SAFETY ANALYSIS REPORT
TEN HOLE SOURCE CHANGER PACKAGE

Docket No. 71-9360
Revision 1
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Industrial Nuclear Company, Inc.
14320 Wicks Blvd.
San Leandro, California 94577
(510) 352-6767

1.0 TABLE OF CONTENTS

1.0 GENERAL INFORMATION

This chapter of the Ten Hole Source Changer (hereto referred to as the THSC) Safety Analysis Report presents a general introduction and description of the THSC package. A detailed description of the major packaging and payload components is presented in the following sections. Detailed drawings are presented in Appendix 1.3.1, *General Arrangement Drawings*.

1.1 Introduction

The THSC is a transportation package designed to transport up to ten (10), special form iridium-192 (Ir-192) or selenium-75 (Se-75) source capsules. The design is optimized to provide maximum safety during both operations and transport conditions. The packaging consists of a welded circular shell, a bolted closure lid, a welded mounting plate with ten (10) lock box assemblies, a depleted uranium (DU) gamma shield, and interior polyurethane foam.

Authorization is sought for shipment of ten (10), special form Ir-192 or Se-75 source capsules (per package) as a Type B(U)-96, special form material package per the definitions delineated in 10 CFR §71.4[1]. The transport index (TI) for the package, determined in accordance with the definition of 10 CFR §71.4, is determined for each shipment. The TI is based on the radiation dose rate at 1 meter (3.3 feet) from the package surface (method for the transport index is defined in Chapter 7.0, *Package Operations*).

1.2 Package Description

1.2.1 Packaging

The THSC, is a Type B(U)-96 package designed for transportation of Ir-192 or Se-75 special form capsules. The maximum gross weight of the package is 340 pounds (154 kg), and its primary components of construction are identified in Figure 1.2-1. The payload is special form capsules containing Ir-192 or Se-75, and is described in Section 1.2.2, *Contents of Packaging*. Primary shielding is provided by DU. The DU gamma shield, which is composed of approximately 0.2 wt% U-235, and 99.8 wt% U-238, is a solid form casting, and illustrated in Figure 1.2-2. Detailed drawings of the THSC are provided in Appendix 1.3.1, *General Arrangement Drawings*.

1.2.2 Contents of Packaging

The THSC is designed to transport up to a maximum of ten (10) 150 Ci (5.55 TBq) Ir-192 or Se-75 special form capsules. Each special form capsule is attached to a pigtail assembly that, along with a lock box and a lockball, secures the capsule against or near the titanium hub in the DU gamma shield. For the total number of ten special form capsules, the maximum radioactive content for the THSC package is 1,500 Ci (55.5 TBq).

1.2.3 Special Requirements for Plutonium

This section does not apply, since plutonium is not transported in the THSC.

[1] Title 10, Code of Federal Regulations, Part 71 (10 CFR 71), *Packaging and Transportation of Radioactive Material*, 1-1-18 Edition.

1.2.4 Operational Features

There are no operationally complex features of the THSC. The contents (described in Section 1.2.2, *Contents of Packaging*) are confined within in the package by the lock boxes and the DU, as shown in Figure 1.2-2. Integral to the mounting plate and DU gamma shield, the lock box assemblies prevent unauthorized removal or unshielded exposure of the contents. The lock box assemblies, which allow access to the contents, conform to the requirements of 10 CFR §34.23[2]. The bolted closure lid is fitted with two (2) 8-32 UNC threaded holes to attach a standard lifting ring to facilitate handling. Sequential steps of operation are provided in Chapter 7.0, *Package Operations*.

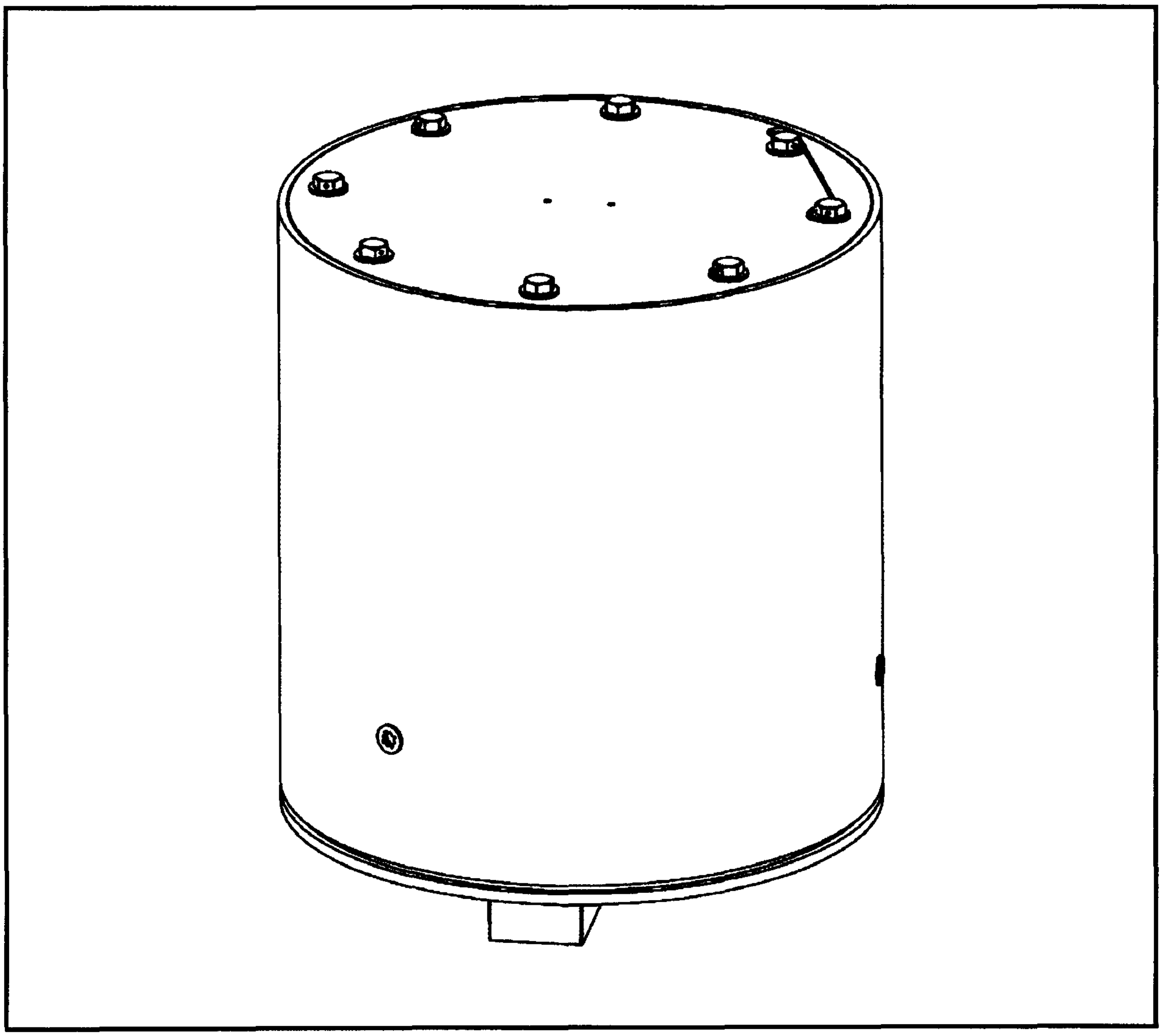

Figure 1.2-1 – Overall View of the THSC Packaging

[2] Title 10, Code of Federal Regulations, Part 34 (10 CFR 34), *Licenses for Radiography and Radiation Safety Requirements for Radiographic Operations*, 1-1-18 Edition.

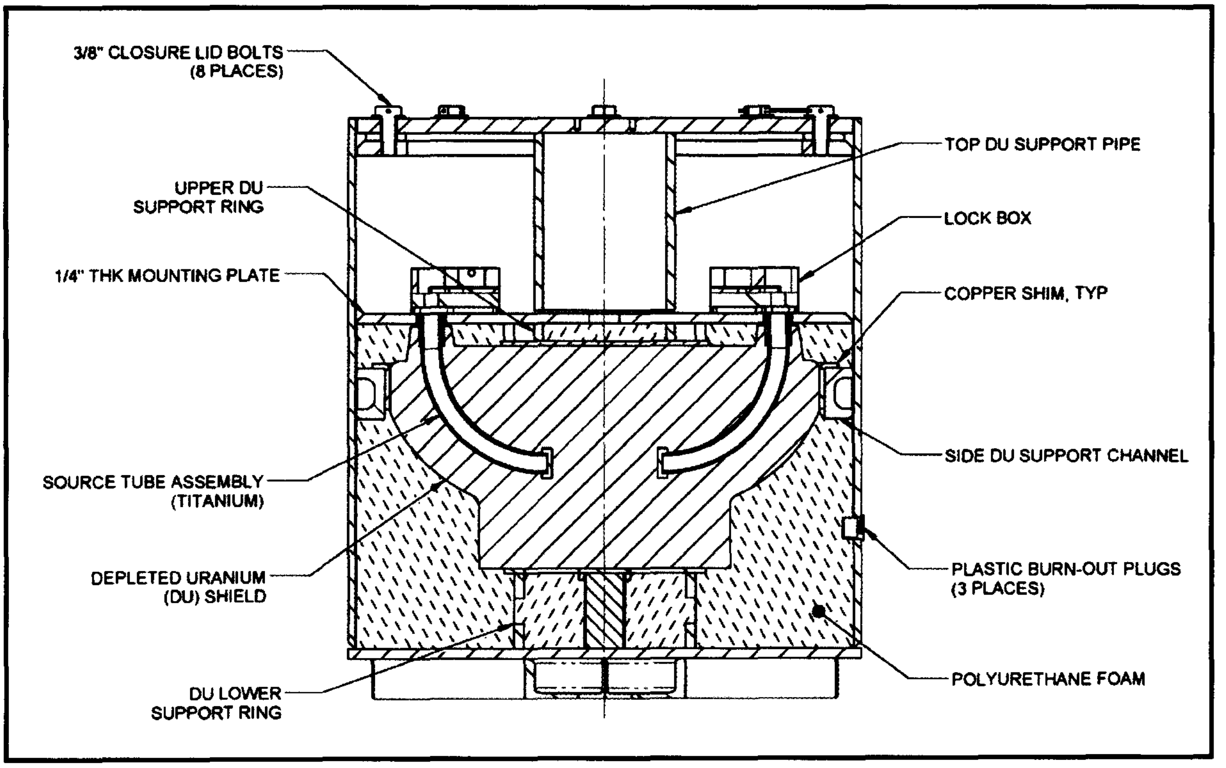

Figure 1.2-2 – Sectional View of the THSC Packaging

1.3 Appendices

1.3.1 General Arrangement Drawings

Security-Related Information
Withheld Under 10 CFR 2.390

2.0 STRUCTURAL EVALUATION

This chapter presents the structural design criteria, weights, mechanical properties of material, and structural evaluations that demonstrate that the THSC meets all applicable structural criteria for transportation as defined in 10 CFR 71[3].

