Safety Analysis Report

Model 650L
Source Changer,
Type B(U)
Transport Package

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Contents

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Section 1 - GENERAL INFORMATION

1.1 Introduction

The Model 650L is designed for use as a source changer and shipping container for Type B quantities of radioactive material in special form. The Model 650L source changer conforms to the criteria for Type B(U) packaging and transportation of radioactive materials in accordance with the Code of Federal Regulations, 10 CFR Part 71, revised as of January 1, 1997, and the IAEA Regulations for the Safe Transport of Radioactive Material, Safety Series No. 6, 1985 Edition (As Amended 1990).

The Model 650L source changer can be equipped with either the current (standard) lock assemblies or the multiple wire lock assemblies. The current lock assembly has been in use since 1995, and the testing performed in support of this safety analysis was performed using this lock assembly. A Model 650L source changer equipped with the multiple wire lock assembly is shown to satisfy the requirements for Type B(U) Transport Packages by comparison to the standard lock assembly. This evaluation is provided in Appendix D. 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).

1.2 Source Changer Description

The Model 650L is constructed in accordance with the descriptive assembly drawing R65006, shown in Appendix A. An overview of the source changer is provided in Sections 1.2.1 and 1.2.2.

1.2.1 Description of the Model 650L Source Changer

The Model 650L source changer is shown in Figure 1. The overall dimensions of the device are 13 1/4 inches (337 mm) high, 10 inches (254 mm) long, and 8 1/4 inches (210 mm) wide, with a maximum weight of 90 lb (41 kg). The source changer consists of the following major components:

- Source Capsule and Shield Assembly: The special form source capsule is shielded by a Titanium "U" tube set in depleted uranium (DU). The tube is crimped in the middle of the "U" to provide a positive stop for the source assembly. The "U" tube is cased inside a DU shield assembly. On some source changers, additional shielding is provided by lead positioned at various locations around the DU shield. The lead is secured with glass tape and held in position by rigid polyurethane foam.

- Inner and Outer Shells: The shield assembly is protected by two carbon steel shells. The inner shell is rectangular and the outer shell is cylindrical. The shells are positioned between two stainless steel top and bottom plates. The plates are secured with four stainless steel, 5/16-18 hex head through-bolts. All steel-uranium interfaces are separated with copper shims. The void between the DU shield and the inner and outer shells is filled with rigid 8 lb/cubic foot Polyurethane foam.

- Protective Lid: During transport, the locking assembly is protected by a carbon steel lid. The lid is secured to the top plate by four strain-hardened stainless steel, 3/8-16 hex head bolts. The lid is provided with a tamper-indication seal during shipment.

- Source Locking Assembly: Model 650L has two stainless steel and brass locking assemblies, which secure the source inside the shield. Each locking assembly is attached to the top plate by four 1/4-20 stainless steel screws.

1.2.2 Operational Features

The Model 650L has a stainless steel and brass locking assembly that secures the source inside the source tube within the shield. Currently, the lock assembly secures the source in the stored position by engaging the teleflex cable of the source by means of the lock slide. The source is also secured by the source hold down cap. When the source is secured, the lock slide is held in place with a key operated lock. Each lock assembly is bolted to the top plate by four 1/4-20 stainless steel screws. Two of the screws on each lock assembly are safety wired.

Operation of the multiple wire locking assembly is described in Appendix D.

1.3 Contents of Packaging

The Model 650L source changer is designed for the transport of Iridium-192 in quantities up to 240 Curies. The radioactive material is sealed in a stainless steel source capsule, which is swaged to one end of a flexible cable. This source assembly is inserted into the source changer's depleted uranium shield and is secured by the lock assembly.

The capsule must be in special form as prescribed in 10 CFR 71, 49 CFR 173, and IAEA Safety Series No. 6, 1985 Edition (as amended 1990). In addition, the maximum activity must be defined as output Curies as required in ANSI N432 and 10 CFR 34.20.

1.4 Containment Boundary

1.4.1 Containment Vessel

The containment system for the Model 650L source changer is the radioactive source capsule referred to in Section 4.1 of this Safety Analysis Report. The source capsule is certified as special form radioactive material under 10 CFR Part 71 and IAEA Safety Series No. 6, 1985 Edition (As Amended 1990).

1.5 Drawings

A descriptive drawing of the test specimen Model 650L source changer (with the current (standard) lock assembly) is provided in Appendix A. A descriptive assembly drawing for the Model 650L source changer (with the multiple wire lock assembly) is also provided in Appendix A.

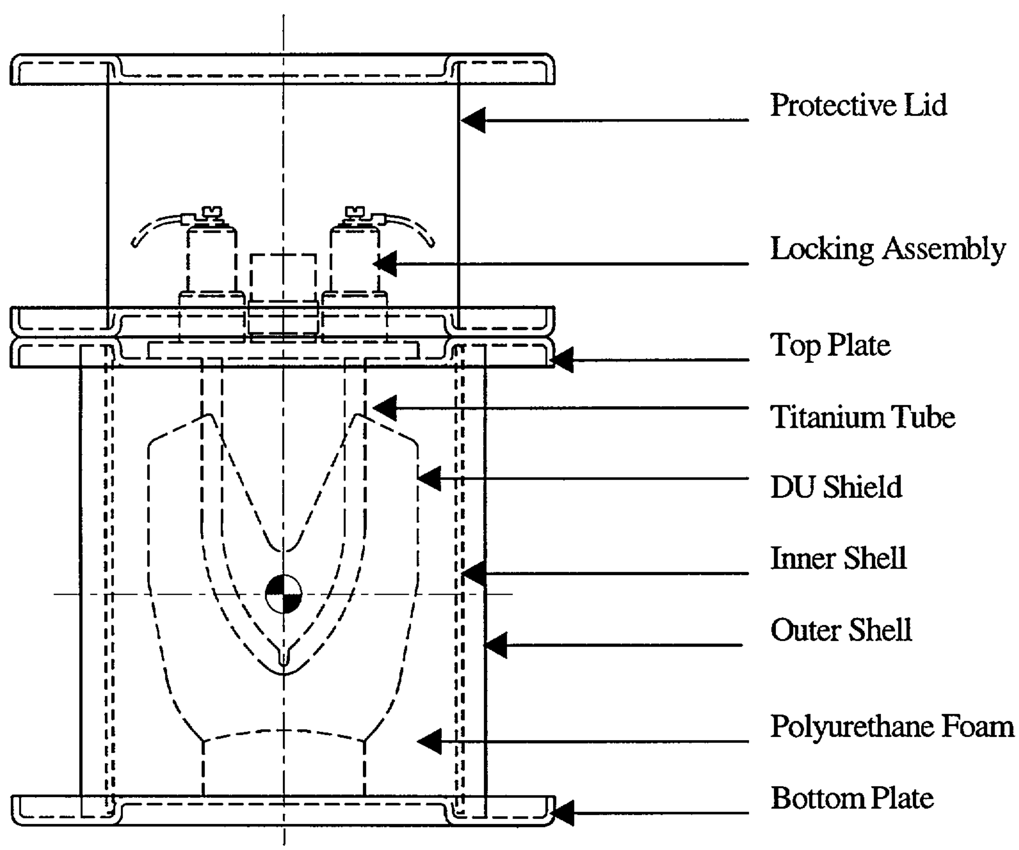


Figure 1: Side View of Model 650L Source Changer

Section 2 - STRUCTURAL EVALUATION

This section identifies and describes the principal structural engineering design of the packaging, components, and systems important to safety, and describes compliance with the performance requirements of 10 CFR Part 71, 49 CFR 173 and IAEA Safety Series 6.

2.1 Structural Design

2.1.1 Overview

The Model 650L source changer is described in Section 1.2.1, "Description of the Model 650L Source Changer."

2.1.2 Design Criteria

The Model 650L source changer is designed to comply with the requirements for Type B(U) packaging as prescribed by 10 CFR 71 and IAEA Safety Series No. 6, 1985 Edition (as amended 1990). All design criteria are evaluated by a straightforward application of the appropriate section of 10 CFR 71 or IAEA Safety Series No. 6.

2.2 Weight and Center of Gravity

The source changer weighs up to 90 lb (41 kg) including the depleted uranium shield, which weighs approximately 42 lb (19 kg), and the lid, which weighs about 9 lb (4 kg). The center of gravity of the source changer is approximately 4.25 inches (108 mm) above the bottom plate and along its central axis.

2.3 Mechanical Properties of Materials

Table 1 lists the relevant mechanical properties (at ambient temperature) of the principal materials used in the Model 650L source changer. The sources referred to in the last column are listed after the table.

Table 1: Mechanical Properties of Principal Source Changer Materials

Material	Tensile Strength	Yield Strength	Source
Depleted Uranium	65 ksi	30 ksi	Reference #2
Titanium	80 ksi	65 ksi	Reference #4, p. 637
Copper	25 ksi	9 ksi	Reference #4, p. 224
Lead	1.8 ksi	8 ksi	Reference #4, p. 550
Carbon Steel (nominal)	53 ksi	36 ksi	Reference #1, p. 205
Stainless Steel	75 ksi	30 ksi	Reference #1, p. 854
Stainless Steel Bolts	75 ksi	30 ksi	Reference #3, p 25
Strain-Hardened Stainless Steel Bolts	125 ksi	100 ksi	Reference #3, p. 25

The compressive strength of the 8 lb/cubic foot Polyurethane foam is 155 psi (Reference: General Latex and Chemical Company).

Resource references:

1. American Society for Metals. Metals Handbook, Volume 1, Tenth Edition. Ohio: Materials Park, 1990.

2. Lowenstein, Paul. *Industrial Uses of Depleted Uranium.* American Society for Metals. Metals Handbook, Volume 3, Ninth Edition.

3. ASTM Standard A193, "Standard Specification for Alloy-Steel and Stainless Steel Bolting Materials for High-Temperature Service," 1992.

4. American Society for Metals. Metals Handbook, Volume 2, Tenth Edition. Ohio: Materials Park, 1990.

2.4 General Standards for All Packages

2.4.1 Minimum Package Size

Reference:
- *USNRC, 10 CFR 71.43(a)*
- *USDOT, 49 CFR 173.412(b)*
- *IAEA Safety Series No. 6, Section V, paragraph 525*

The source changer is 10 inches (254 mm) long, 8 1/4 inches (210 mm) wide, and 13 1/4 inches (337 mm) high and therefore meets the minimum package size

requirements specified by 10 CFR 71.43(a) and IAEA Safety Series No. 6, Section V, paragraph 525.

2.4.2 Tamperproof Feature

Reference:

- *USNRC, 10 CFR 71.43(b)*
- *USDOT, 49 CFR 173.412(a)*
- *IAEA Safety Series No. 6, Section V, paragraph 526*

The source locking assembly is protected by a lid, a source hold down cap, a key operated lock, and a lock slide. A tamper indication seal wire is attached through two of the lid bolts, which are drilled to accommodate the seal wire. This feature meets the tamperproof feature requirements of 10 CFR 71.43(b) and IAEA Safety Series No. 6, Section V, paragraph 526.

2.4.3 Positive Closure

Reference:

- *USNRC, 10 CFR 71.43(c)*
- *USDOT, 49 CFR 173.412(d)*
- *IAEA Safety Series No. 6, Section V, paragraph 530*

The Model 650L source 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. The lid is secured to the source changer top plate with four bolts. One pair of lid bolts is seal wired.

The locking assembly cannot release the source until the following conditions are met:

1. The source hold down cap is manually removed.

2. The key lock is unlocked.

3. The lock slide is manually moved to the unlocked position.

The radioactive material is sealed inside a special form capsule. This source capsule acts as a containment vessel for the radioactive material.

The source capsules used in conjunction with the 650L source changers satisfy the requirements for special form radioactive material as prescribed in 10 CFR 71 and IAEA Safety Series No. 6, 1985 Edition (as amended 1990).

These features maintain positive closure of the source changer during transport. Therefore, there will be no release of radioactive material under normal conditions of transport.

2.4.4 Chemical and Galvanic Reactions

Reference:

- *USNRC, 10 CFR 71.43(d)*
- *USDOT, 49 CFR 173.410 (g)*
- *IAEA Safety Series No. 6, Section V, paragraph 512*

The materials used in the construction of the Model 650L source changer are depleted uranium metal, carbon and stainless steels, titanium, rigid polyurethane foam, and copper. In some source changers, supplementary shielding may be provided using lead. There will be no significant chemical or galvanic action between any of these components.

To prevent the possible formation of a eutectic alloy of steel and depleted uranium during the Hypothetical Accident Conditions thermal scenario, defined by 10CFR71.73(c)(4), copper shims are used. The shims are positioned between the depleted uranium shield and the stainless steel bottom plate.

2.5 Lifting and Tie-down Standards for All Packages

2.5.1 Lifting Devices

Reference:

- *USNRC, 10 CFR 71.45(a)*
- *USDOT, 49 CFR 173.410 (b)*
- *IAEA Safety Series No. 6, Section V, paragraphs 506 and 507*

The Model 650L is designed to be lifted by the bottom or top plates or the top lid. The top lid is secured to the top plate by four 3/8-16, strain-hardened stainless steel hex head bolts. The bottom plate is secured to the top plate by four 5/16-18 stainless steel hex head bolts. Since the source changer can be lifted by either the top or bottom plate, analysis of the stress due to lifting considers the strength of the 5/16-18 through bolts, which are more limiting than the lid bolts. Each 5/16-18 bolt has a cross-sectional area of 0.0524 in^2 (33.8 mm^2). The yield strength of the material is 30,000 psi. Thus, each bolt can support at least 1572 pounds (713 kg) of force, or approximately 17 times the source changer weight, and is adequate for lifting.

2.5.2 Tie-Down Devices

Reference:
- *USNRC, 10 CFR 71.45(b) (1) (2) (3)*
- *USDOT, 49 CFR 173.412 (I)*
- *USDOT, 49 CFR 177.842 (d)*
- *IAEA Safety Series No. 6, Section V, paragraph 527*

The Model 650L source changer has no handles or attached tie down devices.

2.6 Normal Conditions of Transport

2.6.1 Heat

Reference:
- *USNRC, 10 CFR 71.71(c)(1)*
- *IAEA Safety Series No. 6, Section V, paragraph 543*

The heat source in the Model 650L source changer is a maximum of 240 Curies of Iridium-192 (Iridium-192 being the highest heat generating isotope used in this changer). Iridium-192 decays with a total energy liberation of 1.45 MeV per disintegration or 8.6 milliwatts per Curie (Reference: Radiological Health Handbook). Assuming all the decay energy is transformed into heat, the heat generation rate for the 240 Curies of Iridium-192 would be approximately 2.1 Watts.

2.6.1.1 Engineering Analysis

This analysis determines the maximum surface temperature produced by solar heating of the source changer surface in accordance with 10 CFR 71.71(c)(1) and Table XII of IAEA Safety Series No. 6 (as amended 1990).

The model consists of taking a steady state heat balance over the surface of the source changer. In order to assure conservatism, the following assumptions are made:

- The source changer is assumed to undergo free convective heat transfer and radiative heat transfer from the lid top sides and the outer shell.

- The inside source changer faces are considered perfectly insulated so there is no conduction into the source changer. The faces are considered to be sufficiently thin so that no temperature gradients exist in the faces.

- The lid of the source changer is modeled as a rectangular solid, 10 inches (254 mm) long, 8 1/4 inches (210 mm) wide, and 5 inches (127 mm) high. The outer shell of the source changer is modeled as a cylinder, 7 7/16 inches (189 mm) in diameter and 8 1/4 (210 mm) long.

- The decay heat load (2.1 Watts) is added to the solar heat input load.

- The emissivity coefficient of the steel source changer is assumed to be 0.8.

- The absorptivity coefficient of the steel source changer is conservatively assumed to be 1.0.

The maximum surface temperature is computed using the steady state heat balance relationship; heat input (Q_{in}) equals heat output (Q_{out}).

$$Q_{in} = Q_{out}$$

Heat Input:

The solar heat input is the combined solar heating of the top (horizontal, flat) and side (vertical, flat) surfaces of the lid and the surface of the outer shell (vertical, curved). The insolation data, provided in 10 CFR 71.71(c)(1), is shown below in Table 2.

Table 2: Insolation Data

Surface	Insolation for a 12 hour period (g-cal/cm² or W/m²)
Horizontal base	None
Other horizontal flat surfaces	800
Non-horizontal flat surfaces	200
Curved surfaces	400

Top surface heat input: $Q_{IT} = 800\ W/m^2 \times 0.053\ m^2 = 42.4\ W$

Lid side surface heat input: (assume rectangular box) $Q_{ILS} = 200\ W/m^2 \times 0.118\ m^2 = 23.6\ W$

Outer shell surface heat input: (assume cylinder) $Q_{IOS} = 400\ W/m^2 \times 0.124\ m^2 = 49.6\ W$

Decay heat input: $Q_{DT} = 2.1\ W$

Absorptivity coefficient: $\alpha = 1.0$

The total heat input is the sum of the solar heat input multiplied by the absorptive constant (α) for the material plus the decay heat input.

Total heat input: $Q_{IN} = \alpha\,(Q_{IT} + Q_{ILS} + Q_{IOS}) + Q_{DT} = 118$ W

<u>Heat Output</u>:

The total heat output is the sum of the radiation and convection heat transfer (Reference: Fundamentals of Heat and Mass Transfer, F. P. Incropera, 4th Edition, 1996, p. 9-10).

Radiation heat transfer: $Q_R = B\,E\,A_{TS}\,\{(T_W + 273)^4 - (T_A + 273)^4\}$

Where:

B	=	5.67×10^{-8} W/m^2 K^4 (Stefan-Boltzmann Constant)
E	=	0.8 (emissivity)
A_{TS}	=	0.295 m^2 (lid top and side surface and outer shell surface area)
T_W	=	The maximum surface temperature of the source changer
T_A	=	38°C (ambient temperature, per 10 CFR 71.71(c)(1))

Therefore:

$$Q_R = 1.34 \times 10^{-8}\{(T_W + 273)^4 - (311)^4\} \qquad \text{(Equation 1)}$$

Lid top surface convection: $Q_{LT} = H_{LT}\,A_{LT}\,(T_W - T_A)$ (Equation 2)

Where:

A_{LT}	=	0.053 m^2 (lid top surface area)
H_{LT}	=	The free convection coefficient for a flat horizontal surface

For a heated plate facing up, the free convection coefficient for laminar flows is (Reference: Fundamentals of Heat and Mass Transfer, F. P. Incropera, 4th Edition, 1996, Ch. 9).

$$H_{LT} = 0.54\,[(g\,\beta\,(T_W - T_A)\,L^3) / (\nu\,\alpha)]^{1/4}\,(K / L)$$

Where:

g	=	9.8 m/s^2
β	=	0.00303 ($1/T_{avg}$ assuming T_{avg} = 330 K)
L	=	0.0572 m (Area / Perimeter)
ν	=	18.9×10^{-6} m^2/s
α	=	26.9×10^{-6} m^2/s

$K = 28.52 \times 10^{-3}$ W/mK

Therefore:

$$H_{LT} = 2.75\,(T_W - 38)^{0.25}$$

Substituting into Equation 2:

$$Q_{LT} = 0.146\,(T_W - 38)^{1.25} \quad \text{(Equation 3)}$$

Lid side surface convection: $Q_{LS} = H_{LS}\,A_{LS}\,(T_W - T_A)$ (Equation 4)

Where:

A_{LS} = 0.118 m^2 (total surface area of lid sides)

H_{LS} = The free convection coefficient for a vertical surface

For a vertical plate, the free convection coefficient for laminar flows is (Reference: Fundamentals of Heat and Mass Transfer, F. P. Incropera, 4th Edition, 1996, Ch. 9).

$$H_{LS} = [0.68+0.67[\{g\beta(T_W-T_A)L^3/\nu\alpha\}^{1/4}]/\{1+(0.492/\nu/\alpha)^{9/16}\}^{4/9}](K/L)$$

Where:

L = 0.056 m (Area / Perimeter)

Therefore:

$$H_{LS} = 0.346 + 2.64\,(T_W - 38)^{0.25}$$

Substituting into Equation 4:

$$Q_{LS} = 0.041\,(T_W - 38) + 0.312\,(T_W - 38)^{1.25} \quad \text{(Equation 5)}$$

Outer shell surface convection: $Q_{OS} = H_S\,A_S\,(T_W - T_A)$ (Equation 6)

Where:

A_{OS} = 0.124 m^2 (total surface area of outer shell)

H_{OS} = The free convection coefficient for a vertical surface

For a vertical plate, the free convection coefficient for laminar flows is (Reference: Fundamentals of Heat and Mass Transfer, F. P. Incropera, 4th Edition, 1996, Ch. 9).

$$H_{OS} = [0.68+0.67[\{g\beta(T_W-T_A)L^3/\nu\alpha\}^{1/4}]/\{1+(0.492/\nu/\alpha)^{9/16}\}^{4/9}](K/L)$$

Where:

$L \quad = \quad 0.077$ m (Area / Perimeter)

Therefore:

$$H_{OS} = 0.252 + 2.44\,(T_W - 38)^{0.25}$$

Substituting into Equation 4:

$$Q_{OS} = 0.031\,(T_W - 38) + 0.303\,(T_W - 38)^{1.25} \qquad \text{(Equation 7)}$$

Total heat output: $Q_{OUT} = Q_R + Q_{LT} + Q_{LS} + Q_{OS}$

Total heat input: $Q_{IN} = Q_R + Q_{LT} + Q_{LS} + Q_{OS} = 118$ W

Substituting for Q_R from Equation 1, Q_{LT} from Equation 3, Q_{LS} from Equation 5, and Q_{OS} from Equation 7:

$$118 \text{ Watts} = 1.34 \times 10^{-8}\{(T_W + 273)^4 - (311)^4\} + 0.146\,(T_W - 38)^{1.25} + 0.041\,(T_W - 38) + 0.312\,(T_W - 38)^{1.25} + 0.031\,(T_W - 38) + 0.303\,(T_W - 38)^{1.25}$$

Iteration of this relationship yields a maximum wall temperature (T_W) of 70°C (158°F).

This temperature would not adversely affect the source changer during normal transport since the melting temperatures of all safety critical components are well above this temperature. Additionally, charring of the polyurethane foam will not begin to occur at such low temperatures. Therefore, the source changer satisfies the requirements of 10 CFR 71.71(c)(1) and paragraph 543 of the IAEA Safety Series No. 6, 1985 Edition (as amended 1990).

2.6.2 Cold

Reference:

- *USNRC, 10 CFR 71.71 (c)(2)*
- *IAEA Safety Series No. 6, Section V, paragraph 528*

The carbon steel components of the Model 650L source changer are susceptible to brittle fracture at low temperatures. The source changer, however, successfully met Type B(U) Transport Test requirements at temperatures below -40°C (-40°F), the minimum specified in the regulations.

2.6.3 Reduced External Pressure

Reference:
- *USNRC, 10 CFR 71.71 (c)(3)*
- *USDOT, 49 CFR 173.412(f)*
- *IAEA Safety Series No. 6, Section V, paragraph 534*

The Model 650L source changer is not a sealed unit. Thus, there will be no differential pressure acting on it.

2.6.4 Increased External Pressure

Reference:
- *USNRC, 10 CFR 71.71(c)(4)*

The Model 650L source changer is not a sealed unit. Thus, there will be no differential pressure acting on it.

