified by:	DANIEL W. KURTZ	D.W. Kurtz	14 APR 99

Checklist 5: Puncture Test

Step	TP81(C)	A CAS 14APR99 TP81(~~B~~)	
1. Immerse specimen in dry ice or cool in freezer to bring carbon steel portions of the specimen below –40°C.	DW	CAS	
2. Measure the ambient temperature.	15°C	10°C	
Note the instrument used:	ENG-12	ENG-12	
3. Attach the test specimen to the release mechanism.	DW	CAS	
4. Begin Video Recording of the test.	DW	CAS	
5. Measure specimen temperatures. Ensure specimen is at specified temperature. Note the instrument used:	ENG-12	ENG-12	
Record the cask temperature:	-48°C	N/A - STAINLESS STEEL	
Record the skid temperature:	see note 1	N/A - SKID NOT IMPACTING	
Record the protective cage temperature:	see note 1	N/A - NO CAGE	
6. Lift and orient the test specimen as shown in the specified referenced figure, or as determined during the assessment of the 9 meter (30 foot) drop test.	see ass. of 9m drop	SEE ASSM'T OF ~~Figure~~ 9M DROP	CAS 14APR99
7. Inspect the orientation setup and verify drop height.		CAS	
8. Photograph the set-up in at least two perpendicular planes.		CAS	
9. Release the test specimen.		CAS	
14. Measure specimen temperatures. Ensure specimen is at specified temperature. Note the instrument used:	ENG-12	ENG-12	
Record the cask temperature:	-47°C	N/A - STAINLESS STEEL	
Record the skid temperature:	see note 1	N/A - SKID NOT IMPACTED	
Record the protective cage temperature:	see note 1	N/A - NO CAGE	
10. Photograph the test specimen and record any damage on Data Sheet 5.		CAS	
11. Profile the shipping cask.	see note 2		
12. **Engineering, Regulatory Affairs and Quality Assurance** make a preliminary assessment, per Section 8.10.5. Record assessment on Data Sheet 5. Determine what changes are necessary in package orientation for thermal test to achieve maximum damage.		CAS	

Verified by:	Print Name:	Signature:	Date:
Engineering	MICHAEL L TREADAY		22 APR 99
Regulatory Affairs	MARC S. NASON		22 APR 99
Quality Assurance	DANIEL W. KURTZ	D.W. Kurtz	20 APR 99

NOTES

1. Cage + skid @ ambient. Puncture is directed @ cask cover through side port plate. Temperature difference between -40°C & 15°C will have no effect on performance of port plate + thus no effect on puncture test

2. Final profile to be performed after all 3 30' and any puncture drops deemed

Data Sheet 5: Puncture Test

Test Unit Model and Serial Number: 702 SN24

Test Specimen: TP81 (~~C~~) A cls 14APR99

Test Date: 14 APR99

Test Time: 5:45 pm

Test Plan 81 Step No.: 8.10

Describe drop orientation and drop height:
CASK, BOLTED TO PORTION OF SKID THAT REMAINED AFTER 9M(30 ft) DROP, WAS DROPPED w/o CAGE AT AN ANGLE ~10°-15° OFF VERTICAL ONTO ONE OF THE CASK COVER BOLTS. THE BOLT CHOSEN FOR IMPACT HAD BEEN DENTED (IMPACTED) DURING THE 30 ft (9M) DROP. DROP HT. ≥ 40"

Describe impact (location, rotation, etc.):
CASK STRUCK PUNCTURE BAR ON BOLT (WHICH LEFT A MARK ON THE PUNC. BAR).

Describe on-site inspection (damage, broken parts, etc.):
BOLT THAT WAS STRUCK WAS FURTHER DENTED, BUT REMAINED SECURE.

On-site assessment:
SPECIMEN SUCCESSFULLY PASSED HYPOTHETICAL ACCIDENT TEST (SUBJECT TO FINAL RAD. PROFILE) BECAUSE CASK AND COVER DID NOT LOSE THEIR STRUCTURAL INTEGRITY (DESPITE BEING DAMAGED PRIOR TO START OF THIS 30 ft DROP-PUNCTURE TEST SEQUENCE).

Engineering: ______ Regulatory: ______ QA: D.W. Kurtz

Describe any post-test disassembly and inspection:
NO FURTHER INSPECTION, OTHER THAN FINAL PROFILE OF CASK.

Describe any change in source position: NOT APPLICABLE

Describe results of any pre- or post-test radiography: N/A

Completed by: ______

Date: 14 APR 99

SENTINEL TP81(A) - AFTER PUNCTURE TEST

Drop Test Unit

SHIELDING PROFILE AND INSPECTION FORM

Model: 702 Serial Number: 24 Radionuclide: Ir-192 Max.Capacity: 10,000 Ci

Shield Data

Shield Heat#: Mass of Shield: Lbs. Lot #:

Initial Profile

Source Model: Source SN: Activity: Ci

Survey Inst.: SN: Date Cal.: Date Due:

Surface	Observed Intensity mR/hr	Surface Correction Factor		Adjusted Intensity mR/hr
Top			Capacity Correction Factor:	
Right				
Front				
Left				
Rear				
Bottom				

Inspector: Date: NCR #:

Final Profile

Source Model: BulkIr192 Source SN: N/A Activity: 82820Ci Mass of Device: N/A Lbs.

Survey Inst.: AN|PDR27T SN: SM392402 Date Cal.: 8Oct98 Date Due: 8Oct99

	Observed Intensity mR/hr				Adjusted Intensity mR/hr	
Surface	At Surface	Surface Corr. Factor	△At One Meter		At Surface	At One Meter
Top	*N/A	N/A	.8	Capacity Correction Factor: 1.20	N/A	1.0
Right			.9			1.1
Front			.9			1.1
Left			.9			1.1
Rear			.7			.8
Bottom	⊛.7		⊛		.8	N/A

Inspector: Michael R Boyd Date: 19 April 99 NCR #: N/A

Comments: * Not Reqd. per Engineering. ⊛ Unable to attain Meter Reading without laying unit on its' side. Not advisable in present condition. Surface reading taken instead.
△ Meter Readings taken from surface of 70202 (Isotope Container Assembly).

Amersham QSA

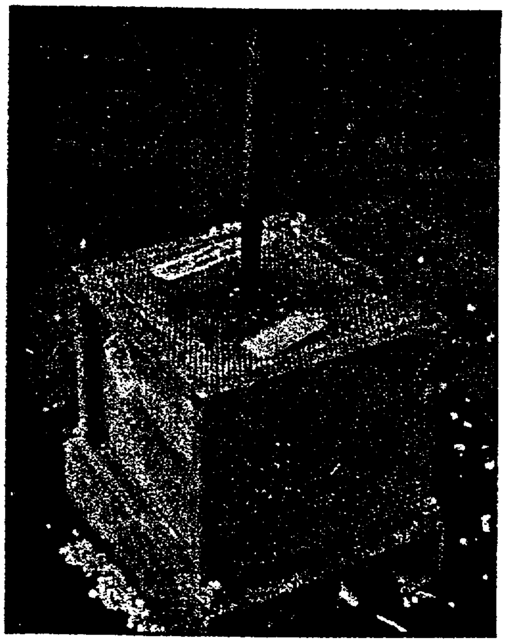
APPENDIX D

TEST PHOTOGRAPHS

Test Plan 81 Photographs

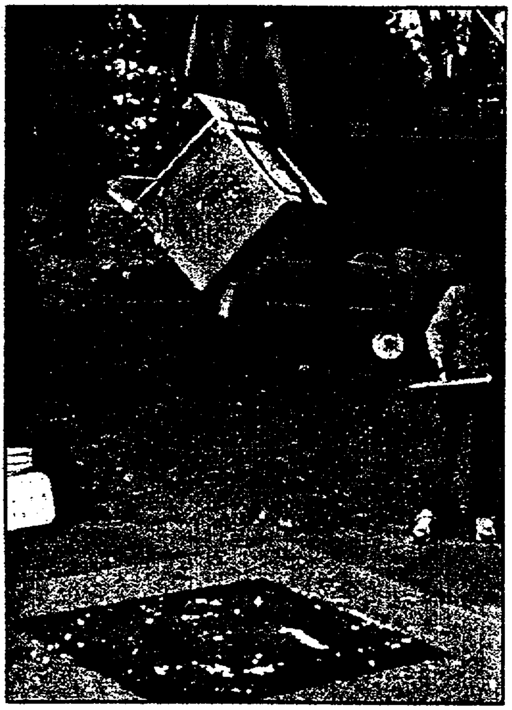
TP81(A) Compression Test Setup

TP81(A) Penetration Test Setup

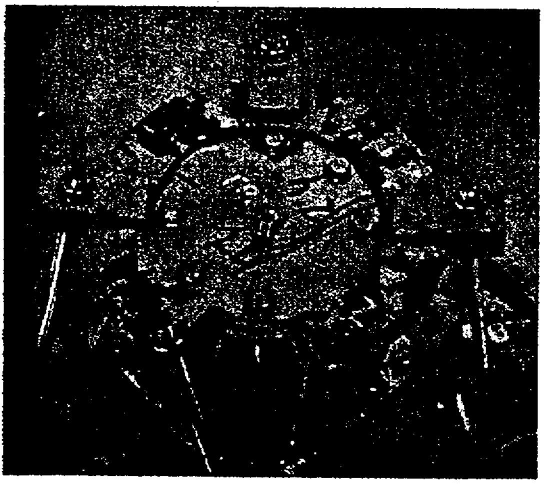


TP81(A) Penetration Test Results

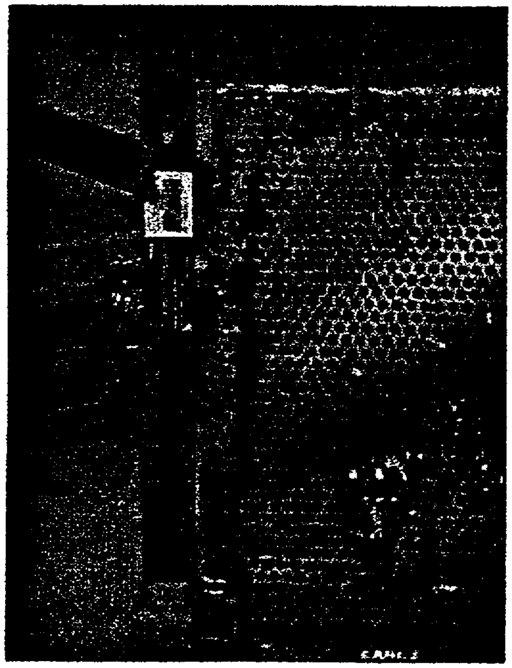
Test Plan 81 Photographs



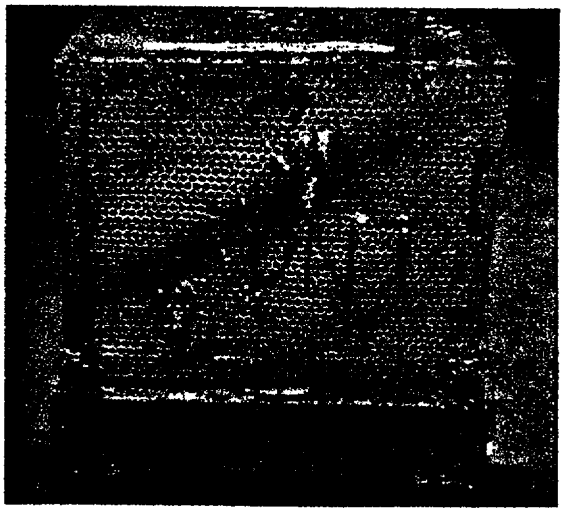
TP81(A) 1.2 Meter Drop Setup



TP81(A) 1.2 Meter Drop Results-Detail of Hold Down Ring

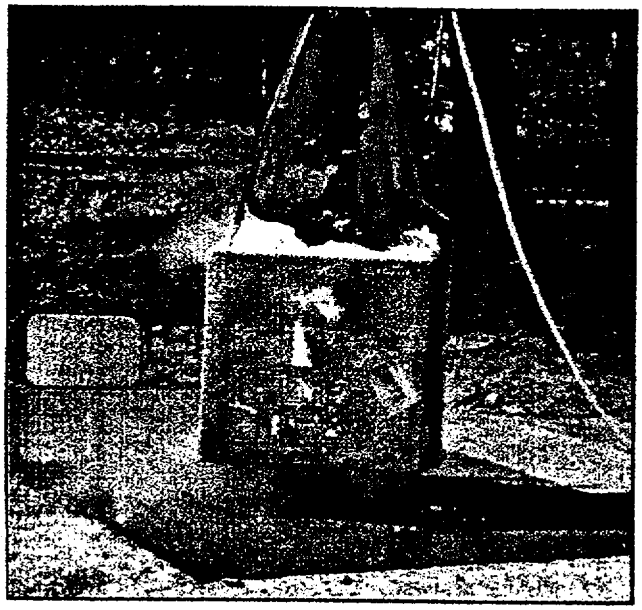


TP81(A) 1.2 Meter Drop Results-Detail of Cage Deformation

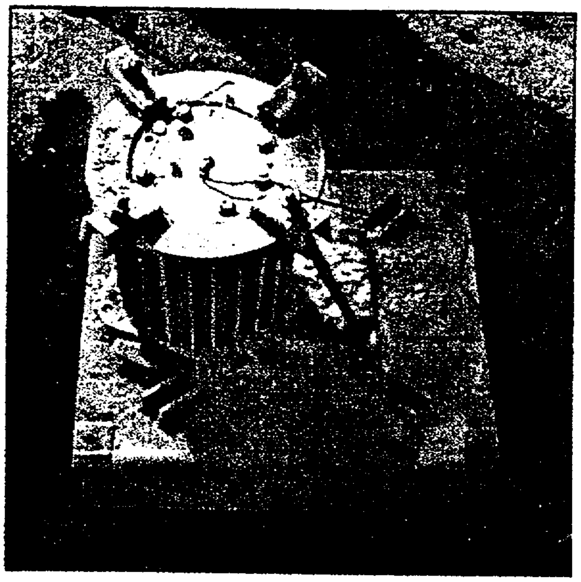


TP81(A) 1.2 Meter Drop Results-Detail of Buckled Cage

Test Plan 81 Photographs

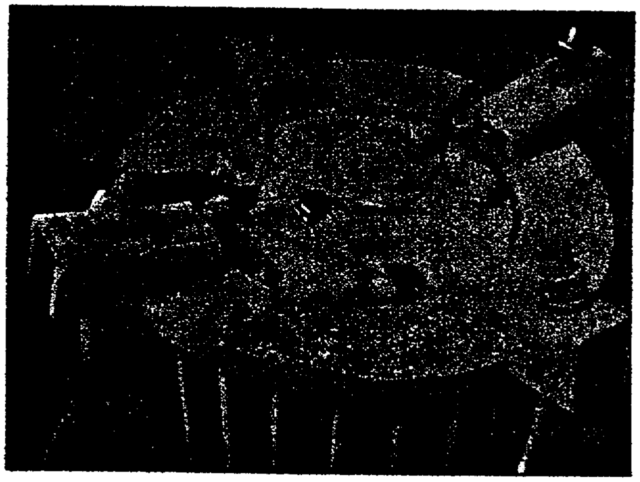


TP81(C) 9 Meter Drop Setup



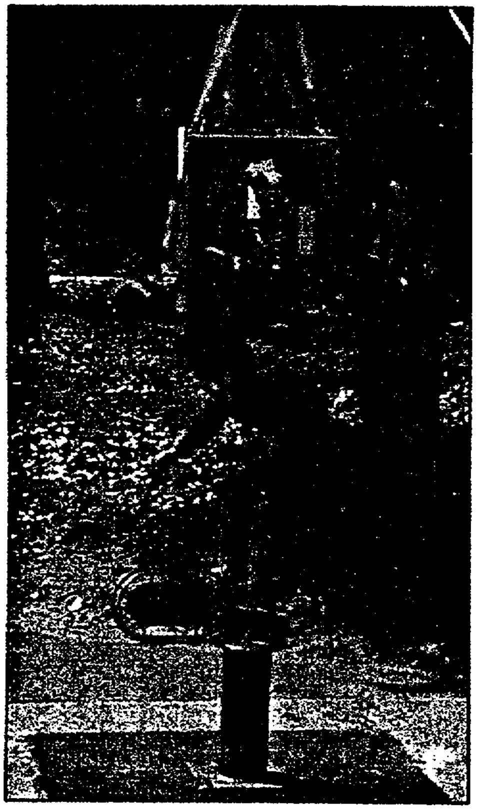
TP81(C) 9 Meter Drop Results-Detail of Cask Detached From Skid