2.1 Description of Structural Design

The primary structural evaluation of the THSC is performed with various full-scale tests. The results of the tests are provided in the following sections. Analyses of non-tested structural aspects are also provided.

The THSC consists of three major fabricated components: 1) a welded, stainless steel pipe with a bolted closure lid and a welded mounting plate with lock box assemblies that enclose and secure the contents, 2) a depleted uranium (DU) gamma shield that provides shielding, and 3) polyurethane foam that provides moisture protection of the DU.

2.1.1 Discussion

The THSC is designed to transport a maximum of 1,500 Ci (55.5 TBq) of Ir-192 or Se-75 in ten (10) special form capsules. Since the payload is designated as special form, the THSC is defined as a confinement system. As shown in the sectional view in Figure 2.2-1, the primary components of the package are a cylindrical stainless steel shell, a closure lid, a welded mounting plate, lock boxes, a DU gamma shield, and internal polyurethane foam. The polyurethane foam, which surrounds the DU gamma shield, is closed cell. The DU gamma shield is a casting of solid form and optimally designed to provide efficient shielding of the ten sources. The DU gamma shield is secured in the cylindrical shell by the welded mounting plate that captures the shield between the mounting plate and the bottom plate of the cylindrical shell.

The packaging consists of ten (10) titanium source tubes that are welded to a titanium hub, which is encased in an enamel-coated, DU casting. The DU gamma shield assembly is enclosed within a welded, 12-inch Schedule 10S stainless steel pipe, with overall dimensions of 12¾ inch diameter × 14½ inch in height. Three stainless steel channels, which are positioned at 120 degrees intervals, are welded to the bottom plate for supporting the package during transport. The DU gamma shield assembly is laterally supported by eight (8) short stainless steel channel sections that are welded to the inner wall of the outer pipe. The DU gamma shield is also supported vertically by a 4-inch diameter Schedule 40S stainless steel pipe and a 1-inch diameter stainless steel bar that are welded to the inner surface of the 1/4-inch thick stainless steel bottom plate. Copper shim stock is installed between the DU-stainless steel interfaces to preclude a galvanic reaction between the two dissimilar metals. The DU gamma shield assembly is enclosed by a 1/4-inch thick stainless steel mounting plate that is welded to the inner surface of the pipe. This welded plate provides the mounting surface for the ten lock box assemblies that secure the special form capsules into the DU gamma shield assembly. The void space between the DU gamma shield assembly and the pipe shell is filled with approximately 10 pounds of rigid polyurethane foam, which provides moisture protection for the DU shield material.

[3] Title 10, Code of Federal Regulations, Part 71 (10 CFR 71), *Packaging and Transportation of Radioactive Material*, 1-1-18 Edition.

To protect the lock boxes and the special form capsules, a 3/8-inch thick stainless steel closure lid plate is secured to the pipe by eight (8) 3/8-16 UNC, ASTM A320 Gr L43 or L7, hex head cap screws (aka closure lid bolts). On the inner surface of the closure lid plate, a 3-inch diameter Schedule 40S pipe is welded to provide additional vertical restraint of the DU gamma shield assembly/mounting plate. All of the structural components of the THSC are constructed of Type 304 or Type 316 austenitic stainless steel.

Each special form pigtail assembly is secured by a lock box that is bolted to the mounting plate by four (4) 1/4-20 UNC stainless steel socket head cap screws (SHCSs). The pigtail assembly maintains the radioactive source in the DU gamma shield assembly against or near the titanium hub, which provides the maximum gamma shielding to the public.

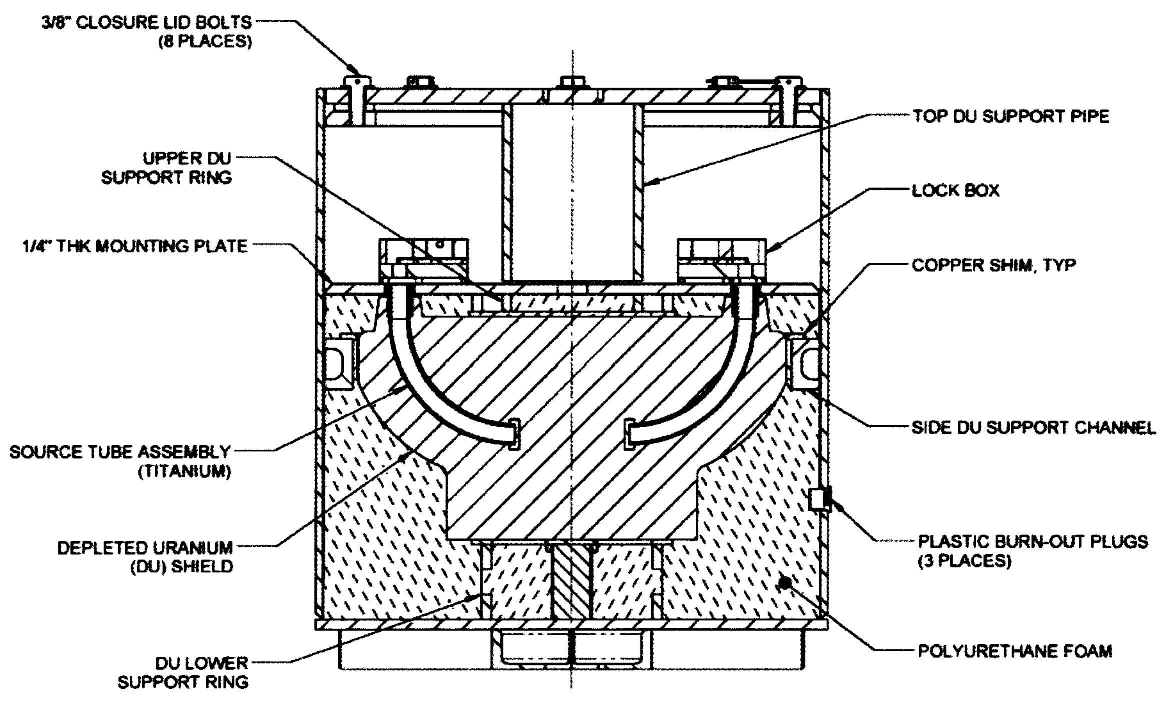

Figure 2.2-3 – Sectional View of the THSC Packaging

2.1.2 Design Criteria

2.1.2.1 Basic Design Criteria

The THSC is primarily demonstrated to satisfy the requirements of 10 CFR 71 via full-scale tests. For evaluation of lifting attachments, the design criteria is that the structural lifting features do not exceed the material's yield strength when subjected to the requirements of 10 CFR §71.45(a).

2.1.2.2 Miscellaneous Structural Failure Modes

2.1.2.2.1 Brittle Fracture

The structural materials of the THSC packaging include stainless steel, DU, and carbon steel. Each material is not susceptible to brittle fracture at temperatures as low as -20 °F (-29 °C) as described below.

The packaging structural materials of the THSC are fabricated from austenitic stainless steel plate and bar. This material does not undergo a ductile-to-brittle transition in the temperature range of interest [i.e., down to -40 °F (-40 °C)], and thus does not require evaluation for brittle fracture.

The enamel-coated DU shield material, which is enclosed by the welded stainless steel shell assembly, and the carbon steel lock box assemblies were previously drop and puncture tested with a IR-50 payload at temperatures less than -20 °F (-49 °F to -23 °F) in the INC OP-100 package (NRC Docket No. 71-9185). As documented in the certification test report[4], the DU gamma shield and lock boxes in the IR-50 payload passed all the tests, which included cumulative damage effects, with no loss of shielding or confinement capability. Additionally, the THSC was drop tested with the DU gamma shield and lock boxes at temperatures below -19 °F (-28 °C) with no loss of shielding of confinement capability. Based on the low temperature testing of both the THSC and the OP-100, brittle fracture of the DU gamma shield and the lock boxes in the THSC is not a concern.

The closure lid bolts are hex bolts fabricated from ASTM A320, Grade L43 or L7 material. This material is specifically intended for low-temperature service applications. The Charpy impact material tests are recommended to be perform at -150 °F (-101 °C)[5] for this material. Therefore, brittle fracture of the closure lid bolts is not a concern.

2.1.2.2.2 Fatigue

The THSC is essentially a rigid body. Therefore, no structural failures of the confinement boundary due to fatigue will occur.

2.1.2.2.3 Buckling

The THSC provides only a confinement boundary. For normal condition and hypothetical accident conditions, the confinement boundary (i.e., the DU gamma shield) will not buckle due to free or puncture drops. This conclusion has been demonstrated via full-scale tests of the THSC (refer to §2.7.1, *Free Drop*).

2.1.3 Weights and Center of Gravity

The maximum gross weight of the THSC is 340 pounds (154 kg). The center of gravity of the assembled package is along the vertical centerline axis, approximately 7.3 inches above the bottom of the package. Because the overall mass is dominated by the DU gamma shield, the package center of gravity is near the center of gravity for the DU gamma shield itself.

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[4] Packaging Technology, Inc., PacTec Document TR-002, *Certification Test Report for the OP-100 Package*, Revision 1, March 1998.

[5] American Society of Testing and Materials (ASTM) International, *Standard Specification for Alloy-Steel and Stainless Steel Bolting Materials for Low-Temperature Service*, A320/A320M-18.

2.1.4 Identification of Codes and Standards for Package Design

Since the package contains limited quantities of Ir-192 or Se-75 radioactive material, and does not contain a pressure boundary, the THSC package is only designed to industrial metal fabrication standards.