2.6.5 Vibration

Reference:
- *USNRC, 10 CFR 71.71(c)(5)*
- *USDOT, 49 CFR 173.410(f)*
- *IAEA Safety Series No. 6 Section V, paragraph 511*

In the 23 years that the source changer has been in use, no source changers have failed due to vibration. The source locking assembly is bolted, the lock slides are secured by the key locks, and the locks cannot be unlocked without a key. The passive, internal parts of the source changer, e.g., the shield, source tubes, and through-bolts, are held in place by the Polyurethane foam.

2.6.6 Water Spray

Reference:
- *USNRC, 10 CFR 71.71(c)(6)*
- *USDOT, 49 CFR 173.465(b)*
- *IAEA Safety Series No. 6 Section V, paragraph 621*

The 650L source changers are constructed of water resistant materials throughout. The outer container, while not being air or water tight, is constructed of waterproof material and will provide protection from rainfall. The source changer lid has a lip, which protects against rain ingress.

2.6.7 Free Drop

Reference:
- *USNRC, 10 CFR 71.71(c)(7)*
- *USDOT, 49 CFR 173.465*
- *IAEA Safety Series No. 6 Section V, paragraph 622*

Three test specimens with standard locking assemblies were subjected to the 1.2 meter (4 foot) free drop in accordance with Test Plan 80 (Appendix B). Three different orientations were used as described below. Photographs of the drop orientations are provided in Appendix D of the Test Plan 80 Report
(Appendix C).

- Horizontal Long-Side Down: The intent of the test was to determine if (1) the DU shield could move laterally through the foam during impact, which could result in source pullout from titanium tubes, and (2) brittle failure of the inner and outer shells could occur due to the low testing temperature. The Long-Side Down orientation was selected because the long side of the package has a stiffer configuration than the short side, which resulted in a shorter deceleration and a higher impact load. (Test Specimen TP80(A))

- Vertical Upside Down: The intent of the test was to determine if deformation of the lid weldment, crushing of the foam between the depleted uranium shield and top plate, deformation (bowing upward) of the top plate due to the impact load of the DU shield applied through titanium source tubes and foam, failure of the through-bolts, or failure of the locking assemblies could occur. These deformations or failures could result in partial pullout of the source from its shielded position during subsequent thermal testing. (Test Specimen TP80(B))

- Vertical Top Corner Down: The intent of the test was to determine if failure of the lid or lid closure bolts could occur, which could expose the locking assembly to damage during subsequent Hypothetical Accident testing. Failure of the locking assembly could result in source pullout. Additionally, this orientation would load the through-bolts in tension, and could cause them to fail. (Test Specimen TP80(C))

The Test Plan 80 Report (Appendix C) documents that the Model 650L source changer maintained its structural integrity and shielding effectiveness under the Normal Conditions of Transport free drop test. Three test specimens were dropped at temperatures below -40°C (-40°F) in the above orientations.

The test results are summarized below:

- For Test Specimen TP80(A), damage was limited to impact witness markings on the bottom plate, top plate, and both lid flanges.

- For Test Specimen TP80(B), damage was limited to impact witness markings on the top of the lid.

- For Test Specimen TP80(C), a 2 inch (51 mm) long crack formed on the top of the lid as a result of the impact. In addition, the lid flange bent over at the impact point.

There was no significant change in the radiation profile of the test specimens after the 1.2 meter (4 foot) drop (see Section 5).

2.6.8 Corner drop

Reference:
- *USNRC, 10 CFR 71.71(c)(8)*
- *IAEA Safety Series No. 6 Section V, paragraph 622*

This test is not applicable, as the source changer does not transport fissile material, nor is the exterior of the source changer made from either fiberboard or wood.

2.6.9 Compression

Reference:
- *USNRC, 10 CFR 71.71(c)(9)*
- *USDOT, 49 CFR 173.465(d)*
- *IAEA Safety Series No. 6 Section V, paragraph 623*

The Test Plan 80 Report (Appendix C) documents that the Model 650L source changer maintained its structural integrity and shielding effectiveness under the Normal Conditions of Transport compression test. The three test specimens, TP80(A), TP80(B), and TP80(C), were subjected to compressive loads of 462 lb (210 kg), 458 lb (208 kg), and 459lb (208 kg), respectively, for a period of 24 hours. These loads exceed five times the source changer maximum weight of 90 lb (41 kg). These weights are also greater than 2 lb/in^2 multiplied by the surface area of the source changer.

Following the tests, no damage to the specimens was observed.

2.6.10 Penetration

Reference:
- *USNRC, 10 CFR 71.71(c)(10)*
- *USDOT, 49 CFR 173.410(e)*
- *IAEA Safety Series No. 6 Section V, paragraph 624*

Three test specimens were subjected to a penetration test, in accordance with Test Plan 80 (Appendix B). Each specimen was impacted by a penetration bar on the long side of the source changer, with the intention of damaging the outer shell. Inspection following each test indicated that no significant damage occurred to the test specimen. In each case, there was a small indentation at the point of impact. There was no loss of structural integrity or reduction of shielding efficiency as a result of the impact.

2.6.11 Summary

Based on the above assessments and physical tests, it is concluded that the Model 650L source changer meets the Normal Conditions of Transport requirements. There was no loss or dispersal of the radioactive contents, no significant increase in radiation levels, and no decrease in the effectiveness of the source changer.

2.7 Hypothetical Accident Conditions of Transport

Sections 2.7.1 through 2.7.5 summarize evaluations and testing for the hypothetical accident conditions of transport. Section 2.7.6 summarizes the results of this testing.

2.7.1 Free Drop

Reference:
- *USNRC, 10 CFR 71.73(c)(1)*
- *IAEA, Paragraph 627(a)*

Three test specimens were subjected to the 9 meter (30 foot) free drop in accordance with Test Plan 80 (Appendix B). All tests were conducted with the test specimen temperatures at or below -40°C (-40°F). The test specimens included standard locking assemblies. Three different orientations were used, as described below. Photographs of the drop orientations are provided in Appendix D of the Test Plan 80 Report (Appendix C).

- Horizontal Long-Side Down: The intent of the test was to determine if (1) the DU shield could move through the foam during impact, which could result in source pullout from titanium tubes, and (2) brittle failure of the inner and outer shells could occur due to the low testing temperature. The Long-Side Down orientation was selected because the long side of the package has a stiffer configuration than the short side, which resulted in a shorter deceleration and a higher impact load. (Test Specimen TP80(A))

- Vertical Upside Down: The intent of the test was to determine if deformation of the lid weldment, crushing of the foam between the depleted uranium shield and top plate, deformation (bowing upward) of the top plate due to the impact load of the DU shield applied through titanium source tubes and foam, failure of the through-bolts, or

failure of the locking assemblies could occur. These deformations or failures could result in partial pullout of the source from its shielded position during subsequent thermal testing. (Test Specimen TP80(B))

- Vertical Top Corner Down: The intent of the test was to determine if failure of lid or lid closure bolts could occur, which could expose the locking assembly to damage during the puncture bar test. Failure of the locking assembly could result in source pullout. Additionally, this orientation would load the through-bolts in tension, and could cause them to fail. (Test Specimen TP80(C))

The test results are summarized below:

- Test Specimen TP80(A) rotated slightly so that the long edge of the bottom plate struck the ground first. The long edge of the bottom plate deformed, but no cracking was observed. The outer shell deformed at the interface with the long edge of the bottom plate. There were impact witness marks on the long edge of the top plate and the long edge of the bottom lid flange. There was a small deformation of the lid top flange.

- Test Specimen TP80(B) impacted flat on the top of the lid. One of the lid rivnuts cracked open, but the lid bolt remained in place. There was no other damage to the lid or lid bolts/rivnuts. The top plate deflected up, resulting in effective source pullouts of about 1/32 inch (0.8 mm) and 1/16 inch (1.6 mm). The stainless steel over wrap (label) unzipped and opened up. The carbon steel outer shell unzipped along the spot weld line and opened up about 1/2 inch (13 mm). The carbon steel inner shell fractured (brittle failure) in the middle of the short side and opened up a crack about 1/2 inch (13 mm) wide and 3 inches (76 mm) high. The crack started at the top (under the top plate). At the end of this opening, the crack turned and continued behind the foam that fills the volume between the inner and outer shells. The foam cracked and several small pieces came out.

- Test Specimen TP80(C) impacted on the top corner of the lid. The crack in the top flange of the lid which initiated during the 1.2 meter (4 foot) drop test, increased, and the top surface of the lid deflected inside the lid about 1/2 inch (13 mm) along one edge, but did not impact the lock assemblies. The column section of the lid, and the bottom flange of the lid, remained intact. There was no damage to the lid bolts or rivnuts.

2.7.2 Puncture

Reference:

- *USNRC, 10 CFR 71.73(c)(3)*
- *IAEA, Paragraph 627(b)*

The three test specimens were subjected to a puncture test, in accordance with Test Plan 80 (Appendix B). All drop tests were conducted with the test specimens at or below -40°C (-40°F). Four different orientations were used, as described below. The orientations were selected based on an assessment following the 9 meter (30 foot) drop tests of which orientation would impart the most damage to each specimen. Photographs of the drop orientations are provided in Appendix D of the Test Plan 80 Report (Appendix C).

- Test Specimen TP80(A): The test specimen was dropped so that the puncture bar would impact the horizontal long side of the specimen. This orientation was the same as for the TP80(A), 1.2 meter (4 foot) and 9 meter (30 foot) drop tests.

- Test Specimen TP80(B): The specimen was dropped horizontally, so that the edge of the puncture bar impacted the axial crack. This orientation was selected to increase the damage from the 9 meter (30 foot) drop test, and to try to further open the axial crack.

Test Specimen TP80(C) was dropped onto the puncture bar in two orientations:

- Test Specimen TP80(C): The specimen was dropped such that the edge of the puncture bar impacted on the crack in the lid. This orientation was selected to increase the damage from the 9 meter (30 foot) drop test, specifically with the intention of further opening the lid crack and trying to impact the lock assemblies.

- Test Specimen TP80(C): The specimen was dropped such that the edge of the puncture bar impacted the underside of the top plate corner, at a lid bolt rivnut. The intent of this orientation was to try and pry up the top plate, and, as a minimum, load the through-bolts in tension. This orientation was also intended to damage the lid bolt connection.

The test results are summarized below:

- Test Specimen TP80(A) impacted on the long side of the source changer. There was a small dent on the long side of the outer shell just above the bottom plate. There were witness marks on the top plate.

- Test Specimen TP80(B) impacted directly on the crack. There were small indentations on both sides of the crack where the puncture bar impacted, but no further opening of the crack was observed.

- For Test Specimen TP80(C), the edge of the puncture bar hit the top plate of the lid within the column of the lid. Damage to the lid increased only slightly. The lock assemblies were not impacted and remained protected by the lid. The lid bolts and rivnuts remained intact.

- The second Test Specimen TP80(C) drop impacted on the under side of the top plate corner. There was a small deformation of the top plate edge at the impact point. The lid bolts/rivnuts were not damaged. No gaps were created at the top plate/shell interface, and the through-bolts remained secure.

2.7.3 Thermal

Reference:
- *USNRC, 10 CFR 71.73(c)(4)*
- *IAEA, Paragraph 628*

The thermal test was considered necessary for the TP80(B) specimen for the following reasons:

- Lead shims placed under the DU shield were expected to melt during thermal testing. This would allow the DU shield to drop down. Significant displacement of the DU shield relative to the top plate/locking assemblies could result in source pullout from the shielded position. Additionally, deflection of the top plate due to the drop testing would increase the total potential source pullout.

- The crack in the inner shell and the opening in the outer shell provided a path for air to reach the DU shield during thermal testing. Therefore, oxidation of the DU shield was possible.

To obtain the largest possible displacement of the shield during thermal testing, the TP80(B) specimen was placed on a jig to raise the side face of the unit to an angle (53° above horizontal) that positioned the center of gravity of the shield over the bottom plate inside edge. The side with the crack was positioned facing down.

During thermal testing, the test period of 30 minutes was started after all specimen thermocouples measured at least 810°C (1,490°F). To allow sufficient air for combustion of the specimen's polyurethane foam, the door of the oven was held open by 1 inch (25 mm) thick insulating strips placed on each side of the furnace door. This created a 1 inch (25.4 mm) wide by 36 inches (914 mm) long opening at the top and bottom of the oven

door (total opening of 72 in^2 (465 cm^2)).

At the end of the 30 minute test interval, the test specimen was removed from the furnace and allowed to self extinguish and cool down. Post-test visual inspections showed that (1) the crack width did not change, but, a cracked piece of the inner shell had dropped out of position, (2) the polyurethane foam had burned off, and (3) some minor oxidation of the DU shield had occurred, as evidenced by a small amount of DU oxide below the cracked shell.

Post-test radiographs showed that, as expected, the shield had shifted down. This resulted in some pullout of the source tubes from the top plate (less than 0.5 inch (13 mm)). The radiation profile of the device performed following the thermal test showed that the highest observed radiation level, 28 mR/hr at one meter, is well below the allowable level of 1000 mR/hr at one meter. Therefore, the unit satisfies the thermal test requirements of 10 CFR 71.73 (c)(4).

2.7.4 Immersion - Fissile Material

Reference:
- *USNRC, 10 CFR 71.73 (c)(5)*

Not applicable.

2.7.5 Immersion - All Packages

Reference:
- *USNRC, 10 CFR 71.73 (c)(6)*
- *IAEA, Paragraph 629*

The primary containment system in the Model 650L source changer is a special form source, which meets the ANSI N542 and ISO2919 requirements for a minimum of Class 3 pressure testing.

2.7.6 Summary of Damage

Table 3 summarizes the results of the Normal Conditions of Transport and Hypothetical Accident testing performed on the Model 650L.

Table 3: Summary of Damages During Performance of TP80

Specimen	Test Performed	Test Results
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
	1 meter (40 inch) puncture on crack in shell	Bent shell inward slightly in area of crack

Specimen	Test Performed	Test Results
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	• 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)

Specimen	Test Performed	Test Results
TP80(C) (con't)	Post-Drop Inspection	• Locks undamaged; source secured • No significant change in source position • Small change in radiation profile

Based on these results, it is concluded that the Model 650L source changer maintains structural integrity and shielding effectiveness during hypothetical accident conditions and normal conditions of transport.

2.8 Special Form

The Model 650L source changer is designed for use with sources that have been certified as special form radioactive material by U.S. Department of Transportation.

2.9 Fuel Rods

Not applicable.

Section 3 - THERMAL EVALUATION

3.1 Description of Thermal Design Characteristics

The Model 650L source changer is a completely passive thermal device having no mechanical cooling system or relief valves. All cooling of the source changer is through free convection and radiative heat losses. The maximum heat source is 240 Curies of Iridium-192. The corresponding decay heat generation rate is approximately 2.1 Watts (See Section 2.6.1.1, "Engineering Analysis").

3.2 Summary of Thermal Properties of Materials

Table 4 lists the relevant thermal properties of the principal materials in the source changer. The sources referred to in the last column are listed below the table.

Table 4: Thermal Properties of Principal Source Changer Materials

Material	Density (lb/in^3)	Melting/Combustion Temperature	Thermal Expansion	Source
Depleted Uranium	0.68	1,130°C (2,066°F)	8μin/in°F	Reference #1, p. 6-11 and Reference #2
Copper	0.32	1,082°C (1,980°F)	9.2μin/in°F	Reference #1, p. 6-7 and 6-11
Lead	0.41	327°C (620°F)	29.3μin/in°F	Reference #1, p. 6-7 and 6-11
Carbon Steel (nominal)	0.28	1,510°C (2,750°F)	6.3μin/in°F	Reference #1, p. 6-7 and 6-11
Stainless Steel-Type 304	0.29	1,427°C (2,600°F)	9.9μin/in°F	Reference #1, p. 6-11
Titanium	0.18	1,704°C (3,100°F)	5.2μin/in°F	Reference #1, p 6-11
Polyurethane Foam	8 lb/ft^3	--	150μin/in°C (average)	Reference #1, p.6-199

Resource references:

1. Eugene A. Avallone and Theodore Baumeister III, *Mark's Standard Handbook for Mechanical Engineers, Tenth Edition*. New York: McGraw-Hill, 1996.

2. Lowenstein, Paul. *Industrial Uses of Depleted Uranium*. American Society for Metals. Metals Handbook, Volume 3, Ninth Edition.

3.3 Technical Specifications of Components

Not applicable.

3.4 Thermal Evaluation for Normal Conditions of Transport

3.4.1 Thermal Model

Three thermal conditions are evaluated. Two thermal conditions are evaluated using analytical models, and the third condition is evaluated by testing.

The heat analysis in Section 2.6.1.1, "Engineering Analysis" demonstrates that under the conditions described in 10 CFR 71.71(c)(1), the surface temperature of the source changer will be approximately 70°C (158°F). At this temperature, no components will suffer a reduction in effectiveness.

The surface temperature analysis in Section 3.6.1, "Surface Temperature Analysis" will demonstrate that there will be no degradation of packaging or shielding effectiveness at the maximum ambient temperature of 38°C (100°F) specified in 10 CFR 71.43(g).

Testing of the Model 650L source changer under Test Plan 80 (Appendix B) demonstrated that there is no degradation of packaging or shielding effectiveness at the minimum temperature of -40°C (-40°F).

3.4.2 Maximum Temperatures

The maximum temperatures encountered under normal conditions of transport will have no adverse effect on the structural integrity or shielding efficiency of the source changer.

As shown in Section 3.6.1, "Surface Temperature Analysis" the maximum surface temperature does not exceed 45.9°C (114.6°F) with the source changer in the shade (i.e., no insolation effects), and an ambient temperature of 38°C (100°F). The source changer meets the requirements of 10 CFR 71.43(g).

The maximum surface temperature when insolation effects are considered (and ambient temperature is 38°C) is 70°C (158°F), as described in Section 2.6.1.1, "Engineering Analysis."

A review of the thermal properties of the materials used in the construction of the Model 650L source changer (Table 4) shows that there will be no reduction in structural integrity or loss of shielding of the source changer due to maximum temperatures.

3.4.3 Minimum Temperatures

Test Plan 80 (Appendix B) tested the Model 650L source changer at or below -40°C (-40°F) to evaluate the possibility of brittle fracture of the carbon steel components during Normal Conditions of Transport. As shown in the Test Plan 80 Report (Appendix C), the source changer can withstand Normal Conditions of Transport at minimum temperature, while maintaining its structural integrity and shielding efficiency.

3.4.4 Maximum Internal Pressures

Normal operating conditions will generate a negligible pressure differential within the source changer. As described in Sections 2.6.3, "Reduced External Pressure," 2.6.4, "Increased External Pressure," and 3.6.2, "Model 650L Series Type B(U) Source Capsule Thermal Analysis," the source changer has the ability to withstand elevated atmospheric pressure because, except for the special form source, the unit is not sealed.

Any pressure generated within the special form source during Normal Transport Conditions is bounded by the internal pressure seen during Hypothetical Accident Conditions which are shown in Section 3.6.2, "Model 650L Series Type B(U) Source Capsule Thermal Analysis" to result in no loss of structural integrity or containment.

3.4.5 Maximum Thermal Stresses

The maximum temperature of the source changer during normal transport (70°C, 158°F) is low enough to ensure that thermal gradients will not result in significant thermal stresses.

3.4.6 Evaluation of Source Changer Performance for Normal Conditions of Transport

The thermal conditions of normal transport will have no adverse effect on the structural integrity or shielding efficiency of the source changer. The applicable conditions of IAEA Safety Series No. 6, 1985 Edition (as amended) for Type B(U) Packages are satisfied by the Model 650L.

3.5 Thermal Evaluation for Hypothetical Accident Conditions of Transport

3.5.1 Thermal Model

The Model 650L source changer was subjected to a Hypothetical Accident Condition thermal test. This section, therefore, is not applicable.

3.5.2 Maximum Internal Pressure

Section 3.6.2, "Model 650L Series Type B(U) Source Capsule Thermal Analysis" provides an analysis of the source capsule, which serves as the primary containment, under the thermal test conditions. This analysis demonstrates that the maximum internal gas pressure at 800°C (1475°F) would be 54 psi (372 kN/m^2). Under these conditions, the maximum stress in the capsule would be less than 4% of the yield strength of the material.

3.5.3 Maximum Thermal Stresses

Post-test inspections concluded that the test specimen was not affected by thermal stresses during the thermal test.

3.5.4 Evaluation of Source Changer Performance for Thermal Test

Thermal testing documented in the Test Plan 80 Report (Appendix C) shows that the Model 650L will not lose its structural integrity or shielding when subjected to the hypothetical accident thermal conditions.

3.6 Thermal Analysis Details

3.6.1 Surface Temperature Analysis

Reference:
- *10 CFR 71.43(g)*
- *IAEA Safety Series No. 6, 1985 Edition (as amended 1990), para 543*

This analysis calculates the maximum surface temperature of the Model 650L source changer in the shade, assuming an ambient temperature of 38°C (100°F), per 10 CFR 71.43(g).

To assure conservatism, the following assumptions are used:

- The entire decay heat (2.1 Watts) is deposited in the exterior surfaces of the source changer.

- The interior of the source changer is perfectly insulated and heat transfer occurs only from the exterior surface to the environment.
- 100% of the total heat is conservatively assumed to be deposited in the package lid.
- The only heat transfer mechanism is free convection.
- The package lid undergoes one-dimensional convective heat transfer.

Using these assumptions, the maximum wall temperature (T_W) is found using:

$$T_W = (q/hA) + T_A$$

Where:

q	=	2.1 W (heat deposited per unit time on the face)
h	=	5 W/m^2 K (free convection heat transfer coefficient for air, Reference: Fundamentals of Heat and Mass Transfer, F. P. Incropera, 4th Edition, 1996)
A	=	0.053 m^2 (surface area of the smallest face)
T_A	=	38°C (ambient air temperature, per 10 CFR 71.43(g))

From this relationship, the maximum temperature of the surface is 45.9°C (114.6°F).

3.6.2 Model 650L Series Type B(U) Source Capsule Thermal Analysis

Reference:

- *IAEA Safety Series No. 6, 1985 Edition (as amended 1990), para 553*

This analysis demonstrates that the pressure inside the Model 650L source capsule, when subjected to the Hypothetical Accident Conditions of Transport thermal test, does not exceed the pressure which corresponds to the minimum yield strength at the thermal test temperature.

The source capsule is fabricated from stainless steel, Type 304 or 304L. The outside diameter of the capsule is 0.250 inches (6.35 mm), and the wall thickness is 0.019 inches (0.48 mm). (Reference: Sentinel Descriptive Drawing R875 OUTER, "875 Series Outer Capsule," Revision A.)

The internal volume of the source capsule contains only Iridium-192 metal (as a solid metal), spacers, and air. It is assumed at the time of loading, the entrapped air is at standard temperature and pressure, 20°C (68°F) and 14.7 psi (101 kN/m^2), respectively. This is a conservative assumption because, during the welding process, the internal air is

heated, causing some of the air mass to escape before the capsule is sealed. When the welded capsule returns to ambient temperature, the internal pressure would be somewhat reduced.

Under the conditions of paragraph 553 of IAEA Safety Series No. 6, 1985 Edition (as amended 1990), it is assumed that the capsule could reach a temperature of 800°C (1475°F). Using the ideal gas law and requiring the air to occupy a constant volume, the internal gas pressure could reach 54 psi (372 kN/m^2).

