AEA TECHNOLOGY

	TEST PLAN NO. 80 Rev.1
TEST PLAN COVER SHEET	
TEST TITLE: TEST PLAN 80, REVISION 1, MODEL 650L SOURCE CHANGER TYPE B TRANSPORT TESTS	
PRODUCT MODEL: 650L	
ORIGINATED BY: [signature] (MPR)	DATE: 12 MAR 99
TEST PLAN REVIEW	
ENGINEERING APPROVAL: Nicholas J. Mauros	DATE: 12 MAR 99
QUALITY ASSURANCE APPROVAL: Daniel W. Kurtz	DATE: 12 Mar 99
REGULATORY APPROVAL: Catalin Rongman	DATE: 12 Mar 99
COMMENTS:	
TEST RESULTS REVIEW	
ENGINEERING APPROVAL: [signature]	DATE: 17 JUL 99
QUALITY ASSURANCE APPROVAL: Daniel W. Kurtz	DATE: 13 Jul 99
REGULATORY APPROVAL: C. Rongman	DATE: 13 Jul 99

SENTINEL

TEST PLAN 80 REPORT

MODEL 650L

June 1999

Prepared By: Laura Ridzon Date: 28 JUN 99
Laura Ridzon, MPR Associates, Inc.

Reviewed By: Nicholas J. Marrone Date: 28 June 99
Nicholas J. Marrone, MPR Associates, Inc.

Approved By: Caroline S. Schlaseman Date: 28 JUN 99
Caroline S. Schlaseman, MPR Associates, Inc.

AEA Technology QSA, Inc.
Burlington, MA

TABLE OF CONTENTS

APPENDICES

1. PURPOSE

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

2. SCOPE OF TESTING

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

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

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

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

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

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

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

3. FAILURE MODES

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

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

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

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

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

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

In selecting test units for the thermal test, it was concluded that an undamaged unit would not be significantly affected by exposure to the conditions of the thermal test. In particular, for an undamaged unit, the depleted uranium shield would still be completely enclosed within the inner and outer shells and be supported by foam and a shim of either copper, steel, or lead. Under the thermal test conditions, degradation of the foam and melting of the shim, if it is lead, will allow

the shield to move by a small amount. This could result in limited movement of the source relative to the shield, but not enough to significantly increase radiation levels.

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

4. TEST UNIT DESCRIPTION

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

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

Important features of the test unit construction include the following:

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

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

5. SUMMARY AND CONCLUSIONS

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

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

Notes:

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

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

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

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

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

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

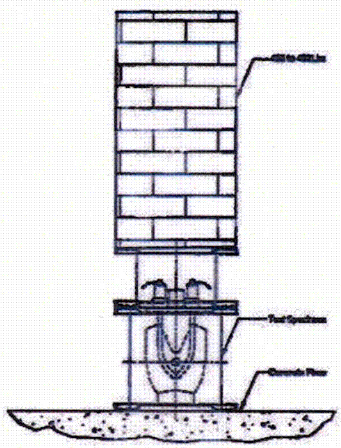
The only significant damage to any unit was the cracked shell in specimen TP80(B). Because of this crack, the depleted uranium shield was exposed to air during the thermal test, and portions of the shield near the crack opening were oxidized. In addition, after the lead shim melted, the shield was free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

6. TP80 NORMAL TESTS

<u>Compression Test</u>

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

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



Compression Test Orientation – All Specimens

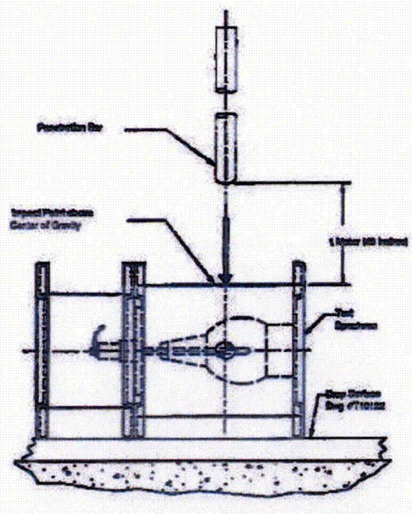
After a period of 24 hours, the weights were removed. No visible deformation or buckling occurred and no other damage was observed for any of the test specimens.