2.2 Materials

2.2.1 Material Properties and Specifications

Mechanical properties for the materials utilized for the structural components of the THSC are provided in this section. Temperature-dependent material properties for structural components are obtained from Section II, Part D, of the ASME Boiler and Pressure Vessel (B&PV) Code[6]. Since the evaluation of the THSC is primarily via full-scale tests, only the material properties that are used in the analysis portion of the evaluation are given. Table 2.2-1 presents the properties of the structural materials for Type 304 stainless steel used in the package. Note that the optional Type 316 stainless steel material for some components has slightly greater yield and ultimate strengths than Type 304 stainless steel. Therefore, the use of Type 304 material strength properties in evaluating their structural function is conservative for any optional Type 316 material utilized in the THSC package, as specified on the drawings in Appendix 1.3.1, *General Arrangement Drawings.*

Table 2.2-1 – Type 304 Stainless Steel Material Properties

Material Specification	Temperature, °F	Yield Strength (S_y), psi ①	Ultimate Strength (S_u), psi ②	Design Stress Intensity (S_m), psi ③	Elastic Modulus, x10^6 psi ④	Coefficient of Thermal Expansion, x10^{-6}, in/in/°F ⑤
Type 304 Stainless Steel	-40	**30,000**	**75,000**	**20,000**	**28.8**	**8.1**
	-20	30,000	75,000	20,000	**28.7**	**8.2**
	70	30,000	75,000	20,000	28.3	8.5
	100	30,000	75,000	20,000	**28.1**	8.6
	200	25,000	71,000	20,000	27.5	8.9
	300	22,400	66,200	20,000	27.0	9.2

Notes:

① ASME B&PV Code, Section II, Part D, Table Y-1

② ASME B&PV Code, Section II, Part D, Table U-2

③ ASME B&PV Code, Section II, Part D, Table 2A

④ ASME B&PV Code, Section II, Part D, Table TM-1, Material Group G

⑤ ASME B&PV Code, Section II, Part D, Table TE-1, Material Group 3, Mean

⑥ When necessary, values are linearly interpolated or extrapolated and given in **bold** text.

⑦ The weight density and Poisson's ratio for stainless steel are 0.285 lb/in^3 and 0.29, respectively

[6] American Society of Engineers (ASME) Boiler and Pressure Vessel Code, Section II, *Materials, Part A – Ferrous Material Specifications*, and *Materials, Part D – Properties*, 2017 Edition.

2.2.2 Chemical, Galvanic, or Other Reactions

The package that fully surrounds the DU gamma shield casting is fabricated from Type 304 stainless steel. The stainless steel does not have significant reactions with the interfacing components, air, or water. The DU casting, which is coated with enamel paint, is further surrounded by polyurethane foam. Copper shims are placed between all of the contact interfaces between the DU and stainless steel to prevent a eutectic reaction. The source tubes/hub assembly is fabricated from titanium, which does not react or form a galvanic corrosion cell with the DU material.

2.2.3 Effects of Radiation on Materials

The gamma radiation associated with the Ir-192 or Se-75 radioactive material will have no effect on the austenitic stainless steel or the DU comprising the structural materials of the THSC. As discussed in Section 2.1.1, *Discussion*, the interior polyurethane foam only provides moisture protection of the DU gamma shield. The effect of the radiation on the polyurethane foam to provide this protection is negligible.

2.3 Fabrication and Examination

2.3.1 Fabrication

The THSC is fabricated utilizing conventional metal forming and joining techniques. Materials are procured in accordance with the standards delineated on the drawings in Appendix 1.3.1, *General Arrangement Drawings*. All welding procedures and welding personnel are qualified in accordance with Section IX of the ASME Boiler and Pressure Vessel (B&PV) Code[7].

2.3.2 Examination

The primary safety function of the THSC is to provide gamma shielding of the special form radioactive material. To verify this function, each DU gamma shield is examined by performing a shielding test and an ultrasonic test, as delineated in Section 8.1.6, *Shielding Tests*, and 8.1.8, *Miscellaneous Tests*, respectively, prior to being used in the fabrication of a THSC packaging. In addition, all welds are visually inspected in accordance with AWS D1.6[8], as identified in Appendix 1.3.1, *General Arrangement Drawings*.

2.4 General Requirements for All Packages

The THSC is evaluated, with respect to the general standards for all packaging specified in 10 CFR §71.43[3]. Results of the evaluations are discussed in the following sections.

2.4.1 Minimum Package Size

The smallest overall dimension of the THSC package is 12½ inch diameter. This dimension is greater than the minimum dimension of 4 inches (10 cm) specified in 10 CFR §71.43(a). Therefore, the requirements of 10 CFR §71.43(a) are satisfied.

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[7] American Society of Mechanical Engineers (ASME), Boiler and Pressure Vessel Code, Section IX, *Qualification Standard for Welding and Brazing Procedures, Welders, Brazers, and Welding and Brazing Operators*, 2017 Edition.

[8] America Welding Society® (AWS), *Structural Welding Code –Stainless Steel, 3rd Edition*, AWS D1.6/D1.6M:2017.

2.4.2 Tamper Indicating Device

A tamper indicating seal (wire/lead security seal) is attached to one pair of the closure lid bolts (Refer to Figure 1.2-1), which provide visual evidence that the closure lid was not tampered during transportation. Therefore, the requirements of 10 CFR §71.43(b) are satisfied.

2.4.3 Positive Closure

The THSC cannot be opened inadvertently. Positive closure of the THSC is provided by the bolted closure lid. The lock box assemblies, which permits access to the contents, conform to the requirements of 10 CFR §34.23[2]. Therefore, the requirements of 10 CFR §71.43(c) are satisfied.

2.4.4 Valves

Because the THSC is a confinement system and designed to transport only special form radioactive materials, there are no valves or other pressure retaining devices on the package. Therefore, the requirements of 10 CFR §71.43(e) are satisfied.

2.4.5 Package Design

As shown in Section 2.6, *Normal Conditions of Transport*, 3.3, *Thermal Evaluation under Normal Conditions of Transport*, and 5.4, *Shielding Evaluation*, the THSC design satisfies the requirements of 10 CFR §71.71. Therefore, the requirements of 10 CFR §71.43(f) are satisfied.

2.4.6 External Temperatures

The maximum decay heat load of the ten (10) Ir-192 or Se-75 special form capsules is 10.55 watts (36 Btu/hr) for the maximum radioactive content of 1,500 Ci (55.5 TBq). With this negligible amount of decay heat, the surface temperature of the package in still air and shade is 113 °F (45 °C). This peak surface temperature does not exceed 122 °F (50 °C) during transport for a nonexclusive use shipment. Therefore, the requirements of 10 CFR §71.43(g) are satisfied.

2.4.7 Venting

With Ir-192 or Se-75 special form source capsules encapsulating the radioactive material, the THSC does not incorporate any feature that would permit continuous venting during transport. Therefore, the requirements of 10 CFR §71.43(h) are satisfied.

2.5 Lifting and Tie-down Devices for All Packages

2.5.1 Lifting Devices

The THSC is lifted by attaching a standard lift ring or other standard lifting component to the two (2) 8-32 UNC threaded holes in the closure lid (refer to Figure 2.2-1). For the maximum gross package weight of 340 pounds (154 kg), each threaded hole will support one-half of the total weight or 170 pounds (77 kg). For added conservatism, a weight of 200 pounds (91 kg) will be applied to each threaded hole as a tensile load, which results in shear stresses in the internal threads.

The closure lid is a 3/8-inch thick, Type 304 steel plate. An 8-32 UNC-2B internal thread has a shear area of 0.3343 in^2/in. Assuming a screw engagement depth of only half of the lid thickness (3/16 inch), the developed shear stress in the thread will be:

$$\tau_{8-32} = \frac{200}{(3/16)(0.3343)} = 3{,}175 \text{ psi}$$

From Chapter 3.0, *Thermal Evaluation*, the maximum package surface temperature is 197 °F (92 °C) on the closure lid surface. At this temperature, the minimum tensile yield strength for Type 304 stainless steel is 25,000 psi (from Table 2.3-1). The shear stress allowable is taken as 0.6 of the tensile yield strength at temperature, or 0.6 (25,000) = 15,000 psi. Therefore, the minimum factor of safety (F.S.) for lifting is:

$$\text{F.S.} = \frac{15{,}000}{3{,}175} = +4.72 > 3.0$$

Additionally, any potential failure of the 8-32 threaded fasteners for a lifting component will not impair the ability of the THSC to perform its shielding and confinement safety functions. Therefore, the requirements of 10 CFR §71.45(a) are satisfied.

2.5.2 Tie-Down Devices

The THSC package design does not contain any tie-down devices that are a structural part of the package. Therefore, the requirements of 10 CFR §71.45(b) are not applicable.

2.6 Normal Conditions of Transport

2.6.1 Heat

The maximum peak surface temperature of any component in an ambient environment of 100 °F (38 °C) and full insolation for the THSC is 197 °F (92 °C), which is located on the closure lid. Additionally, the THSC was exposed to a temperature greater than of 150 °F (66 °C) for several hours in an environmental chamber during the certification drop testing. There was no loss in operational capability or damage to the test units from the free and puncture drop tests performed at the higher test temperature.

2.6.2 Cold

For NCT cold condition, a -40 °F (-40 °C) steady state ambient condition is utilized per 10 CFR §71.71(c)(2), without insulation and any decay heat. This results in a uniform temperature of -40 °F (-40 °C) throughout the package. The THSC was exposed to temperatures less than -20 °F (-29 °C) for several hours in an environmental chamber without negative effects. Additionally, other INC packages that contain a DU gamma shield and stainless steel housing, such as the OP-100 package[9], have been exposed to ambient temperatures less than -40 °F (-40 °C) for several hours in an enclosure without any negative effects. Therefore, the THSC is unaffected by an ambient temperature of -40 °F (-40 °C).

2.6.3 Reduced External Pressure

The THSC is a confinement boundary for a special form payload and does not have a pressure boundary. Therefore, the effect of reduced external pressure per 10 CFR §71.71(c)(3) is not applicable.

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[9] *Safety Analysis Report, OP-100 Package*, Industrial Nuclear Company, Inc., NRC Docket No. 71-9185.

2.6.4 Increased External Pressure

The THSC is a confinement boundary for special form payload and does not have a pressure boundary. Therefore, the effect of increased external pressure per 10 CFR §71.71(c)(4) is not applicable.

2.6.5 Vibration

The THSC package is a welded stainless steel package that surrounds the DU gamma shield. The only components of the package that are bolted and removable are the closure lid and the lock boxes on the mounting plate. The closure lid is secured to the body by eight (8) 3/8-16 UNC hex head cap screws that are tightened to a minimum of 35 lb_f-ft torque, and fitted with tamper indicating seals. Each of the ten lock boxes are secured to the stainless steel mounting plate with four (4) 1/4-20UNC stainless steel socket head cap screws that are securely tightened. The bolted lock box assemblies, which are utilized on other INC licensed packages[8], have been subjected to both normal conditions of transport as well as rugged field use over an extended period of time (1982 to present). As evidence by the certification drop testing, the welded package is extremely stiff, and hence, has a very high fundamental frequency. Based on this field experience and the certification testing, the THSC package will not experience any damage or detrimental effects due to vibration normally incident to normal conditions of transport identified in 10 CFR §71.71(c)(5).