TP81(C) 9 Meter Drop Results-Detail of Skid

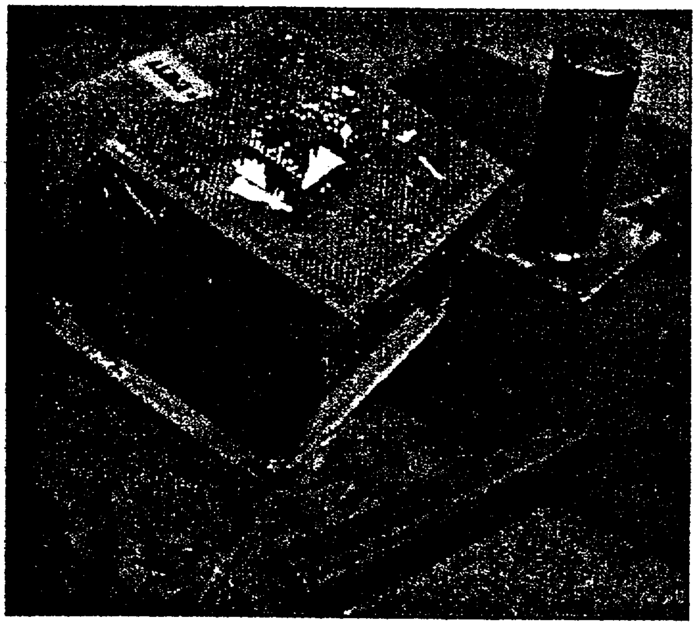


TP81(C) 9 Meter Drop Results-Detail of Missing Cask Cover Bolt

Test Plan 81 Photographs



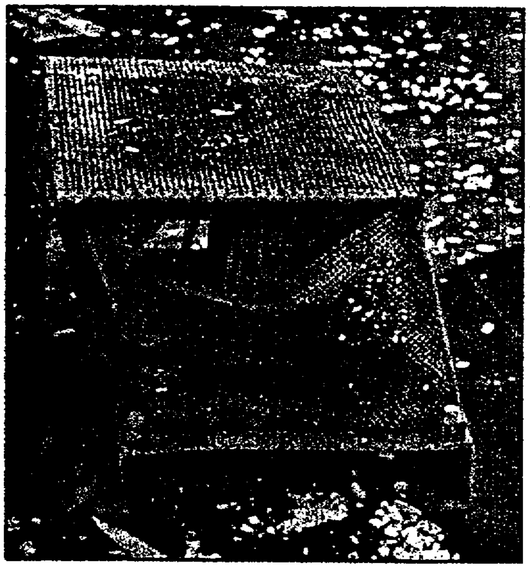
TP81(C) Puncture Test Setup



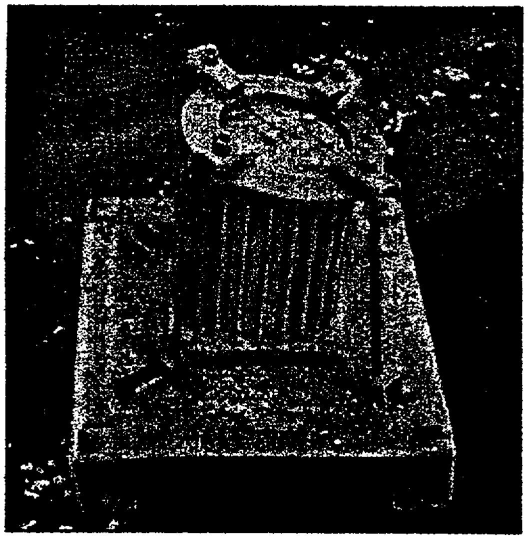
TP81(C) Puncture Test Results

Test Plan 81 Photographs

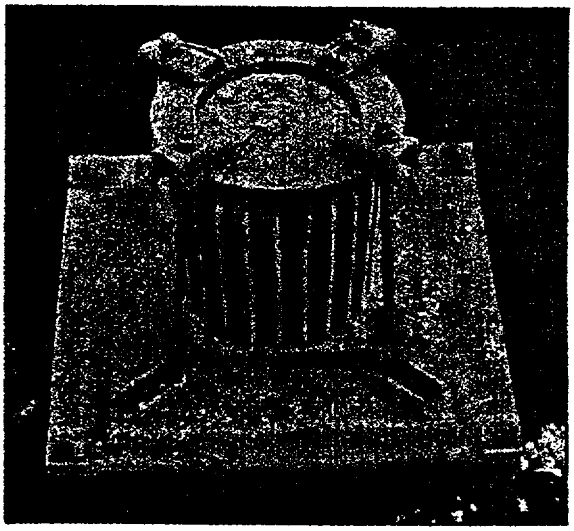
TP81(B) 9 Meter Drop Setup



**TP81(B) 9 Meter Drop Results-
Detail of Cage Deformation**

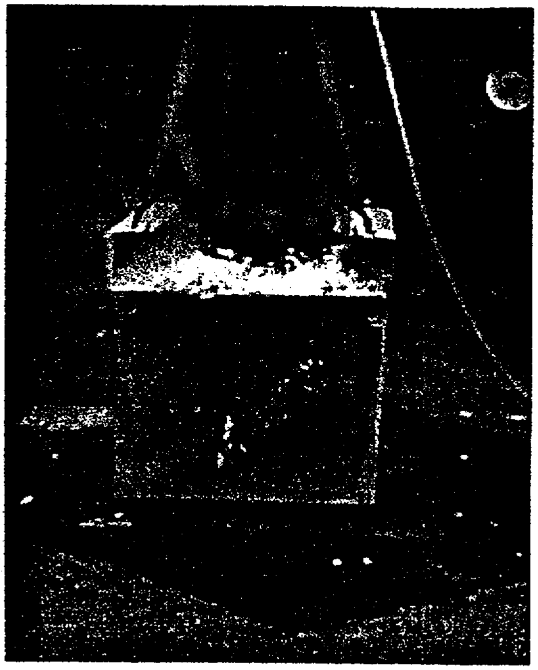


**TP81(B) 9 Meter Drop Results-
Detail of Cask and Skid**

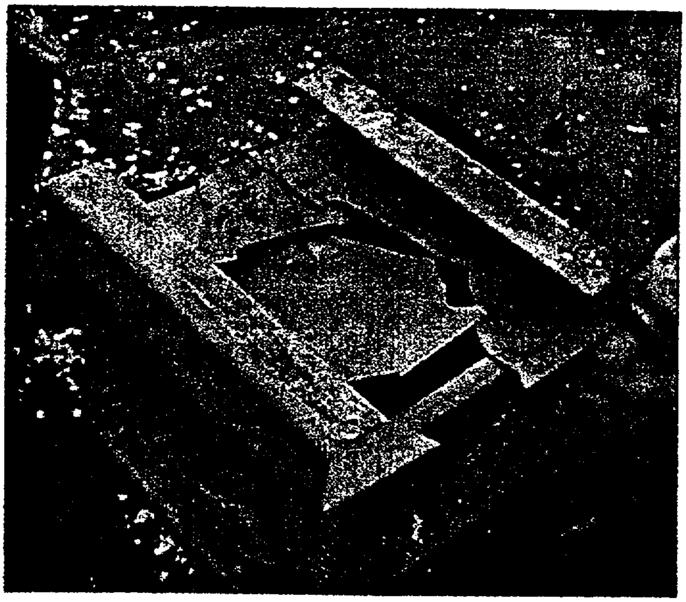


**TP81(B) 9 Meter Drop Results-
Detail of Cask and Skid**

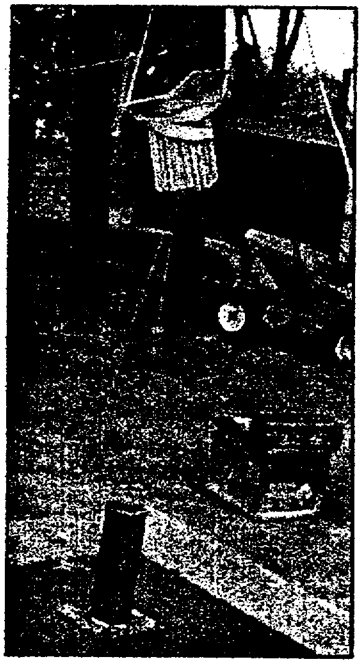
Test Plan 81 Photographs



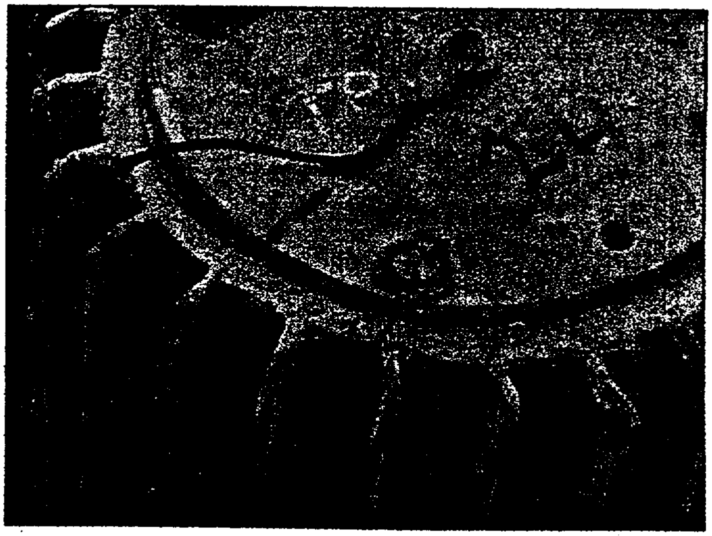
TP81(A) 9 Meter Drop Setup



TP81(A) 9 Meter Drop Results



TP81(A) Puncture Test Setup



TP81(A) Puncture Test Results-Detail of Dented Bolt

Appendix D: Finite Element Analysis (Model 702)

D-1 Finite Element Analysis for the Model 702

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MPR

MPR Associates, Inc.
320 King Street
Alexandria, VA 22314

CALCULATION TITLE PAGE

Client AEA Technology QSA, Inc.	Page 1 of 38 (Attachments 1, 2)
Project Transport Package Qualification	Task No. 420-0001-004-0
Title Model 702 Finite Element Analysis	Calculation No. 420-004-EBB-1

Preparer / Date	Checker / Date	Reviewer & Approver/Date	Rev. No.
E. B. Bird 7-6-00 Edward Bird 7-6-00	Chris Rice 7-6-00 Chris Rice 7-6-00	Nick Marrone 7-6-00	0

QUALITY ASSURANCE DOCUMENT

This document has been prepared, checked and reviewed/approved in accordance with the Quality Assurance requirements of 10CFR50, Appendix B, as specified in the MPR Quality Assurance Manual.

MPR

MPR Associates, Inc.
320 King Street
Alexandria, VA 22314

RECORD OF REVISIONS

Calculation No. 420-004-EBB-1	Prepared By	Checked By	Page: 2 Revision: 0

Revision	Affected Pages	Description
0	All	Initial Issue

Note: *The revision number found on each individual page of the calculation carries the revision level of the calculation in effect at the time that page was last revised.*

CONTENTS

1.0 Purpose

The purpose of this calculation is to document a finite element analysis of the AEA Technology Model 702 transport package for the thermal requirements of 10CFR71.73.4. The Model 702 transport package is designed for use as a shipping container for radio-isotopes. The transport package is shown on Figures 1 and 2.

10CFR71.73 specifies hypothetical accident conditions for which the transport package must be designed. The thermal accident conditions include immersion in a 1475 °F fire for 30 minutes. The acceptance criteria for the test is that there is not a significant increase in radiation levels external to the package following a hypothetical accident. For this calculation, the acceptance criteria is considered to be met if the calculated strains in the stainless steel components which contain the depleted uranium and the stainless steel cover bolts are less than the strain corresponding to the material ultimate strength at the test temperature.

2.0 Summary of Results

Figure 3 shows contours of the stress intensity profile in the transport package at 2 minutes, the time of maximum stress during the transient. The maximum stress intensity is 26 ksi. Figure 4 shows contours of total strain at 2 minutes. The maximum strain is less than 5%. This strain is considerably less than the strain at failure (40 to 50%) for stainless steel at a temperature of 1475 °F.

An additional elastic-plastic stress pass was made at a time of 30 minutes to confirm that there is sufficient material strength at the highest temperatures to react the primary pressure loads. The maximum calculated total strain at 30 minutes is also less than 5%.

3.0 Approach

A three-dimensional finite element model of the transport package was developed with the ANSYS computer program (Reference 1). The shipping cask is mounted on a carbon steel skid with a protective cage. The skid and cage are conservatively assumed to have failed as a result of hypothetical accident drop loads and are not included in the model. The transport package components included in the model are:

- Shipping Cask
- Depleted Uranium Shield
- Cask Cover Assembly (Stainless Steel Liner and Depleted Uranium Shielding)
- Cask Cover Bolts
- Copper Wafers

Half (180 degrees) of the transport package was modeled based on geometric and loading symmetry.

A three part sequential analysis technique was used. In the first part of the analysis, a thermal transient analysis was performed to calculate temperature profiles within the package as a result of immersion in a fire. Radiation and convective heat transfer modes were considered. In the second part of the analysis, stresses in the transport package components due to the calculated temperature profiles were determined on an elastic basis at several times during the transient. In the third part of the analysis, at the time of maximum elastic stress due to temperature, a final analysis was performed with elastic-plastic material properties. The effects of bounding internal pressure and cover bolt pre-load were included in the final analysis.

4.0 Finite Element Model

4.1 Geometry

One half of the transport package is modeled. Figures 5 through 8 show the finite element model components. Dimensions for the model are from References 2 through 16. Figures 9, 10 and 11 show key-point numbers for a cross section of model. Keypoint coordinates for the cross sections are listed in Attachment 1.

The model is meshed with hexahedral (brick) and tetrahedral elements. The bolts are represented by spar (line) elements. A surface effect element is used on the outside of the model to facilitate the application of the thermal boundary conditions.

The transport package includes thin (0.010 inch) copper wafers that separate the depleted uranium from the stainless steel. These wafers are modeled explicitly and are assumed to completely fill the gap and to be in perfect thermal contact with the stainless steel on one side and the depleted uranium on the other. Structurally, these wafers provide little mechanical resistance due to the low strength of copper at high temperature.

4.2 Material Properties

The transport package outer shell, cover, liners and bolts are constructed from 304 stainless steel. Depleted uranium is used for shielding in the cask and cover assemblies. Thin copper wafers are used between the stainless steel and uranium. A neoprene gasket was included between the cover and cask assemblies. Material properties for these four materials from References 17 through 20 are used in the model and listed in Attachment 2. The properties are temperature dependent for all but the neoprene.

The mechanical strength of the copper at elevated temperature was assumed to be negligible. Accordingly, the elastic modulus for this materials was set to 1,000 psi.

Elastic-plastic material properties for the stainless steel components were used for the final analysis runs. Bi-linear stress strain curves as a function of temperature were input. The yield stress values used are shown in Table 4.1. A tangent modulus (slope of the stress strain curve in the plastic region) of 500,000 psi was used for each curve.

Table 4.1: Yield Stress Values for 304 Stainless Steel (Reference 17)

Temperature (°F)	Yield Stress (ksi)
100	29.01
300	22.39
600	18.27
900	16.21
1,200	14.20
1,500	9.50

4.3 Thermal Boundary Conditions

Thermal boundary conditions representing immersion in a fire at 1475 °F were applied to the finite element model on all exterior surfaces. These surfaces include the finned outer surface of the cask, the cover top plate and the cask lower plate. The bottom of the cask lower plate was also heated (i.e. the cask is assumed to be suspended in the fire). The symmetry plane of the model was represented by a no heat flow condition (insulated).

Radiation and convection heat transfer modes were included to account for heat flow from the fire to the cask. For radiation, the shipping cask was conservatively assumed to be a black body; absorbing all radiation. An absorptivity / emissivity of 1.0 was assumed for the exterior; a form factor of 1.0 was assumed indicating the cask is fully engulfed by the fire. Based on a review of typical fossil-fired furnace design coefficients, a heat transfer coefficient of 20 BTU/hr-ft^2-°F was assumed on the exterior surfaces for convection.

Heat flow across the air gaps inside the shipping cask was also considered. Radiation links were used to represent the heat transfer between the cask inner liner and the cover liner. Convective heat transfer in the confined space within the shipping cask was assumed to be negligible.

4.4 Structural Boundary Conditions

Structural boundary conditions were applied to the shipping cask finite element model to determine thermal expansion stresses and stresses due to internal pressure. Thermal expansion stresses result from differential thermal expansion of the shipping cask components. Pressure stresses result from the air inside the shipping cask heating up and expanding (according to the ideal gas law).

Internal pressures were applied in the final elastic-plastic analyses. The limiting condition for internal pressure stress occurs when the neoprene gasket has burned off, relieving the pressure within the source cavity while the air surrounding the depleted uranium contained within the welded portion on the cask and cover assemblies expands (i.e. the inner surfaces of the cask and cover assemblies shown on Figures 6 and 7 are pressurized). The bounding value of the applied pressure is determined as follows:

$$P_2 = \frac{T_2}{T_1} P_1 = \frac{(1475+460)}{(70+460)} 15 = 55 \text{ psi}$$

Displacements are constrained at the plane of symmetry in the direction normal to the plane of symmetry (y direction), along a vertical line through the origin in the x direction , and at a single node on the bottom of the cask lower plate in the z direction.

5.0 Cover Bolt Calculations

An initial strain of 0.004 inches was applied to the bolts in the final elastic-plastic analyses. This strain was determined to result in a bolt pre-load of 1,467 lb for ambient conditions. This pre-load corresponds to a torque of 165 in-lbs from the following relationship:

$$T = K*D*F$$

Where T = the applied torque
K = the nut factor (0.3, Reference 21)
D = the nominal bolt diameter = 3/8 inch
F = the bolt tension force

The 1,467 lb load in the bolts corresponds to a stress of 19 ksi for a stress area of 0.0773 in^2 (Reference 23 for 3/8 inch bolts)

$$S_{pl} = \frac{1467}{0.0773} = 19 \text{ ksi}$$

Other potential loads on the bolts are dead weight and pressure. These loads were not applied in the finite element model but are evaluated below. The weight of the cover assembly is 30 lbs (Reference 13). This weight results in load of 5 lbs and a stress of 0.065 ksi in each of the 6 bolts.

$$S_{dw} = \frac{30}{6\,(0.0773)} = 0.065 \text{ ksi}$$

If the neoprene gasket does not fail, the 55 psi internal pressure is applied on a area conservatively corresponding to the bolt circle diameter of 5.5 inches. This results in a load of 218 lbs and a stress of 2.8 ksi for each bolt.

$$L_P = \frac{55\frac{\pi}{4}(5.5)^2}{6} = 218 \text{ lbs} \qquad S_P = \frac{55\frac{\pi}{4}(5.5)^2}{6\,(0.0773)} = 2.8 \text{ ksi}$$

6.0 Results

6.1 Thermal

Figures 12 through 16 show temperature profiles in the shipping cask at selected times during the temperature transient. At two minutes into the transient (Figure 13) the fins on the outside of the shipping cask have heated up to nearly 1300 °F while the inside of the shipping cask is still relatively cool. By 30 minutes, the shipping cask has nearly reached an equilibrium temperature of 1475 °F. The depleted uranium shielding in the cover is the last component to heat up.

6.2 Stress

Figures 17 through 23 show contours of stress intensity in the shipping cask at selected times during the temperature transient. These stresses were calculated with elastic material properties and do not include pressure loads or bolt pre-load. This phase of the analysis was used to identify the time of maximum thermal stress. The maximum thermal stress intensity occurs at 2 minutes and is located in the outer tip of the fin at its attachment to the lower plate on the plane of symmetry.

The stress in the fin and lower plate results from the expansion of the hot fin which is restrained by the cooler cask and lower plate. The maximum calculated elastic stress of 135 ksi occurs where the bending reinforcement provided by the lower plate is a minimum at the plane of symmetry. This maximum stress would not occur in an actual cask subjected to the specified thermal conditions because the stainless steel shell material would yield and relieve the stress. These thermal expansion stresses are secondary and do not occur in the material that forms the pressure boundary around the depleted uranium.

High stresses also occur in the cover periphery. The depleted uranium shielding in the cover causes the center of the cover to heat up more slowly than the periphery. This temperature difference results in a hoop stress in the cover.

To obtain a more realistic picture of the stress and strain condition in the cask, the stress pass was repeated at the time of maximum elastic thermal stress, 2 minutes, with elastic-plastic material properties. Pressure and bolt pre-load were included in this pass. Figures 3 and 4 show contours of stress intensity and total (elastic + plastic) strain. The maximum stress is reduced from 135 ksi to 26 ksi due to yielding in the material. The maximum calculated strain is less than 5%. Material testing shows that 304 stainless steel at 1475 °F will not rupture until the strain reaches 40 to 50% (Reference 22). Consequently, a strain of less than 5% is judged to be acceptable.

An additional elastic-plastic stress pass was made at a time of 30 minutes to confirm that there is sufficient material strength at the highest temperatures to react the primary pressure loads. Figure 24 shows that the stress results are bounded by the stresses at 2 minutes. The maximum calculated total strain at 30 minutes is also less than 5%.

As discussed in Attachment 2, the analyses reported in this calculation were performed using a curve fit for the uranium and copper material properties which slightly under-predicted the heat capacity of the material at low temperatures. Scoping analyses performed using linear interpolation of the available material properties indicate that the time of maximum stress remains at about 2 minutes into the transient. The curve fit material properties result in a maximum elastic stress about 8% lower than that predicted using linear interpolation of the data. The maximum strain calculated in an elastic-plastic analysis is similarly expected to be no more than 8% greater than that shown in Figure 4, i.e. less than 5%.

6.3 Cover Bolts

The stress and load in the cover bolts were evaluated for the elastic-plastic stress passes. These evaluations show that the stress and load in the bolts was lower at high temperature than under cold pre-load conditions. The load decreases at high temperature because the stainless steel bolt expands more than the joint formed by the cover plate, gasket and shell.

The decrease in load more than offsets any potential load due to internal pressure if the gasket does not rupture or deadweight of the cover. At 2 minutes, the load in each bolt decreases from 1,467 lb to 114 – 176 lbs (the three bolts have different loads). This decrease in load of more than 1,000 lbs more than offsets the 5 lb load due to dead weight or the 218 lb potential pressure load.

The bolts are adequate for the thermal accident conditions and will retain the cover in place.

7.0 References

1. ANSYS Finite Element Analysis Computer Program, Version 5.6 installed on a Sun Ultra 2 workstation running the Solaris 7 operating system. The ANSYS installation verification is documented in QA-56-1
2. AEA Drawing No. D70202, Isotope Shipping Container, Rev. K
3. AEA Drawing No. D70202-1, Outside Shell, Rev. N
4. AEA Drawing No. D70202-2, Uranium Shield, Rev. C
5. AEA Drawing No. C70202-3, Inner Liner, Rev. H
6. AEA Drawing No. A70202-4, Copper Spacer, Rev. A
7. AEA Drawing No. A70202-5, Copper Spacer, Rev. A
8. AEA Drawing No. A70202-6, Copper Spacer, Rev. A
9. AEA Drawing No. A70202-7, Copper Spacer, Rev. A
10. AEA Drawing No. A70202-8, Copper Spacer, Rev. B
11. AEA Drawing No. A70202-9, Copper Spacer, Rev. A
12. AEA Drawing No. A70202-10, Copper Spacer, Rev. B
13. AEA Drawing No. B70203, Cover Assembly, Rev. F
14. AEA Drawing No. B70203-1, Cover Outer Shell, Rev. E
15. AEA Drawing No. B70203-2, Cover Top Plate, Rev. G
16. AEA Drawing No. B70203-4, Cover Shielding, Rev. C
17. Marchbanks, M.F., Moen, R.A., and Irvin, J.E., Nuclear Systems Materials Handbook, Part I - Structural Materials, Group 1 - High Alloy Steels, Section 2 - 304 SS Annealed, Revision 8, 1976.
18. Rohsenhow, W.M., Hartnett, J.P., and Cho, Y.I. (Eds.), Handbook of Heat Transfer, Third Edition, McGraw-Hill (Properties for Copper and Uranium obtained from Chapter 2 - Thermophysical Properties).
19. Metals Handbook, Volume 2, Tenth Edition, 1990.
20. Mark, J.E., Erman, B., and Eirich, F.R., Science and Technology of Rubber, Second Edition, 1994.