The capsule is assumed to be a thin walled cylindrical pressure vessel.

The maximum longitudinal stress is calculated using:

$$\sigma_L = Pd/4t$$

Where:

σ_L = Longitudinal stress
P = Pressure (54 psi)
t = Thickness of the cylinder (0.019 inches)
d = Inside diameter (0.212 inches)

From this relationship, the maximum longitudinal stress is calculated to be 151 psi.

The hoop stress is calculated using:

$$\sigma_h = Pd/2t$$

Where:

σ_h = Hoop stress

From this relationship, the hoop stress is calculated to be 301 psi.

At a temperature of 870°C (1598°F), the yield strength of type 304 stainless steel is 10,000 psi. Therefore, under the conditions of paragraph 553 of IAEA Safety Series No. 6, the stress generated is less than 4% of the yield strength of the material.

Section 4 - CONTAINMENT

4.1 Containment Boundary

4.1.1 Containment Vessel

The containment system for the Model 650L source changer is the radioactive source capsule. This source capsule is certified as Special Form radioactive material under 49 CFR and IAEA Safety Series No.6, 1985 Edition (as amended 1990).

4.1.2 Containment Penetrations

There are no penetrations of the containment

4.1.3 Seals and Welds

The containment vessel is seal-welded in accordance with AEA Technology QSA, Inc. Standard Operating Procedures. Leak testing of the source capsule has demonstrated compliance with special form requirements.

4.1.4 Closure

The closure device is the welded special form source capsule. The confinement system maintains the source in the shielded position as described in Section 1.2.1, "Description of the Model 650L Source Changer."

4.2 Requirements for Normal Conditions of Transport

4.2.1 Containment of Radioactive Material

The source capsules used in conjunction with the source changer satisfy the requirements of special form as prescribed in 10 CFR 71.75, 49 CFR 173.469 and IAEA Safety Series No. 6, 1985 Edition (as amended 1990). There will be no release of radioactive material under the Normal Conditions of Transport.

4.2.2 Pressurization of the Containment Vessel

Pressurization of the source capsules under the conditions of the Hypothetical Accident Conditions thermal test results in stresses well below the yield strength of the capsule material, as analyzed in Section 3.6.2, "Model 650L Series Type B(U) Source Capsule Thermal Analysis." Therefore, the containment will withstand the pressure variations of normal transport.

4.2.3 Containment Criterion

The normal conditions of transport criteria listed in 10 CFR 71.71 will result in no loss of source changer containment as prescribed in 10 CFR 71.51(a)(1). This conclusion is based on information presented in Sections 2.6, "Normal Conditions of Transport" and 3.4, "Thermal Evaluation for Normal Conditions of Transport."

4.3 Containment Requirements for Hypothetical Accident Conditions

4.3.1 Containment of Radioactive Material

The hypothetical accident conditions outlined in 10 CFR 71.73 will result in no loss of source changer containment. This conclusion is based on information presented in Section 2.7, "Hypothetical Accident Conditions of Transport."

4.3.2 Containment Criterion

Sections 2.7, "Hypothetical Accident Conditions of Transport," and 3.5, "Thermal Evaluation for Hypothetical Accident Conditions of Transport," show that the source changer meets the containment requirements of 10 CFR 71.51(a)(2).

4.4 Special Requirements

Not applicable.

Section 5 - SHIELDING EVALUATION

5.1 Design Features

The principal shielding in the 650L source changer is the depleted uranium shield assembly. The uranium shield weighs approximately 42 pounds (19 kg). On some source changers, lead shielding is added to assist in attenuating dose levels. The uranium metal is cast around the titanium "U" tubes which hold the source capsules.

5.2 Source Specification

5.2.1 Gamma Source

The gamma source is Iridium-192 in a sealed capsule as special form radioactive material. The source changer can contain up to 240 Curies. The maximum activity is defined in output Curies as required by ANSI N432 (1980) and 10 CFR 34.20.

5.3 Model Specification

Not applicable, as actual radiation profiles were performed to demonstrate compliance.

5.4 Shielding Evaluation

The Model 650L shielding evaluation was performed on the three Model 650L test specimens. The TP80(A), TP80(B), and TP80(C) test specimens were each profiled three times: before testing, after the 4 foot drop test, and after the final test. Data were extrapolated to 240 Curies (using Iridium-192) when profiles were performed using sources with less radioactivity.

All radiation profile data are within regulatory acceptance limits, as shown in Table 5.

Table 5: Maximum Radiation Profiles for All Test Specimens

	Before Tests		After 1.2 Meter (4 Foot) Drop Test		After Puncture Test	After Thermal Test
Location	At Surface	At One Meter	At Surface	At One Meter	At One Meter (Notes 1 and 2)	At One Meter (Notes 1 and 3)
Regulatory Limits (mR/hr)	200	10	200	10	1000	1000
Maximum Activity All Surfaces All Packages (mR/hr)	127	3.2	106	2.4	2.7	28

Notes:

1. Radiation profile at the surface is not required for the Hypothetical Accident Condition test (see 10 CFR 71.51(a)(2)).

2. Radiation levels measured after puncture test apply to Specimens TP80(A) and TP80(C) only. Maximum activity of 2.7 mR/hr was measured for Specimen TP80(A).

3. Radiation levels measured after thermal test apply to Specimen TP80(B) only.

Section 6 - CRITICALITY EVALUATION

Not applicable.

Section 7 - Operating Procedure

7.1 Procedure for Loading the Source Changer

Routine Checks Prior to Loading

1. Ensure labels are securely fastened to container and are legible.
2. Visually examine the package and ensure that the housing integrity is secure and does not have any significant dents, cracks of any type, or rust.
3. Assure the locking assembly allows free movement of the lock slide when performing an operational test.
4. Assure threaded holes used to secure the housing lid do not have damaged threads.
5. Assure all the conditions of the Certificate of Compliance are met and the source changer has all the required markings.

If the package fails to meet any of the above criteria, the package must not be shipped unless the discrepancy is corrected. Contact AEA Technology QSA, Inc. for assistance.

Routine Checks Prior to Shipping

1. Ensure that the source is locked into its storage position. The source assembly must be fully inserted into the source tube, the lock slide pushed in, the key lock secured, the key removed, the spring plunger fully engaged and the shipping cap in place. Place the lid on the 650L and secure with the four strain-hardened bolts. Attach a tamper indicator seal wire between two of the drilled bolt heads.

CAUTION: ***Use only the provided bolts for securing the lid. Use of bolts other than those provided invalidates the certification.***

2. Survey the source changer with a survey meter at the surface and at a distance of one meter from the surface to determine the proper radioactive shipping labels to be applied to the source changer as required by 49 CFR 172.403. If radiation levels above 200 mR/hr at the surface or 10 mR/hr at 1 meter (40 inches) from the surface are measured, the container must not be shipped.

3. Assure that the levels of removable contamination on the outside surface of the source changer do not exceed 0.00001 μCi per square centimeter as required by 49 CFR 173.443.

NOTE: If an overpack is used to ship the model 650L, surveys and a wipe test must be first performed on the 650L and then on the outer surface of the overpack.

If the package fails to meet any of the above criteria, the package must not be shipped unless the discrepancy is corrected. Contact AEA Technology QSA, Inc. for assistance.

4. Brace the source changer so that it cannot change position during transport.

5. Ship the container according to proper procedures for transporting radioactive material as established in 49 CFR 171-178.

Note: *The US Department of Transportation, in 49 CFR 173.22(c), requires each shipper of Type B quantities of radioactive material to provide prior notification to the consignee of the dates of shipment and expected arrival.*

7.2 Procedure for Unloading the Source Changer

The consignee of a source changer of radioactive material must make arrangements to receive the source changer when it is delivered. If the source changer is to be picked up at the carrier's terminal, 10 CFR 20.1906 requires that this be done expeditiously upon notification of its arrival.

Upon receipt of a source changer of radioactive material:

1. Survey the source changer with a survey meter as soon as possible, preferably at the time of pick-up and no more than three hours after it was received during normal working hours.

   Radiation levels should not exceed 200 mR/hr at the surface of the source changer, nor 10 mR/hr at a distance of 1 meter (40 inches) from the surface.

2. Record the actual radiation levels on the receiving report.

3. If the radiation levels exceed these limits, secure the container in a Restricted Area and notify the appropriate personnel in accordance with 10 CFR 20.

4. Inspect the source changer for physical damage.

5. Record the radioisotope, activity, model number, and serial number of the source. Record the source changer model number and serial number.

Operation of the Model 650L source changer must be in accordance with the Operating Instructions supplied with the source changer per 10 CFR 71.89.

7.3 Preparation of an Empty Source Changer for Transport

In the following instructions, an *empty* source changer refers to a Model 650L source changer without an active source.

To ship an empty source changer:

1. Perform the following procedure to confirm that there are no unauthorized source assemblies or cropped sources within the 650L source changer. Use only the gauge provided with the source changer. Do not use any other tool or a gauge for another device. If you do not have the proper gauge to perform the test, contact AEA Technology QSA Inc. before conducting the test.

   a. Insert the proper gauge in the empty tube(s) of the source changer. Read the gauge at the top of the outlet fitting.

   b. The gauge should bottom out in the empty source tube and indicate a safe condition. The redline should be flush with the top of the outlet fitting. Verify that each empty tube indicates a safe condition and proceed to step 2.

   c. If the gauge indicates an unsafe condition (redline is above the outlet fitting) there may be an obstruction in the tube. Remove the gauge slowly while observing the survey meter. If the radiation levels increase as the gauge is being removed keep the gauge within the device, secure the device and contact AEA Technology QSA Inc. for further instructions.

   d. If radiation levels remain normal as the gauge is being removed, completely remove gauge and contact AEA Technology QSA Inc. for shipping instructions.

2. When it is assured the container is empty, slide the lock slides over each source tube, lock the slides, remove the key, and attach the source hold down caps. Place the lid on the 650L and secure with the four strain-hardened stainless steel bolts supplied with the changer. Attach a tamper indicator seal wire between two of the drilled bolt heads.

CAUTION: Use only the provided bolts for securing the lid. Use of bolts other than those provided invalidates the certification.

3. Assure that the levels of removable radioactive contamination on the outside surface of the outer source changer do not exceed 0.00001 μCi per cm^2, as required by 49 CFR 173.443.

4. Assure all the conditions of the Certificate of Compliance are met and the source changer has all the required markings.

5. When it is confirmed that the Model 650L source changer is empty, survey the device and prepare the source changer for transport depending upon the radiation levels obtained, as given in 49 CFR 173.

Section 8 - ACCEPTANCE TESTS AND MAINTENANCE PROGRAM

8.1 Acceptance Test

8.1.1 Visual Inspection

Visually inspect each Model 650L source changer to be shipped to assure the following:

1. The source changer was constructed properly in accordance with its applicable drawings.

2. All fasteners as required by the applicable drawings are the correct type, properly installed and secured.

3. The relevant labels are attached, contain the required information, and are marked in accordance with 10 CFR 20.1904, 10 CFR 40.13(c)(6)(i), 10 CFR 34, and 10 CFR 71.

8.1.2 Structural and Pressure Tests

When applicable, subject the swage coupling between the source capsule and cable to a static tensile test with a load of 100 pounds (45 kg). The source assembly will not be used if it fails this test.

8.1.3 Leak Tests

The source capsule (primary containment) is bubble leak and wipe tested for leakage of radioactive contamination upon initial manufacture. The contamination must be less than 0.005 microcuries. The source assembly is not used if it fails.

8.1.4 Component Tests

All components of the source changer are inspected in accordance with an inspection instruction for conformance with engineering drawings and specifications.

8.1.5 Tests for Shielding Integrity

The radiation levels at the surface of the source changer and at one meter from the surface are measured upon manufacture. These radiation levels, when extrapolated to the rated capacity of the source changer, must not exceed 200 mR/hr at the surface, nor 10mR/hr at one meter from the surface of the source changer. Failure of this test will prevent use of the source changer as a Type B(U) package.

8.1.6 Thermal Acceptance Tests

Not applicable.

8.2 Maintenance Program

8.2.1 Structural and Pressure Tests

Not applicable.

8.2.2 Leak Tests

As described in Section 8.1.3, "Leak Tests," the radioactive source assembly is leak-tested at manufacture. Additionally, the source assembly is wipe-tested for leakage of radioactive contamination at intervals not to exceed every six months.

8.2.3 Subsystem Maintenance

The source changer is inspected for tightness of fasteners, proper type of fasteners, proper safety wires, and general condition prior to each use.

Prior to shipping:

a. The source changer locking assembly is checked to ensure free movement of the lock slide. Sticking or jamming of the lock slide is criteria for rejection, and requires replacement or repair of the locking assembly.

b. The source changer locking assembly source hold down cap is inspected to ensure proper functioning of the spring mechanism. Improper functioning is criteria for rejection and requires replacement or repair of the source hold down cap.

c. The source changer threaded adapter is examined for signs of cracking, wear or damage. Special attention should be paid to the two (2) "ears" that secure the adapter to the locking housing. ANY damage is cause for rejection of the adapter. Replacement of the adapter will be required before shipping or use of the changer.

8.2.4 Valves, Rupture Discs and Gaskets on Containment Vessel

Not applicable.

8.2.5 Shielding

Prior to each use, a radiation survey of the source changer is made to assure that the radiation levels do not exceed 200 mR/hr at the surface, nor 10mR/hr at one meter from the surface.

8.2.6 Thermal

Not applicable.

8.2.7 Miscellaneous

Inspections and tests designed for secondary users of this source changer under the general license provisions of 10 CFR 71.12(b) are provided in Section 7.

Appendix A: Model 650L Drawings

A-1 Model 650L Drawing: R-TP80, Revision E (Unit as Tested)

A-2 Model 650L Drawing: R65006, Revision D (Unit as to be Modified)

FIGURE WITHHELD UNDER 10 CFR 2.390

AEA TECHNOLOGY QSA 40 NORTH AVE, BURLINGTON, MA 01803	DESCRIPTIVE DRAWING
TITLE	650L SOURCE CHANGER TEST UNITS
SIZE A	DWG. NO. R-TP80	REV E
	SCALE: NONE	SHEET 1 OF 2

FIGURE WITHHELD UNDER 10 CFR 2.390

UNLESS OTHERWISE SPECIFIED: ALL DIMENSIONS ARE REFERENCE				
SIZE A	DWG. NO. R-TP80			REV E
	SCALE: NONE	SHEET 2 OF 2		

FIGURE WITHHELD UNDER 10 CFR 2.390

DESCRIPTIVE ASSEMBLY DRAWING					
DIMENSIONS IN INCHES	AEA TECHNOLOGY QSA 40 NORTH AVE, BURLINGTON, MA 01803		TITLE 650L SOURCE CHANGER		
TOLERANCES: FRACTIONS ± 1/16 .X ± 0.1 .XX ± 0.01 .XXX ± 0.005	DRAWN	23JUL99	SIZE A	DWG. NO. R65006	REV D
	CHECKED	27JUL99			
	APPR.	27JUL99	SCALE: NONE	SHEET 1 OF 3	

FIGURE WITHHELD UNDER 10 CFR 2.390

DIMENSIONS IN INCHES TOLERANCES: FRACTIONS ± 1/16 .X ± 0.1 .XX ± 0.01 .XXX ± 0.005	AEA TECHNOLOGY QSA 40 NORTH AVE, BURLINGTON, MA 01803	SIZE A	DWG. NO. R65006	REV D
		SCALE: NONE	SHEET 2 OF 3	

FIGURE WITHHELD UNDER 10 CFR 2.390

DIMENSIONS IN INCHES TOLERANCES: FRACTIONS ± 1/16 .X ± 0.1 .XX ± 0.01 .XXX ± 0.005	AEA TECHNOLOGY QSA 40 NORTH AVE, BURLINGTON, MA 01803	SIZE A	DWG. NO. R65006	REV D
		SCALE: NONE	SHEET 3 OF 3	

Appendix B: Test Plan 80 (Model 650L)

B-1 Test Plan 80, Revision 1

AEA TECHNOLOGY
QSA

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: [signature]	DATE: 12 MAR 99
QUALITY ASSURANCE APPROVAL: Daniel W. Kurtz	DATE: 12 Mar 99
REGULATORY APPROVAL: [signature]	DATE: 12 Mar 99
COMMENTS:	

TEST RESULTS REVIEW

ENGINEERING APPROVAL:	DATE:
QUALITY ASSURANCE APPROVAL:	DATE:
REGULATORY APPROVAL:	DATE:

SENTINEL

Test Plan 80

Revision 1

Model 650L
Source Changer
Type B Transport Tests

March 1999

Prepared By: *[signature]* Date 12 MAR 99

C. SCHLASEMAN
MPR

Checked By: Date 12 MAR 99

E. CLAUDE *[signature]*
MPR

Approved By: *[signature]* Date 12 MAR 99

N. MARRONE
MPR

Contents

List of Figures, Tables and Worksheets

AEA Technology/QSA Test Plan 80

1.0 Introduction

This document describes Type B(U) transport package testing of the SENTINEL Model 650L Source Changer, Certificate of Compliance Number 9269. The purpose of the testing is to demonstrate that the package meets the NRC requirements for Type B(U) packages under Normal Conditions of Transport (10 CFR 71.71), Hypothetical Accident Conditions (10 CFR 71.73), and the criteria stated in IAEA, Safety Series 6 (1985, as amended 1990).

The test plan specifies the test package configurations, testing equipment and scenarios, justifies the package orientations, and provides test worksheets to record key steps in the testing sequence.

Refer to Appendix A for a drawing of the test specimen.

2.0 Transport Package Description

The Model 650L source changer shown in Appendix A is 13 ¼" high, 10" long, and 8 ¼" wide in overall dimension, and has a maximum weight of 90 lb. The package consists of the following components:

- Source Capsule and Shield Assembly: The Special Form Source is contained in a capsule and is attached to the source wire assembly. The source is shielded by a Titanium "U" tube that is enclosed in a depleted uranium (DU) shield.

- Outer Casing: The shield assembly is encased in two Carbon Steel shells. The inner shell is rectangular and is 0.135" thick. The outer shell is circular and is 0.048" thick. The shells are positioned between two, Stainless Steel, 0.135" thick top and bottom plates. The plates are secured with four 5/16-18 hex head stainless steel through-bolts. The voids between the depleted uranium shield and the inner and outer shells are filled with a rigid 8 pound Polyurethane foam.

- Protective Lid: During transport, the locking assembly is protected by a 0.135" thick, Carbon Steel lid. The lid is secured to the top plate by four 3/8-16 hex head strain-hardened stainless steel bolts.

- Source Locking Assembly: Model 650L has two Stainless Steel locking assemblies that keep the source inside the Titanium "U" tube. Each locking assembly is secured to the top plate by four ¼-20 Stainless Steel screws.

The 650L package is shown below in Figure 1.

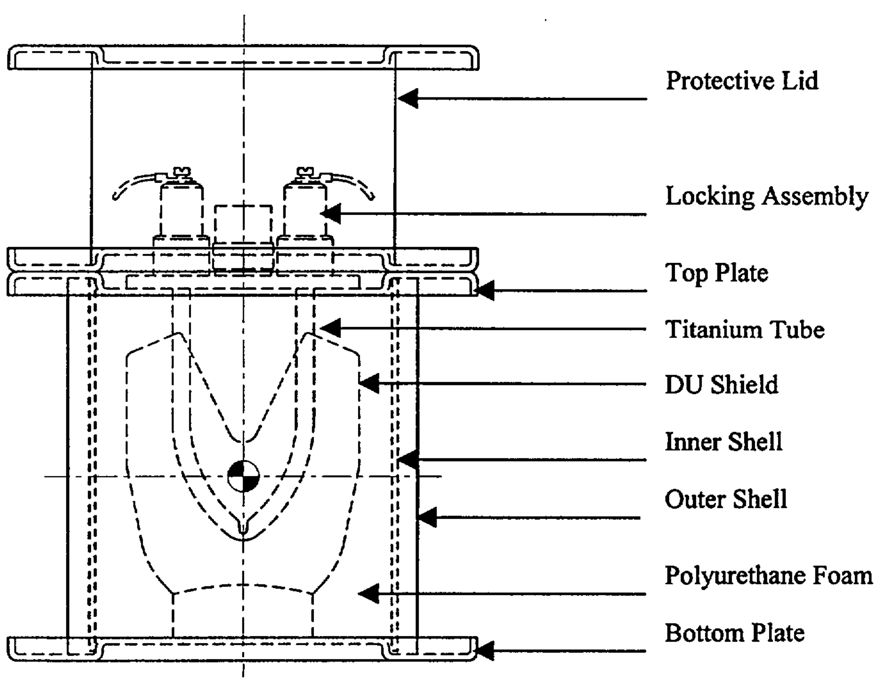


Figure 1. Side View of Model 650L Package

3.0 Regulatory Compliance

The purpose of this plan, which was developed in accordance with AEAT/QSA SOP-E005, is to ensure that the Model 650L Source Changer shown in the descriptive drawing provided in Appendix A meets the Type B(U) transport package requirements of 10 CFR 71 and IAEA Safety Series No. 6 (1985, as amended 1990).

The Normal Conditions of Transport tests (10 CFR 71.71) to be performed are the compression test, penetration test, and 1.2 meter (4 foot) free drop.

Water spray preconditioning of the package is not performed as the Model 650L packages are constructed of waterproof materials throughout. The water spray would not contribute to any degradation in structural integrity.

The Hypothetical Accident Tests (10 CFR 71.73) to be performed are the 9 meter (30 foot) free drop, puncture test, and thermal test.

The crush test (10 CFR 71.73(c)(2)) is not performed because the radioactive contents are special-form radioactive material.

The immersion test and all other conditions specified in 10 CFR 71 will be evaluated separately.

4.0 System Failures and Package Orientations

The location of the source relative to its stored position in the shield is an important safety element. Displacement of the source and/or shield from its original stored position could elevate the dose rate at the surface of the package above regulatory limits. Tests in this plan focus on damaging those components of the package which could cause displacement of the source, relative to its stored position, within the shield and which affect the integrity of the shield itself.

System failures that could affect package integrity and cause radiological dose rates to exceed the regulatory limits include:

- Oxidation of DU Shield during the thermal test could occur if either distortion/local buckling 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 Shield could occur if there is significant relative displacement between the shield and the top cover plate penetration and locking assembly.

Three orientations are considered most likely to cause damage during the 1.2 meter and 9 meter drop tests, i.e., the most likely to cause unacceptable external dose rates. For all three orientations, the worst case temperature is the lower limit of -40°C due to embrittlement of the DU and Carbon Steel components.

- Case 1, Horizontal, Long-Side Down: The DU shield could move through the foam during impact, which could result in source pullout from titanium tubes. Also, due to the low testing temperature, brittle failure of the inner and outer shells could occur. The failure(s) may be sufficient to open a significant path to the depleted uranium shield during thermal test and cause burning of the DU shield. The Long-Side Down orientation is selected because the long side of the package has a stiffer configuration than the short side, which will result in a shorter deceleration and a higher impact load.
- Case 2, Vertical, Upside Down: Deformation of the lid weldment, crushing of the foam between the depleted uranium shield and top plate, deformation (bowing upward) of the top plate due to the impact load of the DU shield applied through titanium source tubes and foam, failure of the through-bolts, and failure of the locking assembly could occur. When the package is turned upright for the thermal test, the DU shield and its integral titanium tubes could drop down to their original positions while the source is pulled out of the tubes by the bowed top plate or failed locking assembly. Also, a lead shim (which will melt during thermal testing) under the DU shield could cause additional source pullout.
- Case 3, Vertical, Top Corner Down: Failure of lid or lid closure bolts could expose the locking assembly to damage during the puncture bar test. Failure of the locking assembly could result in source pullout. Additionally, this orientation will load the through-bolts in tension, and could cause them to fail.