2.6.6 Water Spray

The stainless steel materials of construction utilized for the THSC are such that the water spray test identified in 10 CFR §71.71(c)(6) will have a negligible effect on the package.

2.6.7 Free Drop

Since the gross weight of the THSC is less than 11,000 pounds (5,000 kg), a 4-foot (1.2 meter) free drop is required per 10 CFR §71.71.(c)(7). As discussed in Appendix 2.12.1, *Certification Tests*, a NCT, 4-foot (1.2-meter) free drop with impact on the package bottom was performed on a THSC certification test unit (CTU-1) as an initial condition for the subsequent hypothetical accident condition (HAC) tests. As noted in the appendix, there was no visible deformation to the THSC test unit. A radiation survey following all certification testing demonstrated the ability of the THSC packaging to maintain its shielding and confinement integrity. Therefore, the requirements of 10 CFR §71.71(c)(7) are satisfied.

2.6.8 Corner Drop

This test does not apply, since the materials of construction do not include wood or fiberboard, as delineated in 10 CFR §71.71(c)(8).

2.6.9 Compression

A 1,652-pound (749 kg) force, which is equal to five times the gross package weight, was applied to the THSC while sitting in its normal vertical position for a period of 24 hours (refer to Figure 2.6-4). No observable deformation and damage was detected. Therefore, the requirements of 10 CFR §71.71(c)(9) are satisfied.

Figure 2.6-4 – View of THSC Compression Test After 24 Hours

2.6.10 Penetration

Per 10 CFR §71.71(c)(10), a 1¼ inch (3.2 cm) diameter, 13 pound (6 kg), hemispherical end steel rod is required to be dropped from a height of 40 inches (1 meter) onto the exposed surface of a package that is expected to be most vulnerable to puncture. The THSC package was puncture tested more severely in accordance with the hypothetical accident conditions (HAC) per §71.73(c)(3), which requires the heavier package to be dropped 40 inches (1 meter) onto a 6-inch

(15 cm) diameter bar in the most vulnerable orientation. As noted in Appendix 2.12.1, *Certification Tests*, there was no visible damage from either of the puncture drops. Therefore, the requirements of 10 CFR §71.71(c)(10) are satisfied by the HAC puncture drop tests.

2.7 Hypothetical Accident Conditions

When subjected to the hypothetical accident conditions (HAC) as specified in 10 CFR §71.73, the THSC meets the performance requirements specified in Subpart E of 10 CFR 71. This conclusion is demonstrated in the following subsections, where each accident condition is addressed and the package is shown to meet the applicable design criteria. The method of demonstration is primarily by test. The tests specified in 10 CFR §71.73 are applied sequentially, per Regulatory Guide 7.8.

Test results are summarized in Section 2.7.7, *Summary of Damage*, with details provided in Appendix 2.12.1, *Certification Tests.*

2.7.1 Free Drop

Subpart F of 10 CFR 71 requires performing a free drop test in accordance with the requirements of 10 CFR §71.73(c)(1). The free drop test involves performing a 30 foot (9 meter) free drop onto a flat, essentially unyielding, horizontal surface, with the package striking the surface in an orientation for which the maximum damage is expected. For the THSC, the free drop test is addressed by two full-scale THSC CTUs, in which several orientations are utilized. The free drop test precedes both the puncture and thermal tests.

2.7.1.1 Technical Basis for the Free Drop Tests

To properly select a worst-case package orientation for the 30 foot (9 meter) free drop event, items that could potentially compromise shielding integrity and/or the special form source of the THSC must be clearly identified. For the THSC design, the foremost item to be addressed is the shielding integrity, with confinement of the special form capsules being a secondary consideration.

For the confinement system to fail, the THSC would need to move or separate one or more of the radioactive sources from their stored shield location within the DU gamma shield assembly. This potential failure mode may only occur if either of the following conditions occurs:

1. One or more of the lock boxes fail, which then moves one or more pigtail assemblies from their stored shielded position.
2. The DU gamma shield assembly translates away from the mounting plate, and one or more of the pigtail assemblies with the special form capsule moves significantly from its stored shielded position.

For either of these potential conditions to occur, the THSC would need to sustain significant damage due to the HAC free drops. Therefore, the primary objective of the 30 foot (9 meter) HAC free drops is to damage the THSC package that causes significant movement of a special form source within the DU gamma shield assembly. A secondary objective of the 30 foot (9 meter) HAC free drops is to attempt to damage the THSC such that the DU gamma shield assembly would become exposed, which could result in a self-sustaining oxidation reaction from the HAC thermal event and hence, result in a loss of shielding.

For the above reasons, testing must include orientations that potentially may affect the lock boxes, which secure the special form sources, and/or the THSC welded body, which may result in an excessive opening into the cavity for a subsequent thermal event. Therefore, the drop orientations selected for testing are intended to maximize the damage to the THSC package and cause a potential opening of the stainless steel body and/or movement of one or more of the special form sources.

2.7.1.2 Test Sequence for the Selected Tests

Based on the above discussions, the THSC was tested for three specific, HAC 30 foot (9 meter) free drop conditions: 1) an impact on the bottom, 2) an impact on the side, and 3) CG-over-the top corner. Although only a single "worst-case" 30 foot (9 meter) drop is required by 10 CFR §71.73(c)(1), multiple tests were performed on a single test unit, and with multiple test units to ensure that the most vulnerable package features were subjected to "worst-case" impact loads and deformations. The specific conditions selected for the THSC certification test units (CTUs) are summarized in Table 2.7-1.

2.7.1.3 Summary of Results from the Free Drop Tests

Successful HAC free drop testing of the CTUs indicates that the various THSC design features are adequately designed to withstand the HAC 30 foot (9 meter) free drop event in the worst-case orientation. The most important result of the testing program was the demonstrated ability of the THSC to maintain its shielding integrity. Significant results of the free drop testing are as follows:

- No significant damage to the welded package structure from the free drop impacts.
- No evidence of distortion or damage to the lock boxes occurred that would have significantly displaced the special form sources from their desired shielded position.
- There was no rupturing of the stainless steel body that could have resulted in thermal degradation of the DU gamma shield by excessive oxidation in a subsequent thermal (fire) event.

Further details of the free drop test results are provided in Appendix 2.12.1, *Certification Tests.*

2.7.2 Crush

Subpart F of 10 CFR 71 requires performing a dynamic crush test accordance with the requirements of 10 CFR §71.73(c)(2). The crush test is required only when the specimen has mass not greater than 1,100 lbs. (500 kg), an overall density not greater than 62.4 lb_m/ft^3 (1,000 kg/m^3), and radioactive contents greater than 1,000 A_2, not as special form. Since the density of the THSC is greater than 62.4 lb_m/ft^3 (1,000 kg/m^3), and the payload is special form, the dynamic crush test is not applicable to the THSC.

2.7.3 Puncture

Subpart F of 10 CFR 71 requires performing a puncture test in accordance with the requirements of 10 CFR §71.73(c)(3). The puncture test involves performing a 40 inch (1 meter) drop onto the upper end of a solid, vertical, cylindrical, mild steel bar mounted on an essentially unyielding, horizontal surface. The bar must be 6 inches (15 cm) in diameter, with the top surface horizontal and its edge rounded to a radius of not more than 1/4 inch (6 mm). The minimum length of the bar is to be 8 inches (20 cm). The ability of the THSC to adequately withstand this specified drop condition is demonstrated via testing of two full-scale THSC CTUs.

2.7.3.1 Technical Basis for the Puncture Drop Tests

To properly select a worst-case package orientation for the puncture drop event, items that could potentially compromise shielding integrity and/or the special form sources of the THSC must be clearly identified. For the THSC design, the foremost item to be addressed is the shielding integrity, with confinement of the special form capsules being a secondary consideration.

For the confinement system to fail, the THSC would need to move or separate one or more of the radioactive sources from the stored shield location within the DU gamma shield assembly. This potential failure mode may only occur if either of the following conditions occurs:

1. One or more of the lock boxes fail, which then moves one or more pigtail assemblies from their stored shielded position.
2. The DU shield assembly translates away from the mounting plate and one or more of the pigtail assemblies moves significantly from its stored shielded position.

For either of these potential conditions to occur, the THSC would need to sustain significant damage due to the HAC puncture drops. Therefore, the primary objective of the 40 inch (1 meter) HAC puncture drop is to cause further damage from the 30 foot (9 meter) free drop damage to the THSC package that could cause significant movement of a special form source within the DU gamma shield assembly. A secondary objective of the 40 inch (1 meter) HAC puncture drops is to attempt to damage the THSC such that the DU shield assembly would become exposed, which could result in a self-sustaining oxidation reaction from the HAC thermal event and hence, result in a loss of shielding.

Therefore, testing must include orientations that potentially may affect the lock boxes, which secure the special form sources, and/or the THSC welded body, which may result in an excessive opening into the cavity for a subsequent thermal event. The drop orientations selected for testing are intended to maximize the existing free drop damage to the THSC package and cause a potential opening of the stainless steel body and/or movement of one or more of the special form sources.

2.7.3.2 Test Sequence for the Selected Tests

Based on the above general discussions, the CTUs were specifically tested for two HAC puncture drop conditions as part of the certification test program. Although only a single "worst-case" puncture drop is required by 10 CFR §71.73(c)(3), multiple puncture tests were performed to ensure that the most vulnerable package features were subjected to "worst-case" loads and deformations. The specific conditions selected for the THSC Certification Test Units (CTUs) are summarized in Table 2.7-1.

2.7.3.3 Summary of Results from the Puncture Drop Tests

Successful HAC puncture drop testing of the CTUs indicates that the THSC design features are adequately designed to withstand the HAC puncture drop event. The most important result of the testing program was the demonstrated ability of the THSC to maintain its shielding integrity. Significant results of the puncture drop testing are as follows:

- No evidence of any damage to the THSC body due to the impact with the puncture bar.

- No evidence of distortion or damage to the lock boxes occurred that would have significantly displaced the special form sources from their desired shielded position.
- There was no rupturing of the stainless steel body that could have resulted in thermal degradation of the DU gamma shield by excessive oxidation in a subsequent thermal (fire) event.