21. Bickford J. H., and Nassar, S., Handbook of Bolts and Bolted Joints.
22. Aerospace Structural Metals Handbook, 1991 edition.
23. Marks Engineering Handbook, seventh edition, 1958.

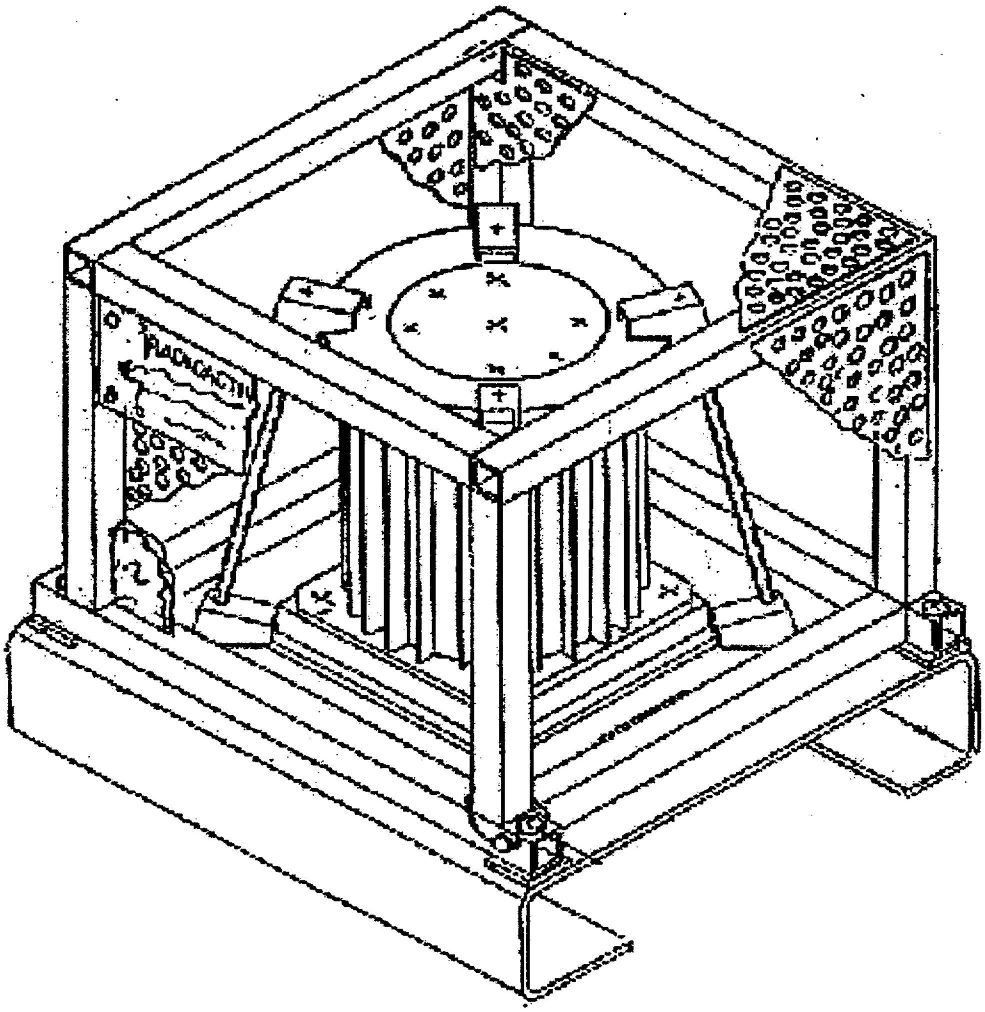

Figure 1: Isometric View of Model 702 Transport Package

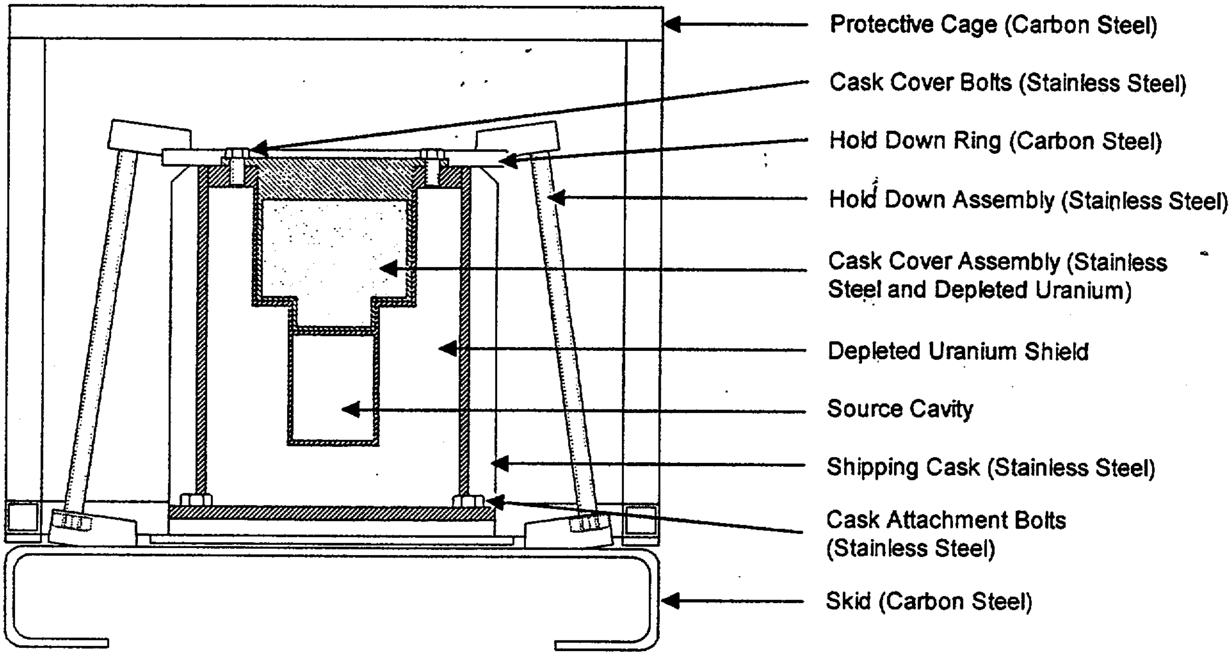

Figure 2: Model 702 Transport Package Schematic

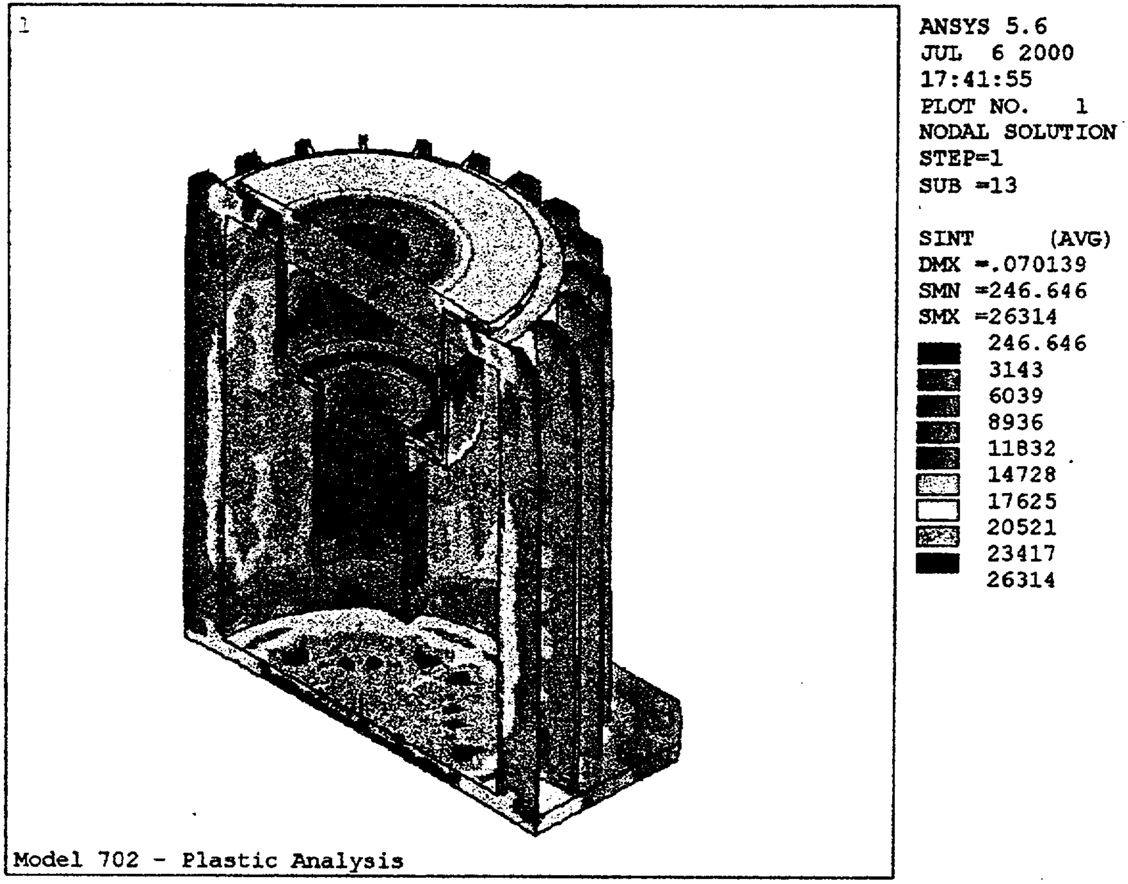

Figure 3: Model 702 Stress Intensity Profile at 2 Minutes

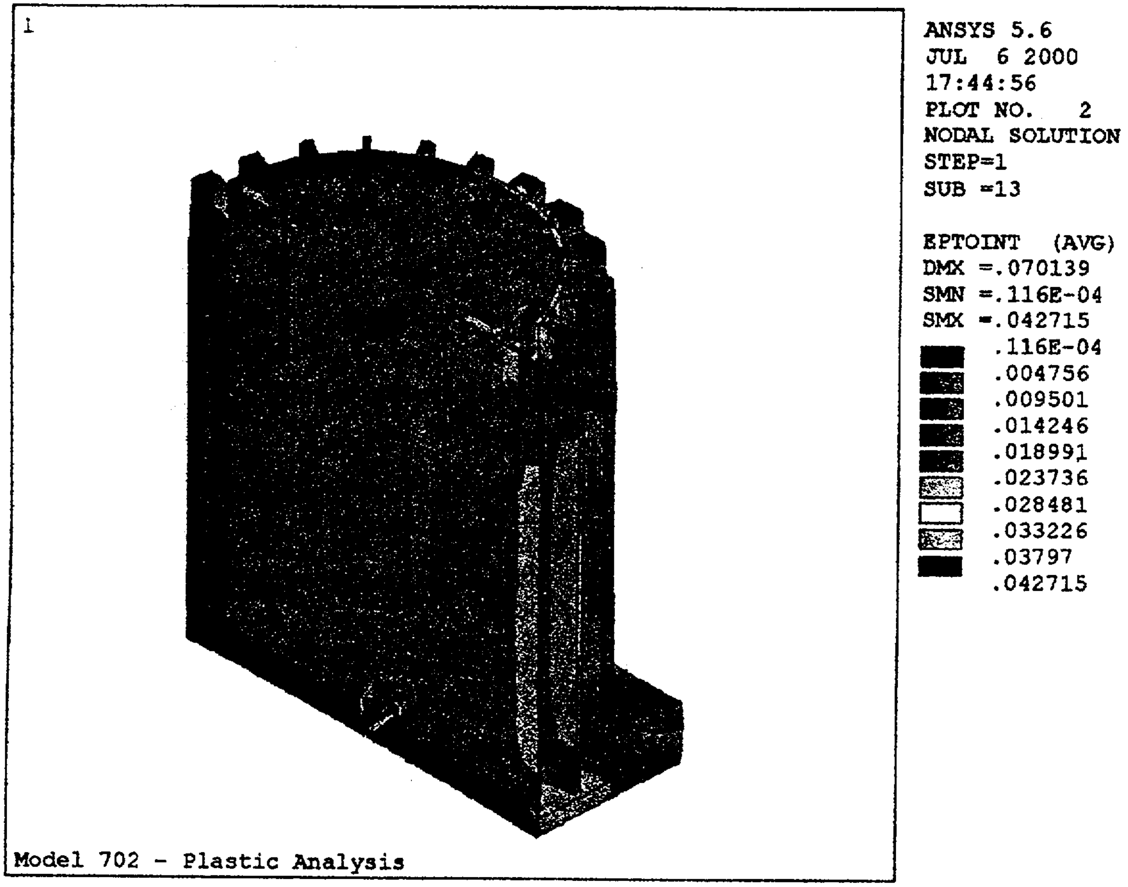

Figure 4: Model 702 Strain Intensity Profile at 2 Minutes

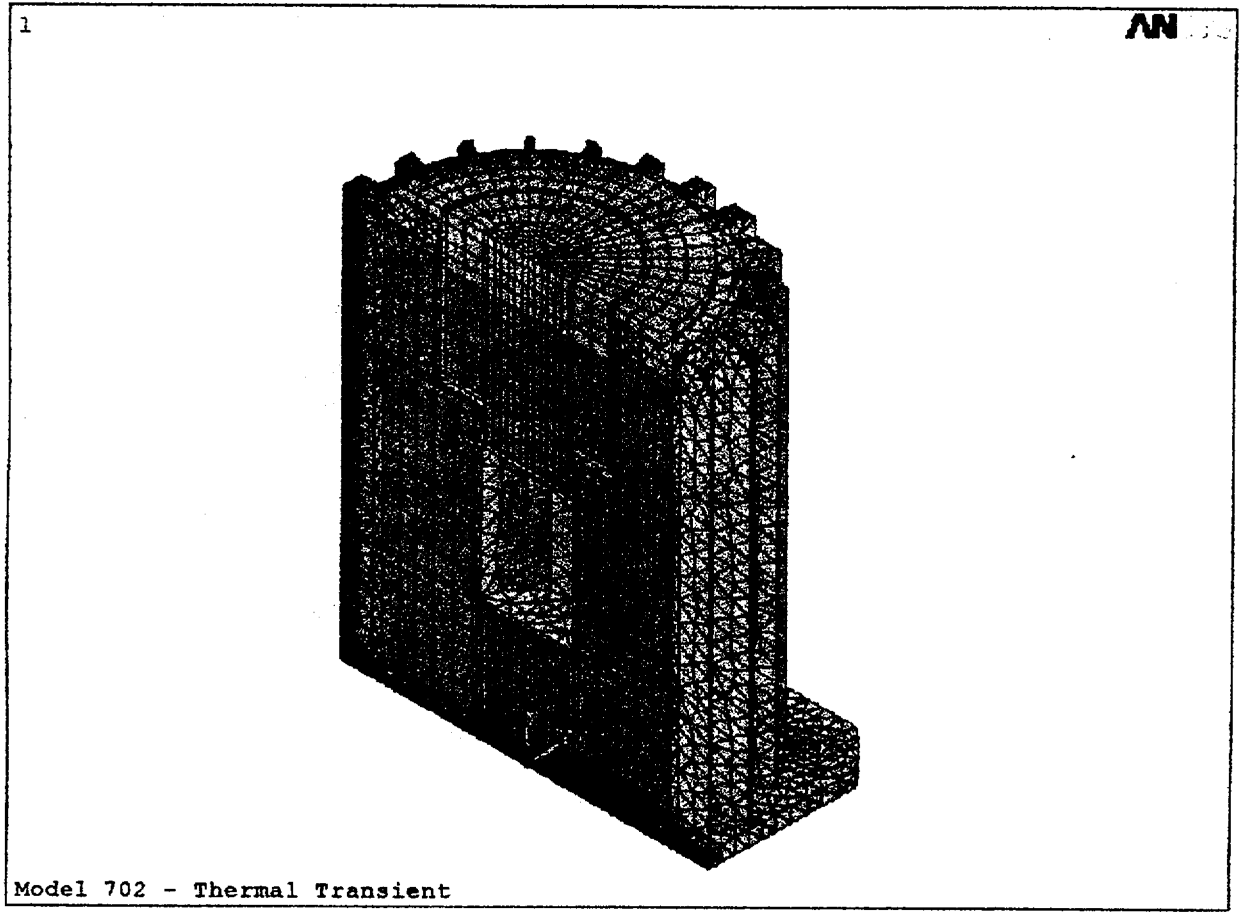

Figure 5: Model 702 Finite Element Model

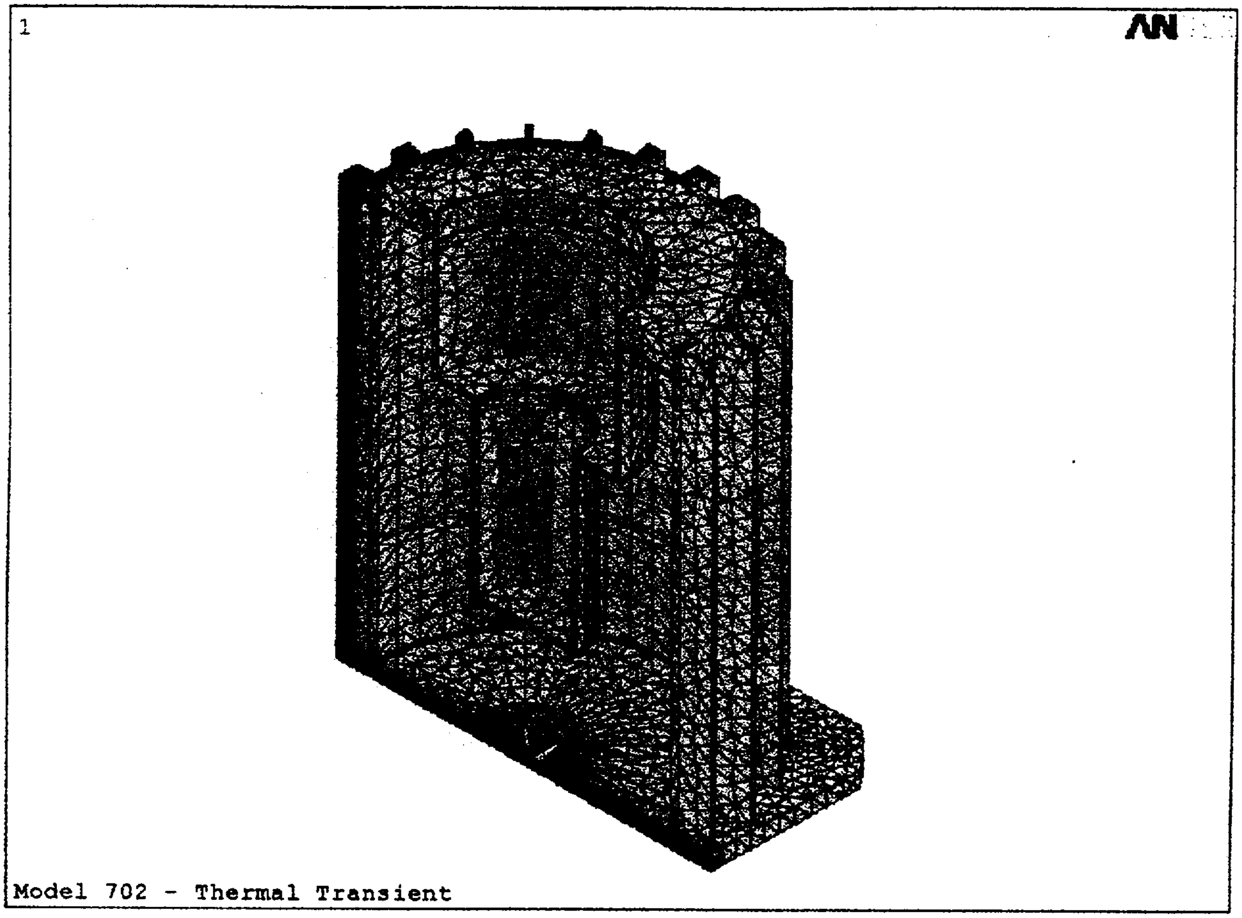

Figure 6: Model 702 Finite Element Model - Cask

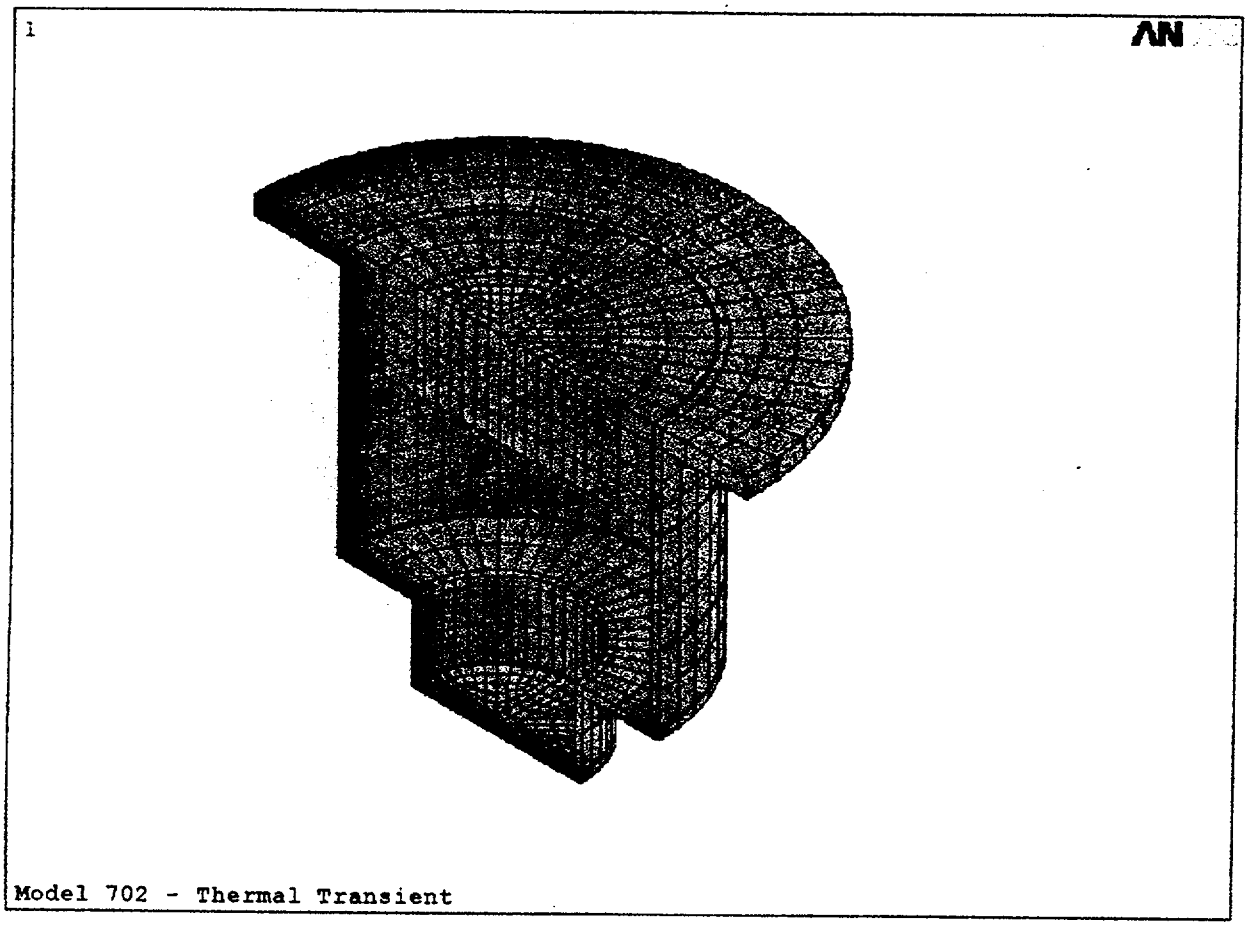

Figure 7: Model 702 Finite Element Model - Cover

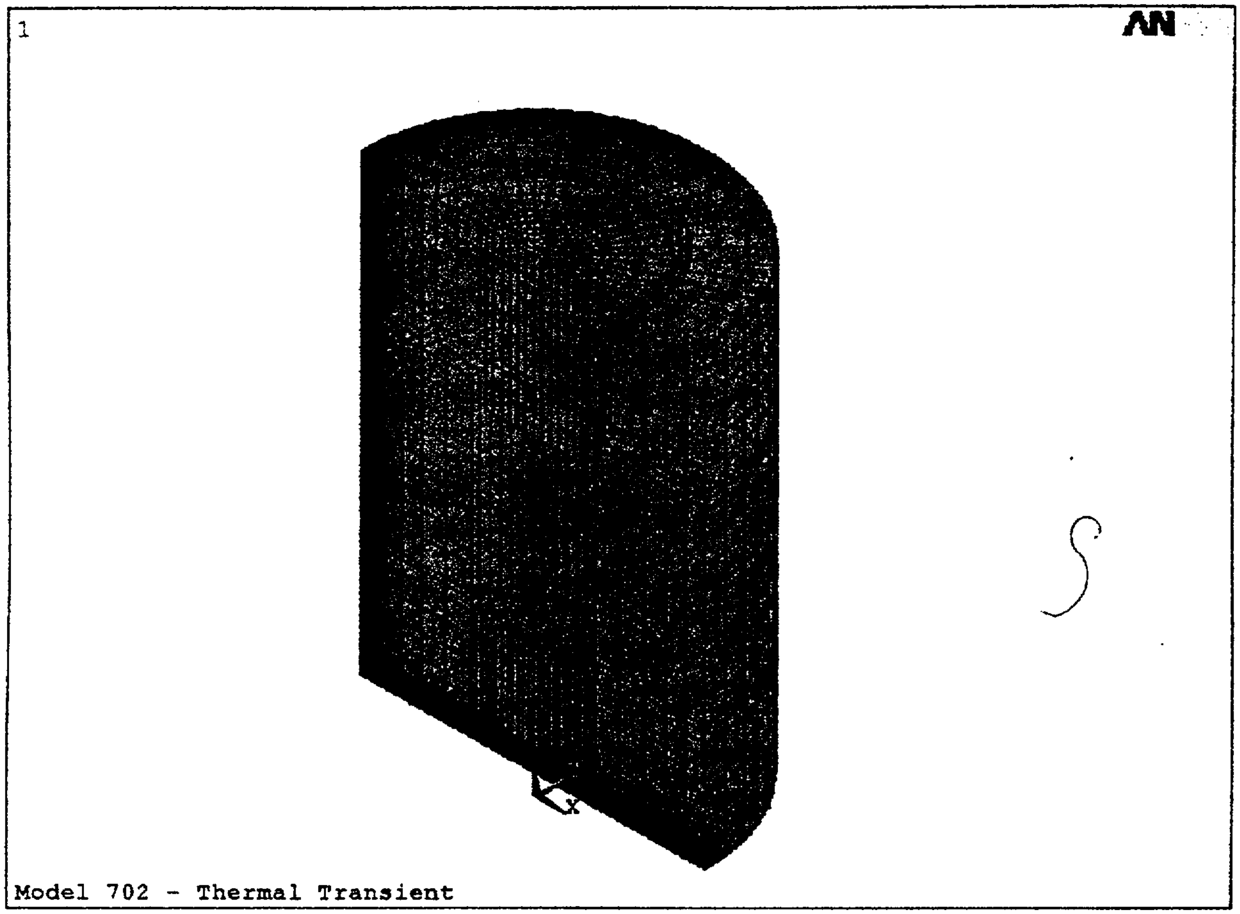

Figure 8: Model 702 Finite Element Model – Depleted Uranium Shielding

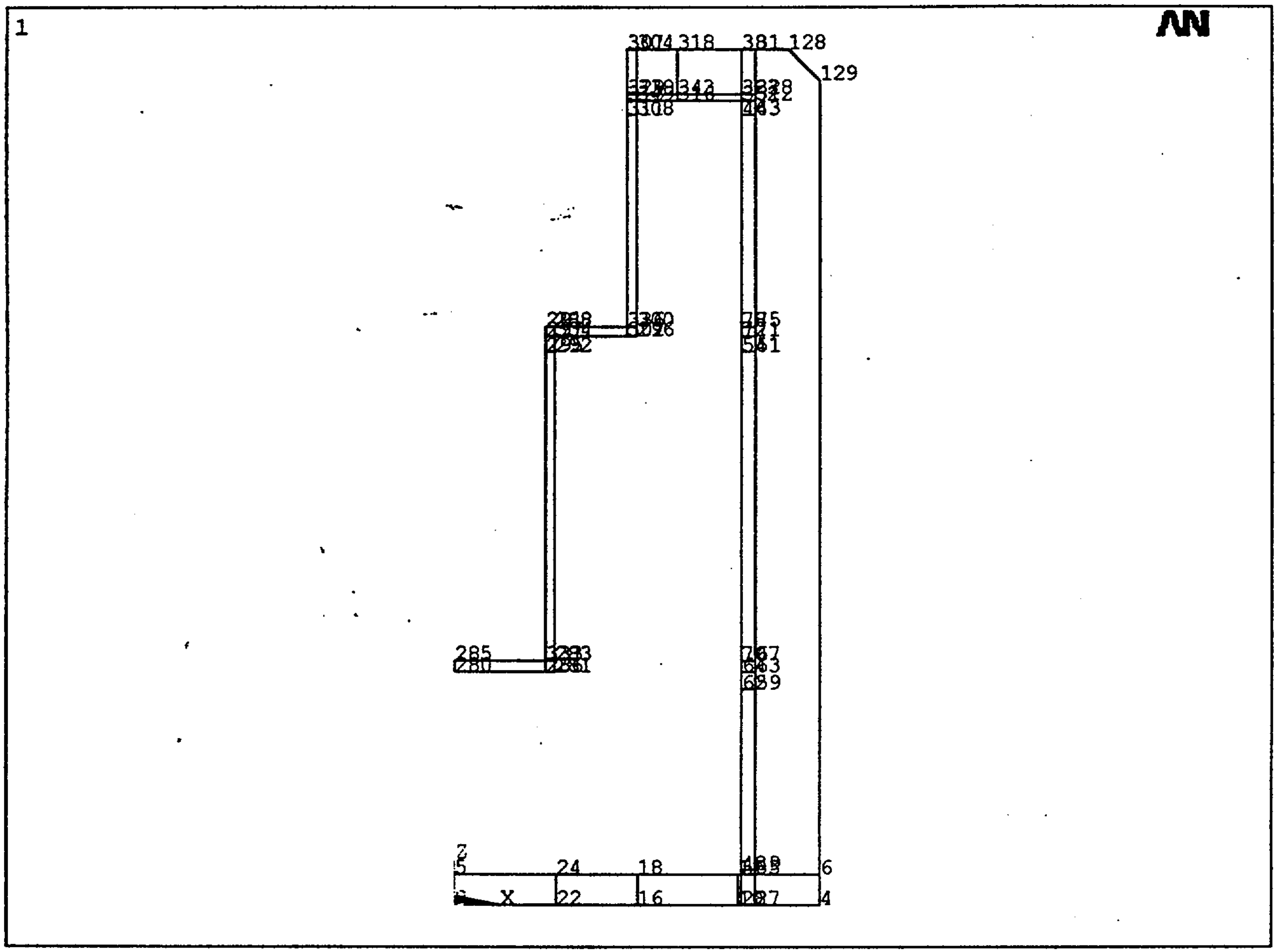

Figure 9: Geometric Keypoints - Shell

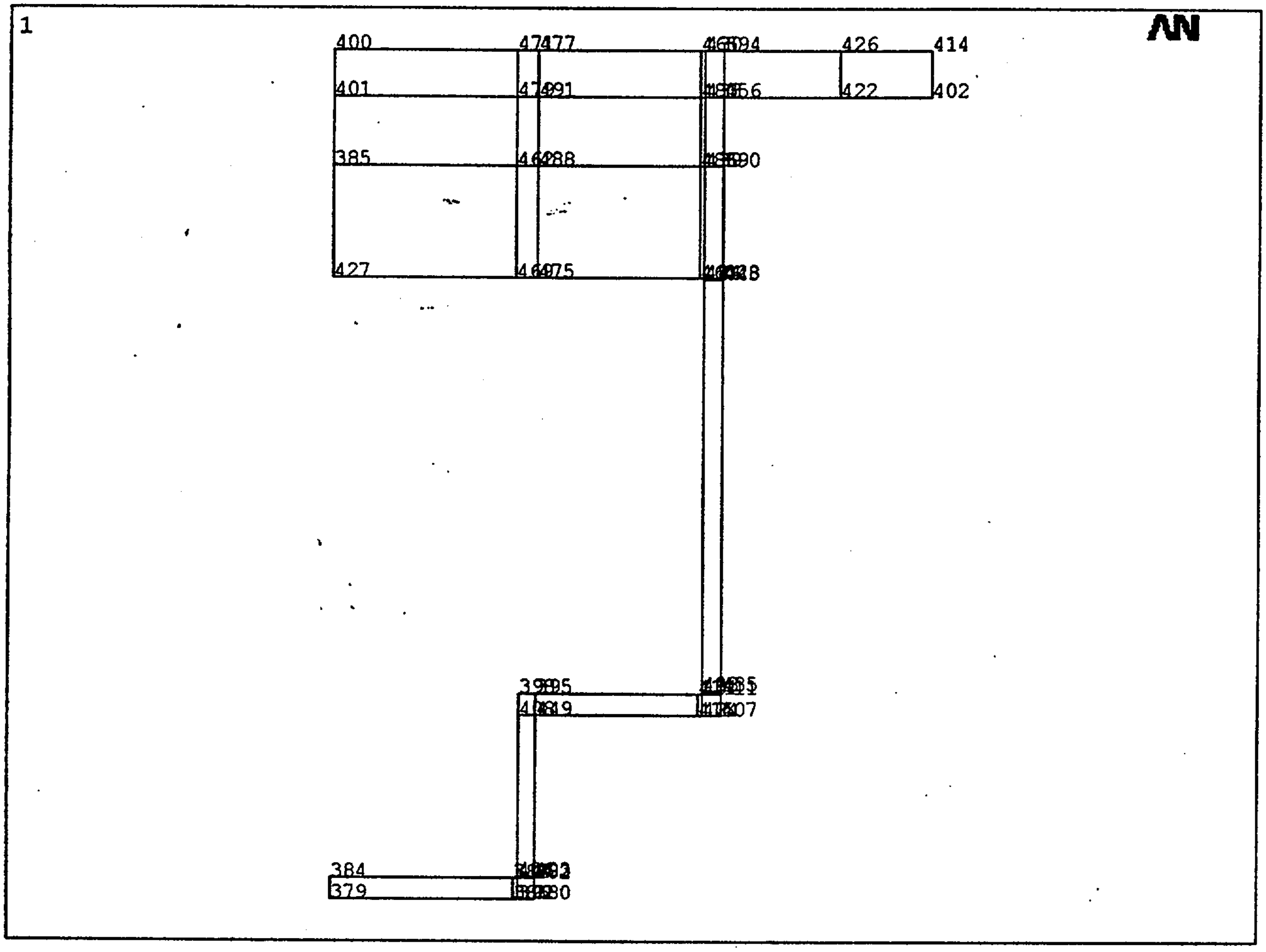

Figure 10: Geometric Keypoints - Cover

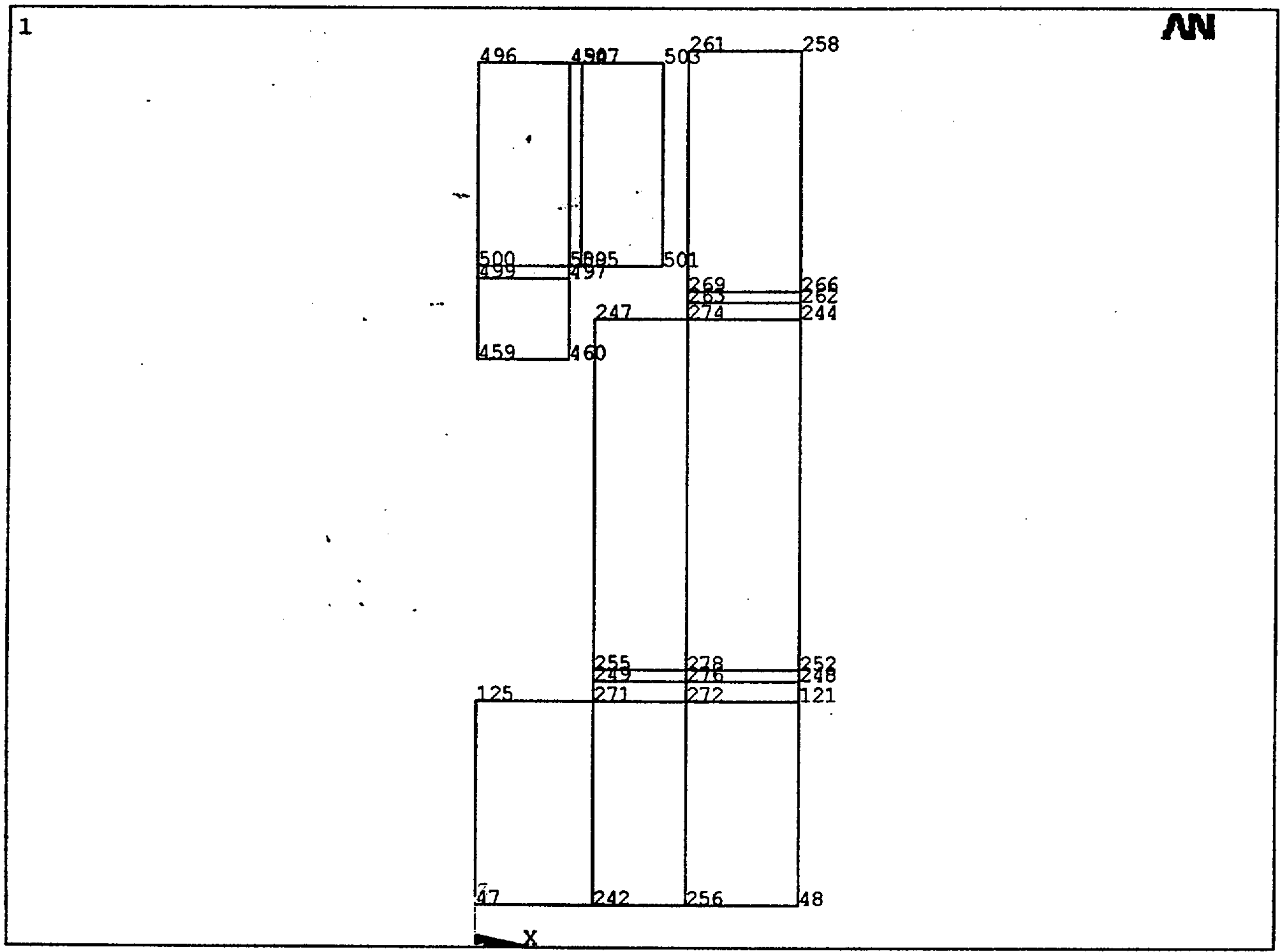

Figure 11: Geometric Keypoints – Depleted Uranium

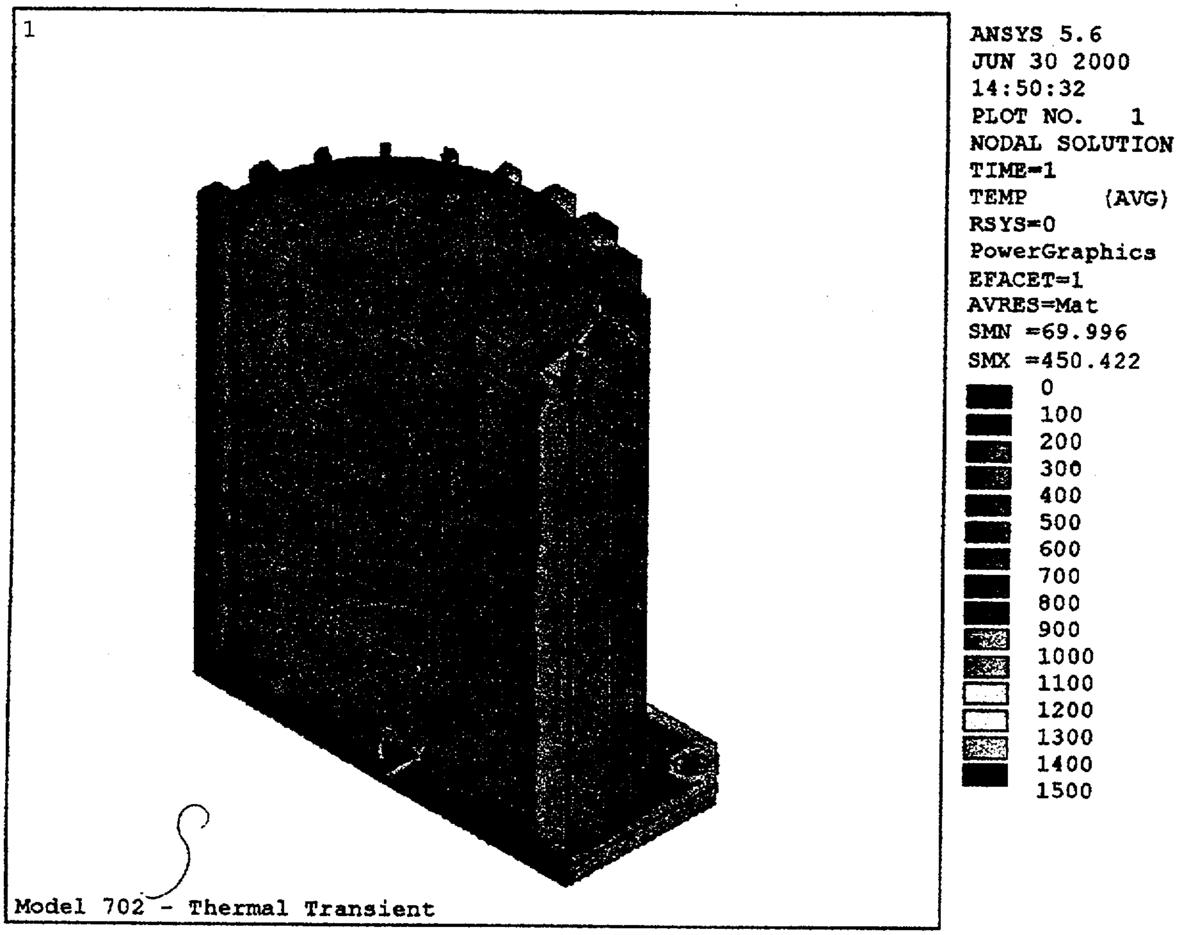

Figure 12: Temperature Profile at 1 Second

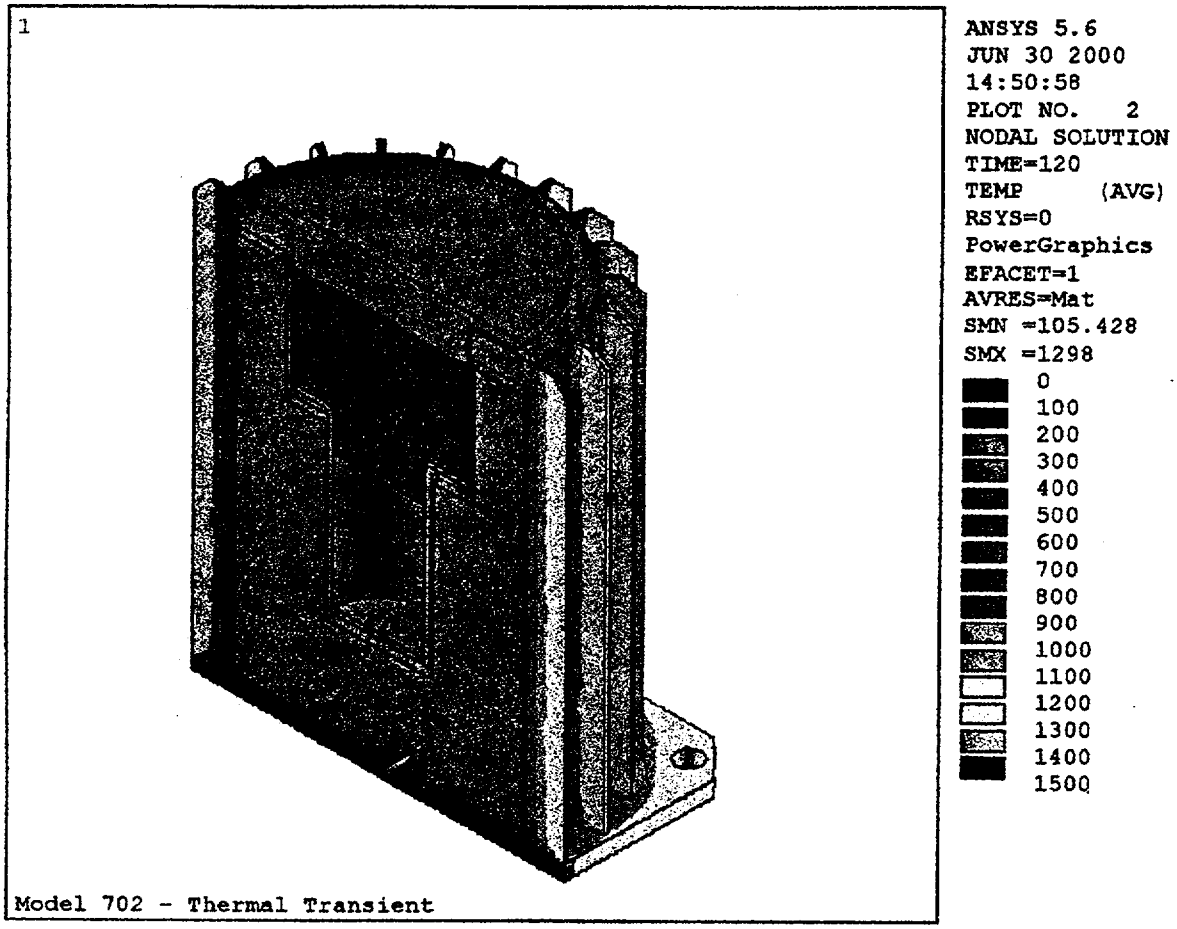

Figure 13: Temperature Profile at 2 Minutes

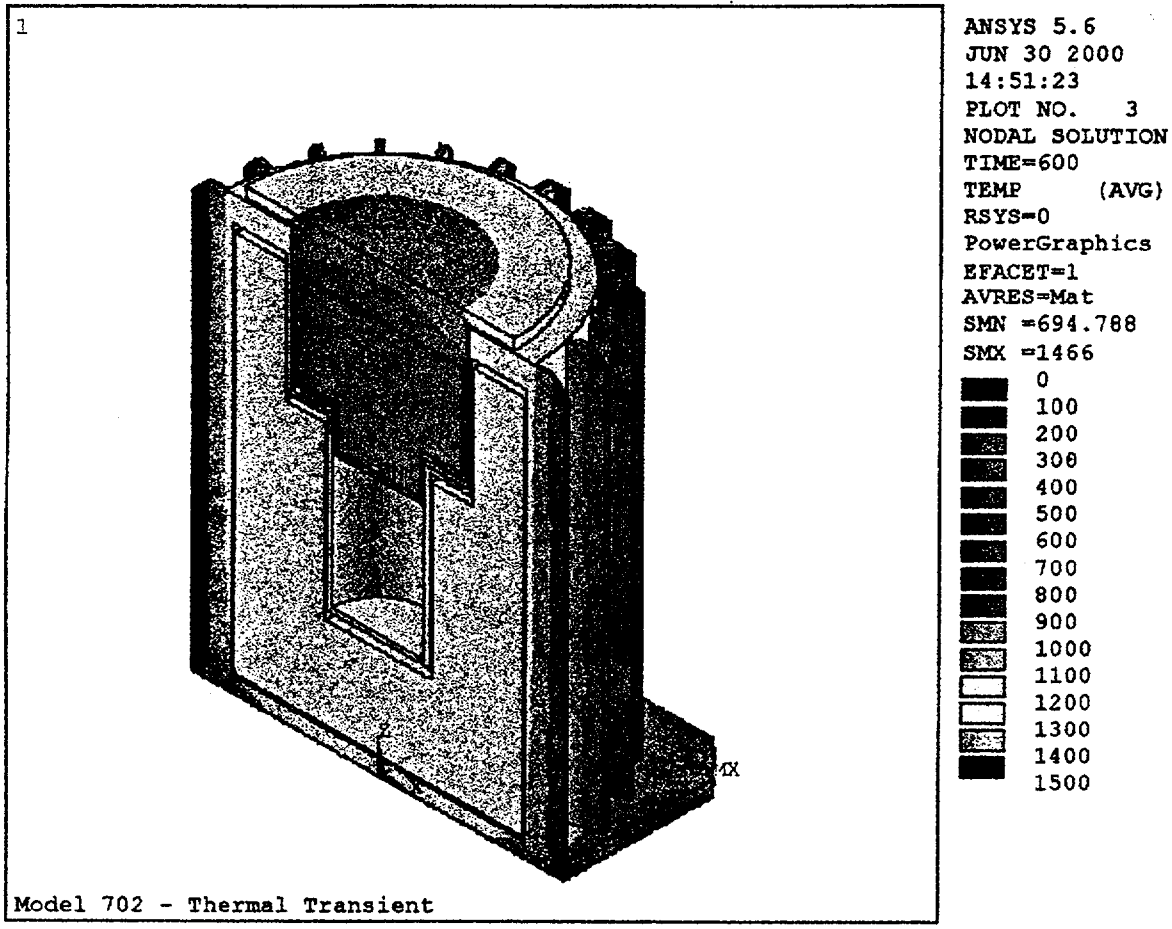

Figure 14: Temperature Profile at 10 Minutes

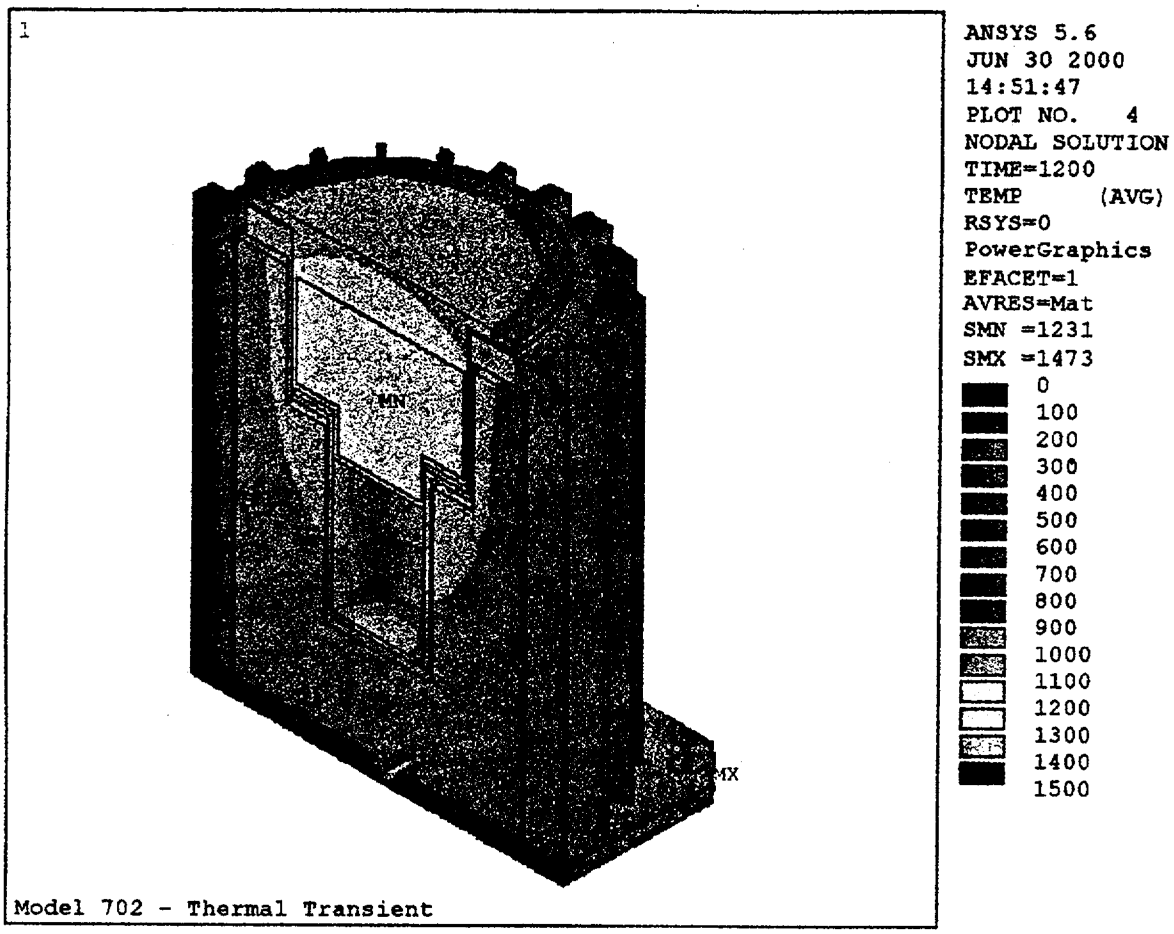

Figure 15: Temperature Profile at 20 Minutes

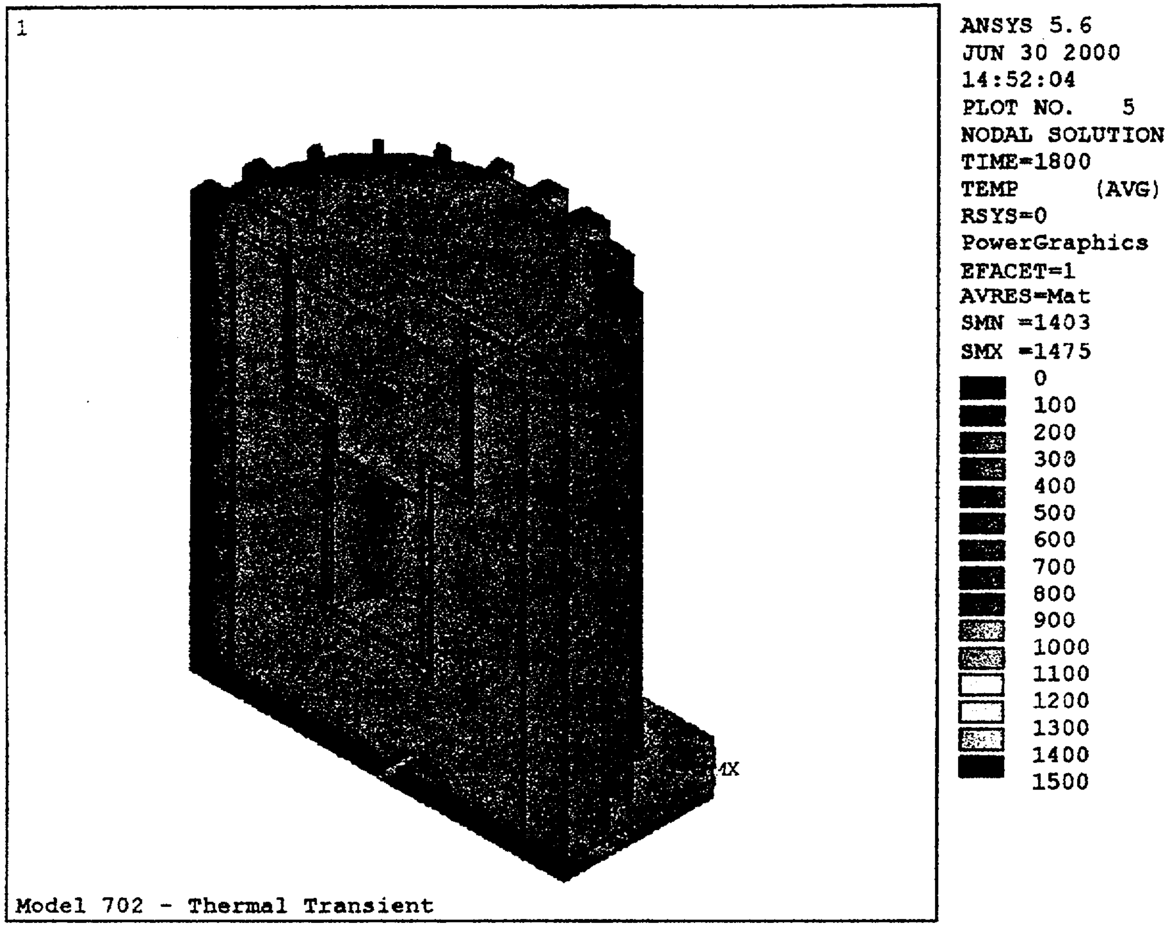

Figure 16: Temperature Profile at 30 Minutes

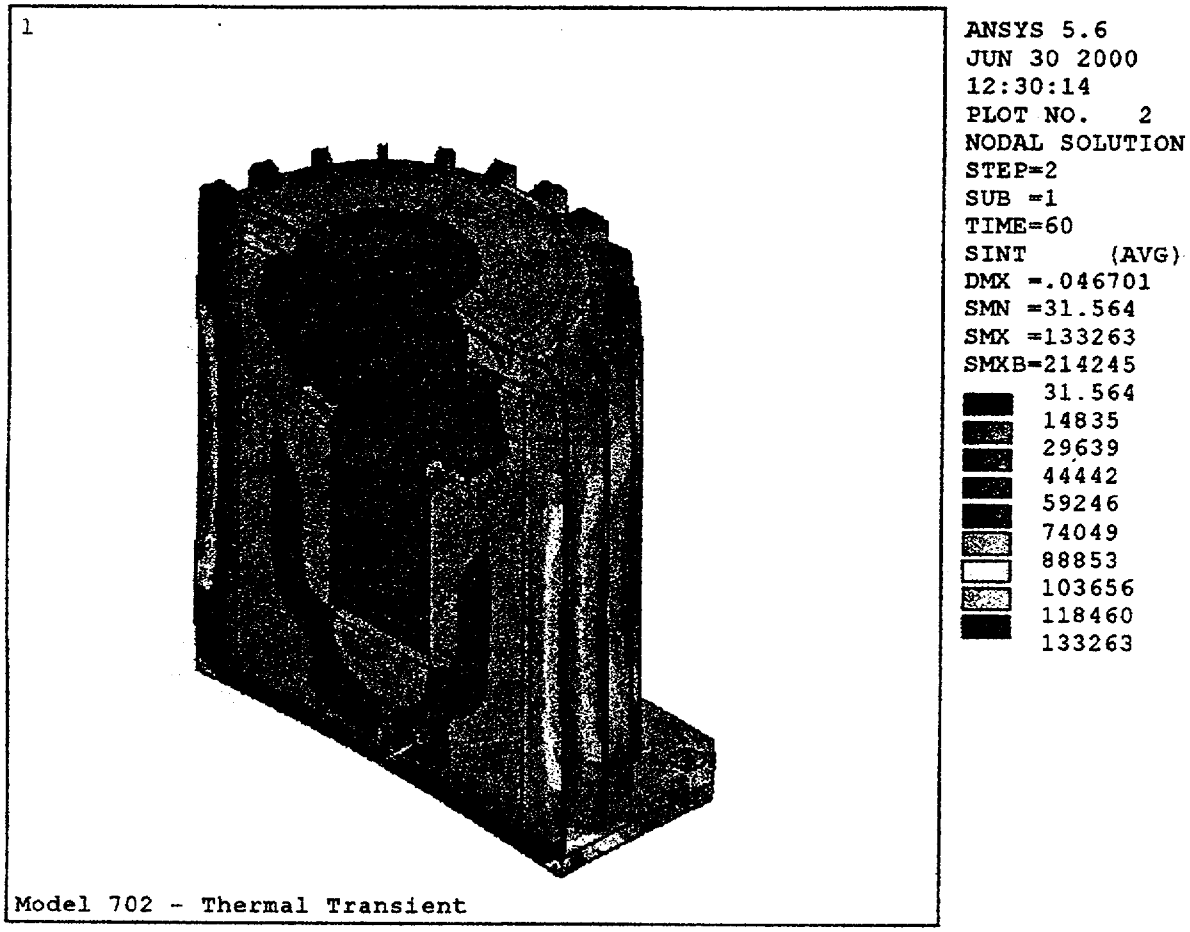

Figure 17: Stress Intensity Profile at 1 Minute

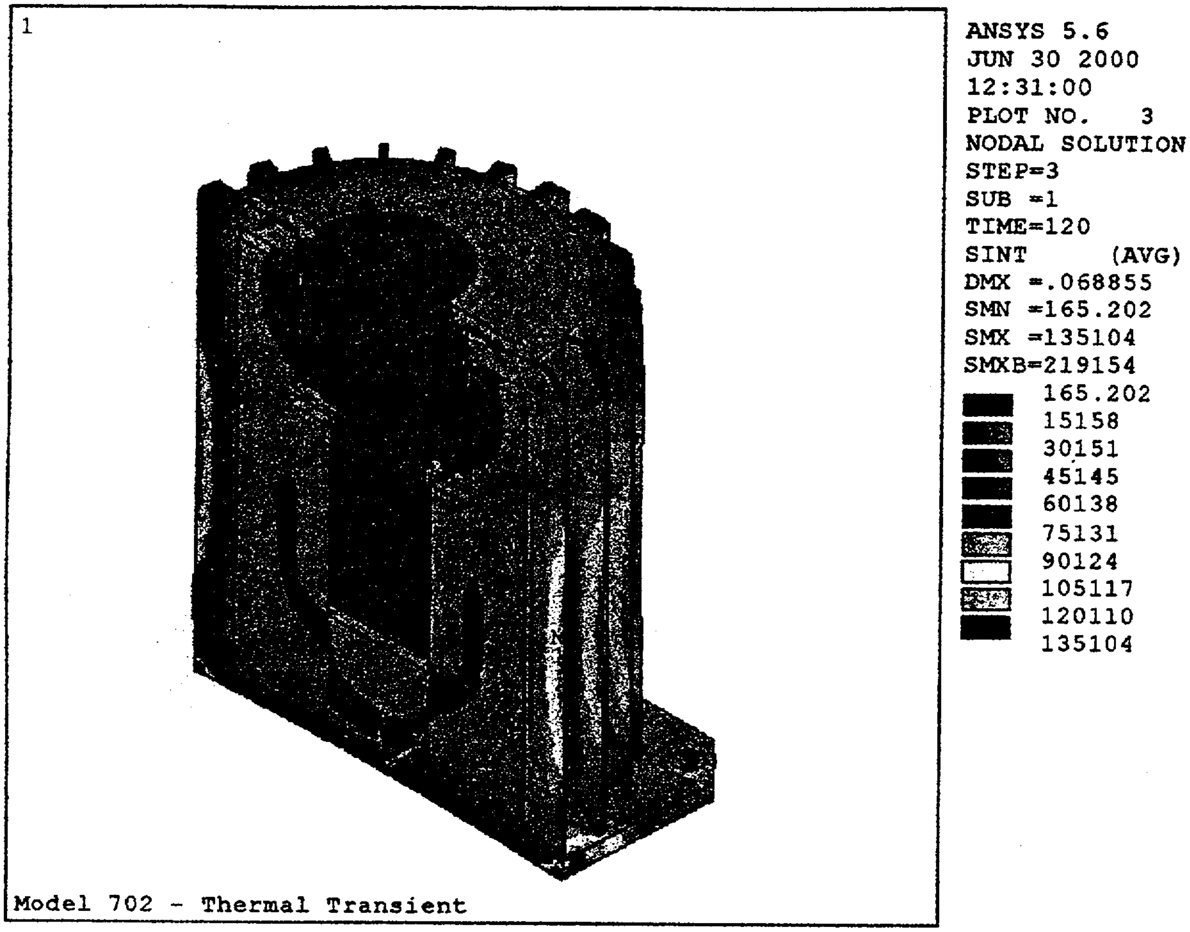

Figure 18: Stress Intensity Profile at 2 Minutes

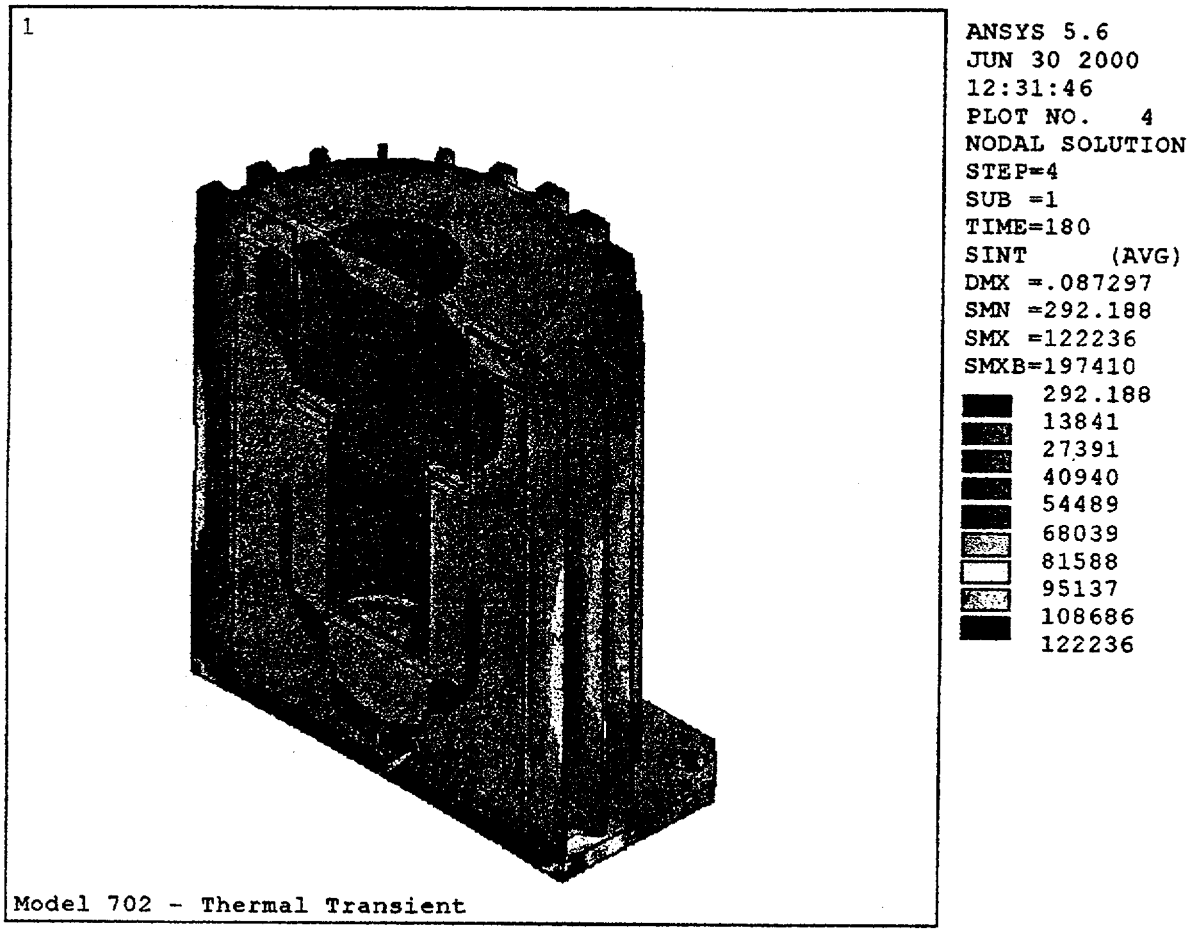

Figure 19: Stress Intensity Profile at 3 Minutes

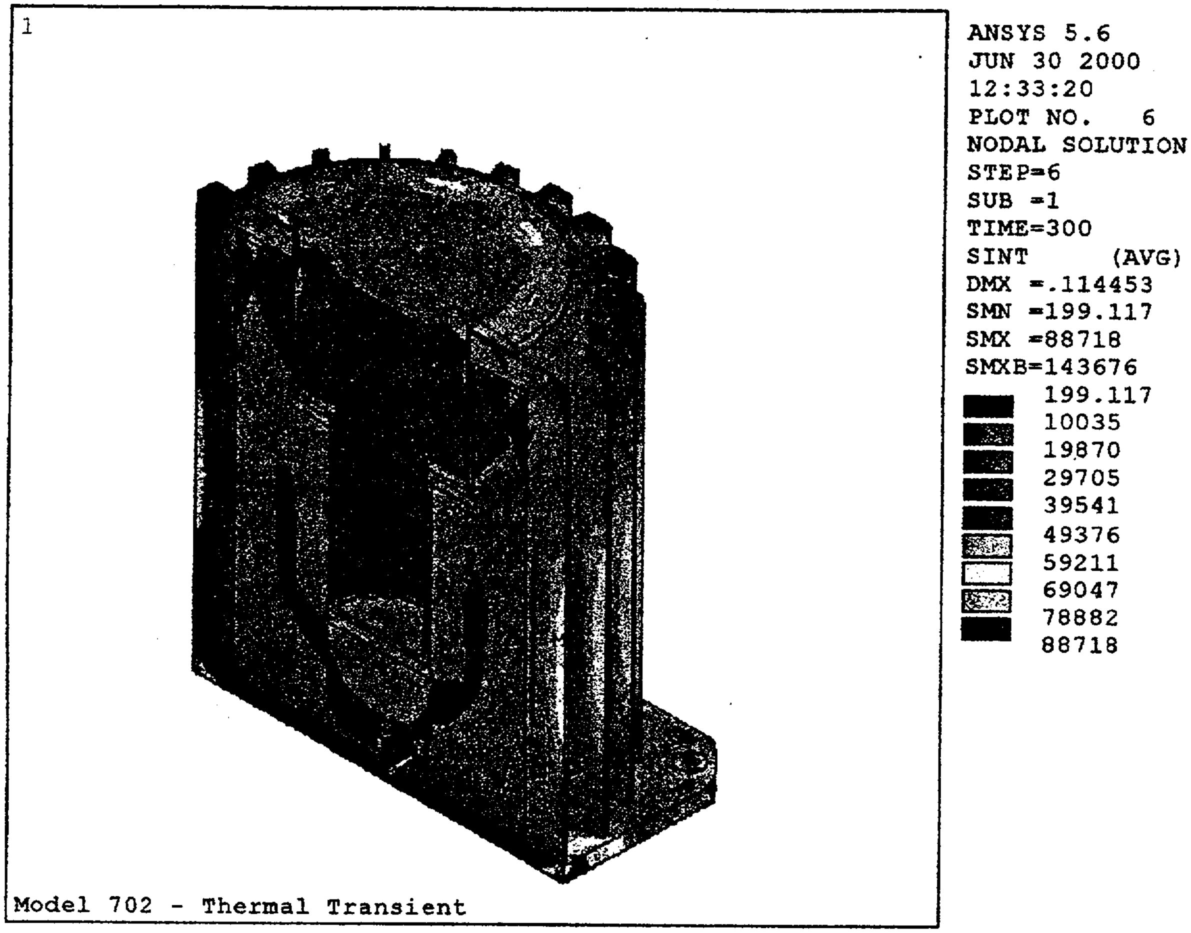

Figure 20: Stress Intensity Profile at 5 Minutes

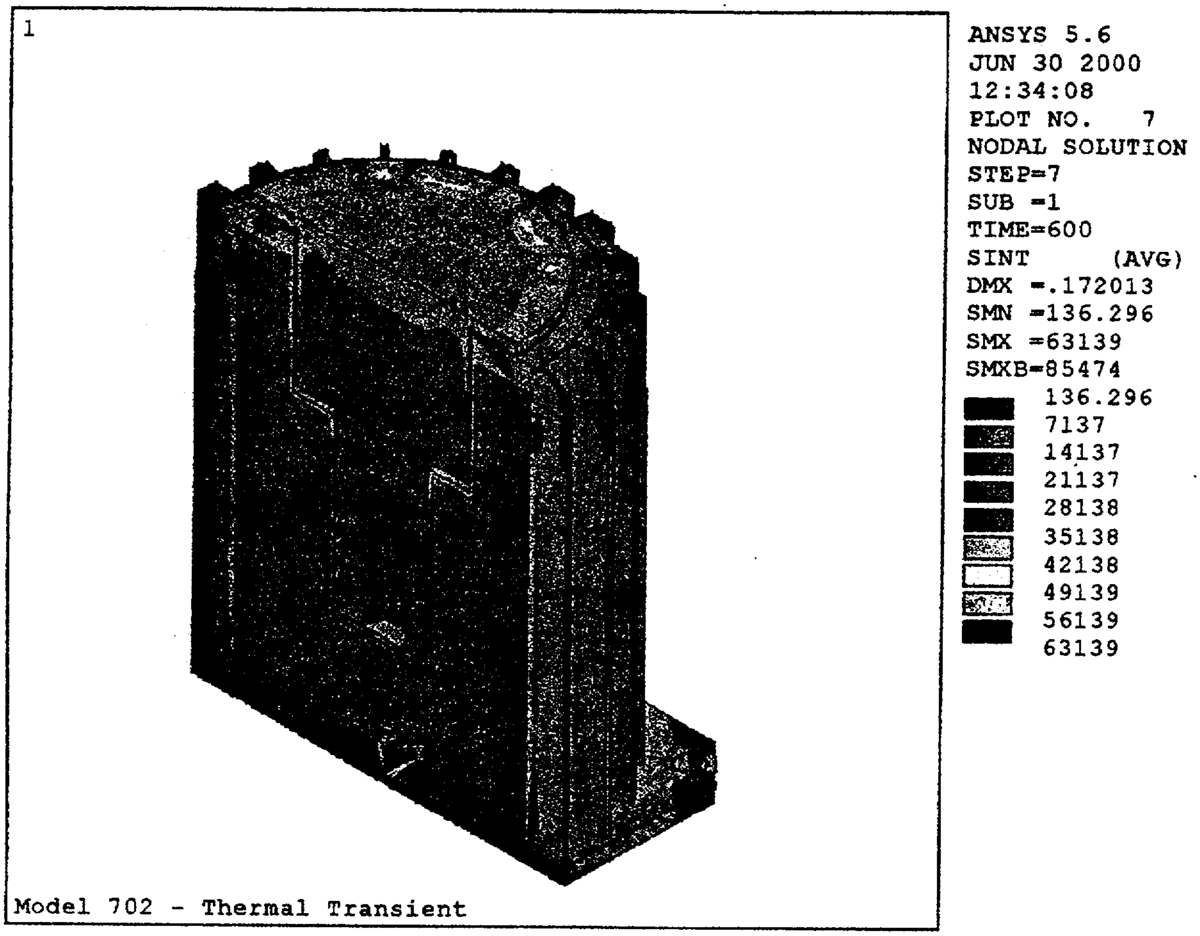

Figure 21: Stress Intensity Profile at 10 Minutes

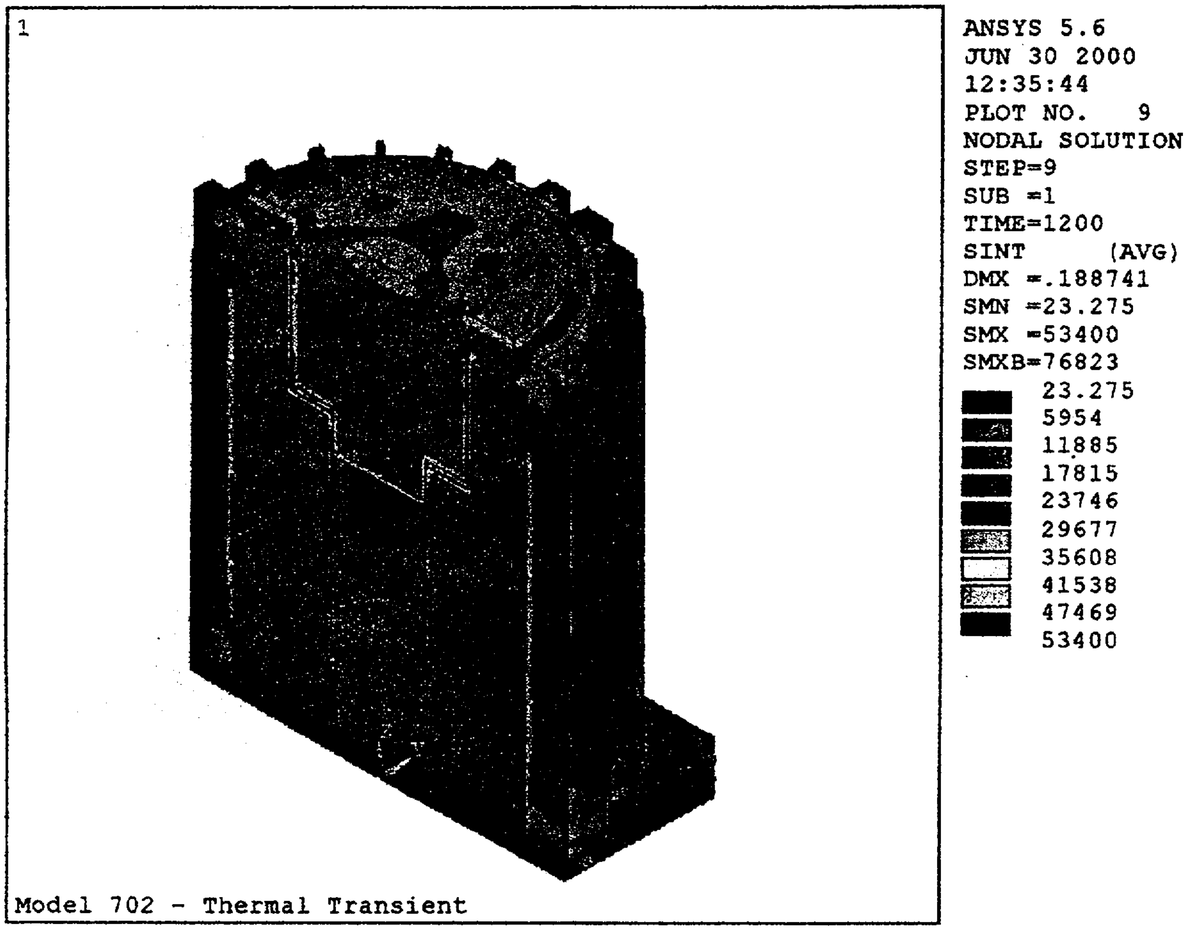

Figure 22: Stress Intensity Profile at 20 Minutes

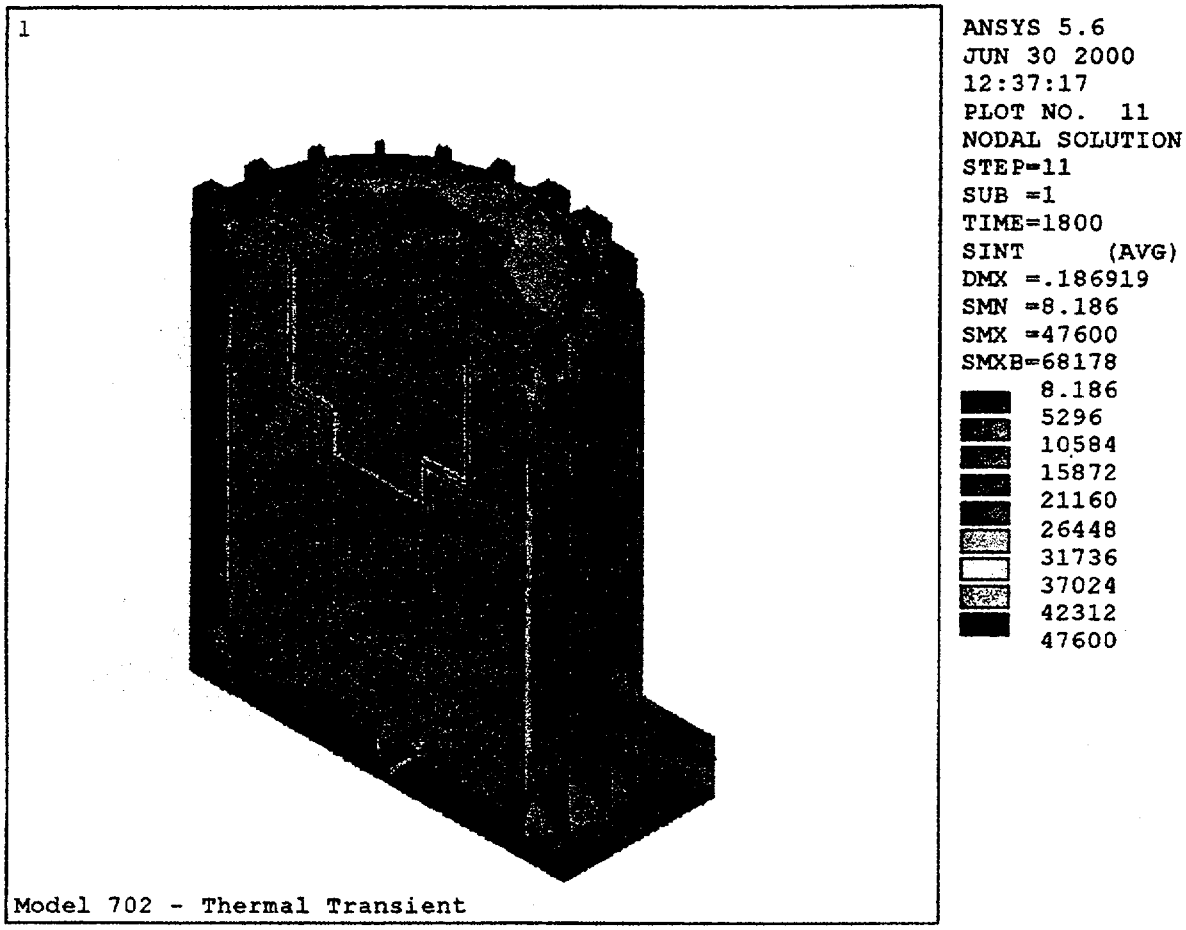

Figure 23: Stress Intensity Profile at 30 Minutes

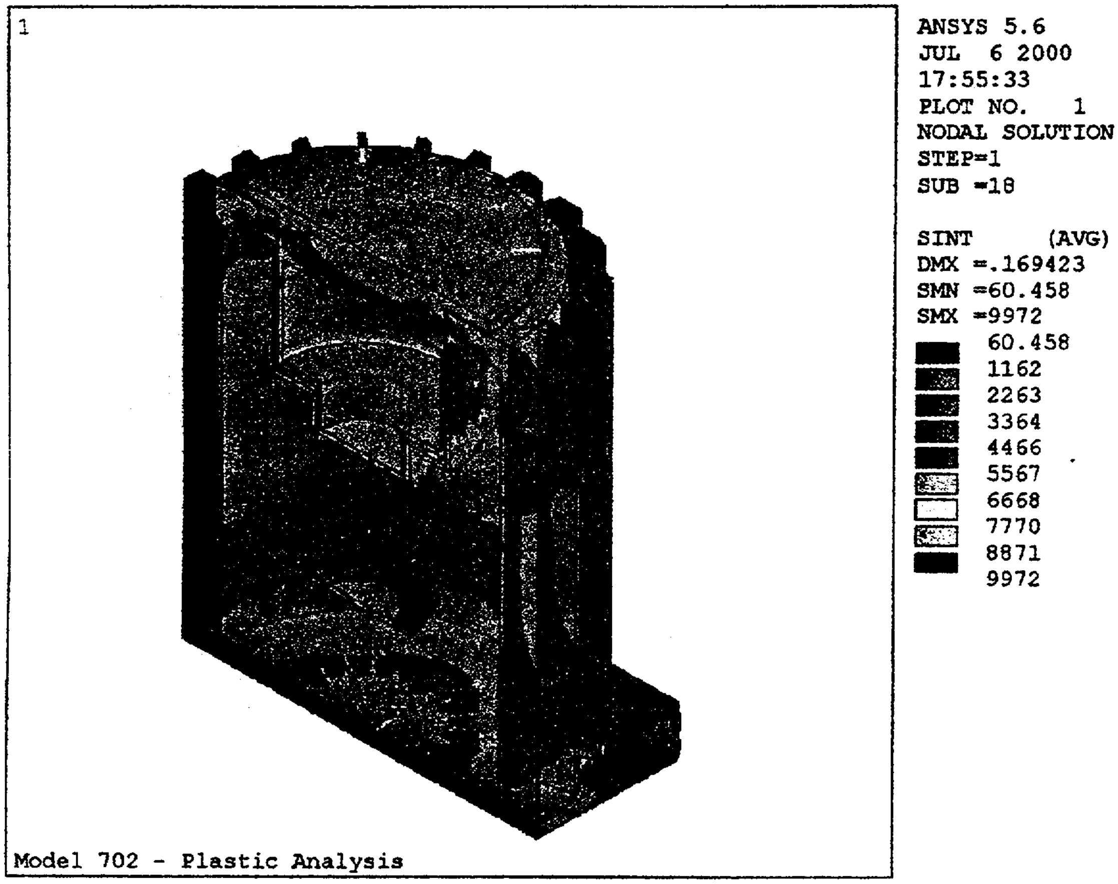

Figure 24: Stress Intensity Profile at 30 Minutes – Elastic Plastic

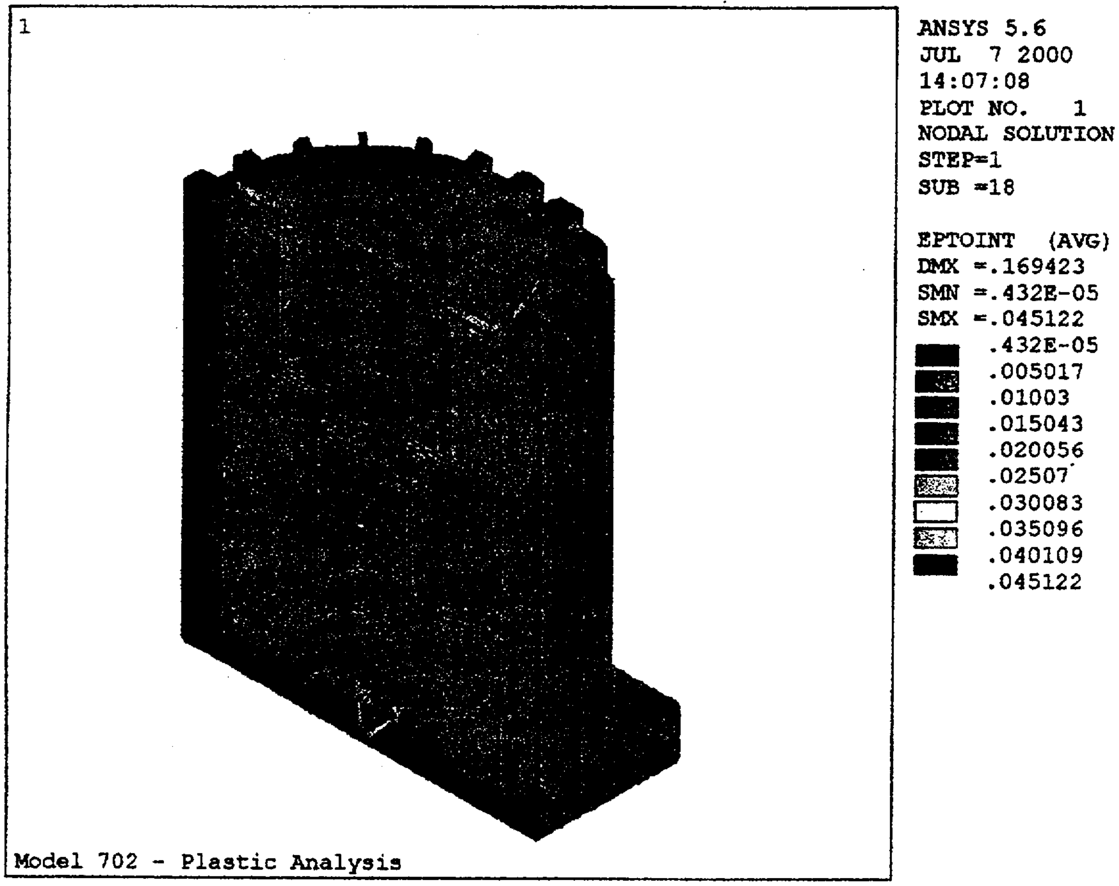

Figure 25: Strain Profile at 30 Minutes – Elastic Plastic

Attachment 1: Geometric Keypoint Coordinates

```
 LIST ALL SELECTED KEYPOINTS.   DSYS=    0

   NO. X,Y,Z LOCATION                      KESIZE      NODE  ELEM MAT  REAL TYP  ESYS
    2     0.          0.          0.         0.        3685     0   0     0   0     0
    4   4.50          0.          0.       0.300       3923     0   0     0   0     0
    5     0.          0.       0.375         0.        2661     0   0     0   0     0
    6   4.50          0.       0.375       0.300       3929     0   0     0   0     0
   10   3.50          0.          0.         0.        3418     0   0     0   0     0
   12   3.50          0.       0.375         0.        2801     0   0     0   0     0
   16   2.27          0.          0.         0.        3446     0   0     0   0     0