Penetration Test

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

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

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



Penetration Test Orientation – All Specimens

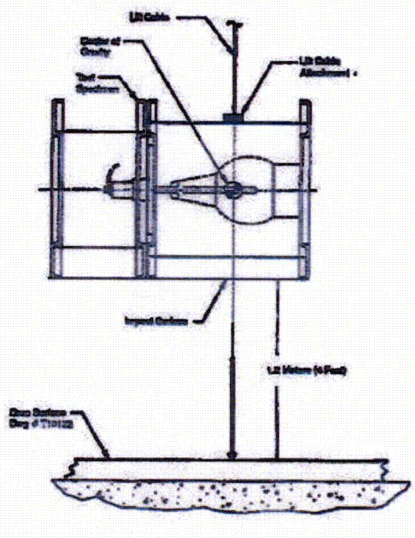
The penetration bar was dropped from a height of at least 1 meter (40 inches) above the impact point. The bar hit as intended on each package, leaving a visible impact mark, but no other damage.

1.2 Meter (4 Foot) Drop Test

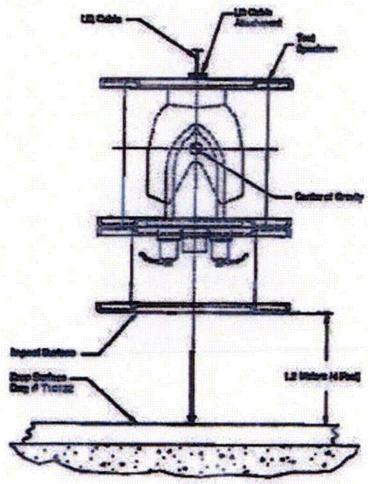
The three test specimens were then subjected to the 1.2 meter (4 foot) drop test. Temperature readings taken just before the test are summarized below.

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

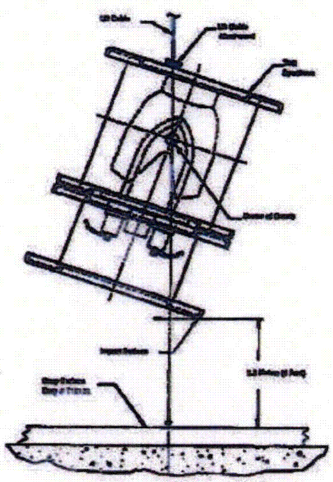
The drop orientations for each unit are shown below and on the next page. These orientations are the same as those used for each specimen in the 9 meter (30 foot) drop tests.



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



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



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

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

Post-Test Inspection and Assessment

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

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

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

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

7. TP80 ACCIDENT DROP TESTS – TP80(A)

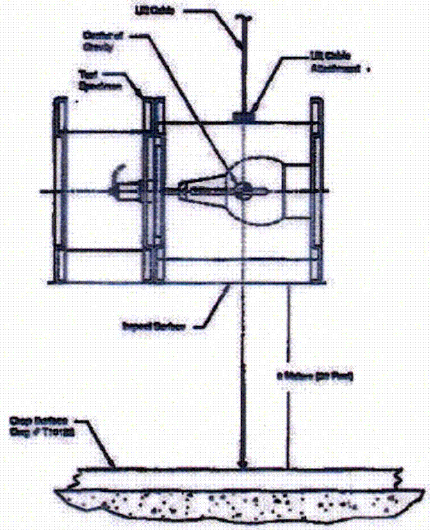
Specimen TP80(A) was subjected to a 9 meter (30 foot) drop test and a puncture test in accordance with Test Plan 80. The results are described below.

9 Meter (30 Foot) Drop Test

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

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

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

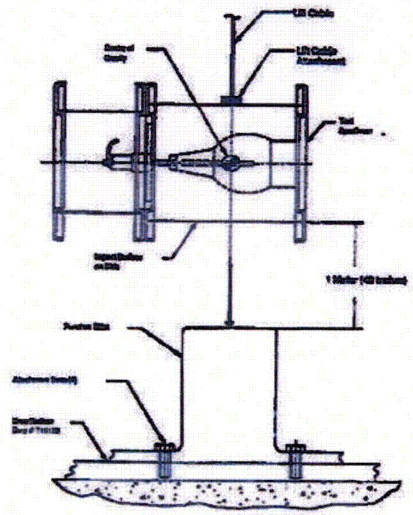


9 Meter (30 Foot) Drop Orientation for Specimen TP80(A)

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

Puncture Test

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



Puncture Drop Orientation for Specimen TP80(A)