Further details of the free drop test results are provided in Appendix 2.12.1, *Certification Tests.*

2.7.4 Thermal

Subpart F of 10 CFR 71 requires performing a thermal test in accordance with the requirements of 10 CFR §71.73(c)(4), which requires a package to be exposed to a hydrocarbon fuel/air fire with a minimum temperature of 1,475 °F (800 °C) for 30 minutes. As discussed in Section 2.7.1, *Free Drop*, and Section 2.7.3, *Puncture*, there was no rupturing of the THSC body that directly exposed the DU gamma shield to this fire environment.

The potential oxidation of the DU gamma shield from exposure to the 1,475 °F (800 °C) fire could reduce the shielding safety function of the THSC. For oxidation of the DU metallic surface, several conditions are required to occur:

1. **Melting of Polyethylene Pipe Plugs:** The purpose of the three (3) 1/4-inch NPT pipe plugs, which are installed symmetrically around the THSC body shell, is to melt during the HAC fire event, and allow a passageway for the escaping of gases from the combustion of the polyurethane foam. With the pipe plugs melted, the total open area of these three ∅0.49163 inch pipe threaded holes in the 0.18 inch thick body shell is 0.57 square inches.
2. **Damaged Polyurethane Foam:** As a result of the 30-foot free drops, the maximum deformation of the THSC stainless steel structure that affected the polyurethane foam occurred during the side drop. For this orientation, the deformation of the outer shell was a flat area approximately 0.2 inch deep × 3¾ inch wide along the height. For this degree of deformation, the polyurethane foam would have been compressed slightly, and possibly created some cracks within the in-situ poured expanded foam. However, the overall damage to the foam would be minimal. All other free drop and puncture drop orientations resulted in no observed damage to the THSC package that would have significantly affecting the polyurethane foam. Since the foam was not significantly affected by the free and puncture drop events, the foam will be fully consumed during the 30-minute fire event. After fully combusted, the polyurethane foam will remain as a charred layer surrounding the DU gamma shield. This charred layer provides some insulating benefit to the DU gamma shield surface.
3. **Availability of Oxygen to Reach the DU Shield:** As noted above, the total open area for the (3) 1/4-inch NPT thread holes is 0.57 square inches. In addition, there is a ∅3/4 inch hole in the center of the mounting plate that also accesses the polyurethane foam cavity, which has an open area of 0.44 square inches. Since no other structural weld joint failures had occurred in either certification test unit (CTU), the total open area to permit oxygen to enter the interior cavity where the DU gamma shield is located is slightly more than 1.0 square inch. Conservatively assuming there is no further out-gassing occurring following combustion of the foam during the remaining fire duration, and no credit for the closure lid providing an additional flow restriction, there is minimal access for

oxygen to enter and oxidize the DU metallic surface with the restricted open areas and the charred polyurethane foam surrounding the DU gamma shield.

For comparison, the IR-100 Exposure Device[10] is similarly constructed with a ∅3/4 inch thru hole into the inner cavity. In addition, one of the certification test units (CTU) sustained a failed fillet weld on the lower weld joint of the body that resulted in a gap into the DU gamma shield cavity. The gap measured approximately 3/16-inch maximum wide × 7 inches long (~80% of the package length). The IR-100 CTU was then tested in accordance with the HAC thermal test of 10 CFR §71.73(1)(4) with this failed weld joint and the ∅3/4 inch thru hole. A post- test radiation survey of the IR-100 CTU demonstrated that the DU gamma shield safety function was not degraded from the accumulated damage of the free and puncture drops, and the subsequent fire test. Following the radiation survey, visual examination of the inner cavity revealed the charred foam surrounding the shield, and that no significant oxidation of the DU gamma shield had occurred.

4. **Temperature of the DU Metal:** During the transient HAC thermal test, the THSC package would be exposed to a 1,475 °F (800 °C) fully-engulfing fire. Radiation and conduction heat transfer would then gradually increase the bulk temperature of the THSC package, including the heavy DU gamma shield that is located in the interior. Since the DU gamma shield is surrounded by the polyurethane foam, the foam will act as an insulator until it is fully combusted by the increased temperature. The total mass of the 20 lb_m/ft^3 polyurethane foam is approximately 10 pounds. Once the foam is fully consumed, the foam char will continue to insulate the DU gamma shield to some degree as the duration of the fire continues for the remainder of the 30-minute period. As evidenced of the charred foam behavior, the post-test examination of the much smaller and lighter IR-100 Exposure Device following the full-scale burn test demonstrated that the charred foam remained in-place, surrounding the DU gamma shield, which exhibited no significant oxidation. As documented in the IR-100 Exposure Device SAR, there was no deterioration of the package's shielding safety function due to the accumulated damaged from the free and puncture drops, followed by the thermal test. Note that the IR-100 Exposure Camera has a total of approximately 2 pounds of the same 20 lb_m/ft^3 polyurethane foam, and a DU gamma shield mass of 36-38 pounds. Comparing the mass values of the smaller and lighter IR-100 Exposure Camera to the larger and heavier THSC package, the THSC has five times the polyurethane foam mass, and over six times the DU gamma shield mass. Additionally, the minimum distance from the THSC outer package surface to the DU gamma shield surface is 0.845 inches versus no distance (i.e., contacts the metallic body sides) between the IR-100 outer package surface to the DU gamma shield surface. By this comparison, the peak temperature from the 30-minute thermal test for the THSC DU shield is bounded by the peak temperature experienced by the DU gamma shield in the IR-100 Exposure Device, which did not experience any deterioration of the shielding effectiveness, from the thermal test.

Additionally, all of the structural and shielding materials, which are Type 304 stainless steel and DU, of the THSC have melting temperatures of 2,550 – 2,640 °F (1,400 – 1,450 °C) and 2,071 °F (1,132 °C), respectively. These melting temperatures are significantly above the specified fire temperature of 1,475 °F (800 °C). The only combustible materials in the THSC package are the

[10] *Safety Analysis Report, IR-100 Exposure Device*, Industrial Nuclear Company, Inc., NRC Docket No. 71-9157.

non-structural polyurethane foam, which fills the cavity around the DU gamma shield for moisture protection, and the closure lid gasket. The combustion of the foam and the gasket has no effect on the structural materials of the THSC. Since the certification testing demonstrated that the package was not significantly affected by the accumulated damage from the free and puncture drops, and did not directly expose the DU gamma shield that could result in oxidation of the DU gamma shield, the THSC package satisfies the requirements of 10 CFR §71.73(c)(4).

2.7.5 Immersion – Fissile Material

The THSC does not transport fissile material. Therefore, 10 CFR §71.73(c)(5)does not apply.

2.7.6 Immersion – All Packages

The THSC is a confinement boundary for special form payload and does not have a pressure boundary. Therefore, the effect of external pressure due to immersion per 10 CFR §71.73(c)(6) is not applicable.

2.7.7 Deep Water Immersion Test (for Type B Packages Containing More than 10^5 A_2)

The THSC contains a maximum of 1,500 Ci (55.5 TBq) of Ir-192 or Se-75 isotopes, which have A_2 values of 16 Ci (0.6 TBq) and 81 Ci (3.0 TBq), respectively. Since the THSC does not contain more than 10^5 A_2 quantities of radioactive material, deep immersion per 10 CFR §71.61 does not apply.

2.7.8 Summary of Damage

As discussed in the previous sections, the cumulative damaging effects of free drop and puncture drop tests were satisfactorily withstood by the THSC certification testing. Additionally, the thermal event has no effect on the structural materials or the shielding function of the THSC package. Subsequent radiation post-test surveys of the CTUs confirmed that shielding and confinement integrity was maintained throughout the test series. Therefore, the requirements of 10 CFR §71.73 have been adequately demonstrated.

2.8 Accident Conditions for Air Transport of Plutonium

This section does not apply, since plutonium is not transported in the THSC.

2.9 Accident Conditions for Fissile Material Packages for Air Transport

This section does not apply, since fissile material is not transported in the THSC.

Table 2.7-1 - Summary of THSC Certification Test Unit (CTU) Tests and Results

Test No.	Test Description (Certification Test Unit No.)	Test Unit Angular Orientation: Longitudinal Axis (0° = upright)	Test Unit Angular Orientation: Circumferential Axis (0° = as marked)	Test Results
1	4 foot, bottom down (CTU-1)	0°	N/A	No visible deformation of channels on bottom
2	30 foot, bottom down (CTU-1)	0°	N/A	Bottom channels deformed into inner cavity ~1/4-inch
3	30 foot, top down, CG-over corner (CTU-1)	121.7°	N/A	Impacted top edge, deformed ~2 inches, outer shell deformed outward ~9/16 inches, (2) lid bolts failed
4	30 foot, top down (CTU-2)	180°	N/A	Center of lid deformed ~1/4 inch, lift ring damaged, outer shell deformed ~0.03 inches
5	30 foot, side drop (CTU-2)	90°	N/A	Body deformed ~0.2 inches deep × ~3¾ inches wide flat
6	Puncture drop, top down, CG-over-corner (CTU-1)	120°	0°	Bar struck previous free drop damage, no additional damage noted
7	Puncture drop, side (CTU-2)	90°	N/A	Bar struck inner mounting plate/shell joint, no additional damage noted

2.10 Special Form

The contents of the THSC are special form Ir-192 or Se-75 source capsules. All source capsules are limited to a maximum of 150 Ci (5.55 TBq). The special form certifications for the Ir-192 or Se-75 capsules that would be transported in THSC are as follows:

Manufacture	Model Number	Certification Number
Industrial Nuclear Co., Inc.	A[1]	USA/0297/S-96
	791[1]	USA/0393/S-96
Source Production & Equipment Co., Inc.	VSe Source Capsule[2]	USA/0785/S-96

Notes: 1. Source capsule is limited to a maximum of 150 Ci (5.55 TBq) of Ir-192 material
2. Source capsule is limited to a maximum of 150 Ci (5.55 TBq) of Ir-192 or Se-75 material.

2.11 Fuel Rods

This section does not apply, since fuel rods are not transported in the THSC.

2.12 Appendix

2.12.1 Certification Tests

Presented herein are the results of normal conditions of transport (NCT) and hypothetical accident condition (HAC) tests that address free drop, puncture, and thermal test performance requirements of 10 CFR 71[11]. The certification tests are fully documented in the Certification Test Report[12].

2.12.1.1 Introduction

The THSC, when subjected to the sequence of HAC tests specified in 10 CFR §71.73, subsequent to the NCT tests specified in 10 CFR §71.71, is shown to meet the performance requirements specified in Subpart E of 10 CFR 71. As indicated in the introduction to Chapter 2.0, *Structural Evaluation*, the primary proof of performance for the HAC tests is via the use of full-scale testing. In particular, free drop and puncture testing of THSC CTUs confirms that the packaging will retain its shielding integrity following a worst-case HAC sequence.