   18   2.27          0.       0.375         0.        2788     0   0     0   0     0
   22   1.27          0.          0.         0.        3605     0   0     0   0     0
   24   1.27          0.       0.375         0.        2662     0   0     0   0     0
   27   3.72          0.          0.       0.300       3087     0   0     0   0     0
   28   3.54          0.          0.       0.300       3088     0   0     0   0     0
   31   3.72          0.        10.6         0.        6543     0   0     0   0     0
   38   3.54          0.        10.6         0.       10391     0   0     0   0     0
   39   3.72          0.       0.438         0.        6589     0   0     0   0     0
   40   3.54          0.       0.438         0.        2349     0   0     0   0     0
   43   3.72          0.        9.81         0.        6551     0   0     0   0     0
   46   3.54          0.        9.81         0.        2440     0   0     0   0     0
   47     0.          0.       0.438         0.           1     0   0     0   0     0
   48   3.50  -0.563E-15       0.438         0.         841     0   0     0   0     0

   NO. X,Y,Z LOCATION                      KESIZE      NODE  ELEM MAT  REAL TYP  ESYS
   51   3.72          0.        6.88         0.        6567     0   0     0   0     0
   54   3.54          0.        6.88         0.        2531     0   0     0   0     0
   55   3.72          0.       0.375       0.300       3090     0   0     0   0     0
   56   3.54          0.       0.375       0.300       3092     0   0     0   0     0
   59   3.72          0.        2.69         0.        6587     0   0     0   0     0
   62   3.54          0.        2.69         0.        2362     0   0     0   0     0
   63   3.72          0.        2.90         0.        6585     0   0     0   0     0
   64   3.54          0.        2.90         0.        2648     0   0     0   0     0
   67   3.72          0.        3.02         0.        6569     0   0     0   0     0
   70   3.54          0.        3.02         0.        2518     0   0     0   0     0
   71   3.72          0.        7.06         0.        6565     0   0     0   0     0
   72   3.54          0.        7.06         0.        2635     0   0     0   0     0
   75   3.72          0.        7.18         0.        6553     0   0     0   0     0
   78   3.54          0.        7.18         0.        2427     0   0     0   0     0
  121   3.50  -0.563E-15        2.69         0.         842     0   0     0   0     0
  125     0.          0.        2.69         0.         193     0   0     0   0     0
  128   4.12          0.        10.6         0.        6539     0   0     0   0     0
  129   4.50          0.        10.2         0.        6489     0   0     0   0     0
  242   1.27  -0.204E-15       0.438         0.           2     0   0     0   0     0
  244   3.50  -0.563E-15        6.88         0.        1492     0   0     0   0     0

   NO. X,Y,Z LOCATION                      KESIZE      NODE  ELEM MAT  REAL TYP  ESYS
  247   1.27  -0.204E-15        6.88         0.        2141     0   0     0   0     0
  248   3.50  -0.563E-15        2.90         0.        1556     0   0     0   0     0
  249   1.27  -0.204E-15        2.90         0.        2089     0   0     0   0     0