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

Post-Test Inspection and Assessment

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

8. TP80 ACCIDENT DROP TESTS – TP80(B)

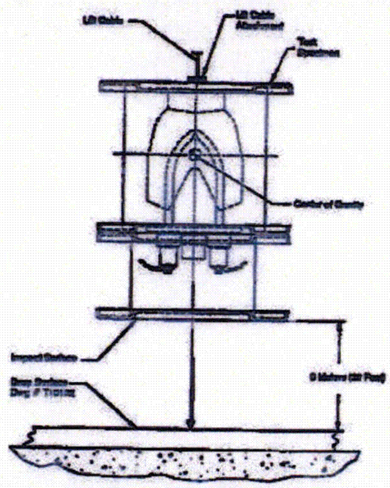
Specimen TP80(B) was subjected to a 9 meter (30 foot) drop test and a puncture test in accordance with Test Plan 80. The results are described below.

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

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

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

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



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

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

Puncture Test

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

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

Post-Test Inspection and Assessment

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

9. TP80 ACCIDENT DROP TESTS – TP80(C)

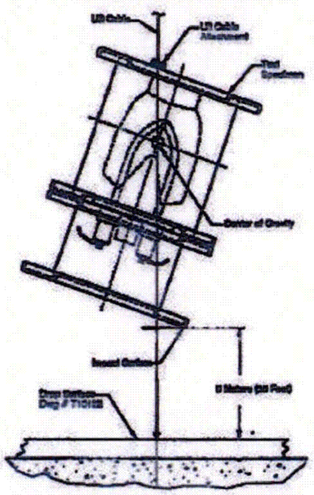
Specimen TP80(C) was subjected to a 9 meter (30 foot) drop test and a puncture test in accordance with Test Plan 80 and results are described below.

9 meter (30 Foot) Drop Test

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

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

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



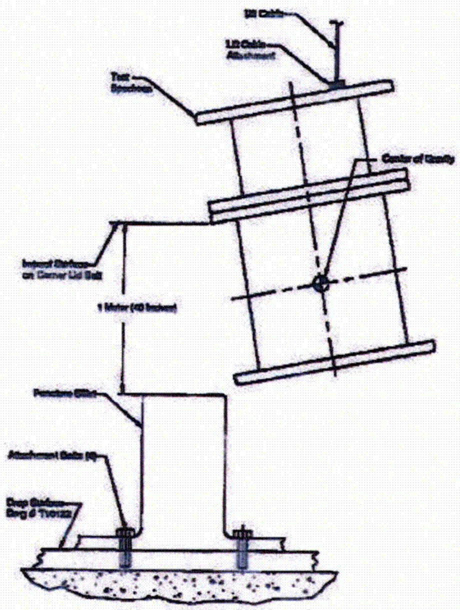
9 Meter (30 Foot) Drop Orientation for Specimen TP80(C)

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

Puncture Test

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

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



Second Puncture Drop Orientation for Specimen TP80(C)

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

Post-Test Inspection and Assessment

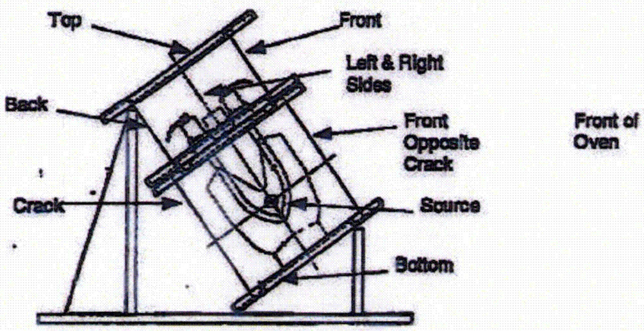
Following the test, the protective lid was removed and the unit was inspected. No damage to the locks was observed and no significant movement of the source was measured. The post-test radiation profile showed no significant change in radiation levels from the pre-test profile (see Appendix B). Because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