2.12.1.2 Summary

As seen in the figures presented in Section 2.12.1.7, *Test Results*, successful testing of the CTUs indicates that the various THSC packaging design features are adequately designed to withstand the HAC tests specified in 10 CFR §71.73. The most important result of the testing program was the demonstrated ability of the THSC packaging to maintain its shielding and confinement integrity.

Significant results of the free drop tests are as follows:

- No significant damage to the package structure from the free drop impacts.
- No evidence of excessive distortion of the lock boxes occurred that would have significantly displaced the special form sources from their designed shielded position.
- There was no evidence of rupturing of the stainless steel body that could have resulted in thermal degradation of the DU gamma shield by excessive oxidation in a subsequent fire event.

Significant results of the puncture drop testing are as follows:

- No evidence of any damage to the THSC body due to the impact with the puncture bar.
- No evidence of excessive distortion of the lock boxes occurred that would have significantly displaced the special form source from its desired shielded position.
- There was no evidence of rupturing of the stainless steel body that could have resulted in thermal degradation of the DU gamma shield by excessive oxidation in a subsequent fire event.

2.12.1.3 Test Facilities

The free and puncture drop testing was performed at the Oak Ridge National Laboratory (ORNL), Oak Ridge, Tennessee. The drop pad consisted of a horizontal concrete pad that weighs

[11] Title 10, Code of Federal Regulations, Part 71 (10 CFR 71) *Packaging and Transportation of Radioactive Material*, 1-1-18 Edition.

[12] Orano Federal Services, Document No. TR-3021828, *Certification Test Report for the INC Ten Hole Source Changer*, Revision 1, September 2018.

approximately 40 tons. The top pad surface has an 8-foot (2.4-meter) square steel armor plate embedded in the concrete pad. Additionally, several sections of 6-inch (15 cm) thick steel plate were welded to the original steel armor plate, which increased the drop pad mass by approximately 20 tons. The total mass of the drop pad was approximately 60 tons. With the maximum weight of the THSC CTUs not exceeding 340 lb_m, this drop pad size/mass easily satisfied the requirement of at least 10 times the package weight to qualify as an unyielding impact surface per 10 CFR 71.

The puncture bar assembly for the puncture tests was a 6-inch (15 cm) diameter × 12 inch (30 cm) long bar that was welded to a 1-inch (25-mm) thick square steel plate. The top circumferential edge of the bar was rounded to a 1/4-inch (6-mm) radius. The free length of the bar was 12 inches (30 cm) (i.e., height above the base plate), thus ensuring an adequate length to facilitate maximum damage to the CTU as required by 10 CFR §71.73(c)(3). Following the 30-foot (9-meter) free drop tests, the 1-inch (25 mm) thick plate of the puncture bar assembly was welded to the 6-inch (15 cm) thick steel plate on the drop pad. This configuration ensured that the puncture bar assembly was fully restrained for the puncture drop tests.

2.12.1.4 Certification Test Unit Description

The THSC consists of titanium source tubes and hub surrounded by an enamel-coated, DU gamma shield. The DU gamma shield assembly is encased within a welded 12-inch diameter, Schedule 10S stainless steel pipe. The DU gamma shield assembly is laterally supported by eight stainless steel channel sections that are welded to the inner wall of the outer pipe. The DU gamma shield assembly is also supported vertically by a 4-inch diameter Schedule 40S stainless steel pipe and a 1-inch diameter stainless steel bar that are welded to the inner surface of the 1/4-inch thick stainless steel bottom plate. Copper shim stock is installed between the DU-stainless steel interfaces to preclude a galvanic reaction between the two dissimilar metals. The DU gamma shield assembly is enclosed by a 1/4-inch thick stainless steel mounting plate that is welded to the inner surface of the outer pipe. This welded plate provides the mounting surface for the lock boxes that secure the special form capsules into the DU shield assembly. The void space between the DU gamma shield assembly and the outer pipe is filled with approximately 10 pounds of rigid polyurethane foam. To protect the lock boxes and the special form capsules, a 3/8-inch thick stainless steel closure lid plate is secured to the outer pipe by eight (8) 3/8-16 UNC hex head cap screws. On the inner surface of the closure lid plate, a 3-inch diameter Schedule 40S pipe is welded to provide additional vertical restraint of the DU gamma shield assembly/mounting plate for potential impact events.

Each special form pigtail assembly is secured in the DU gamma shield by a lock box that is attached to the mounting plate by four (4) 1/4-20 UNC stainless steel socket head cap screws (SHCSs). The pigtail assembly maintains the radioactive source in the DU gamma shield assembly against or near the titanium hub, which provides the maximum gamma shielding to the public. Maintaining the location of the radioactive sources is an important safety requirement since significant displacement of the source from the stored position would elevate the surface and 1-meter dose rates.

Prior to free drop and puncture testing, the two THSC CTUs were loaded with dummy source capsule/pigtail assemblies to simulate the special form capsules. The actual weights of CTU-1 and CTU-2 were 328 pounds and 320 pounds, respectively. In addition to the dummy source capsule assemblies, the CTUs differed slightly from the THSC packaging design depicted in Appendix 1.3.1, *General Arrangement Drawings*:

- One of the source tubes in CTU-1 was damaged during the casting of the DU gamma shield. Therefore, only nine (9) special form capsule/pigtail assemblies could be installed for testing purposes. This damage had no effect on the response of the CTU to the free drop and puncture tests.
- The specified all-around 1/4 inch bevel weld that joins the closure lid support ring to the body shell could not be performed near the threaded holes. This condition was caused by the holes being located too close to the inner wall of the shell. For the test units, a 3/16 inch bevel weld size was performed in these locations. Although the undersized weld slightly reduced the strength of the circumferential weld joint, this condition is conservative for testing.

2.12.1.5 Technical Basis for Tests

For the confinement system to fail, the THSC would need to move or separate the radioactive source from the stored shield location within the DU shield assembly. This potential failure mode may only occur if either of the following conditions occurs:

1. One or more of the lock boxes fail, which then moves one or more pigtail assemblies from their stored shielded position.
2. The DU shield assembly translates away from the mounting plate and one or more of the pigtail assemblies with the special form capsule moves significantly from its stored shielded position.

For either of these potential conditions to occur, the THSC would need to sustain significant damage due to the normal and hypothetical accident condition free drops, and then sustain further damage due to the 40-inch (1-meter) drop onto a 6 inch (15 cm) diameter vertical steel puncture bar. Therefore, the primary objective of the 4 foot (1.2 meter) normal condition and the 30-foot (9-meter) hypothetical accident condition (HAC) free drops is to damage the THSC package that causes significant movement of a special form source within the DU shield assembly. A secondary objective of the 30-foot (9-meter) HAC free drops is to attempt to damage the THSC such that the DU shield assembly would become exposed, which could result in a self-sustaining oxidation reaction from the HAC thermal event and hence, result in a loss of shielding.

The following sections provide the technical basis for the chosen test orientations and sequences for the THSC CTUs.

2.12.1.5.1 Temperature

Both cold and hot conditions for the free drops were utilized for the THSC certification testing. To maximize impact decelerations, a CTU was chilled to below -20 °F (-29 °C). To maximize deformations, a CTU was heated to over 150 °F (66 °C). The results of the package testing demonstrated that extreme temperatures had no effect on the shielding integrity of the THSC. In addition, the austenitic stainless steel and DU materials are not susceptible to brittle fracture, as delineated in Section 2.1.2.2.1, *Brittle Fracture*.

For the puncture tests, ambient temperatures were utilized for the THSC certification testing.

2.12.1.5.2 Free Drop Tests

The THSC is qualified primarily by full-scale testing, with acceptance criterion being the ability to demonstrate shield integrity. Per 10 CFR §71.73(c)(1), the package is required to strike an essentially unyielding surface "*...in a position for which maximum damage is expected.*" Therefore, for determining the drop orientations that satisfy the regulatory "maximum damage" requirement, attention is focused predominately on the issue of shield integrity.

To maximize the damage to the THSC and potentially separating a radioactive special form capsule, three orientations have been selected for the free drop testing:

1. Vertical, Bottom: This orientation targets the THSC and the mounting plate weldment. Should this impact be sufficiently severe, the THSC closure lid and the mounting plate weldment may fail and result in significant movement of one or more of the special form capsules. The intent of this drop orientation is also to simulate a probable orientation that could occur in actual use in the field.
2. Side: This orientation targets the DU gamma shield assembly and the special form source capsules. Should this impact be sufficiently severe, the DU gamma shield or closure lid assembly could become damaged and result in a significant increase in the dose rate. Additionally, should the outer pipe of the THSC package fail, the DU gamma shield would be exposed. Direct exposure of the DU to the HAC thermal event has been shown to be a possible failure mechanism for a DU gamma shield.
3. CG-Over-Top Corner: This orientation targets the THSC closure and the lock box assemblies. The hot test condition also maximizes the deformation to the package. The intent of this orientation is to attempt to damage one or more of the lock boxes, the closure lid, and/or the mounting plate. Should this impact be sufficiently severe:
   - Failure of closure lid and/or mounting plate weldment that results in exposure of the DU gamma shield assembly,
   - One or more of the lock boxes to become dislodged or fail and allow a special form source to be pulled from the shielded stored position,

2.12.1.5.3 Puncture Drop Tests

10 CFR §71.73(c)(3) requires a free drop of the specimen through a distance of 40 inches (1 meter) onto a puncture bar "*...in a position for which maximum damage is expected....*" As discussed in Section 2.12.1.5.2, *Free Drop Tests*, the "maximum damage" criterion is evaluated primarily in terms of loss of shielding integrity. Loss of shielding integrity could occur directly by dislodging and/or failing a lock box body, and allow the special form capsule source to separate from the THSC body.

The orientations selected for the puncture tests were the side and CG-over-top corner tests as discussed in Section 2.12.1.5.2, *Free Drop Tests.* The intent of these orientations is to accumulate puncture damage with the damage from the 30-foot free drops for the same orientations.

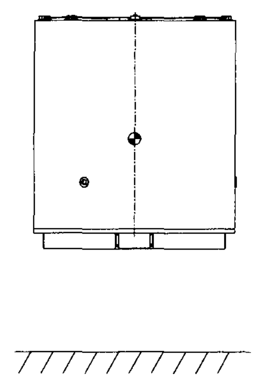
2.12.1.5.4 Thermal Test

Depending on the results of the normal and hypothetical accident condition free drop and puncture tests, the THSC may be subjected to a 30-minute, 1,475 °F (800 °C) thermal test in accordance with 10 CFR §71.73(c)(4). The criteria for whether this test will be performed is dependent on the presence of a cracked and/or opening of the stainless steel body, and subsequently exposing the DU gamma shield. There was no rupture of the welded body structure of either CTU from the accumulated free drop and puncture test impact damage; therefore, the thermal test was unnecessary.