  252   3.50  -0.563E-15        3.02         0.        1777     0   0     0   0     0
  255   1.27  -0.204E-15        3.02         0.        2117     0   0     0   0     0
  256   2.27  -0.365E-15       0.438         0.         763     0   0     0   0     0
  258   3.50  -0.563E-15        9.81         0.        1127     0   0     0   0     0
  261   2.27  -0.365E-15        9.81         0.        1133     0   0     0   0     0
  262   3.50  -0.563E-15        7.06         0.        1439     0   0     0   0     0
```

```
 263   2.27      -0.365E-15   7.06         0.       1440     0    0     0    0     0
 266   3.50      -0.563E-15   7.18         0.       1075     0    0     0    0     0
 269   2.27      -0.365E-15   7.18         0.       1091     0    0     0    0     0
 271   1.27      -0.204E-15   2.69         0.        133     0    0     0    0     0
 272   2.27      -0.365E-15   2.69         0.        781     0    0     0    0     0
 274   2.27      -0.365E-15   6.88         0.       1507     0    0     0    0     0
 276   2.27      -0.365E-15   2.90         0.       1544     0    0     0    0     0
 278   2.27      -0.365E-15   3.02         0.       1681     0    0     0    0     0
 280    0.          0.        2.90         0.      13878     0    0     0    0     0
 281   1.24      -0.200E-15   2.90         0.       2853     0    0     0    0     0
 283   1.24      -0.200E-15   3.02         0.       2867     0    0     0    0     0

  NO. X,Y,Z LOCATION                     KESIZE      NODE  ELEM MAT  REAL  TYP ESYS
 285    0.          0.        3.02         0.      13848     0    0     0    0     0
 286   1.12      -0.181E-15   2.90         0.      13880     0    0     0    0     0
 288   1.24      -0.200E-15   7.18         0.      13512     0    0     0    0     0
 291   1.12      -0.181E-15   7.18         0.      14011     0    0     0    0     0
 292   1.24      -0.200E-15   6.88         0.       2879     0    0     0    0     0
 295   1.12      -0.181E-15   6.88         0.      13625     0    0     0    0     0
 296   2.25      -0.361E-15   7.06         0.       2983     0    0     0    0     0
 297   1.12      -0.181E-15   7.06         0.      13973     0    0     0    0     0
 300   2.25      -0.361E-15   7.18         0.       2997     0    0     0    0     0
 302   2.14      -0.344E-15   7.06         0.      13439     0    0     0    0     0
 304   2.25      -0.361E-15   10.6         0.      13022     0    0     0    0     0
 307   2.14      -0.344E-15   10.6         0.      13058     0    0     0    0     0
 308   2.25      -0.361E-15   9.81         0.       3009     0    0     0    0     0
 311   2.14      -0.344E-15   9.81         0.      13182     0    0     0    0     0
 312   3.72      -0.598E-15   10.0         0.       6549     0    0     0    0     0
 313   2.14      -0.344E-15   10.0         0.      14096     0    0     0    0     0
 316   2.75      -0.442E-15   10.0         0.      10455     0    0     0    0     0
 318   2.75      -0.442E-15   10.6         0.      13002     0    0     0    0     0
 323   3.54         0.        10.1         0.      10435     0    0     0    0     0
 328   3.72      -0.598E-15   10.1         0.       6545     0    0     0    0     0