10. TP80 THERMAL TEST – TP80(B)

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

Orientation and Setup

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



TP80(B) Orientation and Thermocouple Locations

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

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

Test Chronology

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

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

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

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

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

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

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

Post-Test Inspection and Assessment

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

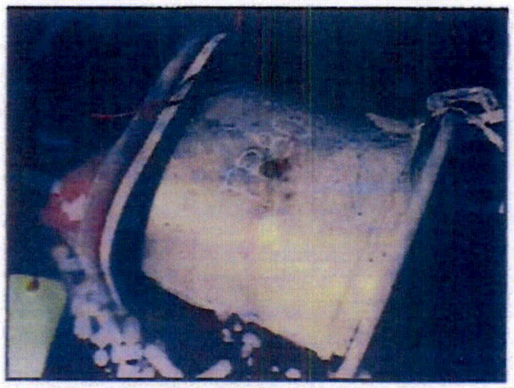
- A cracked piece of the inner shell was dislodged and had dropped out of position.
- Most paint had vaporized. Radiation labels were still legible.
- All the foam had burned off, leaving a small amount of carbon char.
- The lead shielding and shim melted and some lead had dripped out the bottom of the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

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

Test Plan 80 Photographs

Compression Test

Typical Penetration Test Setup

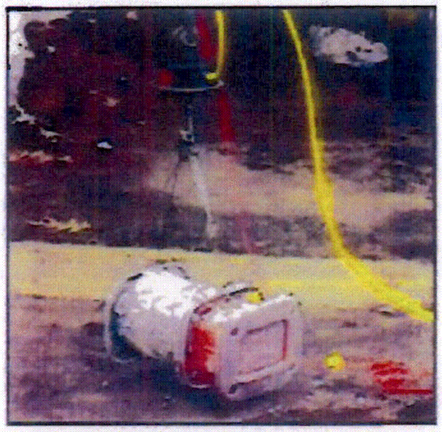


Typical Penetration Impact

Test Plan 80 Photographs

TP80(A) 4 Foot Drop Setup

TP80(A) 4 Foot Drop Results

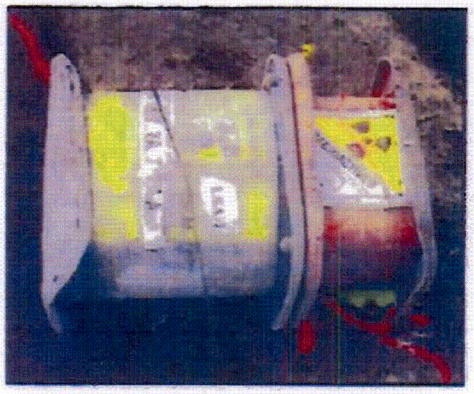


TP80(A) 30 Foot Drop Setup

TP80(A) 30 Foot Drop Results

Test Plan 80 Photographs

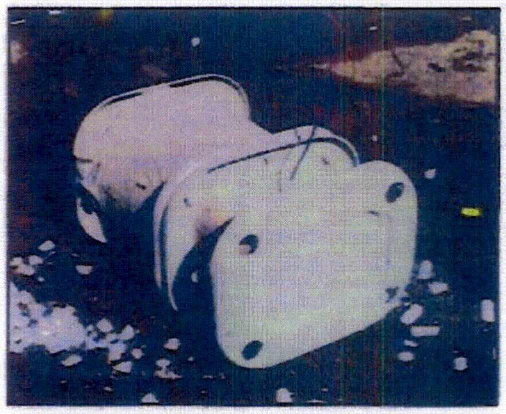
TP80(A) Puncture Test Setup



TP80(A) Puncture Test Results

Test Plan 80 Photographs

TP80(B) 4 Foot Drop Setup

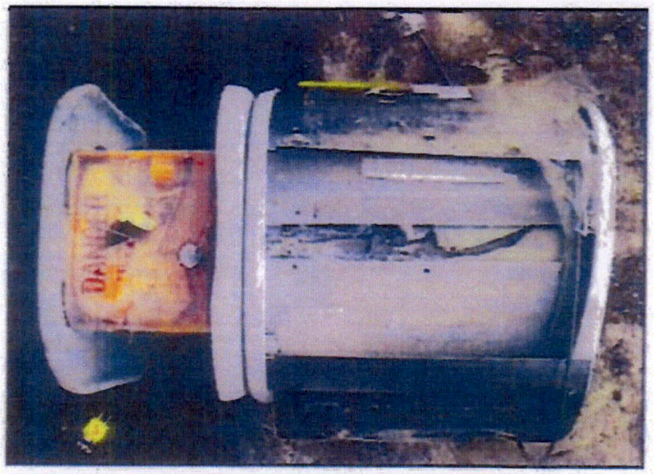