2.12.1.6 Test Sequence for Selected Free Drop and Puncture Drop Tests

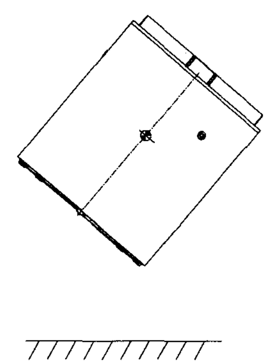
The following sections establish the selected free drop, puncture drop, and thermal test sequence for the THSC CTUs based on the discussions provided in Section 2.12.1.5, *Technical Basis for Tests*. The tests sequences are summarized in Table 2.12.1-1 and illustrated in Figure 2.12.1-1 and Figure 2.12.1-2.

2.12.1.6.1 Certification Test Unit No. 1 (CTU-1)

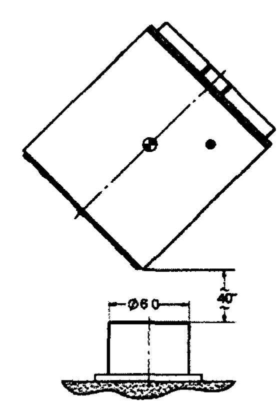


Free Drop No. 1 is a NCT free drop from a height of four feet, impacting the bottom of the package. The 4 foot (1.2 meter) drop height is based on the requirements of 10 CFR §71.71(c)(7) for a package weight not exceeding 11,000 pounds. The purpose of this test was intended to cause maximum damage to the packaging in its most probable orientation. This test was performed at cold temperature.

Free Drop No. 2 is a HAC free drop from a height of 30 feet (9 meter), impacting the bottom of the package, which is the same impact point as the NCT Free Drop No. 1. In this way, NCT and HAC free drop damage is cumulative. The 30 foot (9 meter) drop height is based on the requirements of 10 CFR §71.73(c)(1). The purpose of this test was intended to cause maximum damage to the packaging in its most probable orientation. This test was performed at cold temperature.



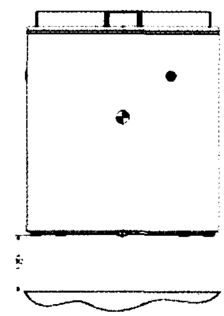
Free Drop No. 3 is a HAC free drop from a height of 30 feet, impacting the top corner. The 30 foot (9 meter) drop height is based on the requirements of 10 CFR §71.73(c)(1). The purpose of this test was intended to cause maximum damage to the closure lid, and possibly damage/move the lock boxes. This test was performed at hot temperature.



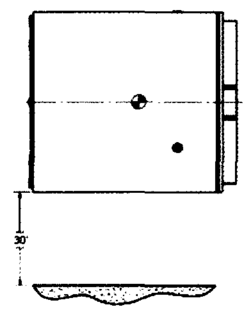
Puncture Drop No. 6 impacts directly onto the damage created by Free Drop Test 3, directly on the top corner. The puncture drop height is based on the requirements of 10 CFR §71.73(c)(3). The purpose of Puncture Drop No. 6 is to cause maximum damage to the closure lid, and possibly damage/move the lock boxes.

2.12.1.6.2 Certification Test Unit No. 2 (CTU-2)

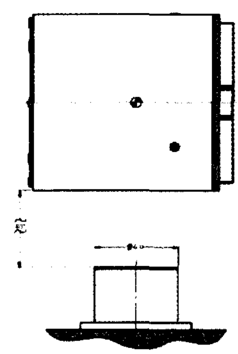
Free Drop No. 4 is a HAC free drop from a height of 30 feet, impacting the top of the package, The 30 foot (9 meter) drop height is based on the requirements of 10 CFR §71.73(c)(1). The purpose of this test was intended to cause maximum damage to the closure lid and the mounting plate/lockboxes. This test was performed at hot temperature.



Free Drop No. 5 is a HAC free drop from a height of 30 feet, impacting the side of the package, The 30 foot (9 meter) drop height is based on the requirements of 10 CFR §71.73(c)(1). The purpose of this test was intended to cause maximum damage to the mounting plate/lockboxes. This test was performed at hot temperature.



Puncture Drop No. 7 impacts directly onto the damage created by Free Drop Test No. 5, directly on the side of the package. The puncture drop height is based on the requirements of 10 CFR §71.73(c)(3). The purpose of Puncture Drop No. 7 is to cause maximum damage to the mounting plate/lock boxes and possibly cause dislodgement of a special form capsule.



2.12.1.7 Test Results

The following sections report the results of free drop, puncture drop, and thermal tests following the sequence provided in Section 2.12.1.6, *Test Sequence for Selected Free Drop, Puncture Drop, and Thermal Tests*. Results are summarized in Table 2.12.1-2 (refer also to Figures 2.12.1-1 and 2.12.1-2).

Figures 2.12.1-3 through 2.12.1-18 sequentially photo-document the certification testing process for the THSC CTUs.

2.12.1.7.1 Certification Test Unit No. 1 (CTU-1)

2.12.1.7.1.1 CTU-1 Free Drop Test No. 1

Free Drop No. 1 is a NCT free drop from a height of four feet, impacting the bottom of the package. As shown in Figure 2.12.1-3, the CTU was oriented vertically with respect to the horizontal impact surface. The following list summarizes the test parameters:

- verified axial angle as 0° ±1°
- verified drop height as 4 feet (1.2 meter), +3/-0 inches
- measured surface temperature of DU gamma shield as -19 °F at time of test
- conducted test at 1:20 p.m. on Tuesday, 3/27/18

The package rebounded (bounced) upon impact off the drop pad, and fell to its side. There was no visible damage to the bottom welded steel channels on the body. The impact damage is shown in Figure 2.12.1-4.

2.12.1.7.1.2 CTU-1 Free Drop Test No. 2

Free Drop No. 2 is a HAC free drop from a height of 30 feet, impacting the bottom of the package. As shown in Figure 2.12.1-5, the CTU was oriented vertically with respect to the horizontal impact surface. The following list summarizes the test parameters:

- verified axial angle as 0° ±1°
- verified drop height as 30 feet (9 meter), +3/-0 inches
- measured surface temperature of DU gamma shield at less than -7 °F at time of test
- conducted test at 1:50 p.m. on Tuesday, 3/27/18

The package rebounded (bounced) upward approximately 2 feet upon impact, and fell to its side. The bottom welded steel channels deformed into the cavity approximately 1/4 inch. No other damage was observed. The impact damage is shown in Figure 2.12.1-6.

2.12.1.7.1.3 CTU-1 Free Drop Test No. 3

Free Drop No. 3 is a HAC free drop from a height of 30 feet, impacting the top edge of the package. As shown in Figure 2.12.1-7, the CTU was oriented so the c.g. of the package was over the top edge with respect to the impact pad. The following list summarizes the test parameters:

- verified longitudinal angle as 121.7° ±1°
- verified drop height as 30 feet (9 meter), +3/-0 inches
- measured surface temperature of DU gamma shield as 156 °F at time of test
- conducted test at 11:23 a.m. on Wednesday, 3/28/18

The package rebounded (bounced) upon impact off the drop pad, and fell to its side. The impact produced a half-moon crescent measured approximately 2 inches deep × 9½ inches wide. Two lid hex head cap screws were sheared off from the impact. The impact damage is shown in Figure 2.12.1-8.

2.12.1.7.1.4 CTU-1 Puncture Drop Test No. 6

Puncture Drop No. 6 impacted directly onto the damage created by Free Drop Test 3, directly on the top corner. As shown in Figure 2.12.1-9, the CTU was oriented with the c.g. of the package was over the top edge with respect to the impact pad so that the puncture bar would strike the damage from the 30-foot free drop. The following list summarizes the test parameters:

- verified longitudinal angle as 120° ±2°
- verified drop height as 40 inches (1 meter), +3/-0 inches
- measured surface temperature of DU gamma shield as 70 °F at time of test
- conducted test at 2:24 p.m. on Wednesday, 3/28/18

The package rebounded (bounced) off the puncture bar immediately following impact. The impact struck the previous damage from the 30-foot free drop. No other external damage was observed. The impact damage is shown in Figure 2.12.1-10.

2.12.1.7.1.5 CTU-1 Post-Test Disassembly

Post-test disassembly of CTU-1 was performed on Thursday, 5/3/18. A portion of the closure lid/body shell was removed in order to access the lock box/mounting plate area. Inspection of this area revealed that all of the brass dust covers were no longer threaded into the lock boxes and loose on top of the mounting plate, as shown in Figure 2.12.1-11. There was no damage to any of the lock boxes from any of the free drop and puncture drop tests.

2.12.1.7.1.6 CTU-1 Post-Test Radiation Survey

Post-test radiation survey of the THSC CTU-1 was performed on Wednesday, 6/27/18. The post-test radiation survey was performed using an Ir-192 special form radioactive capsule/pigtail assembly installed in each lock box. The strength of the Ir-192 source capsules that were utilized for CTU-1 on the day of the survey were (7) 103 Ci [3.8 TBq] and (2) 100 Ci [3.7 TBq]. The total radioactive payload for the post-test survey was 921 Ci [34.1 TBq]. To account for the maximum design radioactive payload of 1,500 Ci (55.5 TBq), the measured values were adjusted upward by the ratio of 1,500/921 or 1.6287 to determine the dose rate for the maximum radioactive content. Since CTU-1 could only be loaded with 9 sources, another adjustment ratio of 10/9 or 1.1111 was applied. To account for the effect of the two slightly lower 100 Ci (3.7TBq) sources, a final adjustment of 103/100 or 1.03 was also applied. The total upward adjustment factor applied to the measured dose rates was then (1.6287)(1.1111)(1.03) = 1.8639. The post-test measured dose rates for the maximum radioactive content of 1,500 Ci (55.5 TBq) are as follows:

Test Unit No.	Adjusted Maximum Dose Rate [Top/Bottom/Side] (mrem/hr)								
	Surface			1-meter			2-meters		
CTU-1	5.6	26.1	106	0.0	0.0	0.0	0.0	0.0	0.0

As indicated above, the radiation dose levels were well below the requirements of 10 CFR §71.47(a) for NCT and 10 CFR §71.51(a)(2) for HAC for a non-exclusive use shipment.