  NO. X,Y,Z LOCATION                     KESIZE      NODE  ELEM MAT  REAL  TYP ESYS
 329   2.14      -0.344E-15   10.1         0.      13067     0    0     0    0     0
 333   1.12      -0.181E-15   3.02         0.      13627     0    0     0    0     0
 334   1.24      -0.200E-15   7.06         0.      13440     0    0     0    0     0
 336   2.14      -0.344E-15   7.18         0.      13184     0    0     0    0     0
 339   2.25      -0.361E-15   10.1         0.      13026     0    0     0    0     0
 343   2.75      -0.442E-15   10.1         0.      10451     0    0     0    0     0
 349   2.25      -0.361E-15   10.0         0.      13146     0    0     0    0     0
 352   3.54         0.        10.0         0.      10457     0    0     0    0     0
 379    0.          0.        6.31         0.      20023     0    0     0    0     0
 380   1.11      -0.179E-15   6.31         0.      20278     0    0     0    0     0
 382   1.11      -0.179E-15   6.43         0.      20266     0    0     0    0     0
 384    0.          0.        6.43         0.      20030     0    0     0    0     0
 385    0.          0.        10.3         0.      19787     0    0     0    0     0
 386  0.990      -0.159E-15   6.31         0.      20102     0    0     0    0     0
 388  0.990      -0.159E-15   6.43         0.      20096     0    0     0    0     0
 390   2.12      -0.341E-15   10.3         0.      20214     0    0     0    0     0
 392   1.02      -0.164E-15   6.31         0.      20279     0    0     0    0     0
 394   2.12      -0.341E-15   10.9         0.      21009     0    0     0    0     0
 395   1.11      -0.179E-15   7.43         0.      20336     0    0     0    0     0
 398   1.02      -0.164E-15   7.43         0.      20318     0    0     0    0     0

  NO. X,Y,Z LOCATION                     KESIZE      NODE  ELEM MAT  REAL  TYP ESYS
```

```
 400     0.          0.          10.9        0.      20876    0    0     0    0     0
 401     0.          0.          10.7        0.      19986    0    0     0    0     0
 402   3.25      -0.523E-15      10.7        0.      20971    0    0     0    0     0
 403   1.11      -0.179E-15      6.44        0.      20408    0    0     0    0     0
 406   1.02      -0.164E-15      6.44        0.      20414    0    0     0    0     0
 407   2.12      -0.341E-15      7.31        0.      20382    0    0     0    0     0
 408   1.02      -0.164E-15      7.31        0.      20324    0    0     0    0     0
 411   2.12      -0.341E-15      7.43        0.      20370    0    0     0    0     0
 414   3.25      -0.523E-15      10.9        0.      20989    0    0     0    0     0
 415   2.00      -0.321E-15      7.31        0.      20474    0    0     0    0     0
 419   2.00      -0.321E-15      7.43        0.      20486    0    0     0    0     0
 422   2.75      -0.442E-15      10.7        0.      20977    0    0     0    0     0
 424   2.02      -0.325E-15      7.31        0.      20383    0    0     0    0     0
 426   2.75      -0.442E-15      10.9        0.      20983    0    0     0    0     0
 427     0.          0.          9.70        0.      19793    0    0     0    0     0
 428   2.12      -0.341E-15      9.70        0.      20694    0    0     0    0     0