The following orientations are planned for the puncture tests. These orientations will be modified, if necessary, based on the results of the engineering assessments conducted after the 9 meter drop tests. The puncture test orientations will be selected to maximize damage to the test specimens.

- Case 1, Horizontal, Long-Side Down: This orientation is the same as for the Case 1, 1.2 meter and 9 meter drop tests.

- Case 2, Underside of Top Plate at Lid Bolt: The top plate could be pried up, and, as a minimum, load the through-bolts in tension. The impact on the lid bolt rivnut could damage the lid bolt connection.

- Case 3, Bottom of Package: Impact on the four Stainless Steel rivnuts could damage the through-bolt connection. If the lid is removed during the Case 3 9 meter drop, the test specimen will be dropped upside down such that the lock assemblies strike the puncture bar.

The limiting orientation for the penetration bar test is discussed in Section 8.6.2.

5.0 Assessment of Package Conformance

The Model 650L Source Changer must meet the Type B(U) transport package requirements of 10 CFR 71. The conformance criteria are detailed in the following two sections.

5.1 Regulatory Requirements

- Normal Conditions of Transport Tests (71.43(f)): There should be no loss or dispersal of radioactive contents, no significant increase in external surface radiation levels and no substantial reduction in the effectiveness of the packaging.

- Hypothetical Accident Conditions (71.51(a)(2)): There should be no escape of radioactive materials greater than A_2 in one week and no external dose rate greater than 1 R/hr at 1 meter from the external surface when the package contains its maximum design radioactive contents.

5.2 Test Package Contents

The Model 650L is designed to carry Special Form Sources. Containment of the radioactive source is tested at manufacture. The source capsules have been certified by the Competent Authority in accordance with the performance requirements for Special Form as specified in 10 CFR Part 71 and 49 CFR.

The test plan therefore does not discuss/specify tests of the containment of the radioactive source. The purpose of the tests is to demonstrate that the shielding remains effective within the limits specified by the regulations, and that the source capsule remains contained within the source changer.

A simulated source will be used during testing of the package. The radiation levels after the test will be monitored by replacing the simulated source with an active source.

6.0 Construction and Condition of Test Specimens

The Test Plan 80 (TP 80) test specimens will be Model 650L units constructed in accordance with AEAT/QSA Drawing R-TP80, Revision D.

Drawing TP650L specifies the Model 650L package in its worst case transport conditions, which vary depending on the Test Case. Lead shielding placement should be as described below:

Test Case	Lead Shielding Placement	Rationale
1—Horizontal, Long-Side Down Specimen TP80(A)	No lead between DU shield and long side of inner shell.	Lead between DU and shell or through-bolts might stop DU from travelling through foam during drop impact.
2—Vertical, Upside Down Specimen TP80(B)	Thickest lead under DU shield, use heavy package.	Lead under DU may melt during thermal test and could allow DU to settle, which could allow source pullout. Impact force will be larger for heavier packages, which would result in larger top plate deflection.
3—Top Corner Down Specimen TP80(C)	Any location, use heavy package.	Lead placement will not affect lid failure, and impact force will be larger for heavier packages.

For all Drop Test Cases the temperature of the specimen must be below -40°C at the time of each test, a minimum temperature required by IAEA, Safety Series 6 (1985, as amended 1990). The low temperature represents the worst-case condition for the package because of the potential for brittle fracture of the shield and Carbon Steel lid.

7.0 Material and Equipment List

The equipment checklists, test worksheets, and data sheets in Section 9.0 list the key materials and equipment specified in 10 CFR 71 and the necessary measurement instruments.

When video recording is specified, select video cameras with the highest shutter speed practical to record testing.

Additional materials and equipment may be used to facilitate the tests.

8.0 Test Procedure

Three specimens are to be tested to determine the transport integrity of the package. The testing sequence is shown below:

1. Test specimen preparation and inspection
2. Compression test (10 CFR 71.71(c)(9))
3. Penetration test (10 CFR 71.71(c)(10))
4. 1.2 Meter (4 foot) free drop test (10 CFR 71.71(c)(7))
5. First intermediate test inspection
6. 9 Meter (30 foot) free drop test (10 CFR 71.73(c)(1))
7. Puncture test (10 CFR 71.73(c)(3))
8. Second intermediate test inspection
9. Thermal test (10 CFR 71.73(c)(4)) (If applicable, see Section 8.12.1)
10. Final test inspection

Each specimen must be put through the entire test sequence, unless the thermal test is considered unnecessary based on the test specimen condition after the puncture test and the assessment by Engineering, Quality Assurance and Regulatory Affairs. If test conditions such as the orientation at impact are not met during the test of a particular specimen, it may be replaced with a specimen of equivalent construction. The replacement must go through the entire test sequence.

8.1 Roles and Responsibilities

The responsibilities of the groups identified in this plan are:

- **Engineering** executes the tests according to the test plan and summarizes the test results. **Engineering** also provides technical input to assist Regulatory Affairs and Quality Assurance as needed.
- **Regulatory Affairs** monitors the tests and reviews test reports for compliance with regulatory requirements.
- **Quality Assurance** oversees test execution and test report generation to ensure compliance with AEAT/QSA Quality Assurance Program.
- **Engineering, Regulatory Affairs,** and **Quality Assurance** are jointly responsible for assessing test and specimen conditions relative to 10 CFR 71.
- **Quality Control,** a function that reports directly to Quality Assurance, is responsible for measuring and recording test and specimen data throughout the test cycle.

8.2 Specimen Temperature Measurement

The penetration, drop, and puncture tests are to be carried out while the package is at or below -40°C. Temperature measurements will be made by positioning thermocouples on the package surface and the shield (inside the source tube).

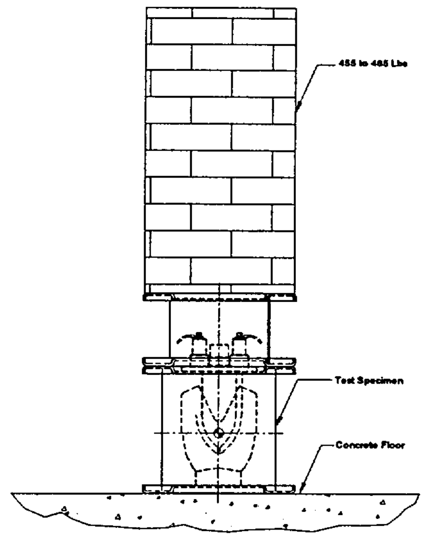
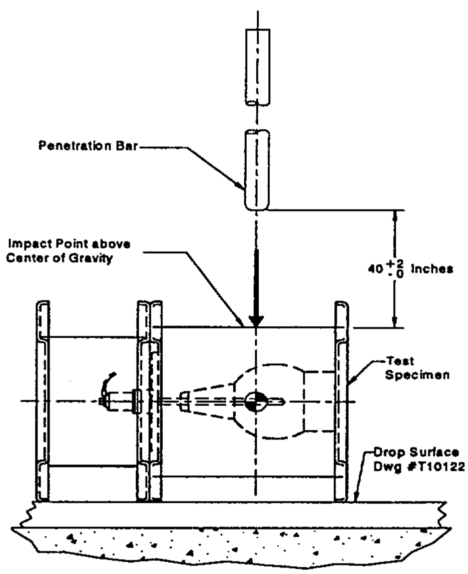
8.3 Test Specimen Preparation and Inspection

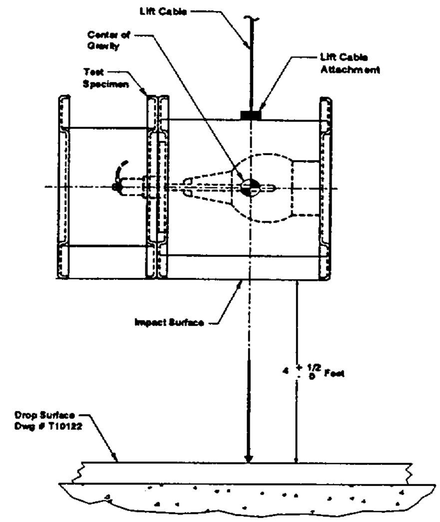
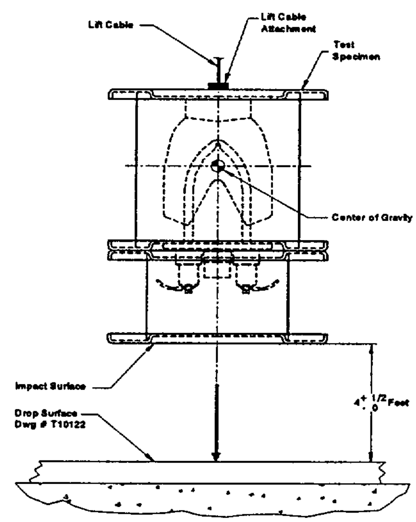
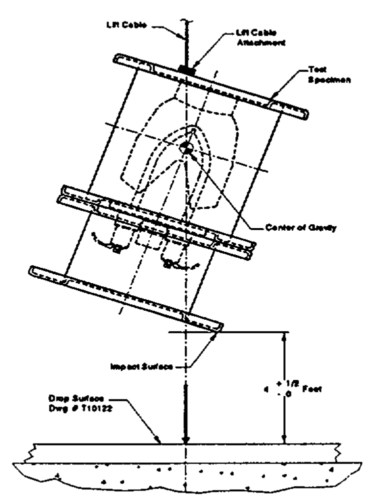
Refer to the *Specimen Preparation List* in Section 9.0 to ensure that test sequence is followed. Sign and date the list when completed.

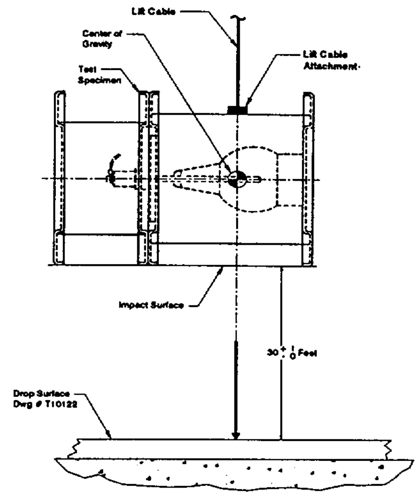
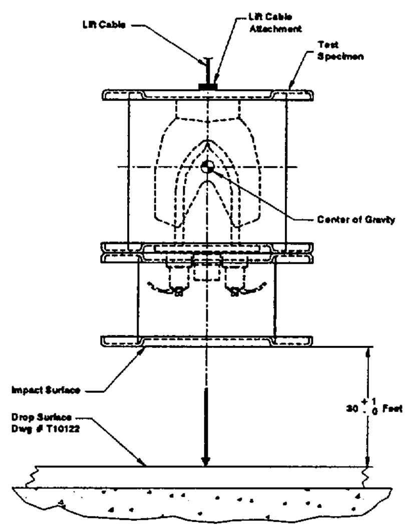
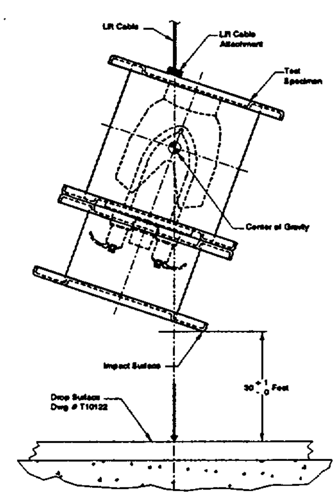
To prepare the test units:

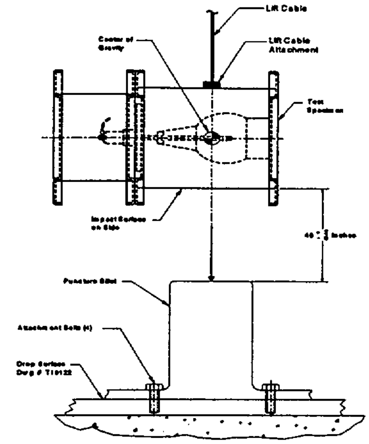
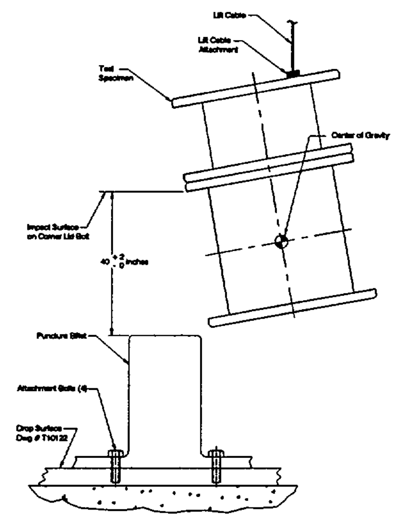
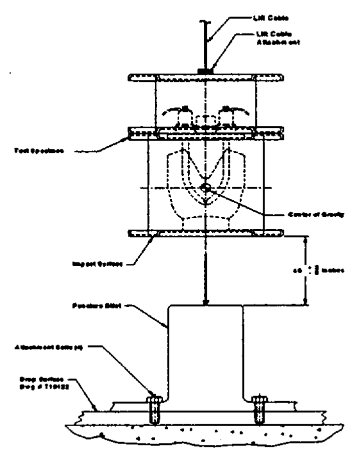
1. Inspect the test units to ensure that they comply with the requirements of Drawing R-TP80, Revision D.
2. Weigh the test package, including the lid.
3. Perform and record the radiation profile in accordance with AEAT/QSA Work Instruction WI-Q09.
4. **Quality Control, Engineering, Regulatory Affairs**, and **Quality Assurance** will jointly verify that the test specimens comply with Drawing R-TP80, Revision D, and the AEAT/QSA Quality Assurance Program.
5. Measure and record the location of the simulated source.
6. Place thermocouples on package surface and inside one of the source tubes.
7. Prepare the package for transport.
8. Clearly and indelibly mark the units with identification.

8.4 Summary of Test Schedule

Test	Paragraph	Specimen	Diagram
Compression	71.71(c)(9)	ALL	
Penetration	71.71(c)(10)	ALL	

Test	Paragraph	Specimen	Diagram
1.2 Meter (4 Foot) Free Drop, Case 1, Horizontal, Long Side Down	71.71(c)(7)	TP80(A)	
1.2 Meter (4 Foot) Free Drop, Case 2, Vertical, Upside Down	71.71(c)(7)	TP80(B)	
1.2 Meter (4 Foot) Free Drop, Case 3, Top Corner Down	71.71(c)(7)	TP80(C)	

<table>
<tr><th>Test</th><th>Paragraph</th><th>Specimen</th><th>Diagram</th></tr>
<tr><td>9 Meter (30 Foot) Free Drop, Case 1, Horizontal, Long Side Down</td><td>71.73(c)(1)</td><td>TP80(A)</td><td>
</td></tr>
<tr><td>9 Meter (30 Foot) Free Drop, Case 2, Vertical, Upside Down</td><td>71.73(c)(1)</td><td>TP80(B)</td><td>
</td></tr>
<tr><td>9 Meter (30 Foot) Free Drop, Case 3, Top Corner Down</td><td>71.73(c)(1)</td><td>TP80(C)</td><td>
</td></tr>
</table>

Test	Paragraph	Specimen	Diagram
Puncture, Case 1, Horizontal, Long Side Down	71.73(c)(3)	TP80(A)	
Puncture, Case 2, Underneath Corner of Top Plate	71.73(c)(3)	TP80(B)	
Puncture, Case 3, Vertical Upright	71.73(c)(3)	TP80(C)	
Thermal	71.73(c)(4)	ALL	Requirement for thermal test to be determined for each unit following completion of drop and puncture tests.

8.5 Compression Test (10 CFR 71.71(c)(9))

The first test is the compression test, per 10 CFR 71.71(c)(9), in which the package is placed under a load of 455 pounds which is greater than five times the maximum package weight and greater than 2 lbf/in^2 multiplied by the vertically projected area:

5 x 90 lbf = 450 lbf

8 ¼" wide x 10" long x 2 lbf/in^2 = 165 lbf

Refer to *Equipment List 1* for information about required tools. Use *Checklist 1* to ensure that the test sequence is followed. Use *Data Sheet 1* to record testing results. Sign and date all action items and record required data on the appropriate worksheets.

8.5.1 Compression Test Setup

To prepare a specimen for the compression test:

1. Review the setup shown in Figure 2.
2. Place the specimen on a concrete surface oriented in its normal, upright transport position.
3. Gradually place 455 to 465 pounds uniformly distributed onto the specimen as shown in Figure 2.
4. Test specimen in accordance with *Checklist 1*.

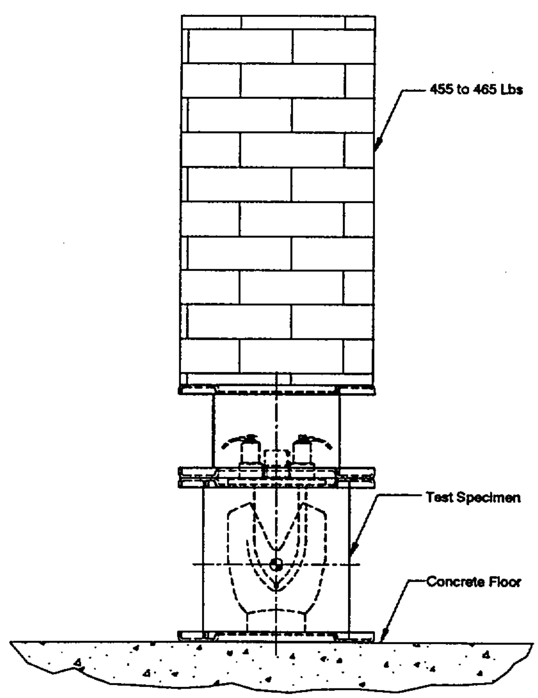


Figure 2. Compression Test Setup

8.5.2 Compression Test Assessment

Upon completion of the test, **Engineering, Regulatory Affairs**, and **Quality Assurance** team members will jointly take the following actions:

1. Review the test execution to ensure that the test was performed in accordance with 10 CFR 71.

2. Make a preliminary evaluation of the specimen relative to the requirements of 10 CFR 71.

3. Assess the damage to the specimen to decide whether testing of that specimen is to continue.

4. Evaluate the condition of the specimen to determine if changes are necessary in the package orientation for the penetration test to achieve maximum damage.

8.6 Penetration Test (10 CFR 71.71(c)(10))

The compression test is followed by the penetration test, per 10 CFR 71.71(c)(10), in which a penetration bar is dropped from a height of at least 40 inches to impact a specified point on the package. The bar is dropped through free air.

Refer to *Equipment List 2* for information about required tools. Use *Checklist 2* to ensure that the test sequence is followed. Use *Data Sheet 2* to record testing results. Sign and date all action items and record required data on the appropriate worksheets.

8.6.1 Penetration Test Setup

This test requires that the test specimen be at -40°C or below at the time of the penetration bar release. The worksheet calls for measuring and recording the specimen temperature before and after the test.

To set up a package for the penetration test:

1. Place the specimen on the drop surface (Drawing AT10122, Revision B) and position it according to the orientation described in the next section. Use shims to position the package, if necessary.

2. Position the penetration bar shown in Drawing BT10129, Revision B, directly above the specified point of impact, and raise the bar 40 to 42 inches above the target.

3. Measure the specimen's internal and surface temperature to ensure that the package is at the required temperature.

4. Test specimen in accordance with *Checklist 2*.

8.6.2 Penetration Test Orientation

The 650L package is placed horizontally, long side down on the drop surface specified in Drawing AT10122, Revision B. The orientation of the package is shown in Figure 3. The desired impact point is on the long side of the outer shell, directly above the center of gravity of the package, to try to penetrate the shells.

Other orientations for this specimen were considered including the normal transport position. In the normal transport orientation, the lock assembly is protected by the 0.135" thick steel outer lid. The penetration bar dropped from four feet would cause only minor damage to the outer lid.

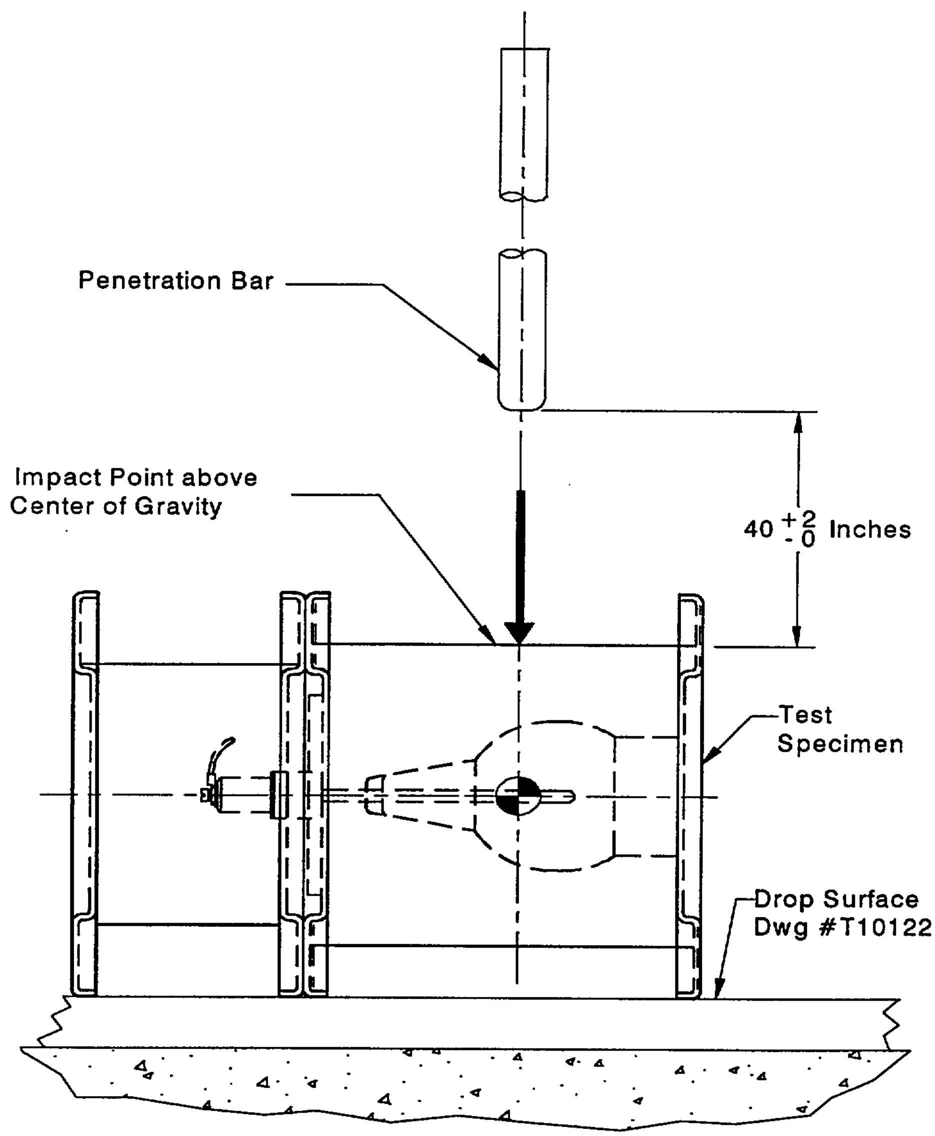


Figure 3. Penetration Test Orientation

8.6.3 Penetration Test Assessment

Upon completion of the test, **Engineering, Regulatory Affairs,** and **Quality Assurance** team members will jointly take the following actions:

1. Review the test execution to ensure that the test was performed in accordance with 10 CFR 71.

2. Make a preliminary evaluation of the specimen relative to the requirements of 10 CFR 71.

3. Assess the damage to the specimen to decide whether testing of that specimen is to continue.

4. Evaluate the condition of the specimen to determine if changes are necessary in the package orientation for the 1.2 meter (4 foot) free drop test to achieve maximum damage.