TP80(B) 4 Foot Drop Test Results

Test Plan 80 Photographs

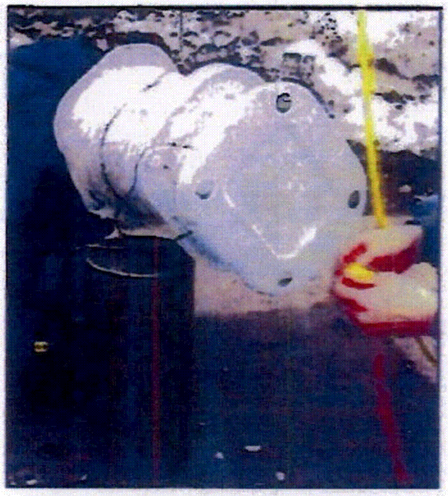
TP80(B) 30 Foot Drop Setup

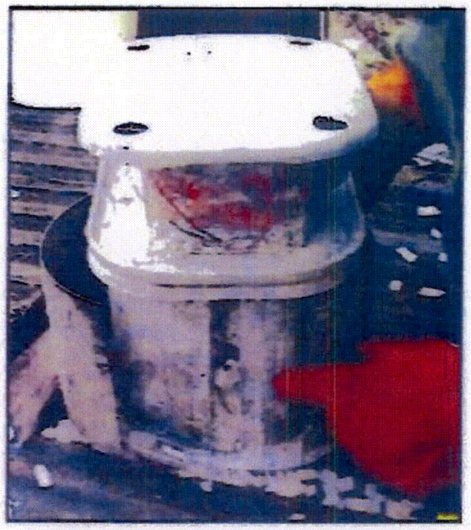
TP80(B) 30 Foot Drop Results



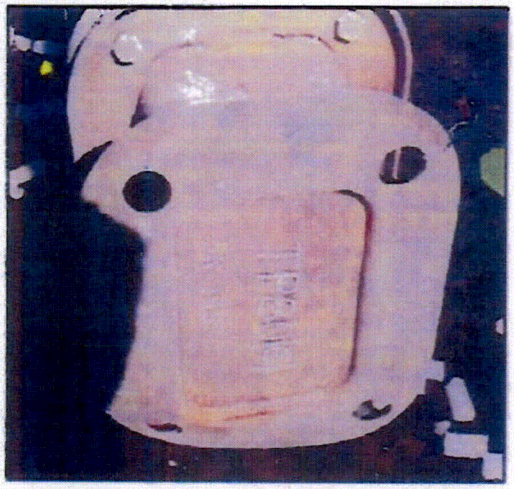
TP80(B) 30 Foot Drop Results

Test Plan 80 Photographs

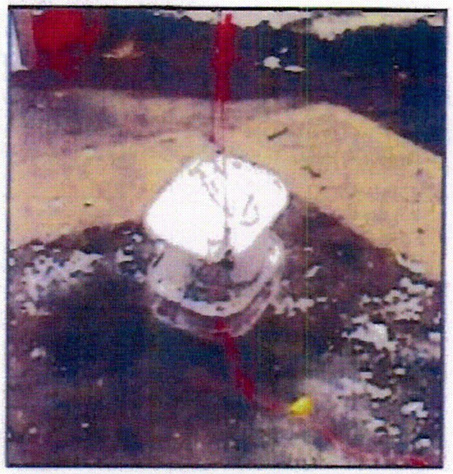

TP80(B) Puncture Test Setup


TP80(B) Puncture Test Results

Test Plan 80 Photographs



TP80(C) 4 Foot Drop Test Results



TP80(C) 30 Foot Drop Setup

TP80(C) 30 Foot Drop Results

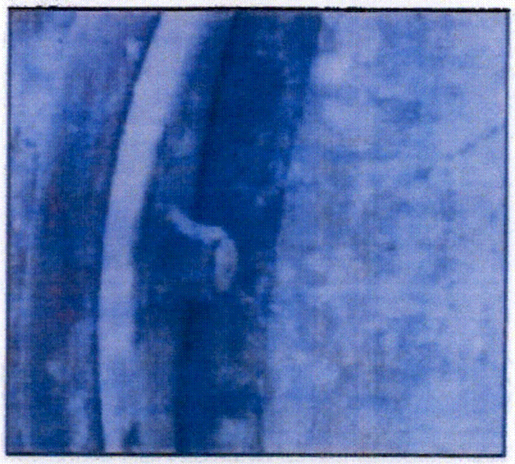
TP80(C) 30 Foot Drop Results

Test Plan 80 Photographs

TP80(C) Puncture Drop 1 Setup

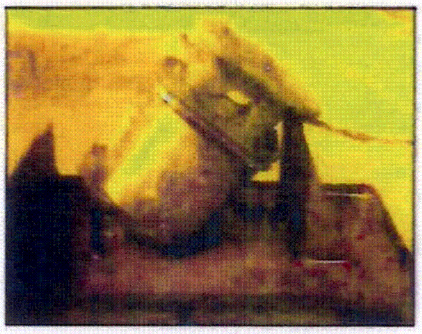
TP80(C) Puncture Drop 1 Results

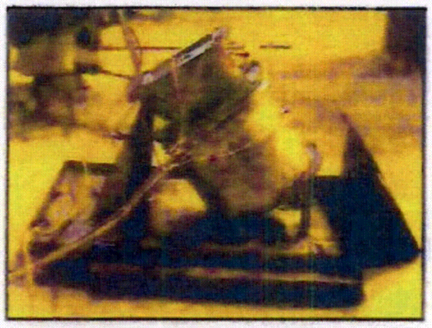
TP80(C) Puncture Drop 2 Setup



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

Test Plan 80 Photographs

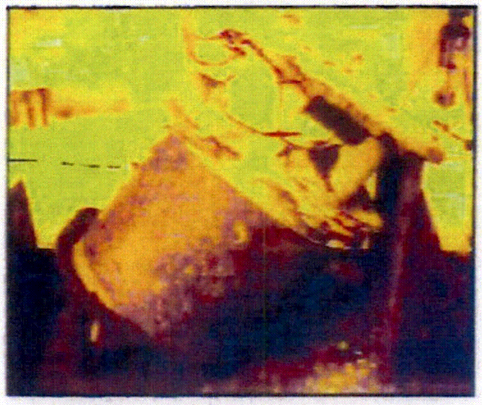

TP80(B) Thermal Test Setup


TP80(B) Thermal Test Setup


TP80(B) Thermal Test After Removal From Oven


TP80(B) Thermal Test After Removal From Oven

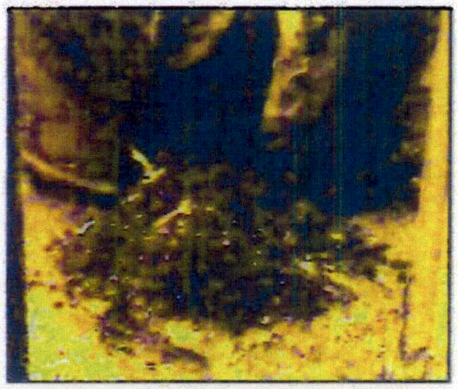
Test Plan 80 Photographs



TP80(B) Thermal Test After Removal From Oven

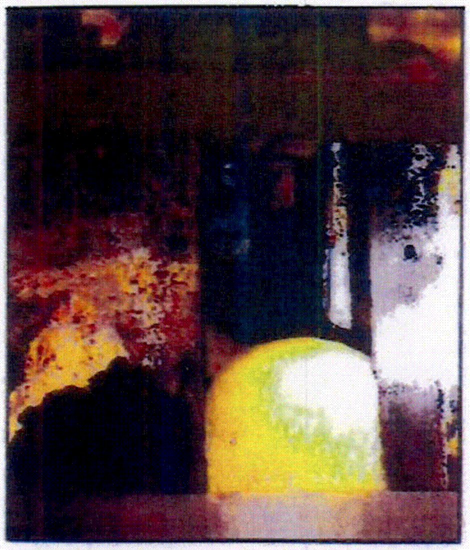
TP80(B) Detail of Cracked Shell

TP80(B) Detail of Uranium Oxide Residue

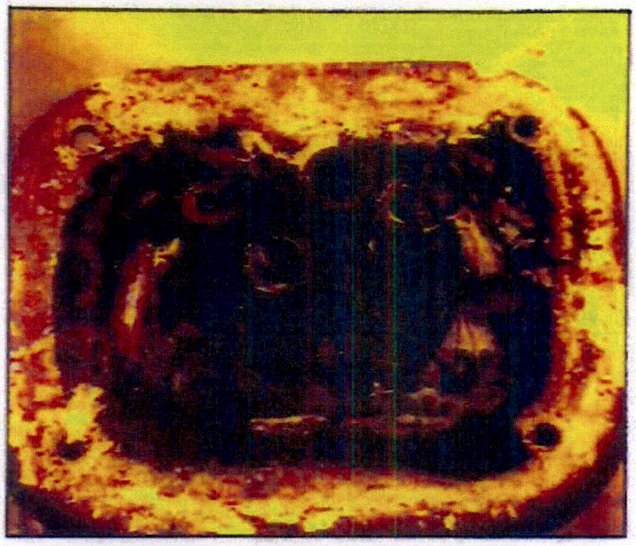


TP80(B) Detail of Uranium Oxide Residue

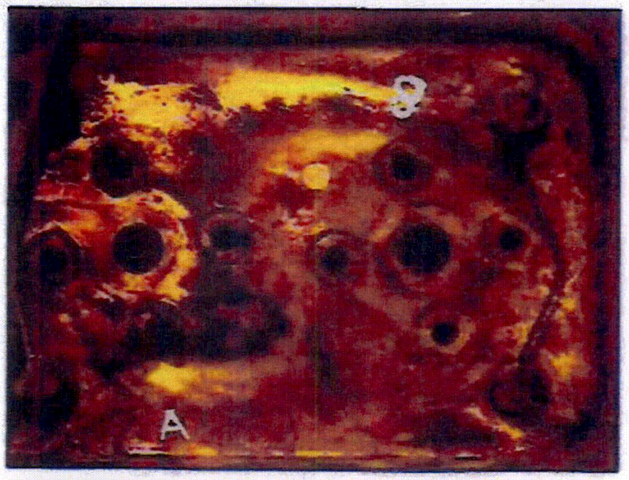
Test Plan 80 Photographs



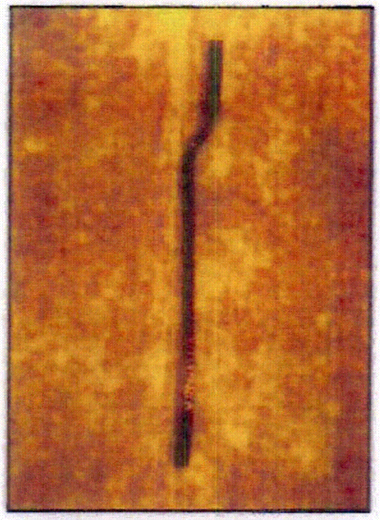
TP80(B) Thermal Test After Removal From Oven--Detail of Crack After Foaming to Stabilize Shield



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



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



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

Appendix D: Multiple Wire Locking Assembly

D.1 Background

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