 430   2.02      -0.325E-15      10.9        0.      21027    0    0     0    0     0
 433   2.02      -0.444E-15      10.7        0.      20226    0    0     0    0     0
 435   2.12      -0.341E-15      7.45        0.      20588    0    0     0    0     0
 438   2.02      -0.325E-15      7.45        0.      20618    0    0     0    0     0

  NO.  X,Y,Z LOCATION                      KESIZE      NODE   ELEM  MAT  REAL  TYP  ESYS
 439   2.02      -0.444E-15      10.3        0.      20227    0    0     0    0     0
 443   2.12      -0.341E-15      9.69        0.      20582    0    0     0    0     0
 446   2.02      -0.325E-15      9.69        0.      20624    0    0     0    0     0
 447   1.02      -0.222E-15      6.43        0.      20272    0    0     0    0     0
 449   1.11      -0.222E-15      7.31        0.      20330    0    0     0    0     0
 451   2.02      -0.444E-15      7.43        0.      20376    0    0     0    0     0
 456   2.12      -0.444E-15      10.7        0.      20220    0    0     0    0     0
 459     0.          0.          6.44        0.      21073    0    0     0    0     0
 460  0.990      -0.159E-15      6.44        0.      21109    0    0     0    0     0
 462  0.990      -0.222E-15      10.3        0.      19835    0    0     0    0     0
 463   2.00      -0.321E-15      9.70        0.      20740    0    0     0    0     0
 465   2.00      -0.321E-15      10.9        0.      21040    0    0     0    0     0
 469  0.990      -0.159E-15      9.70        0.      19805    0    0     0    0     0
 471  0.990      -0.159E-15      10.9        0.      20913    0    0     0    0     0
 475   1.11      -0.179E-15      9.70        0.      20746    0    0     0    0     0
 477   1.11      -0.179E-15      10.9        0.      21046    0    0     0    0     0
 479  0.990      -0.222E-15      10.7        0.      20156    0    0     0    0     0
 483   2.00      -0.444E-15      10.7        0.      20674    0    0     0    0     0
 484   2.02      -0.222E-15      9.70        0.      20700    0    0     0    0     0
 486   2.00      -0.444E-15      10.3        0.      20668    0    0     0    0     0

  NO.  X,Y,Z LOCATION                      KESIZE      NODE   ELEM  MAT  REAL  TYP  ESYS
 488   1.11      -0.222E-15      10.3        0.      20758    0    0     0    0     0
 491   1.11      -0.222E-15      10.7        0.      20838    0    0     0    0     0
 494  0.990      -0.159E-15      9.69        0.      21146    0    0     0    0     0
 496     0.          0.          9.69        0.      21139    0    0     0    0     0
 497  0.990      -0.159E-15      7.31        0.      21241    0    0     0    0     0
 499     0.          0.          7.31        0.      21362    0    0     0    0     0
 500     0.          0.          7.45        0.      21422    0    0     0    0     0
 501   2.00      -0.321E-15      7.45        0.      21274    0    0     0    0     0
 503   2.00      -0.321E-15      9.69        0.      21215    0    0     0    0     0
 505   1.11      -0.179E-15      7.45        0.      21280    0    0     0    0     0
 507   1.11      -0.179E-15      9.69        0.      21209    0    0     0    0     0
 509  0.990      -0.111E-15      7.45        0.      21457    0    0     0    0     0
```