8.7 1.2 Meter (4 Foot) Free Drop Test (10 CFR 71.71(c)(7))

The final Normal Transport Conditions test is the 1.2 meter (4 foot) free drop as described in 10 CFR 71.71(c)(7). The drop compounds any damage caused in the first two tests. Upon completion of this step, the first intermediate test inspections will be performed.

Refer to *Equipment List 3* for information about required tools. Use *Checklist 3* to ensure that the test sequence is followed. Use *Data Sheet 3* to record testing results. Sign and date all action items and record required data on the appropriate worksheets.

8.7.1 1.2 Meter (4 Foot) Free Drop Test Setup

In this test, the package is released from a height of four feet and lands on the steel drop surface specified in Drawing AT10122, Revision B.

This test requires that all test specimen be at -40°C or below at the time of impact. Follow the instructions in the appropriate checklist for measuring and recording the test specimen temperature before and after the drop.

To set up a package for the 1.2 meter (4 foot) free drop test:

1. Use the drop surface specified in Drawing AT10122, Rev. B.

2. Measure and record the test specimen temperature to ensure that the package is at the specified temperature.

3. Place the specimen on the drop surface and position it according to the appropriate orientation:

   - Refer to Figure 4 for the Specimen TP80(A) package orientation

   - Refer to Figure 5 for the Specimen TP80(B) package orientation

   - Refer to Figure 6 for the Specimen TP80(C) package orientation

4. Align the selected center-of-gravity as shown in the referenced drawing.

5. Raise the package so that the impact target is 4.0 to 4.5 feet above the drop surface.

6. Test specimen in accordance with *Checklist 3*.

8.7.2 1.2 Meter (4 Foot) Free Drop Test Orientation, Specimen TP80(A)

The impact surface of Specimen TP80(A) is horizontal, long-side down.

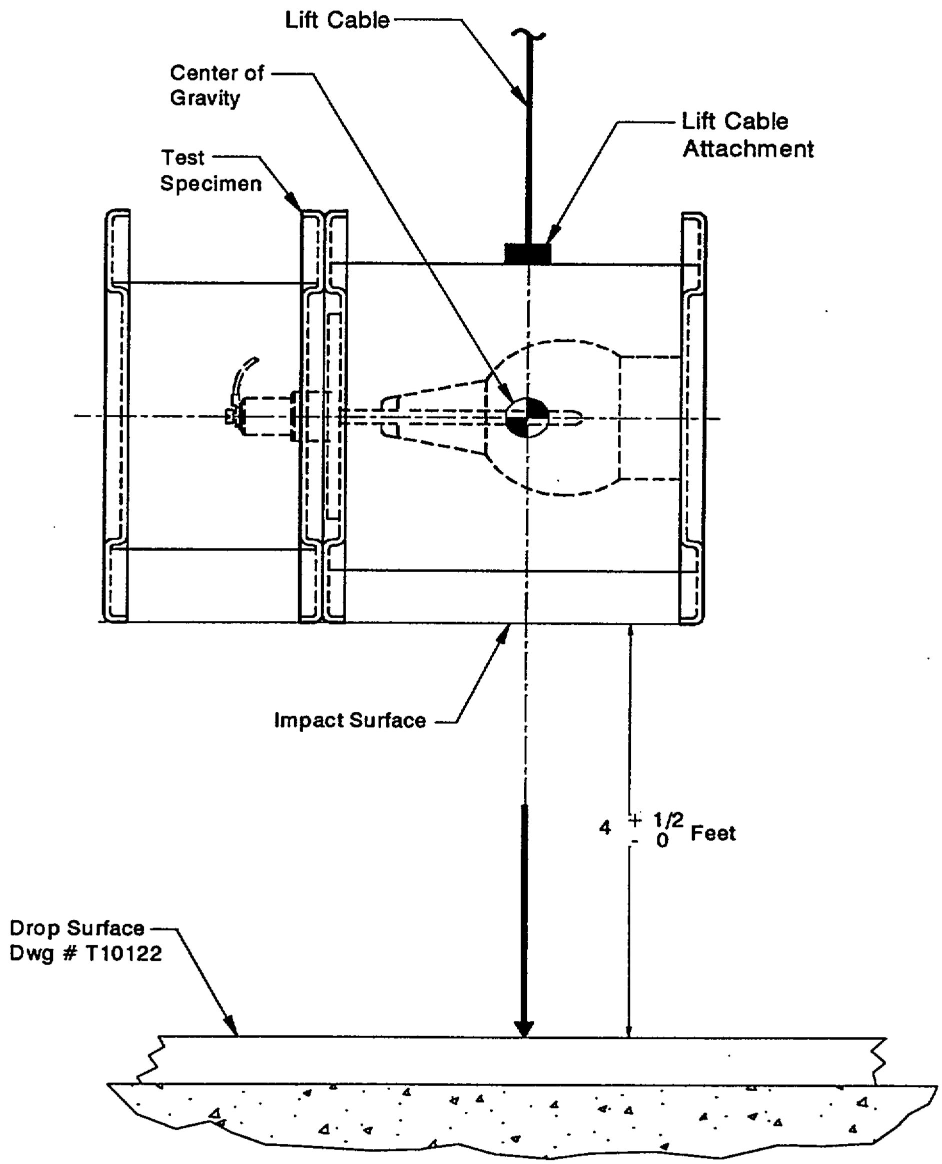


Figure 4. 1.2 Meter (4 Foot) Free Drop Orientation, Specimen TP80(A)

8.7.3 1.2 Meter (4 Foot) Free Drop Test Orientation, Specimen TP80(B)

The impact surface for Specimen TP80(B) is vertical, upside down.

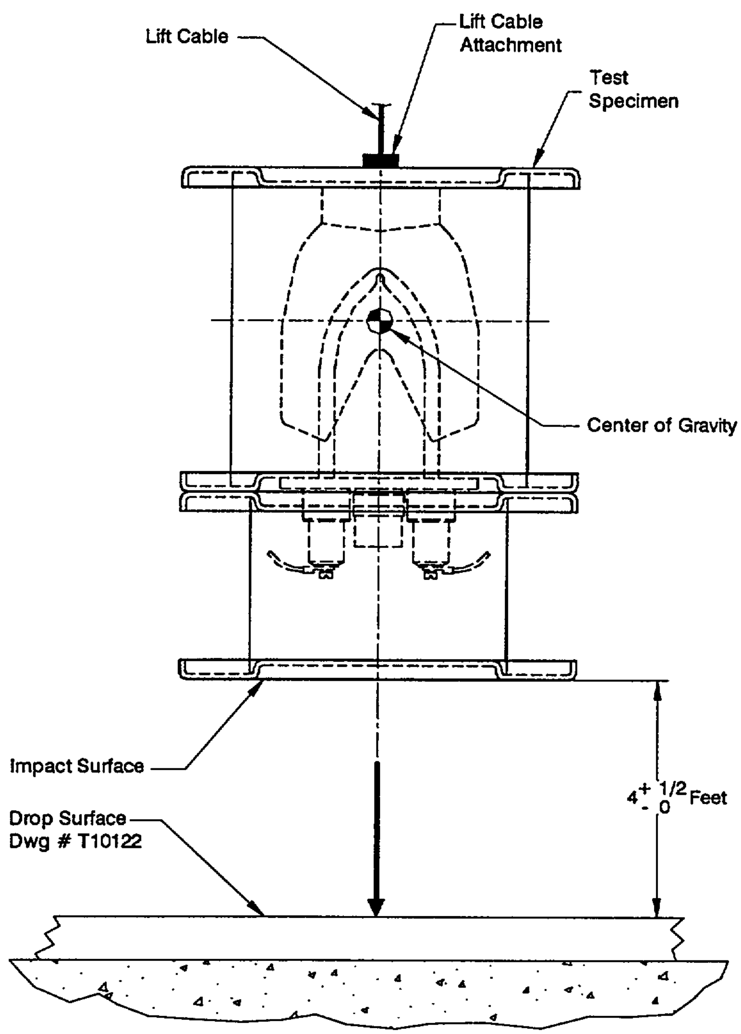


Figure 5. 1.2 Meter (4 Foot) Free Drop Orientation, Specimen TP80(B)

8.7.4 1.2 Meter (4 foot) Free Drop Test Orientation, Specimen TP80(C)

The impact surface for Specimen TP80(C) is the top (lid) corner.

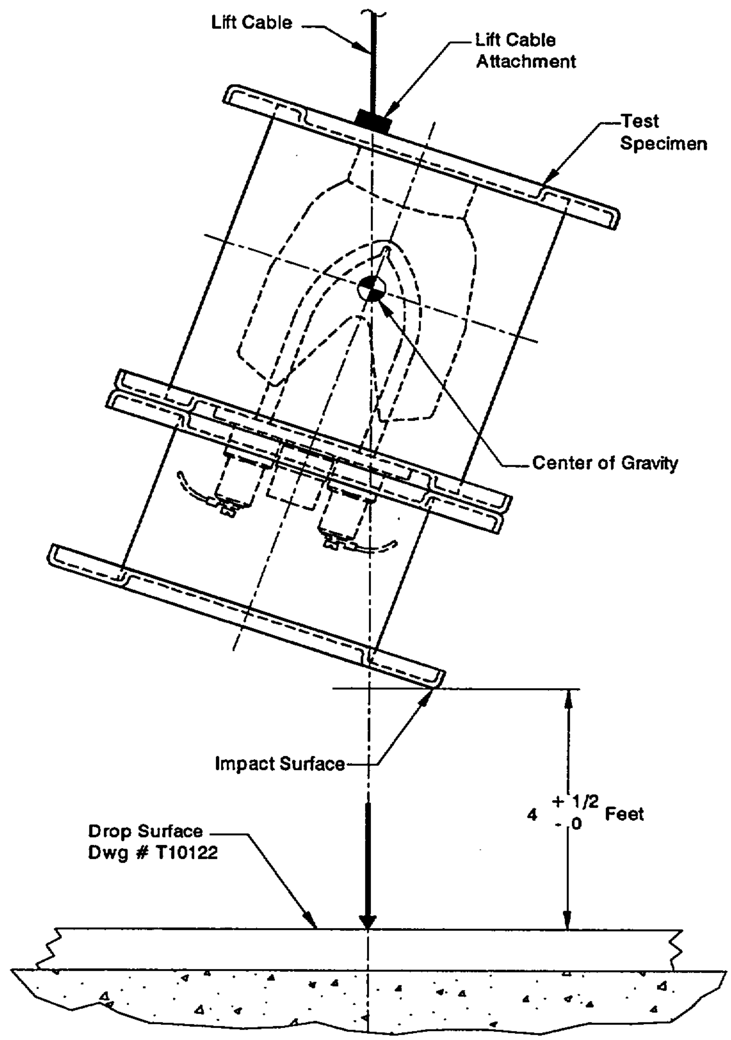


Figure 6. 1.2 Meter (4 Foot) Free Drop Orientation, Specimen TP80(C)

8.7.5 1.2 Meter (4 Foot) Free Drop Test Assessment

Upon completion of the test, **Engineering, Regulatory Affairs,** and **Quality Assurance** team members will jointly perform the following tasks:

1. Review the test execution to ensure that the test was performed in accordance with 10 CFR 71.71.

2. Make a preliminary evaluation of the specimen relative to the requirements of 10 CFR 71.71.

3. Assess the damage to the specimen to decide whether testing of that specimen is to continue.

4. Evaluate the condition of the specimen to determine if changes are necessary in package orientation for the 9 meter (30 foot) free drop to achieve maximum damage.

5. Measure and record any damage to the test specimen.

6. Measure and record a radiation profile of the test specimen in accordance with AEAT/QSA Work Instruction WI-Q09.

8.8 First Intermediate Test Inspection

Engineering, Regulatory Affairs, and **Quality Assurance** team members will make an assessment of the test specimen and jointly determine whether the specimen meets the requirements of 10 CFR 71.71.

8.9 9 Meter (30 Foot) Free Drop Test (10 CFR 71.73(c)(1))

The first Hypothetical Accident Conditions test is the 9 meter (30 foot) free drop as described in 10 CFR 71.73(c)(1). This drop uses the same orientations as the 1.2 meter (4 foot) free drop and compounds any damage caused in that test.

Refer to *Equipment List 4* for information about required tools. Use *Checklist 4* to ensure that the test sequence is followed. Use *Data Sheet 4* to record testing results. Sign and date all action items and record required data on the appropriate worksheets.

8.9.1 9 Meter (30 Foot) Free Drop Test Setup

In this test, the package is released from a height of thirty feet and lands on the steel drop surface specified in Drawing AT10122, Revision B.

This test requires that the test specimen be at -40°C or below at the time of impact. Follow the instructions in the appropriate checklist for measuring and recording the test specimen temperature before and after the drop.

To set up a package for the 9 meter (30 foot) free drop test:

1. Use the drop surface specified in Drawing AT10122, Rev. B.

2. Measure and record the test specimen temperature to ensure that the package is at the specified temperature.

3. Place the specimen on the drop surface and position it according to the appropriate orientation:

   - Refer to Figure 7 for the Specimen TP80(A) package orientation
   - Refer to Figure 8 for the Specimen TP80(B) package orientation
   - Refer to Figure 9 for the Specimen TP80(C) package orientation

4. Align the selected center-of-gravity marker as shown in the referenced drawing.

5. Raise the package so that the impact target is 30 to 31 feet above the drop surface.

6. Test the specimen in accordance with *Checklist 4*.

8.9.2 9 Meter (30 Foot) Free Drop Test Orientation, TP80(A)

The impact surface for Specimen TP80(A) is horizontal, long-side down. This orientation is the same as the orientation for the 1.2 meter (4 foot) drop for Specimen TP80(A).

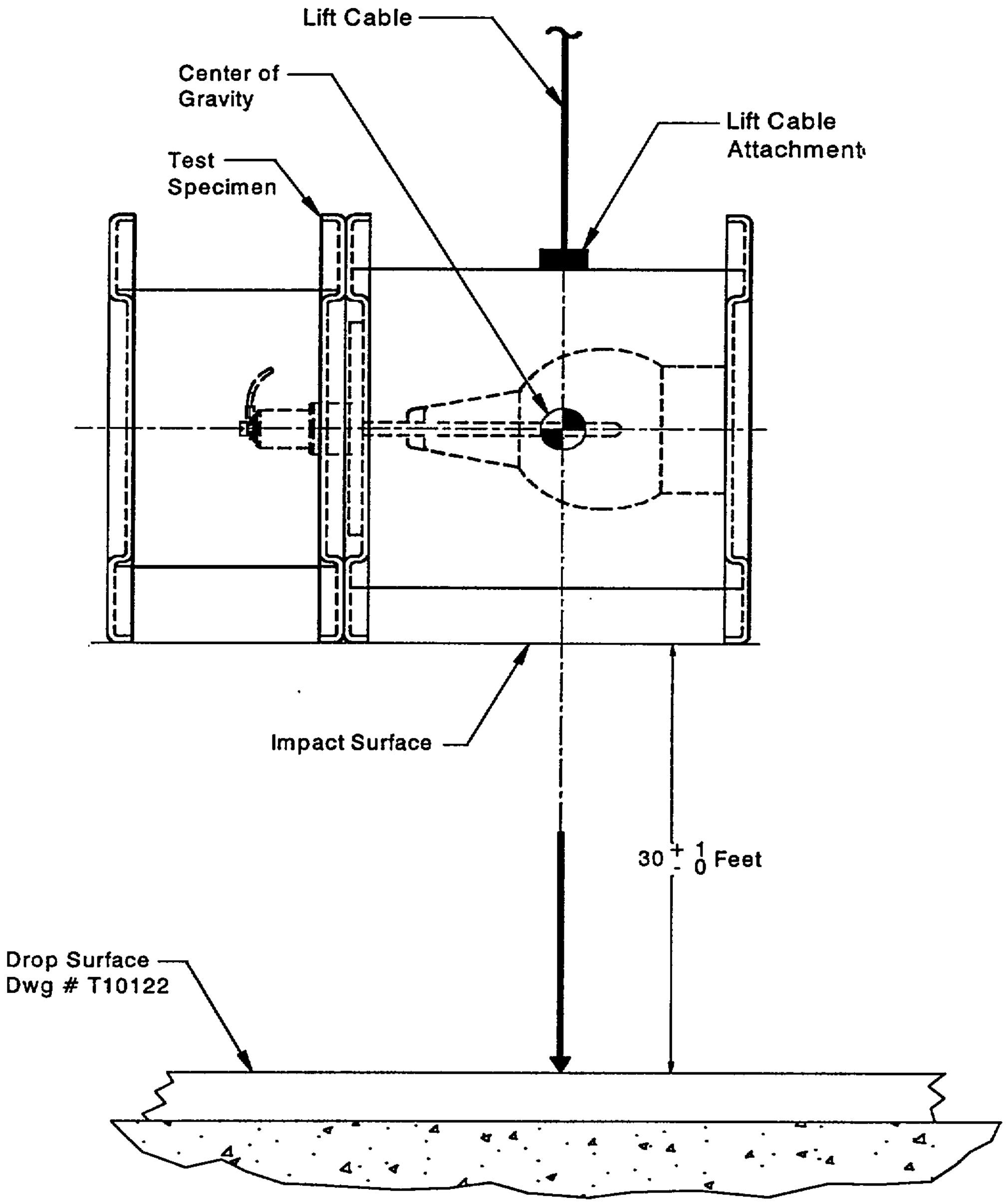


Figure 7. 9 Meter (30 Foot) Free Drop Orientation, Specimen TP80(A)

8.9.3 9 Meter (30 Foot) Free Drop Test Orientation, Specimen TP80(B)

The impact surface for Specimen TP80(B) is vertical, upside down. This orientation is the same as the orientation for the 1.2 meter (4 foot) drop for Specimen TP80(B).

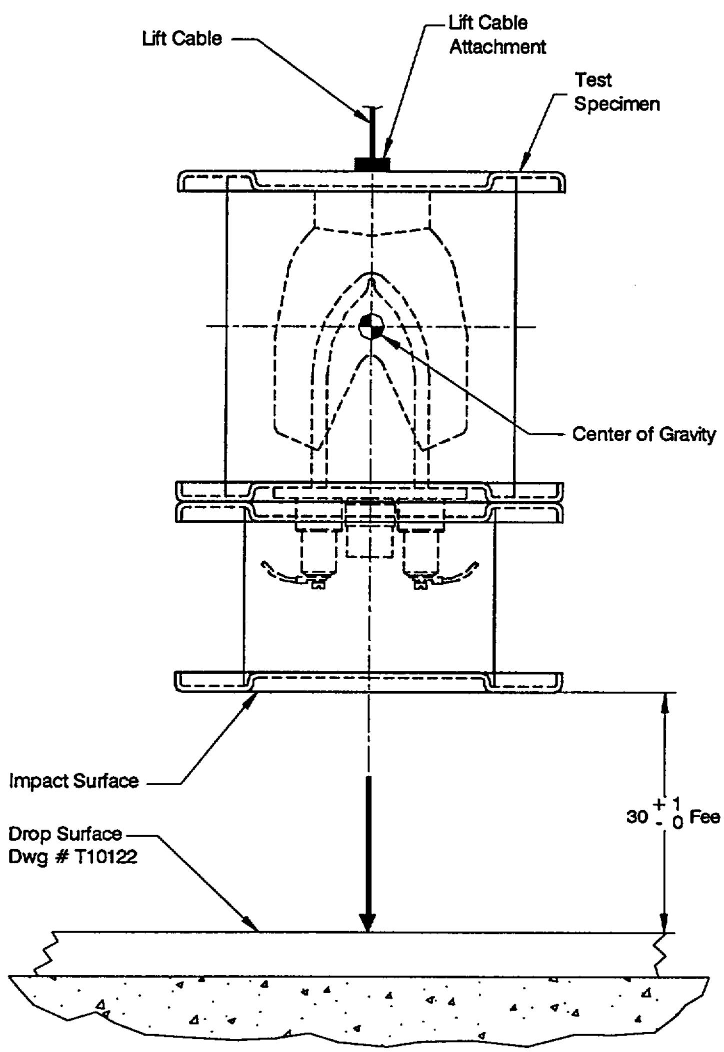


Figure 8. 9 Meter (30 Foot) Free Drop Orientation, Specimen TP80(B)

8.9.4 9 Meter (30 Foot) Free Drop Test Orientation, Specimen TP80(C)

The impact surface for Specimen TP80(C) is the top (lid) corner. This orientation is the same as the orientation for the 1.2 meter (4 foot) drop for Specimen TP80(C).

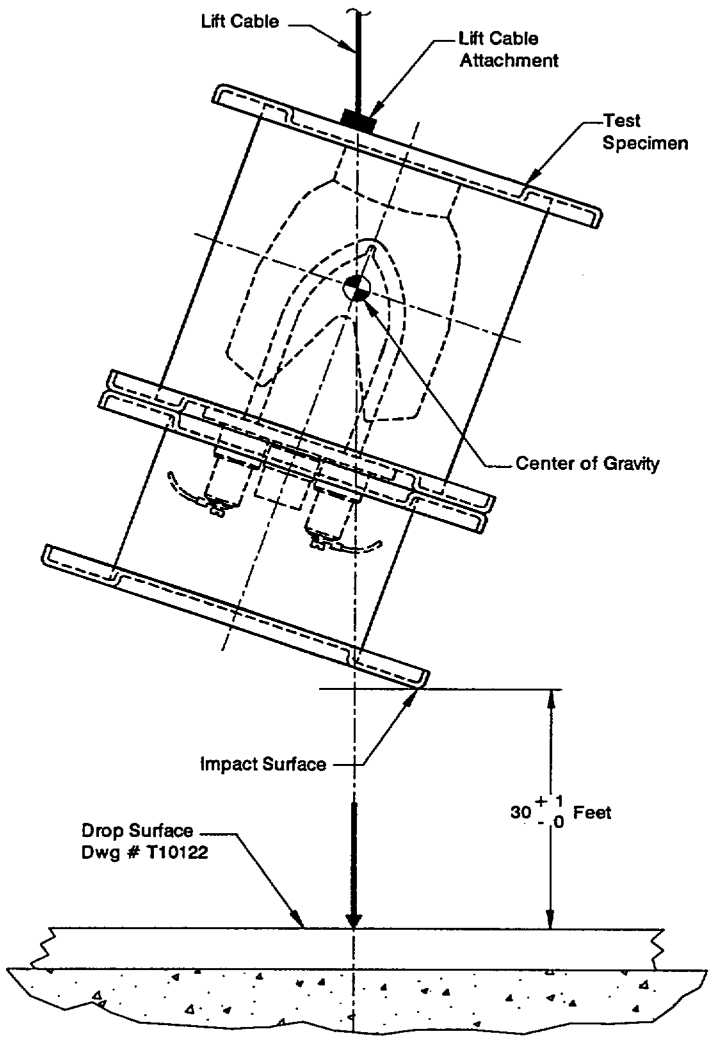


Figure 9. 9 Meter (30 Foot) Free Drop Orientation, Specimen TP80(C)

8.9.5 9 Meter (30 Foot) Free Drop Test Assessment

Upon completion of the test, **Engineering, Regulatory Affairs,** and **Quality Assurance** team members will jointly perform the following tasks:

1. Review the test execution to ensure that the test was performed in accordance with 10 CFR 71.73, and in accordance with the impact orientation and other conditions specified in this plan.