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

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

D.2 Design Description

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

D.2.1 Standard Locking Assembly Design

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

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

D.2.2 Multiple Wire Locking Assembly Design

The main components of the multiple wire locking assembly are the base plate, base plate

adjustment shims, lock slide, key lock, and hold down cap, as shown in the drawings at the end of this appendix. All components are stainless steel, except for the brass key lock and guiding insert.

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

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

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

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

D.3.1 Weight and Center of Gravity

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

D.3.2 Positive Closure

The multiple wire locking assembly, which secures the source assembly in the shielded position and assures positive closure, cannot be exposed without first removing the top lid of the source changer. After removal of the seal-wired lid, the hold down cap must be removed, the key lock unlocked, and the lock slide moved to the unlocked position before the source wire can be removed from the source changer. When the lock slide is in the

locked position, the stop ball on the source wire is contained within the 1/2 inch vertical cavity in the lock slide by the slots in the top and bottom of the slide.

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

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

D.3.3 Normal Conditions of Transport Tests

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

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

D.3.4 Hypothetical Accident Condition Tests

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

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

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

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

These potential damage mechanisms are discussed below.

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

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

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

D.4 Conclusion

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

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

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

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

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

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

1. Source Identification - QSA Global, Inc. Models 60011, 60012, and 60013.

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

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

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

5. Expiration Date - This certificate expires on February 28, 2016.

---

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

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

CERTIFICATE USA/0377/S-96, REVISION 8

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

Certified By:

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

Feb 18 2011
(DATE)

Revision 8 - Issued to extend the expiration date.

Security-Related Information Figure
Withheld Under 10 CFR 2.390

Tech/Ops

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

DWG TITLE			
COBALT 60 SOURCE REFERENCE			
CLASSIFICATION	SIZE A	DWG. NO. 60060	REV. B
SCALE 2:1		SHEET 2 OF 3	

2.12.8 Test Plan 79 Report dated 22 October 1998