Attachment 2: Material Property Listing

The material properties listed in this appendix are based on linear interpolation of the available data and are judged to be the best material property data available. Initially, polynomial curve fits were used for the thermal transport properties (density, specific heat, and thermal conductivity) for uranium and copper. The results reported in this calculation are based on the curve fits which slightly under-predict the heat capacity of the material at lower temperatures. The impact of this modelling approach on the results was evaluated. It was determined that the use of the curve fits resulted in a maximum calculated elastic stress about 8% less than those calculated with linear interpolation of the data. A similar difference is expected for the strain results from the elastic-plastic analyses.

```
LIST MATERIALS       1 TO        4 BY        1
 PROPERTY= ALL

PROPERTY TABLE EX    MAT=        1  NUM. POINTS= 17
  TEMPERATURE       DATA    TEMPERATURE      DATA     TEMPERATURE      DATA
    70.000      0.28120E+08  200.00      0.27620E+08  300.00      0.27160E+08
    400.00      0.26640E+08  500.00      0.26070E+08  600.00      0.25440E+08
    700.00      0.24770E+08  800.00      0.24060E+08  900.00      0.23310E+08
    1000.0      0.22530E+08  1100.0      0.21720E+08  1200.0      0.20890E+08
    1300.0      0.20030E+08  1400.0      0.19170E+08  1500.0      0.18300E+08
    1600.0      0.17420E+08  1700.0      0.16540E+08

PROPERTY TABLE NUXY  MAT=        1  NUM. POINTS= 17
  TEMPERATURE       DATA    TEMPERATURE      DATA     TEMPERATURE      DATA
    70.000      0.26390      200.00      0.27110      300.00      0.27610
    400.00      0.28080      500.00      0.28510      600.00      0.28920
    700.00      0.29310      800.00      0.29700      900.00      0.30080
    1000.0      0.30460      1100.0      0.30860      1200.0      0.31270
    1300.0      0.31710      1400.0      0.32170      1500.0      0.32680
    1600.0      0.33240      1700.0      0.33840

PROPERTY TABLE ALPX  MAT=        1  NUM. POINTS= 17
  TEMPERATURE       DATA    TEMPERATURE      DATA     TEMPERATURE      DATA
    70.000      0.84810E-05  200.00      0.87860E-05  300.00      0.89980E-05
    400.00      0.91930E-05  500.00      0.93710E-05  600.00      0.95340E-05
    700.00      0.96840E-05  800.00      0.98230E-05  900.00      0.99510E-05
    1000.0      0.10070E-04  1100.0      0.10180E-04  1200.0      0.10290E-04
    1300.0      0.10390E-04  1400.0      0.10490E-04  1500.0      0.10590E-04
    1600.0      0.10690E-04  1700.0      0.10790E-04

PROPERTY TABLE DENS  MAT=        1  NUM. POINTS= 17
  TEMPERATURE       DATA    TEMPERATURE      DATA     TEMPERATURE      DATA
    70.000      0.29020      200.00      0.28900      300.00      0.28800
    400.00      0.28710      500.00      0.28620      600.00      0.28530
    700.00      0.28430      800.00      0.28340      900.00      0.28250
    1000.0      0.28150      1100.0      0.28060      1200.0      0.27970
    1300.0      0.27880      1400.0      0.27780      1500.0      0.27690
    1600.0      0.27600      1700.0      0.27500

PROPERTY TABLE KXX   MAT=        1  NUM. POINTS= 17
  TEMPERATURE       DATA    TEMPERATURE      DATA     TEMPERATURE      DATA
    70.000      0.19840E-03  200.00      0.21520E-03  300.00      0.22750E-03
    400.00      0.23950E-03  500.00      0.25110E-03  600.00      0.26240E-03
    700.00      0.27330E-03  800.00      0.28400E-03  900.00      0.29450E-03
    1000.0      0.30480E-03  1100.0      0.31490E-03  1200.0      0.32480E-03
    1300.0      0.33470E-03  1400.0      0.34450E-03  1500.0      0.35430E-03
    1600.0      0.36410E-03  1700.0      0.37390E-03

PROPERTY TABLE C     MAT=        1  NUM. POINTS= 17
  TEMPERATURE       DATA    TEMPERATURE      DATA     TEMPERATURE      DATA
    70.000      0.11410      200.00      0.12020      300.00      0.12410
    400.00      0.12740      500.00      0.13020      600.00      0.13260
    700.00      0.13470      800.00      0.13640      900.00      0.13800
    1000.0      0.13950      1100.0      0.14100      1200.0      0.14260
    1300.0      0.14430      1400.0      0.14620      1500.0      0.14850
    1600.0      0.15110      1700.0      0.15420

PROPERTY TABLE EMIS  MAT=        1  NUM. POINTS= 17
  TEMPERATURE       DATA    TEMPERATURE      DATA     TEMPERATURE      DATA
    70.000        1.0000     200.00        1.0000     300.00        1.0000
    400.00        1.0000     500.00        1.0000     600.00        1.0000
    700.00        1.0000     800.00        1.0000     900.00        1.0000
    1000.0        1.0000     1100.0        1.0000     1200.0        1.0000
    1300.0        1.0000     1400.0        1.0000     1500.0        1.0000
    1600.0        1.0000     1700.0        1.0000

PROPERTY TABLE REFT  MAT=        1  NUM. POINTS= 17
  TEMPERATURE       DATA    TEMPERATURE      DATA     TEMPERATURE      DATA
    70.000        70.000     200.00        70.000     300.00        70.000
    400.00        70.000     500.00        70.000     600.00        70.000
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    700.00      70.000      800.00      70.000      900.00      70.000
    1000.0      70.000      1100.0      70.000      1200.0      70.000
    1300.0      70.000      1400.0      70.000      1500.0      70.000
    1600.0      70.000      1700.0      70.000

PROPERTY TABLE EX    MAT=       2  NUM. POINTS= 12
  TEMPERATURE     DATA    TEMPERATURE     DATA    TEMPERATURE      DATA
    77.000     0.29500E+08  212.00      0.26100E+08  392.00      0.22200E+08
    572.00     0.18600E+08  752.00      0.14300E+08  932.00      0.10100E+08
    1112.0     0.57800E+07  1220.0      0.33700E+07  1231.0      0.57800E+07
    1292.0     0.50600E+07  1429.0      0.83900E+06  1472.0      0.83900E+06

PROPERTY TABLE NUXY  MAT=       2  NUM. POINTS= 17
  TEMPERATURE     DATA    TEMPERATURE     DATA    TEMPERATURE      DATA
    70.000     0.22000      200.00      0.22000      300.00      0.22000
    400.00     0.22000      500.00      0.22000      600.00      0.22000
    700.00     0.22000      800.00      0.22000      900.00      0.22000
    1000.0     0.22000      1100.0      0.22000      1200.0      0.22000
    1300.0     0.22000      1400.0      0.22000      1500.0      0.22000
    1600.0     0.22000      1700.0      0.22000

PROPERTY TABLE ALPX  MAT=       2  NUM. POINTS=  5
  TEMPERATURE     DATA    TEMPERATURE     DATA    TEMPERATURE      DATA
    77.000     0.66700E-05  1161.0      0.15600E-04  1341.0      0.15600E-04
    1656.0     0.11100E-04  2061.0      0.11100E-04

PROPERTY TABLE DENS  MAT=       2  NUM. POINTS= 17
  TEMPERATURE     DATA    TEMPERATURE     DATA    TEMPERATURE      DATA
    70.000     0.68910      200.00      0.68680      300.00      0.68500
    400.00     0.68320      500.00      0.68130      600.00      0.67920
    700.00     0.67690      800.00      0.67460      900.00      0.67210
    1000.0     0.66930      1100.0      0.66490      1200.0      0.66050
    1300.0     0.65600      1400.0      0.65220      1500.0      0.64860
    1600.0     0.64520      1700.0      0.64160

PROPERTY TABLE KXX   MAT=       2  NUM. POINTS= 17
  TEMPERATURE     DATA    TEMPERATURE     DATA    TEMPERATURE      DATA
    70.000     0.35710E-03  200.00      0.40210E-03  300.00      0.41600E-03
    400.00     0.43340E-03  500.00      0.45130E-03  600.00      0.47010E-03
    700.00     0.49320E-03  800.00      0.51780E-03  900.00      0.54180E-03
    1000.0     0.56120E-03  1100.0      0.56110E-03  1200.0      0.60400E-03
    1300.0     0.60370E-03  1400.0      0.60390E-03  1500.0      0.60450E-03
    1600.0     0.60490E-03  1700.0      0.60530E-03

PROPERTY TABLE C     MAT=       2  NUM. POINTS= 17
  TEMPERATURE     DATA    TEMPERATURE     DATA    TEMPERATURE      DATA
    70.000     0.27900E-01  200.00      0.29100E-01  300.00      0.30100E-01
    400.00     0.31500E-01  500.00      0.32900E-01  600.00      0.34300E-01
    700.00     0.36200E-01  800.00      0.38100E-01  900.00      0.40000E-01
    1000.0     0.41600E-01  1100.0      0.41900E-01  1200.0      0.42100E-01
    1300.0     0.42400E-01  1400.0      0.42700E-01  1500.0      0.42900E-01
    1600.0     0.43200E-01  1700.0      0.43500E-01

PROPERTY TABLE EMIS  MAT=       2  NUM. POINTS= 17
  TEMPERATURE     DATA    TEMPERATURE     DATA    TEMPERATURE      DATA
    70.000      1.0000      200.00      1.0000      300.00      1.0000
    400.00      1.0000      500.00      1.0000      600.00      1.0000
    700.00      1.0000      800.00      1.0000      900.00      1.0000
    1000.0      1.0000      1100.0      1.0000      1200.0      1.0000
    1300.0      1.0000      1400.0      1.0000      1500.0      1.0000
    1600.0      1.0000      1700.0      1.0000

PROPERTY TABLE REFT  MAT=       2  NUM. POINTS= 17
  TEMPERATURE     DATA    TEMPERATURE     DATA    TEMPERATURE      DATA
    70.000      70.000      200.00      70.000      300.00      70.000
    400.00      70.000      500.00      70.000      600.00      70.000
    700.00      70.000      800.00      70.000      900.00      70.000
    1000.0      70.000      1100.0      70.000      1200.0      70.000
    1300.0      70.000      1400.0      70.000      1500.0      70.000
    1600.0      70.000      1700.0      70.000
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PROPERTY TABLE EX    MAT=        3  NUM. POINTS= 17
  TEMPERATURE      DATA     TEMPERATURE      DATA     TEMPERATURE       DATA
    70.000       1000.0       200.00       1000.0       300.00       1000.0
    400.00       1000.0       500.00       1000.0       600.00       1000.0
    700.00       1000.0       800.00       1000.0       900.00       1000.0
    1000.0       1000.0       1100.0       1000.0       1200.0       1000.0
    1300.0       1000.0       1400.0       1000.0       1500.0       1000.0
    1600.0       1000.0       1700.0       1000.0

PROPERTY TABLE NUXY  MAT=        3  NUM. POINTS= 17
  TEMPERATURE      DATA     TEMPERATURE      DATA     TEMPERATURE       DATA
    70.000      0.30800       200.00      0.30800       300.00      0.30800
    400.00      0.30800       500.00      0.30800       600.00      0.30800
    700.00      0.30800       800.00      0.30800       900.00      0.30800
    1000.0      0.30800       1100.0      0.30800       1200.0      0.30800
    1300.0      0.30800       1400.0      0.30800       1500.0      0.30800
    1600.0      0.30800       1700.0      0.30800

PROPERTY TABLE ALPX  MAT=        3  NUM. POINTS=  9
  TEMPERATURE      DATA     TEMPERATURE      DATA     TEMPERATURE       DATA
    68.000      0.92800E-05  171.00      0.96100E-05  261.00      0.97800E-05
    441.00      0.10170E-04  621.00      0.10500E-04  801.00      0.10890E-04
    981.00      0.11330E-04  1521.0      0.13110E-04  1701.0      0.13780E-04

PROPERTY TABLE DENS  MAT=        3  NUM. POINTS= 17
  TEMPERATURE      DATA     TEMPERATURE      DATA     TEMPERATURE       DATA
    70.000      0.32270       200.00      0.32150       300.00      0.32060
    400.00      0.31960       500.00      0.31870       600.00      0.31770
    700.00      0.31670       800.00      0.31570       900.00      0.31460
    1000.0      0.31360       1100.0      0.31240       1200.0      0.31120
    1300.0      0.31000       1400.0      0.30890       1500.0      0.30780
    1600.0      0.30670       1700.0      0.30560

PROPERTY TABLE KXX   MAT=        3  NUM. POINTS= 17
  TEMPERATURE      DATA     TEMPERATURE      DATA     TEMPERATURE       DATA
    70.000      0.55190E-02  200.00      0.51410E-02  300.00      0.51990E-02
    400.00      0.52560E-02  500.00      0.53770E-02  600.00      0.50360E-02
    700.00      0.50970E-02  800.00      0.51360E-02  900.00      0.46550E-02
    1000.0      0.46810E-02  1100.0      0.46530E-02  1200.0      0.46330E-02
    1300.0      0.46090E-02  1400.0      0.46480E-02  1500.0      0.47290E-02
    1600.0      0.42690E-02  1700.0      0.43440E-02

PROPERTY TABLE C     MAT=        3  NUM. POINTS= 17
  TEMPERATURE      DATA     TEMPERATURE      DATA     TEMPERATURE       DATA
    70.000      0.92000E-01  200.00      0.93800E-01  300.00      0.95100E-01
    400.00      0.96400E-01  500.00      0.99000E-01  600.00      0.10230
    700.00      0.10380       800.00      0.10500       900.00      0.10600
    1000.0      0.10700       1100.0      0.10680       1200.0      0.10670
    1300.0      0.10660       1400.0      0.10790       1500.0      0.11010
    1600.0      0.11230       1700.0      0.11460

PROPERTY TABLE EMIS  MAT=        3  NUM. POINTS= 17
  TEMPERATURE      DATA     TEMPERATURE      DATA     TEMPERATURE       DATA
    70.000       1.0000       200.00       1.0000       300.00       1.0000
    400.00       1.0000       500.00       1.0000       600.00       1.0000
    700.00       1.0000       800.00       1.0000       900.00       1.0000
    1000.0       1.0000       1100.0       1.0000       1200.0       1.0000
    1300.0       1.0000       1400.0       1.0000       1500.0       1.0000
    1600.0       1.0000       1700.0       1.0000

PROPERTY TABLE REFT  MAT=        3  NUM. POINTS= 17
  TEMPERATURE      DATA     TEMPERATURE      DATA     TEMPERATURE       DATA
    70.000       70.000       200.00       70.000       300.00       70.000
    400.00       70.000       500.00       70.000       600.00       70.000
    700.00       70.000       800.00       70.000       900.00       70.000
    1000.0       70.000       1100.0       70.000       1200.0       70.000
    1300.0       70.000       1400.0       70.000       1500.0       70.000
    1600.0       70.000       1700.0       70.000

PROPERTY TABLE EX    MAT=        4  NUM. POINTS= 17
  TEMPERATURE      DATA     TEMPERATURE      DATA     TEMPERATURE       DATA
```

```
    70.000      0.29000E+06  200.00      0.29000E+06  300.00      0.29000E+06
    400.00      0.29000E+06  500.00      0.29000E+06  600.00      0.29000E+06
    700.00      0.29000E+06  800.00      0.29000E+06  900.00      0.29000E+06
    1000.0      0.29000E+06  1100.0      0.29000E+06  1200.0      0.29000E+06
    1300.0      0.29000E+06  1400.0      0.29000E+06  1500.0      0.29000E+06
    1600.0      0.29000E+06  1700.0      0.29000E+06

PROPERTY TABLE NUXY  MAT=        4  NUM. POINTS= 17
  TEMPERATURE      DATA    TEMPERATURE      DATA    TEMPERATURE      DATA
    70.000      0.45000      200.00      0.45000      300.00      0.45000
    400.00      0.45000      500.00      0.45000      600.00      0.45000
    700.00      0.45000      800.00      0.45000      900.00      0.45000
    1000.0      0.45000      1100.0      0.45000      1200.0      0.45000
    1300.0      0.45000      1400.0      0.45000      1500.0      0.45000
    1600.0      0.45000      1700.0      0.45000

PROPERTY TABLE ALPX  MAT=        4  NUM. POINTS= 17
  TEMPERATURE      DATA    TEMPERATURE      DATA    TEMPERATURE      DATA
    70.000          0.       200.00          0.       300.00          0.
    400.00          0.       500.00          0.       600.00          0.
    700.00          0.       800.00          0.       900.00          0.
    1000.0          0.       1100.0          0.       1200.0          0.
    1300.0          0.       1400.0          0.       1500.0          0.
    1600.0          0.       1700.0          0.

PROPERTY TABLE DENS  MAT=        4  NUM. POINTS= 17
  TEMPERATURE      DATA    TEMPERATURE      DATA    TEMPERATURE      DATA
    70.000      0.43000E-01  200.00      0.43000E-01  300.00      0.43000E-01
    400.00      0.43000E-01  500.00      0.43000E-01  600.00      0.43000E-01
    700.00      0.43000E-01  800.00      0.43000E-01  900.00      0.43000E-01
    1000.0      0.43000E-01  1100.0      0.43000E-01  1200.0      0.43000E-01
    1300.0      0.43000E-01  1400.0      0.43000E-01  1500.0      0.43000E-01
    1600.0      0.43000E-01  1700.0      0.43000E-01

PROPERTY TABLE KXX   MAT=        4  NUM. POINTS= 17
  TEMPERATURE      DATA    TEMPERATURE      DATA    TEMPERATURE      DATA
    70.000      0.17390E-06  200.00      0.17390E-06  300.00      0.17390E-06
    400.00      0.17390E-06  500.00      0.17390E-06  600.00      0.17390E-06
    700.00      0.17390E-06  800.00      0.17390E-06  900.00      0.17390E-06
    1000.0      0.17390E-06  1100.0      0.17390E-06  1200.0      0.17390E-06
    1300.0      0.17390E-06  1400.0      0.17390E-06  1500.0      0.17390E-06
    1600.0      0.17390E-06  1700.0      0.17390E-06

PROPERTY TABLE C     MAT=        4  NUM. POINTS= 17
  TEMPERATURE      DATA    TEMPERATURE      DATA    TEMPERATURE      DATA
    70.000      0.48000      200.00      0.48000      300.00      0.48000
    400.00      0.48000      500.00      0.48000      600.00      0.48000
    700.00      0.48000      800.00      0.48000      900.00      0.48000
    1000.0      0.48000      1100.0      0.48000      1200.0      0.48000
    1300.0      0.48000      1400.0      0.48000      1500.0      0.48000
    1600.0      0.48000      1700.0      0.48000

PROPERTY TABLE EMIS  MAT=        4  NUM. POINTS= 17
  TEMPERATURE      DATA    TEMPERATURE      DATA    TEMPERATURE      DATA
    70.000        1.0000     200.00        1.0000     300.00        1.0000
    400.00        1.0000     500.00        1.0000     600.00        1.0000
    700.00        1.0000     800.00        1.0000     900.00        1.0000
    1000.0        1.0000     1100.0        1.0000     1200.0        1.0000
    1300.0        1.0000     1400.0        1.0000     1500.0        1.0000
    1600.0        1.0000     1700.0        1.0000

PROPERTY TABLE REFT  MAT=        4  NUM. POINTS= 17
  TEMPERATURE      DATA    TEMPERATURE      DATA    TEMPERATURE      DATA
    70.000        70.000     200.00        70.000     300.00        70.000
    400.00        70.000     500.00        70.000     600.00        70.000
    700.00        70.000     800.00        70.000     900.00        70.000
    1000.0        70.000     1100.0        70.000     1200.0        70.000
    1300.0        70.000     1400.0        70.000     1500.0        70.000
    1600.0        70.000     1700.0        70.000
```