2. Make a preliminary evaluation of the specimen relative to the requirements of 10 CFR 71.73.

3. Perform an assessment to determine if any change in puncture test orientation is necessary in order to sustain maximum specimen damage during the Puncture Test, and document.

8.10 Puncture Test (10 CFR 71.73(c)(3))

The 9 meter (30 foot) free drop is followed by the puncture test, per 10 CFR 71.73(c)(3), in which the package is dropped from a height of at least 40 inches onto the puncture billet specified in the Drawing CT10119, Revision C.

The billet is to be bolted to the drop surface used in the free drop tests. The 12-inch high puncture billet meets the minimum height (8 inches) required in 10 CFR 71.73(c)(3). The specimen has no projections or overhanging members longer than 8 inches, which could act as impact absorbers, thus allowing the billet to cause the maximum damage to the specimen.

Refer to *Equipment List 5* for information about required tools. Use *Checklist 5* to ensure that the test sequence is followed. Use *Data Sheet 5* to record testing results. Sign and date all action items and record required data on the appropriate worksheets.

This test requires that the test specimen be at -40°C or below at the time of impact. Follow the instructions in the appropriate checklist for measuring and recording the test specimen temperature before and after the drop.

8.10.1 Puncture Test Setup

To set up a test specimen for the puncture test:

1. Measure and record the test specimen temperature to ensure that the package is at the specified temperature.

2. Place the specimen on the drop surface and position it according to the appropriate orientation (unless the 9 meter Test Assessment selects different orientations):

    - Refer to Figure 10 for the Specimen TP80(A) package orientation

    - Refer to Figure 11 for the Specimen TP80(B) package orientation

    - Refer to Figure 12 for the Specimen TP80(C) package orientation

3. Check the alignment of the specified center-of-gravity marker with the targeted point of impact.

4. Raise the package so that there are 40 to 42 inches between the package and the top of the puncture billet.

5. Test the specimen in accordance with *Checklist 5*.

8.10.2 Puncture Test Orientation, Specimen TP80(A)

The impact surface for Specimen TP80(A) is the horizontal, long-side of the outer shell.

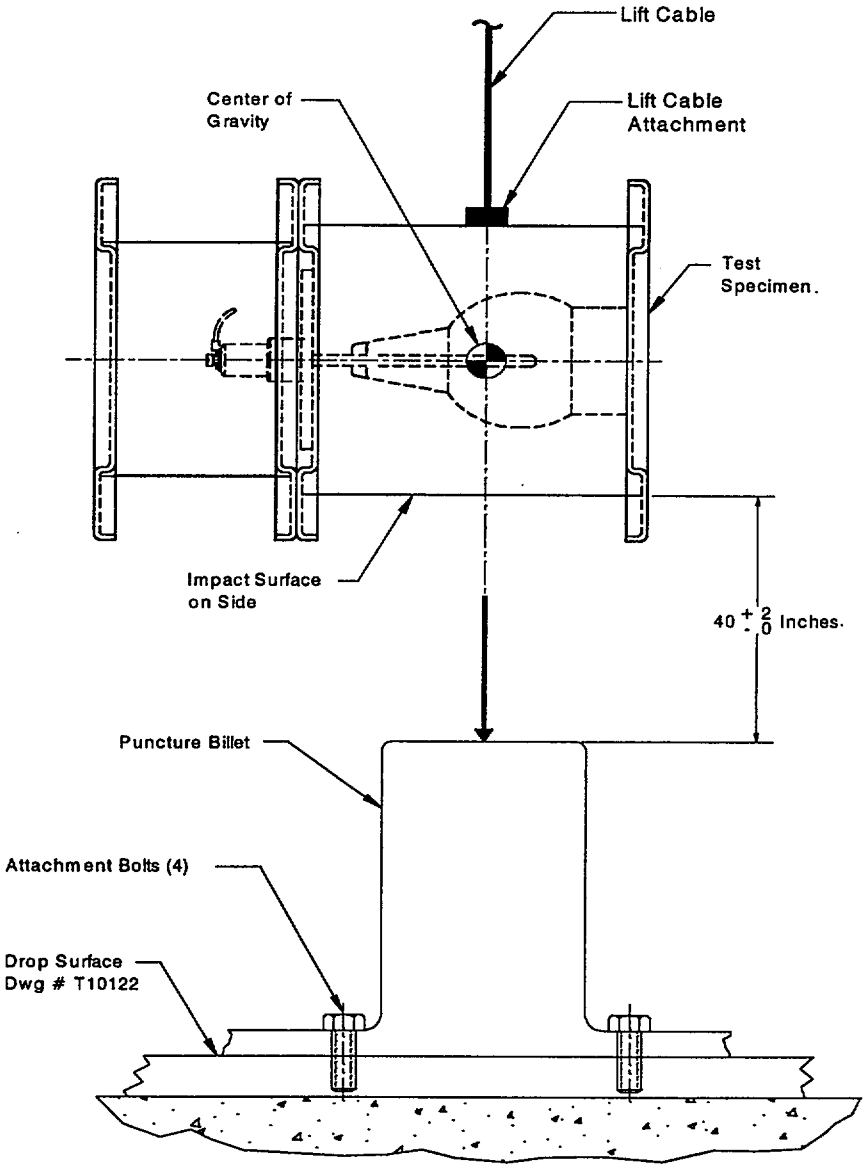


Figure 10. Puncture Test Orientation, Specimen TP80(A)

8.10.3 Puncture Test Orientation, Specimen TP80(B)

The impact surface for Specimen TP80(B) is the underside of the top plate. The puncture bar should impact the corner of the plate on the lid bolt.

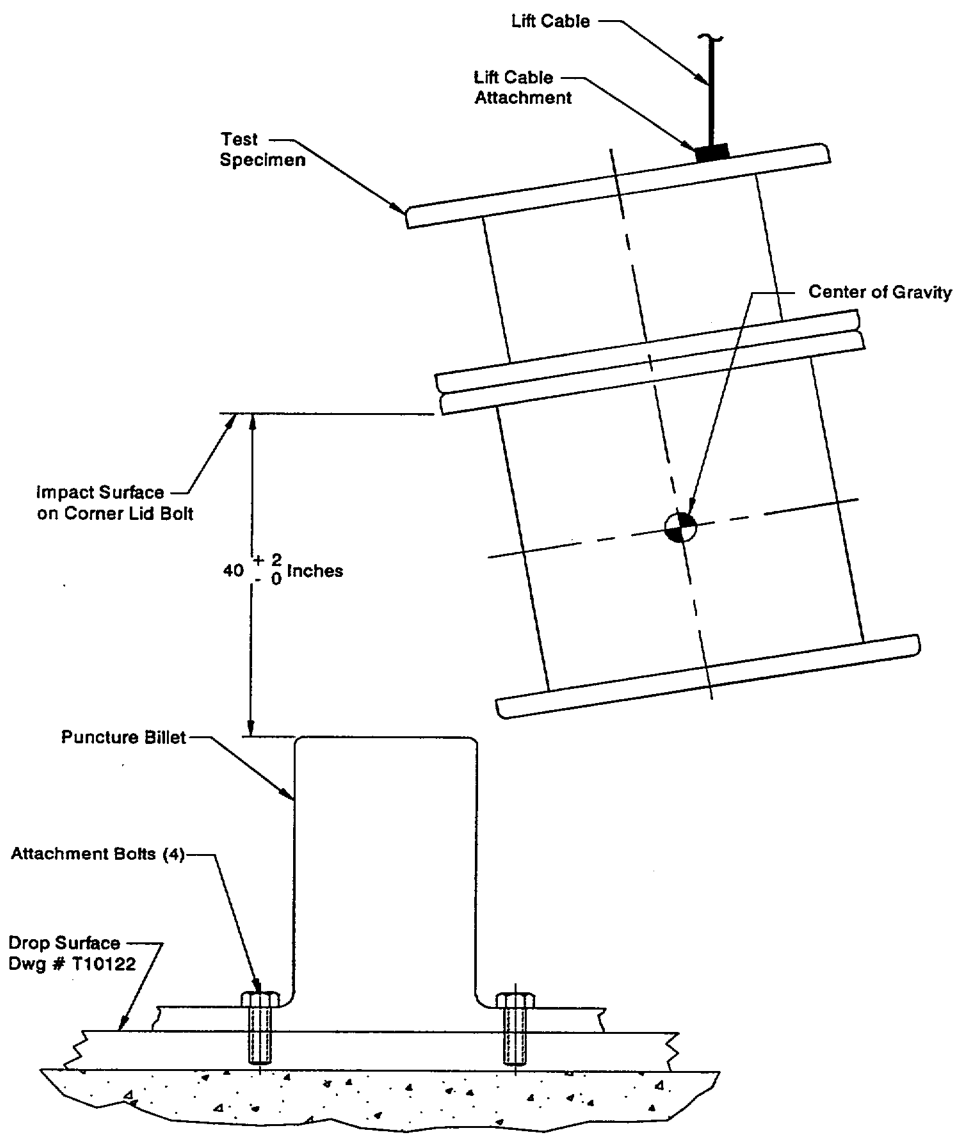


Figure 11. Puncture Test Orientation, Specimen TP80(B)

8.10.4 Puncture Test Orientation, Specimen TP80(C)

The impact surface for Specimen TP80(C) is the bottom of the package.

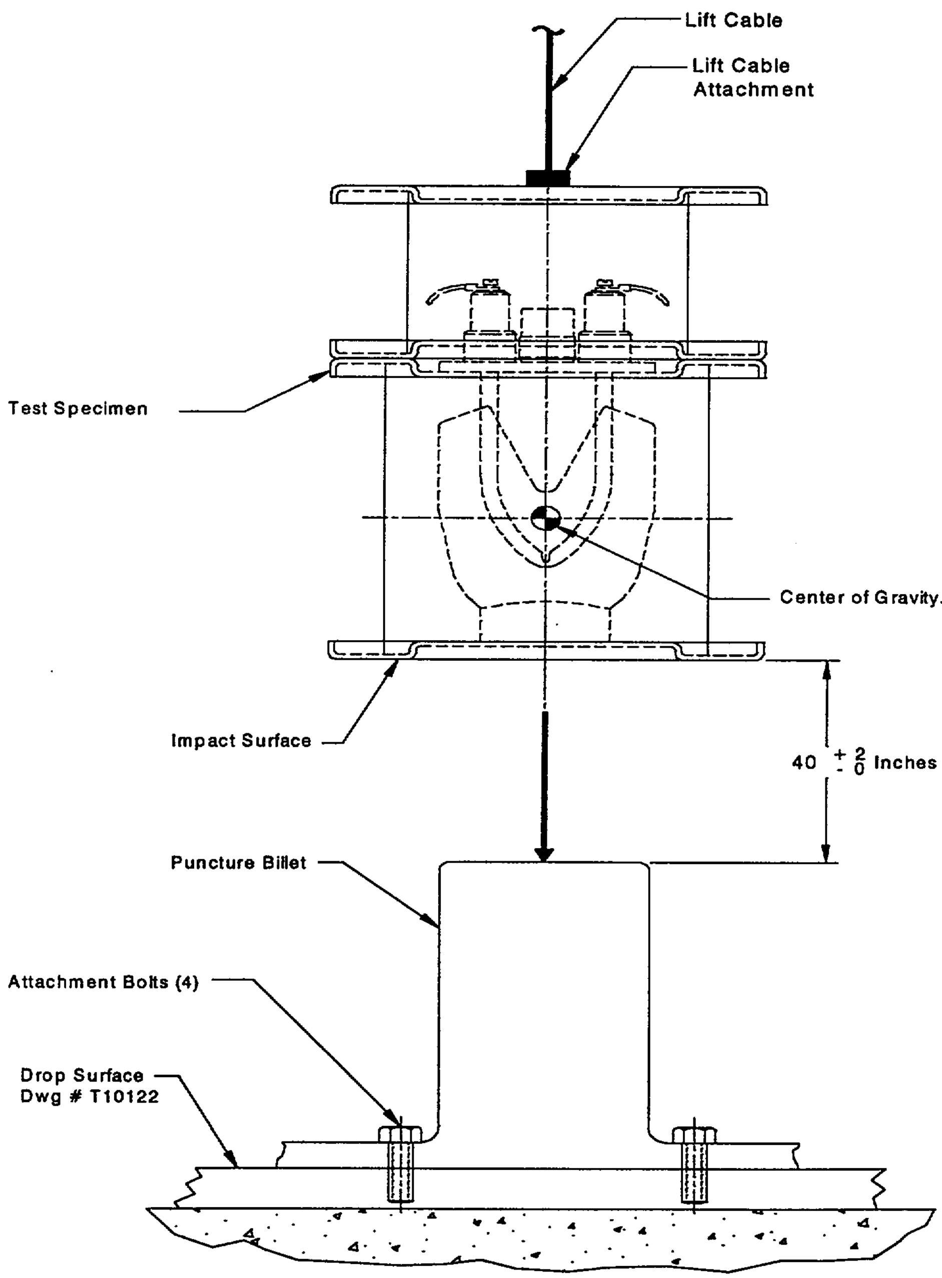


Figure 12. Puncture Test Orientation, Specimen TP80(C)

8.10.5 Puncture Test Assessment

Upon completion of the test, **Engineering, Regulatory Affairs**, and **Quality Assurance** team members will jointly perform the following tasks:

1. Review the test execution to ensure that the test was performed in accordance with 10 CFR 71.73, and in accordance with any other conditions specified in this plan.

2. Make a preliminary evaluation of the specimen relative to the requirements of 10 CFR 71.73.

3. Assess the damage to the specimen to decide whether testing of the specimen is to continue.

8.11 Second Intermediate Test Inspection

Perform a second intermediate test inspection of all specimens after the puncture test and before the thermal test.

1. Measure and record any damage to the test specimen.

2. Determine and record the location of the source.

3. Remove and assess the condition of the simulated source.

4. Reassemble the package using an active source, making sure that the source wire position and the package configuration are the same as they were immediately after the puncture test.

5. Measure and record a radiation profile of the test specimen in accordance with AEAT/QSA Work Instruction WI-Q09.

6. Reassemble the package using the same simulated source used in the specimen during the previous tests.

7. Make sure that the source wire position and the package configuration are the same as they were immediately after the puncture test.

8. Weigh package.

8.12 Thermal Test (10 CFR 71.73(c)(4))

The final requirement is the thermal test specified in 10 CFR 71.73(c)(4).

Refer to *Equipment List 6* for information about required tools. Use *Checklist 6* to ensure that the test sequence is followed. Use *Data Sheet 6* to record testing results. Sign and date all action items and record required data on the appropriate worksheets.

8.12.1 Test Specimen Selection

The specimen(s) selected for thermal testing will be based on an assessment of the damage sustained by the packages following the puncture test. The selected package testing orientation will also be determined based on an assessment of the test specimen condition. As a minimum requirement, the vertical, upside down drop orientation (TP80(B)) will be tested in a vertical, right

side up orientation for the thermal test. The TP80(B) specimen is most likely to have the source pull out from its shielded position due to deflection of the top plate during the drop tests and melting of lead shielding/shims below the DU shield during the thermal test.

8.12.2 Thermal Test Setup

To ensure sufficient heat input to the test specimens, the oven will be pre-heated to a temperature of not less than 810°C. This temperature, above the required 800°C, includes an allowance for measurement uncertainty.

The test environment is a vented electric oven capable of creating a time weighted average temperature of 800°C.

Thermocouples will be attached to the specimen top, bottom, and 2 side surfaces. The 2 side surface thermocouples will be positioned 180° apart, facing the front and back of the oven. A fifth thermocouple will be inserted into one of the source tubes to measure source changer internal temperature. The external thermocouples will be shielded from the radiant heat of the oven so that the surface temperature of the source changer can be accurately measured.

When the oven has been pre-heated to 810°C, the package will be placed in the oven in the orientation determined to be worst case, per Section 8.10.2. When the temperature of the source changer surface has risen to no less than 810°C, the test will start. The package will remain in the oven for a period of 30 minutes after the start of the test.

To allow for combustion of the foam during the thermal test, the oven door will remain slightly open. It has been determined that a gap of one inch at the top and bottom of the oven door allows airflow into the oven and allows the oven to maintain its temperature. The oven door is 36 inches long. As a result, there will be about a 36 square inch opening at both the top and bottom of the furnace door. This allows for the natural convection of air into the furnace.

If the specimen is burning when the oven is opened, the unit will be allowed to extinguish by itself and then cool naturally. Although solar radiation assumed during a hypothetical accident could reduce the rate of package cooldown, such a reduction in cooldown rate is considered to have a negligible effect on the package compared with the 30 minutes of exposure to 810°C. This test plan, therefore, does not require insolation effects to be explicitly modeled during package cooldown. Appropriate measures should be taken to avoid the radiological risks associated with this potential hazard. The final evaluation of the package is performed when the specimen reaches ambient temperature.

8.12.3 Thermal Test Procedure

To perform the thermal test:

1. Attach the thermocouples to the test specimen's measurement locations.
2. Preheat the oven temperature to not less than 810°C.
3. When the oven temperature is stable at above 810°C, place the specimen in the oven, and partially close the door.
4. When the temperature of the surface of the specimen rises above 810°C, start the 30-minute time interval.

5. Throughout the test, measure and record the oven and the test specimen temperatures.

6. At the end of the 30 minute time interval, open the oven door and shut off the oven.

WARNING: If the package is burning, appropriate safety measures must be in place to avoid the risks associated with burning polyurethane foam and/or depleted uranium. Consult with the oven operator and other appropriate personnel.

7. Allow the package to self-extinguish and cool.

8. Record any damage to the package and make a photographic and radiographic record of shield position and damage.

8.12.4 Thermal Test Assessment

Upon completion of the test, **Engineering, Regulatory Affairs,** and **Quality Assurance** team members will jointly perform the following task:

1. Review the test execution to ensure that the test was performed in accordance with 10 CFR 71.73 and the test conditions specified in this plan.

2. Make a preliminary evaluation of the specimen relative to the requirements of 10 CFR 71.73.

8.13 Final Test Inspection

Perform the following inspections after completion of all the required testing:

1. Measure and record any damage to the test specimen.

2. Determine and record the location of the source.

3. Remove and assess the condition of the simulated source.

4. Reassemble the package using an active source, making sure that the source wire position and the package configuration are the same as they were immediately after the thermal test.

5. Measure and record a radiation profile of the test specimen in accordance with AEAT/QSA Work Instruction WI-Q09.

6. Document and assess the radiation level at one meter from the surface of the package.

7. Determine whether it is necessary to dismantle the test specimen for inspection of hidden component damage or failure.

8. If proceeding with the inspection, record and photograph the process of removing any component.

9. Measure and record any damage or failure found in the process of dismantling the test specimen.

Engineering, Regulatory Affairs, and **Quality Assurance** team members will make a final assessment of the test specimen and jointly determine whether the specimen meets the testing requirements of 10 CFR 71.

9.0 Worksheets

Use the following worksheets for executing these tests. There are three worksheets for each test: an equipment list, a test procedure checklist, and a data sheet.

Use the test equipment list to record the serial number of each measurement device used. Attach a copy of the relevant inspection report or calibration certificate after verifying the range of accuracy of the equipment.

Quality Control will initial each step on the checklist as it is executed and record data as required. The **Engineering, Regulatory Affairs,** and **Quality Assurance** representatives must witness all testing to ensure the testing is performed in accordance with this test plan and 10 CFR 71.

Make copies of the forms for additional attempts. Maintain records of all attempts.

Specimen Preparation List

Step		TP80(A)	TP80(B)	TP80(C)
1.	Serial Number:			
2.	Total weight of package (lb):			
3.	Location of simulated source from top plate (in):			
4.	Location of lead shielding:			
5.	All fabrication and inspection records documented in accordance with the AEAT QA Program?			
6.	Does the unit comply with the requirements of Drawing R-TP80, Revision D?			
7.	Has the radiation profile been recorded in accordance with AEAT QSA Work Instruments WI-Q09?			
8.	Is the package prepared for transport?			

Verified by:	Print Name:	Signature:	Date:
Engineering			
Regulatory Affairs			
Quality Assurance			

Equipment List 1: Compression Test

Description	Enter the Model and Serial Number	Attach Inspection Report or Calibration Certificate
Weight Scale		
Record any additional tools used to facilitate the test and attach the appropriate inspection report or calibration certificate.		

	Print Name:	Signature:	Date:
Completed by:			
Verified by:			

Checklist 1: Compression Test

Step	TP80(A)	TP80(B)	TP80(C)
1. Position the specimen on concrete surface, per the appropriate drawing.	Figure 2	Figure 2	Figure 2
2. Measure the ambient temperature.			
Note the instrument used:			
3. Apply a uniformly distributed weight of 455 to 465 pounds on the top of the lid for a period of 24 hours.			
Record the actual weight:			
Note the instrument used:			
Record start time and date:			
4. After 24 hours, remove the weight.			
Record end time and date:			
5. Measure the ambient temperature.			
Note the instrument used:			
6. Photograph the test specimen and record any damage on Data Sheet 1.			
7. **Engineering, Regulatory Affairs and Quality Assurance** make a preliminary assessment relative to 10 CFR 71. 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			
Regulatory Affairs			
Quality Assurance			

Data Sheet 1: Compression Test

Test Unit Model and Serial Number:		Test Specimen:
Test Date:	Test Time:	Test Plan 80 Step No.: **8.5**

Describe test orientation and setup:

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

On-site assessment:

Engineering: ____________________ Regulatory: ____________________ QA: ____________________

Describe any post-test disassembly and inspection:

Describe any change in source position:

Describe results of any pre- or post-test radiography:

Completed by:	Date:

Equipment List 2: Penetration Test

Description	Enter the Model and Serial Number	Attach Inspection Report or Calibration Certificate
Penetration Bar	Drawing BT10129, Rev. B	
Drop Surface	Drawing AT10122, Rev. B	
Thermometer		
Thermocouple		
Thermocouple		
Record any additional tools used to facilitate the test and attach the appropriate inspection report or calibration certificate.		

	Print Name:	Signature:	Date:
Completed by:			
Verified by:			

Checklist 2: Penetration Test

Step	TP80(A)	TP80(B)	TP80(C)
1. Immerse the test specimen in dry ice or cool in freezer as needed to bring specimen temperature below –40°C.			
2. Position the package as shown in the referenced figure, or by Step 7, Checklist 1.	Figure 3	Figure 3	Figure 3
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's internal and surface temperatures. Ensure that the specimen is at the specified temperature.			
Record the ambient temperature:			
Note the instrument used:			
Record the specimen's internal temperature:			
Note the instrument used:			
Record the specimen's surface temperature:			
Note the instrument used:			
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.			
Note the instrument used:			
10. Photograph the test specimen and record any damage on Data Sheet 2.			
11. **Engineering, Regulatory Affairs and Quality Assurance** make a preliminary assessment relative to 10 CFR 71. 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			
Regulatory Affairs			
Quality Assurance			

Data Sheet 2: Penetration Test

Test Unit Model and Serial Number:		Test Specimen:
Test Date:	Test Time:	Test Plan 80 Step No.: **8.6**

Describe test orientation and setup:

Describe impact (location, rotation, etc.):

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

On-site assessment:

Engineering: ____________________ Regulatory: ____________________ QA: ____________________

Describe any post-test disassembly and inspection:

Describe any change in source position:

Describe results of any pre- or post-test radiography:

Completed by:	Date:

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	
Thermometer		
Thermocouple		
Thermocouple		
Record any additional tools used to facilitate the test and attach the appropriate inspection report or calibration certificate.		

	Print Name:	Signature:	Date:
Completed by:			
Verified by:			

Checklist 3: 1.2 Meter (4 Foot) Free Drop

Step	TP80(A)	TP80(B)	TP80(C)
1. Immerse specimen in dry ice or cool in freezer to bring specimen below –40°C.			
2. Measure the ambient temperature.			
Note the instrument used:			
3. Attach the test specimen to the release mechanism.			
4. Begin video recording of the test.			
5. Measure specimen internal and surface temps. Ensure specimen is at specified temp.			
Record the specimen's internal temperature:			
Note the instrument used:			
Record the specimen's surface temperature:			
Note the instrument used:			
6. Lift and orient the test specimen as shown in the specified referenced figure.	Figure 4	Figure 5	Figure 6
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 internal and surface temps. Ensure specimen is at specified temp.			
Record the specimen's internal temperature:			
Note the instrument used:			
Record the specimen's surface temperature:			
Note the instrument used:			
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.			
13. **Engineering, Regulatory Affairs and Quality Assurance** make a preliminary assessment relative to 10 CFR 71, and record on Data Sheet 3. Determine package orientation for the 9 meter free drop to achieve maximum damage.			

Verified by:	Print Name:	Signature:	Date:
Engineering			
Regulatory Affairs			
Quality Assurance			

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

Test Unit Model and Serial Number:		Test Specimen:
Test Date:	Test Time:	Test Plan 80 Step No.: **8.7**

Describe drop orientation and drop height:
Describe impact (location, rotation, etc.):
Describe on-site inspection (damage, broken parts, etc.):
On-site assessment: Engineering: ____________ Regulatory: ____________ QA: ____________
Describe any post-test disassembly and inspection:
Describe any change in source position:
Describe results of any pre- or post-test radiography:

Completed by:	Date:

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	
Thermometer		
Thermocouple		
Thermocouple		
Record any additional tools used to facilitate the test and attach the appropriate inspection report or calibration certificate.		

	Print Name:	Signature:	Date:
Completed by:			
Verified by:			

Checklist 4: 9 Meter (30 Foot) Free Drop

Step	TP80(A)	TP80(B)	TP80(C)
1. Immerse test specimen in dry ice or cool in freezer to bring specimen temperature below –40°C.			
2. Measure the ambient temperature.			
Note the instrument used:			
3. Attach the test specimen to the release mechanism.			
4. Begin Video Recording of the test.			
5. Measure specimen's internal and surface temps. Ensure specimen is at the specified temperature.			
Record the specimen's internal temperature:			
Note the instrument used:			
Record the specimen's surface temperature:			
Note the instrument used:			
6. Lift and orient the test specimen as shown in the specified referenced figure.	Figure 7	Figure 8	Figure 9
7. Inspect the orientation setup and verify drop height.			
8. Photograph the setup in at least two perpendicular planes.			
9. Release the test specimen.			
10. Measure specimen's internal and surface temps. Ensure specimen is at specified temperature.			
Record the specimen's internal temperature:			
Note the instrument used:			
Record the specimen's surface temperature:			
Note the instrument used:			
11. Photograph the test specimen and record any damage on Data Sheet 4.			
12. **Engineering, Regulatory Affairs and Quality Assurance** make a preliminary assessment relative to 10 CFR 71. Record assessment on Data Sheet 4. Determine what changes are necessary in package orientation for the puncture test to achieve maximum damage.			

Verified by:	Print Name:	Signature:	Date:
Engineering			
Regulatory Affairs			
Quality Assurance			

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

Test Unit Model and Serial Number:		Test Specimen:
Test Date:	Test Time:	Test Plan 80 Step No.: **8.9**

Describe drop orientation and drop height:

Describe impact (location, rotation, etc.):

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

On-site assessment:

Engineering: ____________________ Regulatory: ____________________ QA: ____________________

Describe any post-test disassembly and inspection:

Describe any change in source position:

Describe results of any pre- or post-test radiography:

Completed by:	Date:

Equipment List 5: Puncture Test

Description	Enter the Model and Serial Number	Attach Inspection Report or Calibration Certificate
Drop Surface	Drawing AT10122, Rev. B	
Puncture Billet	Drawing CT10119, Rev. C	
Thermometer		
Thermocouple		
Thermocouple		
Record any additional tools used to facilitate the test and attach the appropriate inspection report or calibration certificate.		

	Print Name:	Signature:	Date:
Completed by:			
Verified by:			

Checklist 5: Puncture Test

Step	TP80(A)	TP80(B)	TP80(C)
1. Immerse specimen in dry ice or cool in freezer to bring specimen temp. below –40°C.			
2. Measure the ambient temperature.			
Note the instrument used:			
3. Attach the test specimen to the release mechanism.			
4. Begin Video Recording of the test.			
5. Measure specimen's internal and surface temps. Ensure that specimen is at specified temp.			
Record the specimen's internal temperature:			
Note the instrument used:			
Record the specimen's surface temperature:			
Note the instrument used:			
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.	Figure 10	Figure 11	Figure 12
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 the specimen's internal and surface temperatures.			
Record the specimen's internal temperature:			
Note the instrument used:			
Record the specimen's surface temperature:			
Note the instrument used:			
11. Photograph the test specimen and record any damage on Data Sheet 5.			
12. **Engineering, Regulatory Affairs and Quality Assurance** make a preliminary assessment relative to 10 CFR 71. Record assessment on Data Sheet 5. Determine what changes are necessary in package orientation for thermal test to achieve maximum damage.			

Verified by:	Print Name:	Signature:	Date:
Engineering			
Regulatory Affairs			
Quality Assurance			

Data Sheet 5: Puncture Test

Test Unit Model and Serial Number:		Test Specimen:
Test Date:	Test Time:	Test Plan 80 Step No.: **8.10**

Describe drop orientation and drop height:

Describe impact (location, rotation, etc.):

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

On-site assessment:

Engineering: ______________________ Regulatory: ______________________ QA: ______________________

Describe any post-test disassembly and inspection:

Describe any change in source position:

Describe results of any pre- or post-test radiography:

Completed by:	Date:

Equipment List 6: Thermal Test

Description	Enter the Model and Serial Number	Attach Inspection Report or Calibration Certificate
Bottom Surface Thermocouple 1		
Top Surface Thermocouple 2		
Side Surface Facing Oven Front Thermocouple 3		
Side Surface Facing Oven Rear Thermocouple 4		
Source Tube Thermocouple 5		
Oven		
Oven thermostat		
Record any additional tools used to facilitate the test and attach the appropriate inspection report or calibration certificate.		

	Print Name:	Signature:	Date:
Completed by:			
Verified by:			

Checklist 6: Thermal Test

Step	TP80(A)	TP80(B)	TP80(C)
1. Record Test Specimen Serial Number.			
2. Preheat the oven to 810°C.			
3. Attach the thermocouples as described in Equipment List 6. Ensure the recording devices are active, and that the external thermocouples are shielded.			
4. Place the package in the oven in the worst case orientation and partially close the oven door such that a 1 inch by 36 inch opening is provided. Record the time.			
5. When all of the test specimen's surface temperatures exceed 810°C, begin the 30-minute time interval. Record the time.			
6. Monitor and record the test specimen and the oven temperatures throughout the 30-minute period to ensure that they are above 810°C			
7. At the end of the 30-minute test period, shut off the oven and open the door. Record the time.			
8. Describe combustion when door is opened.			
9. Allow the specimen to cool, then remove the specimen from the oven. Record the time.			
NOTE: If specimen continues to burn, let it self-extinguish and cool naturally.			
10. Measure and record the ambient temperature.			
11. Photograph the test specimen and record any damage on data sheet 6.			
12. Radiograph the unit to determine the shield location.			
13. Measure and record the source location.			
14. **Engineering, Regulatory Affairs and Quality Assurance** make a preliminary assessment relative to 10 CFR 71. Record assessment on Data Sheet 6.			

Verified by:	Print Name:	Signature:	Date:
Engineering			
Regulatory Affairs			
Quality Assurance			

Data Sheet 6: Thermal Test

Test Unit Model and Serial Number:		Test Specimen:
Test Date:	Test Time:	Test Plan 80 Step No.: **8.12**

Describe test orientation and setup:

Describe package during testing:

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

On-site assessment:

Engineering: ____________________ Regulatory: ____________________ QA: ____________________

Describe any post-test disassembly and inspection:

Describe any change in source position:

Describe results of any pre- or post-test radiography:

Completed by:	Date:

Appendix A: Drawing R-TP80, Revision D

FIGURE WITHHELD UNDER 10 CFR 2.390

AEA TECHNOLOGY QSA 40 NORTH AVE, BURLINGTON, MA 01803	DESCRIPTIVE DRAWING
TITLE 650L SOURCE CHANGER TEST UNITS	
SIZE A	DWG. NO. R-TP80
SCALE: NONE	SHEET 1 OF 2
REV D	

FIGURE WITHHELD UNDER 10 CFR 2.390

UNLESS OTHERWISE SPECIFIED: ALL DIMENSIONS ARE REFERENCE			
SIZE A	DWG. NO. R-TP80		REV D
	SCALE: NONE	SHEET 2 OF 2	

Appendix C: Test Plan 80 Report (Model 650L)

C-1 Test Plan 80 Report (Not Including Appendices A, B, and C)

AEA TECHNOLOGY

QSA

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: [signature]	DATE: 12 MAR 99
QUALITY ASSURANCE APPROVAL: Daniel W. Kurtz	DATE: 12 Mar 99
REGULATORY APPROVAL: Catherine Rompau	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. Rompau	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.

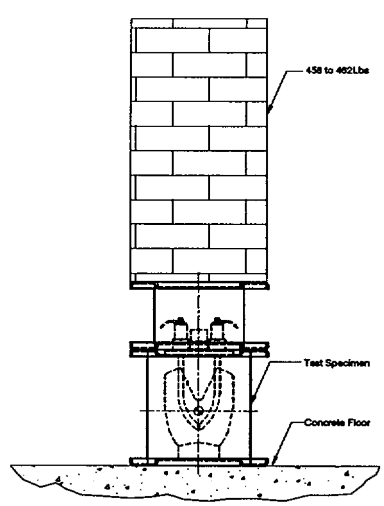
The only significant damage to any unit was the cracked shell in specimen TP80(B). Because of this crack, the depleted uranium shield was exposed to air during the thermal test, and portions of the shield near the crack opening were oxidized. In addition, after the lead shim melted, the shield was free 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

Compression Test

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

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



Compression Test Orientation – All Specimens

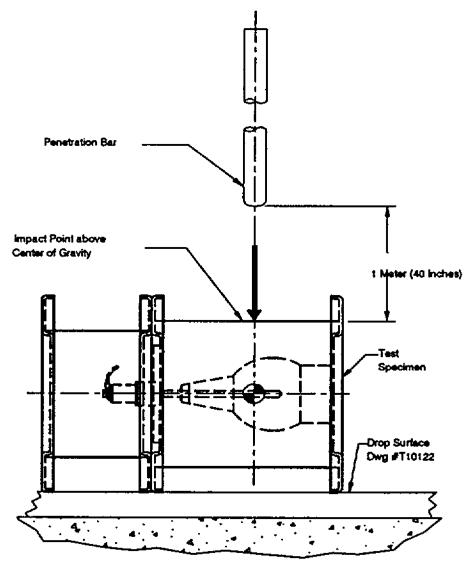
After a period of 24 hours, the weights were removed. No visible deformation or buckling occurred and no other damage was observed for any of the test specimens.

Penetration Test

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

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

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



Penetration Test Orientation – All Specimens

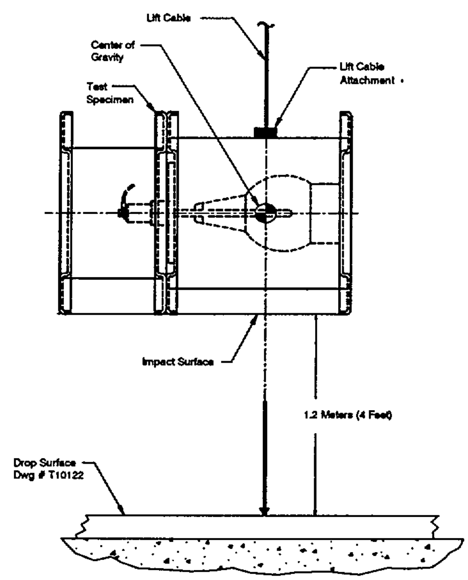
The penetration bar was dropped from a height of at least 1 meter (40 inches) above the impact point. The bar hit as intended on each package, leaving a visible impact mark, but no other damage.

1.2 Meter (4 Foot) Drop Test

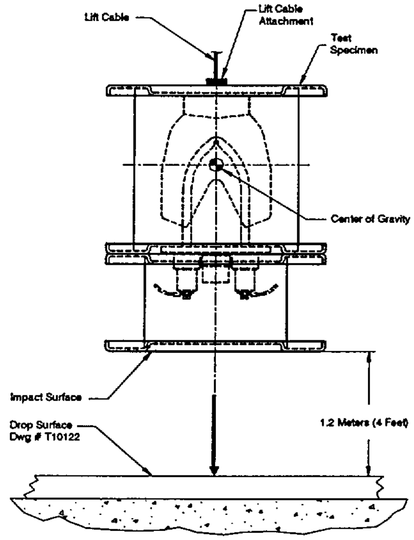
The three test specimens were then subjected to the 1.2 meter (4 foot) drop test. Temperature readings taken just before the test are summarized below.

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

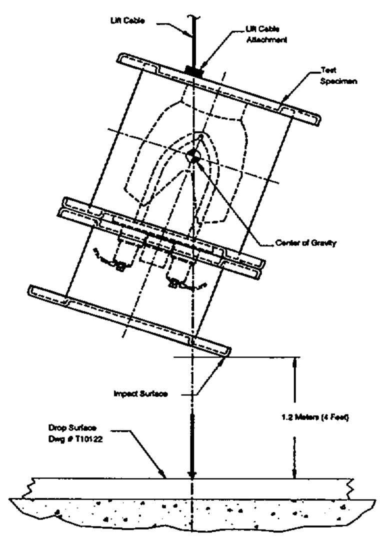
The drop orientations for each unit are shown below and on the next page. These orientations are the same as those used for each specimen in the 9 meter (30 foot) drop tests.



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



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



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

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

Post-Test Inspection and Assessment

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

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

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

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

7. TP80 ACCIDENT DROP TESTS – TP80(A)

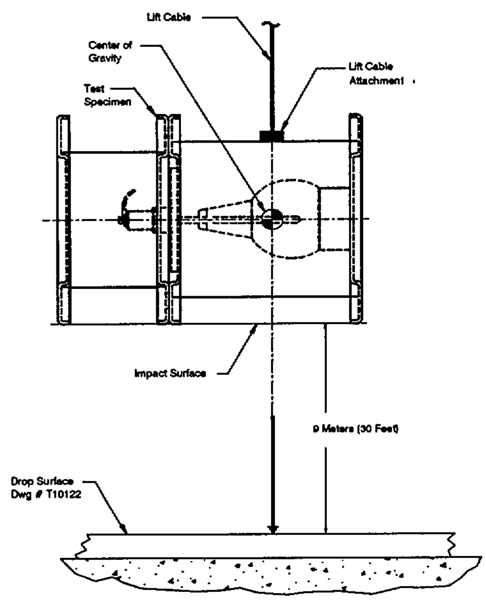
Specimen TP80(A) was subjected to a 9 meter (30 foot) drop test and a puncture test in accordance with Test Plan 80. The results are described below.

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.

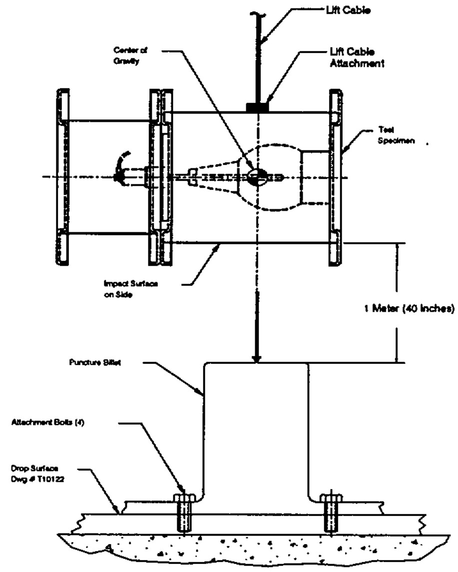


9 Meter (30 Foot) Drop Orientation for Specimen TP80(A)

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)

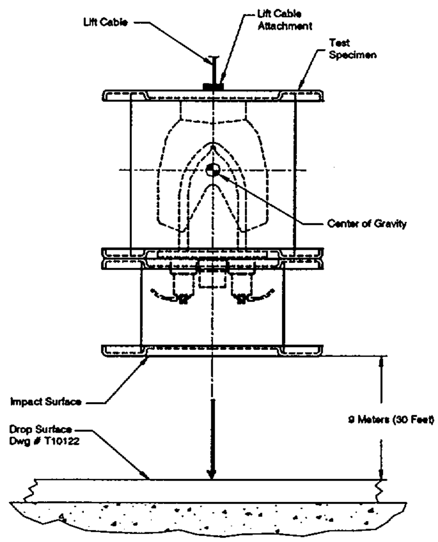
Specimen TP80(B) was subjected to a 9 meter (30 foot) drop test and a puncture test in accordance with Test Plan 80. The results are described below.

9 Meter (30 Foot) Drop Test

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

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

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



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

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

Puncture Test

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

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

Post-Test Inspection and Assessment

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

9. TP80 ACCIDENT DROP TESTS – TP80(C)

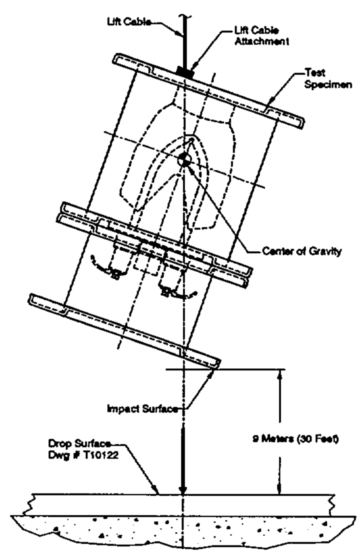
Specimen TP80(C) was subjected to a 9 meter (30 foot) drop test and a puncture test in accordance with Test Plan 80 and results are described below.

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

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

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

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



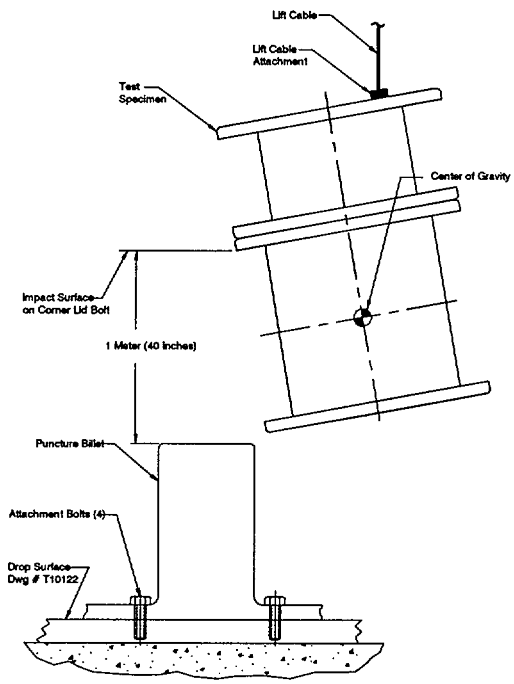
9 Meter (30 Foot) Drop Orientation for Specimen TP80(C)

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

Puncture Test

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

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



Second Puncture Drop Orientation for Specimen TP80(C)

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

Post-Test Inspection and Assessment

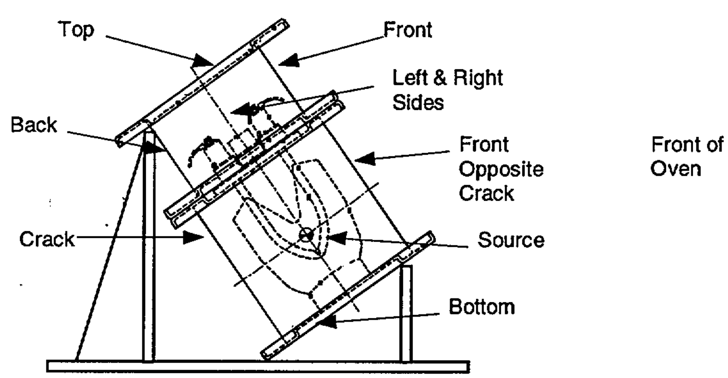
Following the test, the protective lid was removed and the unit was inspected. No damage to the locks was observed and no significant movement of the source was measured. The post-test radiation profile showed no significant change in radiation levels from the pre-test profile (see Appendix B). Because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

10. TP80 THERMAL TEST – TP80(B)

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

Orientation and Setup

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



TP80(B) Orientation and Thermocouple Locations

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

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

Test Chronology

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

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

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

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

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

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

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

Post-Test Inspection and Assessment

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

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

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

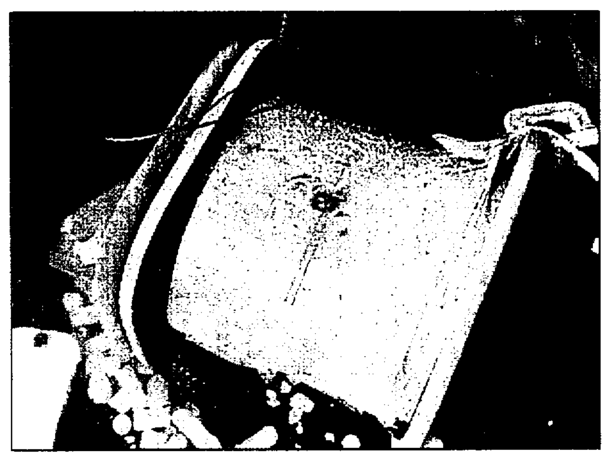
APPENDIX D

TEST PHOTOGRAPHS

Test Plan 80 Photographs

Compression Test

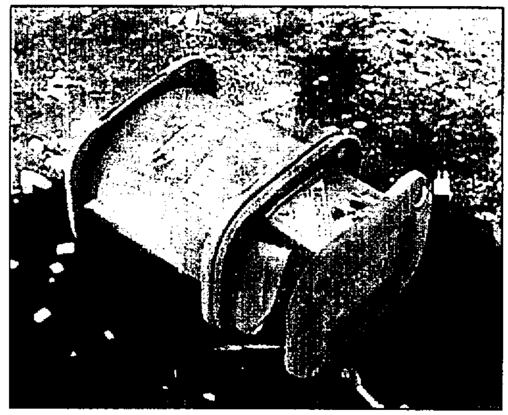
Typical Penetration Test Setup



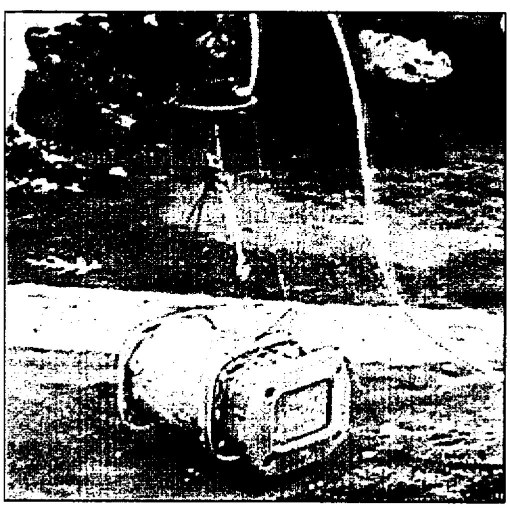
Typical Penetration Impact

Test Plan 80 Photographs

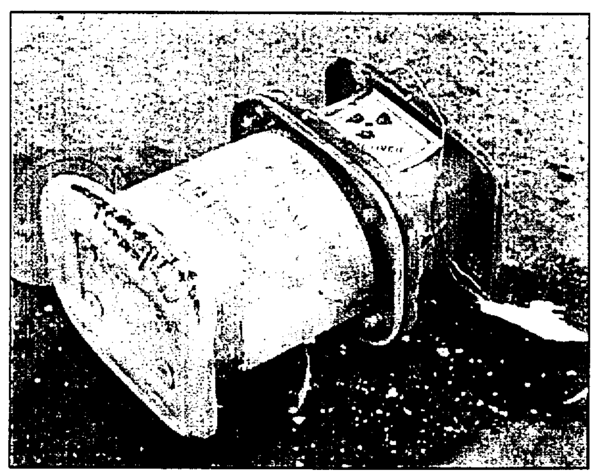
TP80(A) 4 Foot Drop Setup



TP80(A) 4 Foot Drop Results

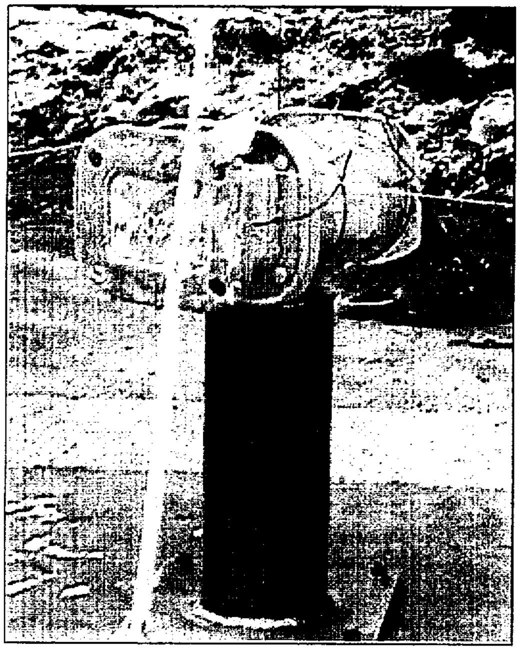


TP80(A) 30 Foot Drop Setup

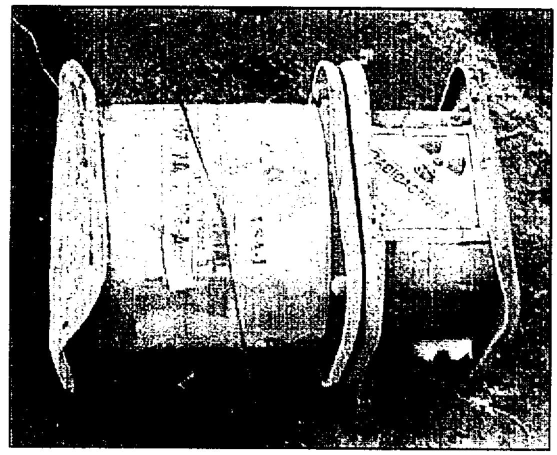


TP80(A) 30 Foot Drop Results

Test Plan 80 Photographs



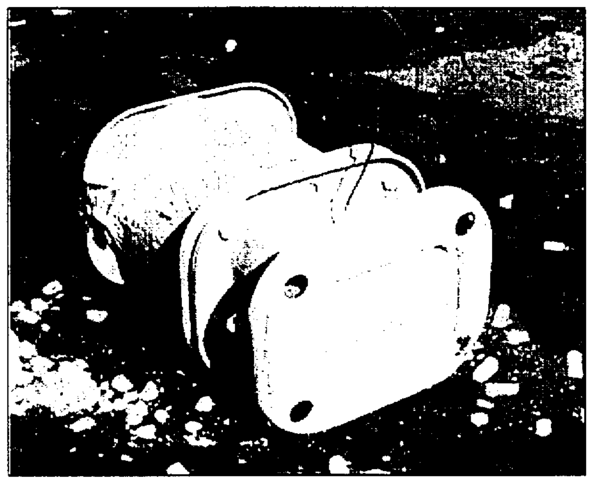
TP80(A) Puncture Test Setup



TP80(A) Puncture Test Results

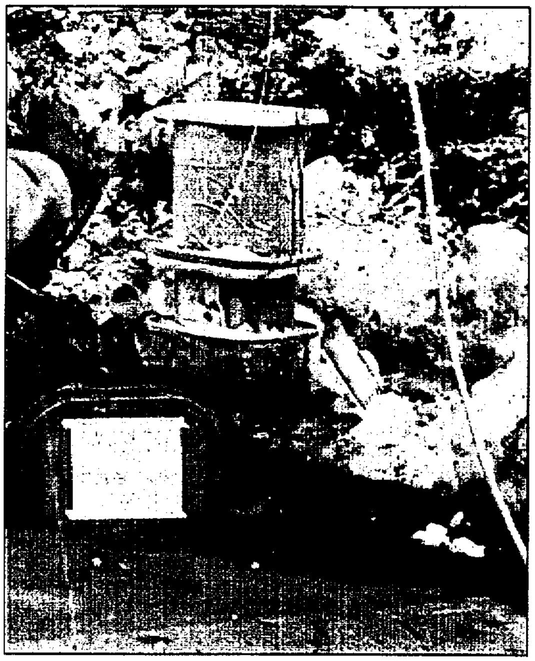
Test Plan 80 Photographs

TP80(B) 4 Foot Drop Setup

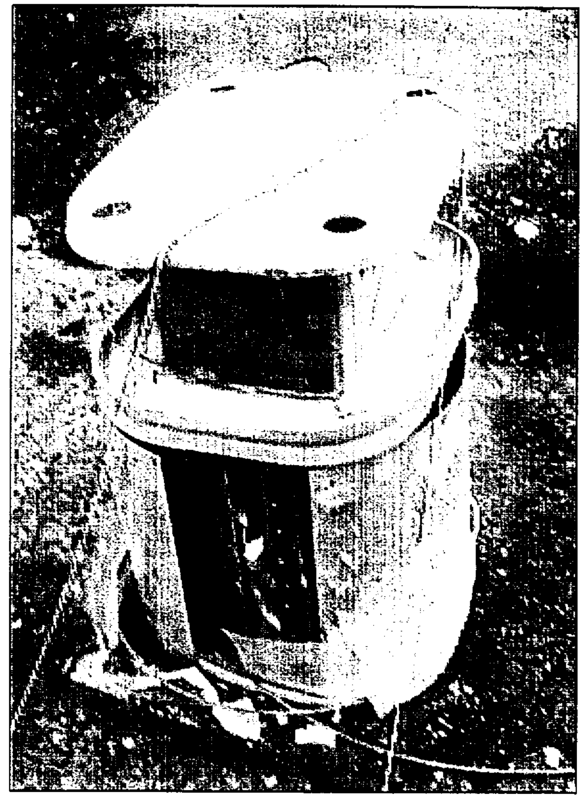


TP80(B) 4 Foot Drop Test Results

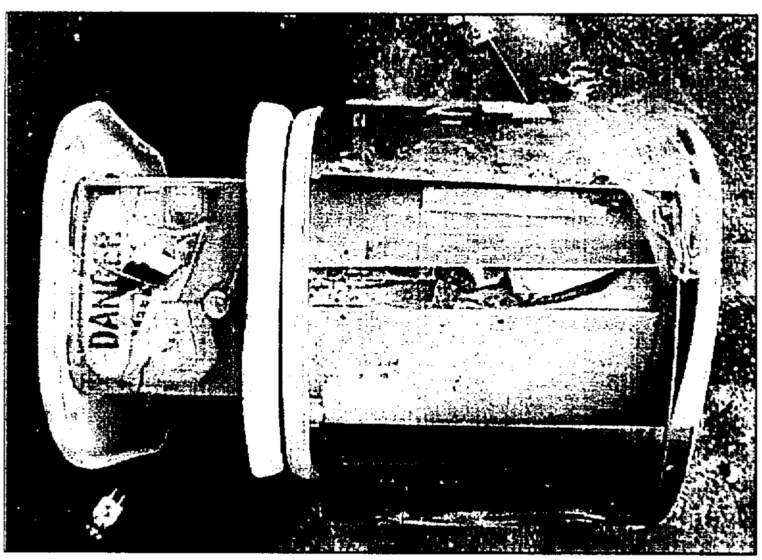
Test Plan 80 Photographs



TP80(B) 30 Foot Drop Setup

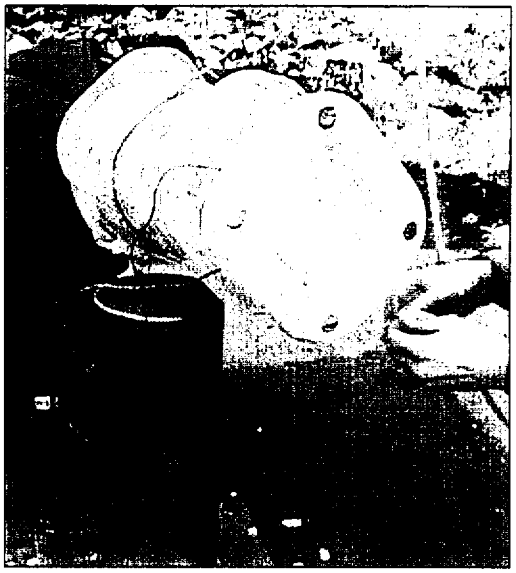


TP80(B) 30 Foot Drop Results

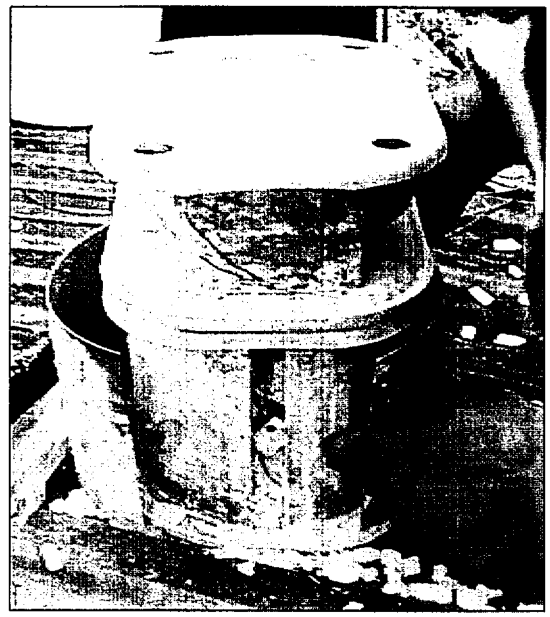


TP80(B) 30 Foot Drop Results

Test Plan 80 Photographs

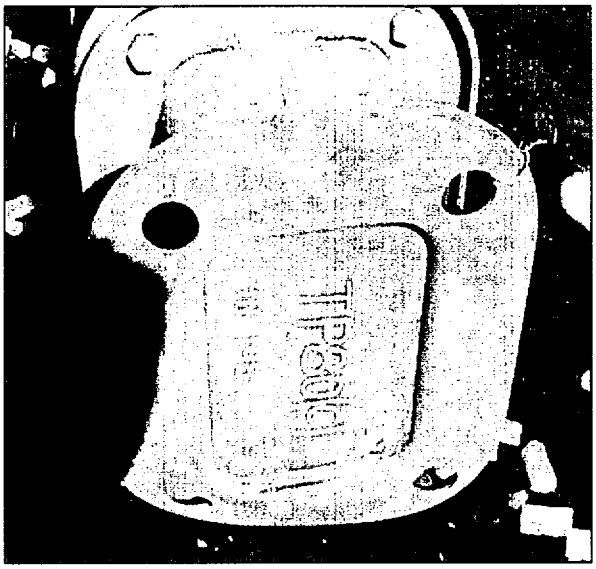


TP80(B) Puncture Test Setup



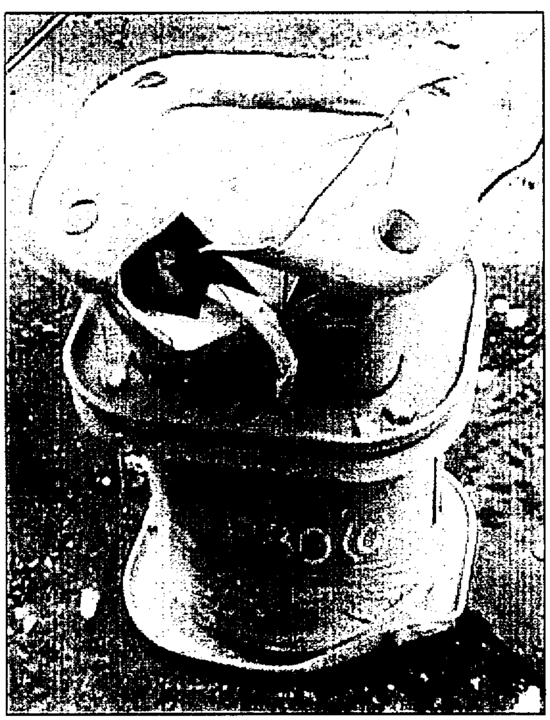
TP80(B) Puncture Test Results

Test Plan 80 Photographs

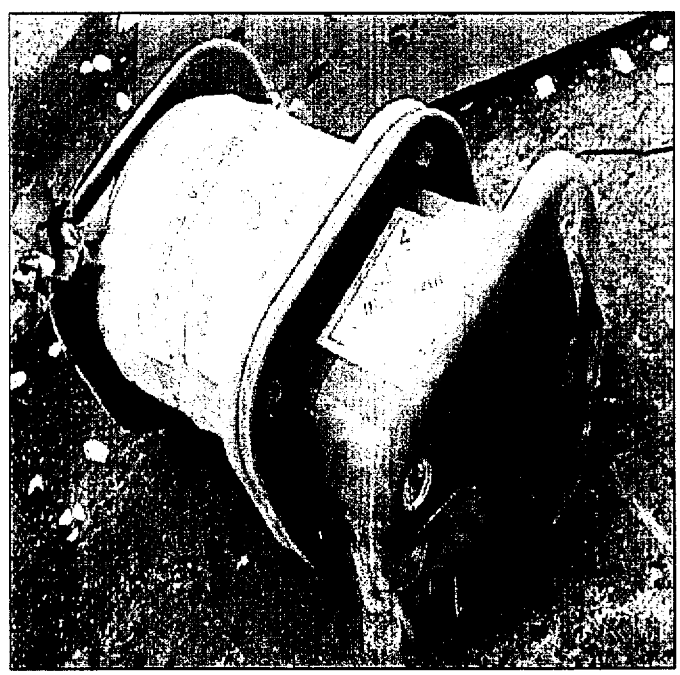


TP80(C) 4 Foot Drop Test Results

TP80(C) 30 Foot Drop Setup



TP80(C) 30 Foot Drop Results



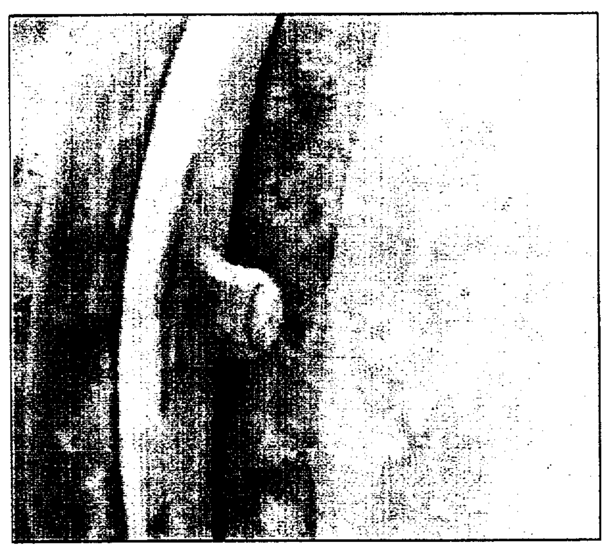
TP80(C) 30 Foot Drop Results

Test Plan 80 Photographs

TP80(C) Puncture Drop 1 Setup

TP80(C) Puncture Drop 1 Results

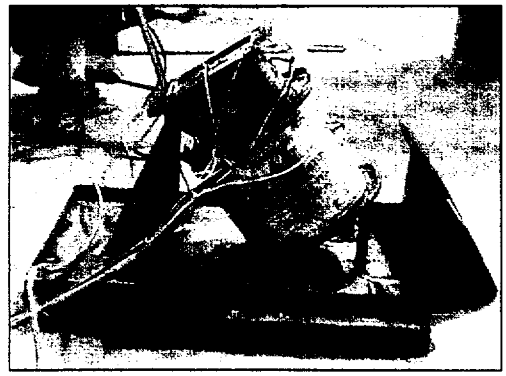
TP80(C) Puncture Drop 2 Setup



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

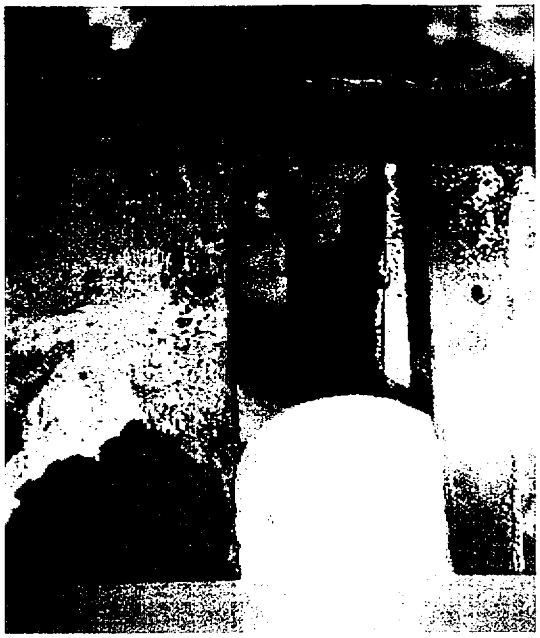
TP80(B) Thermal Test After Removal From Oven

TP80(B) Detail of Cracked Shell

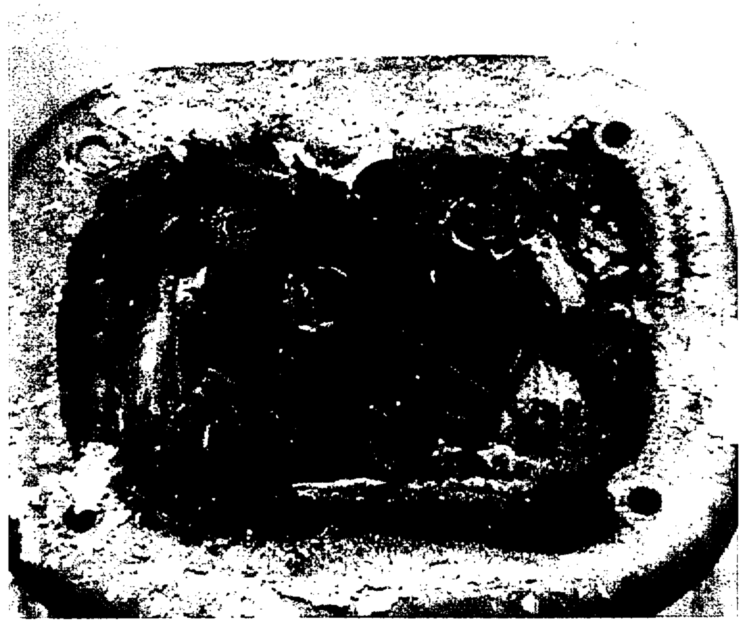
TP80(B) Detail of Uranium Oxide Residue

TP80(B) Detail of Uranium Oxide Residue

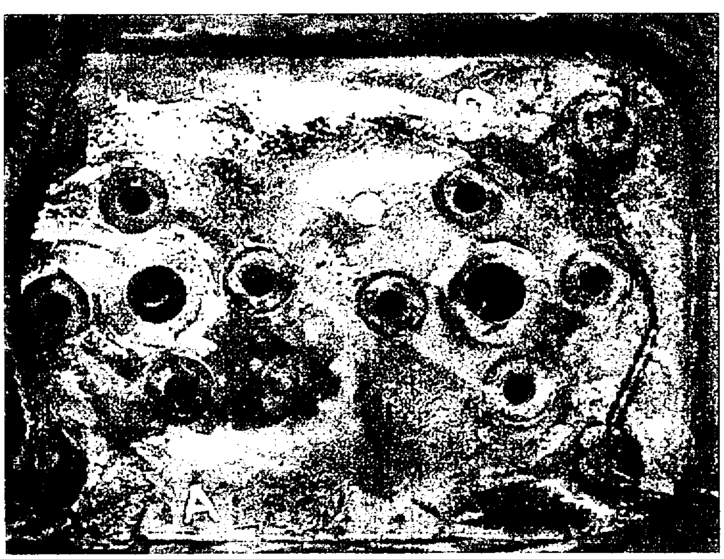
Test Plan 80 Photographs



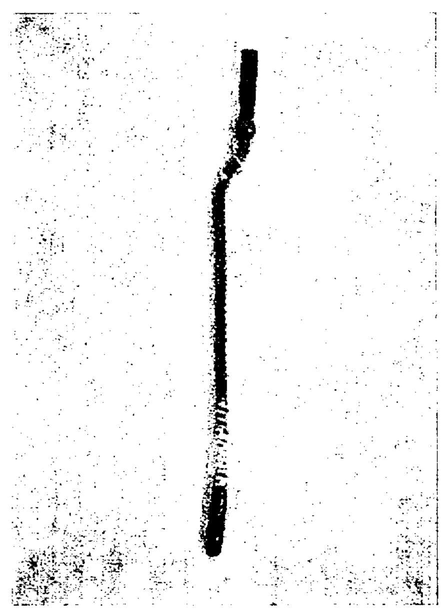
TP80(B) Thermal Test After Removal From Oven--Detail of Crack After Foaming to Stabilize Shield



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.