2.12.1.7.2 Certification Test Unit No. 2 (CTU-2)

2.12.1.7.2.1 CTU-2 Free Drop Test No. 4

Free Drop No. 4 is a HAC free drop from a height of 30 feet (9 meter), impacting the closure lid. As shown in Figure 2.12.1-12, the CTU was oriented 180° with respect to the horizontal impact surface (longitudinal angle 180°, circumferential angle N/A). The following list summarizes the test parameters:

- verified longitudinal angle as 180° ±2°
- verified drop height as 30 feet (9 meter), +3/-0 inches
- measured surface temperature of DU gamma shield as 153 °F at time of test
- conducted test at 11:51 a.m. on Wednesday, 3/28/18

The package rebounded (bounced) upon impact off the drop pad, with the secondary impact striking the lid edge. The package then rolled off the drop pad on its side. The impact deformed the lid center approximately 1/4 inch, with the outer shell deforming approximately 0.03 inches. The lift ring was also damaged with failure of one of the two screws. The impact damage is shown in Figure 2.12.1-13.

2.12.1.7.2.2 CTU-2 Free Drop Test No. 5

Free Drop No. 5 is a HAC free drop from a height of 30 feet (9 meter), impacting the side of the package. As shown in Figure 2.12.1-14, the CTU was oriented 90° with respect to the horizontal impact surface (longitudinal angle 90°, circumferential angle N/A). The following list summarizes the test parameters:

- verified longitudinal angle as 90° ±2°
- verified drop height as 30 feet (9 meter), +3/-0 inches
- measured surface temperature of DU gamma shield as greater than 125 °F at time of test
- conducted test at 12:17 p.m. on Wednesday, 3/28/18

The package rebounded (bounced) upon impact off the drop pad, and fell to its side. The impact produced a flat measuring approximately 0.2 inches deep × 3¾ inches wide. No other damage was visible or noted. The impact damage is shown in Figure 2.12.1-15.

2.12.1.7.2.3 CTU-2 Puncture Drop Test No. 7

Puncture Drop No. 7 was intended to impact directly onto the damage created by Free Drop Test 5, directly impacting the mounting plate/shell weld joint. As shown in Figure 2.12.1-16, the CTU was oriented 90° with respect to the horizontal impact surface (longitudinal angle 90°, circumferential angle N/A). The following list summarizes the test parameters:

- verified longitudinal angle as 90° ±2°
- verified drop height as 40 inches (1 meter), +3/-0 inches
- measured surface temperature of DU gamma shield as 85 °F at time of test
- conducted test at 2:10 p.m. on Wednesday, 3/28/18

The package rebounded (bounced) off the puncture bar immediately following impact. The impact struck the previous damage from the 30-foot free drop with no measureable deformation. No other external damage was noted. The impact damage is shown in Figure 2.12.1-17.

2.12.1.7.2.4 CTU-2 Post-Test Disassembly

Post-test disassembly of CTU-2 was performed on Thursday, 5/10/18. The closure lid was removed to access the lock box/mounting plate area. Inspection of this area revealed that (7) seven of the brass dust covers were no longer threaded into the lock boxes and loose on top of the mounting plate, as shown in Figure 2.12.1-18. There was no damage to any of the lock boxes from any of the free drop and puncture drop tests.

2.12.1.7.2.5 CTU-2 Post-Test Radiation Survey

Post-test radiation survey of the THSC CTU-2 was performed on Wednesday, 6/27/18. The post-test radiation survey was performed using an Ir-192 special form radioactive capsule/pigtail assembly installed in each lock box. The strength of the Ir-192 source capsules that were utilized for CTU-2 on the day of the survey were (7) 103 Ci (3.8 TBq) and (3) 100 Ci (3.7 TBq). The total radioactive payload for the post-test survey was 1,021 Ci (37.8 TBq). To account for the maximum design radioactive payload of 1,500 Ci (55.5 TBq), the measured values were adjusted upward by the ratio of 1,500/1,021 or 1.4691 to determine the dose rate for the maximum radioactive content. To account for the effect of the three slightly lower 100 Ci (3.7TBq) sources, an adjustment of 103/100 or 1.03 was also applied. The total upward adjustment factor applied to the measured dose rates was then (1.4691)(1.03) = 1.6324. The post-test measured dose rates for the maximum radioactive content of 1,500 Ci (55.5 TBq) are as follows:

Test Unit No.	Adjusted Maximum Dose Rate [Top/Bottom/Side/End] (mrem/hr)								
	Surface			1-meter			2-meters		
CTU-2	3.3	13.1	180	0.0	0.0	0.0	0.0	0.0	0.0

As indicated above, the radiation dose levels were below the requirements of 10 CFR §71.47(a) for NCT and 10 CFR §71.51(a)(2) for HAC for a non-exclusive use shipment.

Based on the test results, the THSC package design has been demonstrated to satisfy the requirements of Subpart F of 10 CFR 71 for the transportation of special form radioactive material.

Table 2.12.1-1 – Summary of THSC Certification Tests in Sequential Order[1]

Test No.	Test Description (Certification Test Unit No.)	Test Unit Angular Orientation		Test Unit Temperature (as measured)	Test Results
		Longitudinal Axis (0° = upright)	Circumferential Axis (0° = as marked)		
1	4 foot, bottom down (CTU-1)	0°	N/A	-19 °F (DU surface)	No visible deformation of channels on bottom
2	30 foot, bottom down (CTU-1)	0°	N/A	< -7 °F (DU surface)	Bottom channels deformed into inner cavity ~1/4-inch
3	30 foot, top down, CG-over corner (CTU-1)	121.7°	N/A	156 °F (DU surface)	Impacted top edge, deformed ~2 inches, outer shell deformed outward ~9/16 inches, (2) lid bolts failed
4	30 foot, top down (CTU-2)	180°	N/A	153 °F (DU surface)	Center of lid deformed ~1/4 inch, lift ring damaged, outer shell deformed ~0.03 inches
5	30 foot, side drop (CTU-2)	90°	N/A	> 125 °F (DU surface)	Body deformed ~0.2 inches deep × ~3¾ inches wide flat
6	Puncture drop, top down, CG-over-corner (CTU-1)	120°	0°	70 °F (DU surface)	Bar struck previous free drop damage, no additional damage noted
7	Puncture drop, side (CTU-2)	90°	N/A	85 °F (DU surface)	Bar struck inner mounting plate/shell joint, no additional damage noted

Notes:

1. Tested 3/27/2018 and 3/28/2018.
2. Longitudinal angle is relative to vertical axis of packaging (i.e., 0° is upright).
3. Circumferential angle is relative to rotation of package around vertical axis.

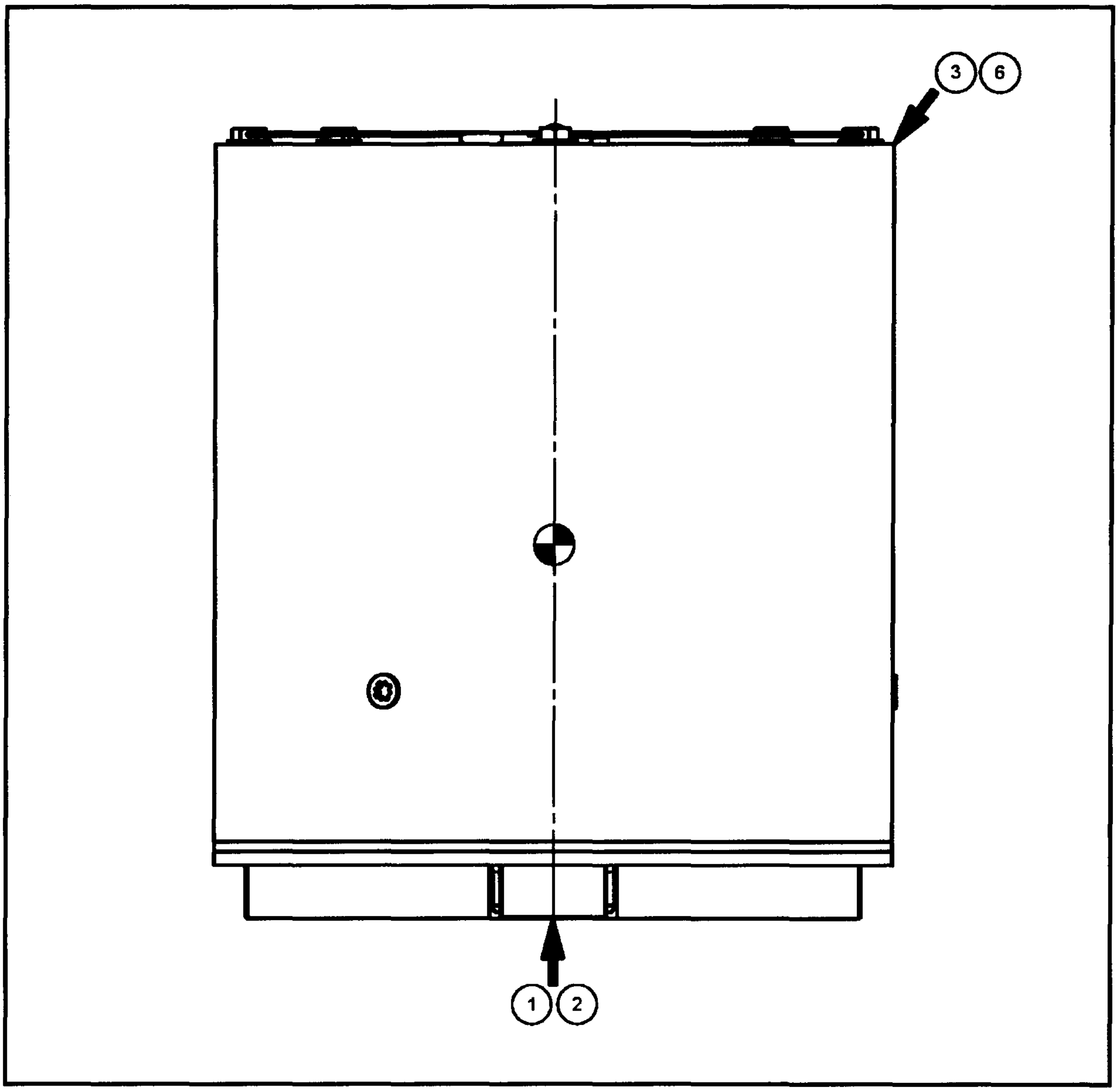


Figure 2.12.1-1 – Schematic Summary of CTU-1 Testing

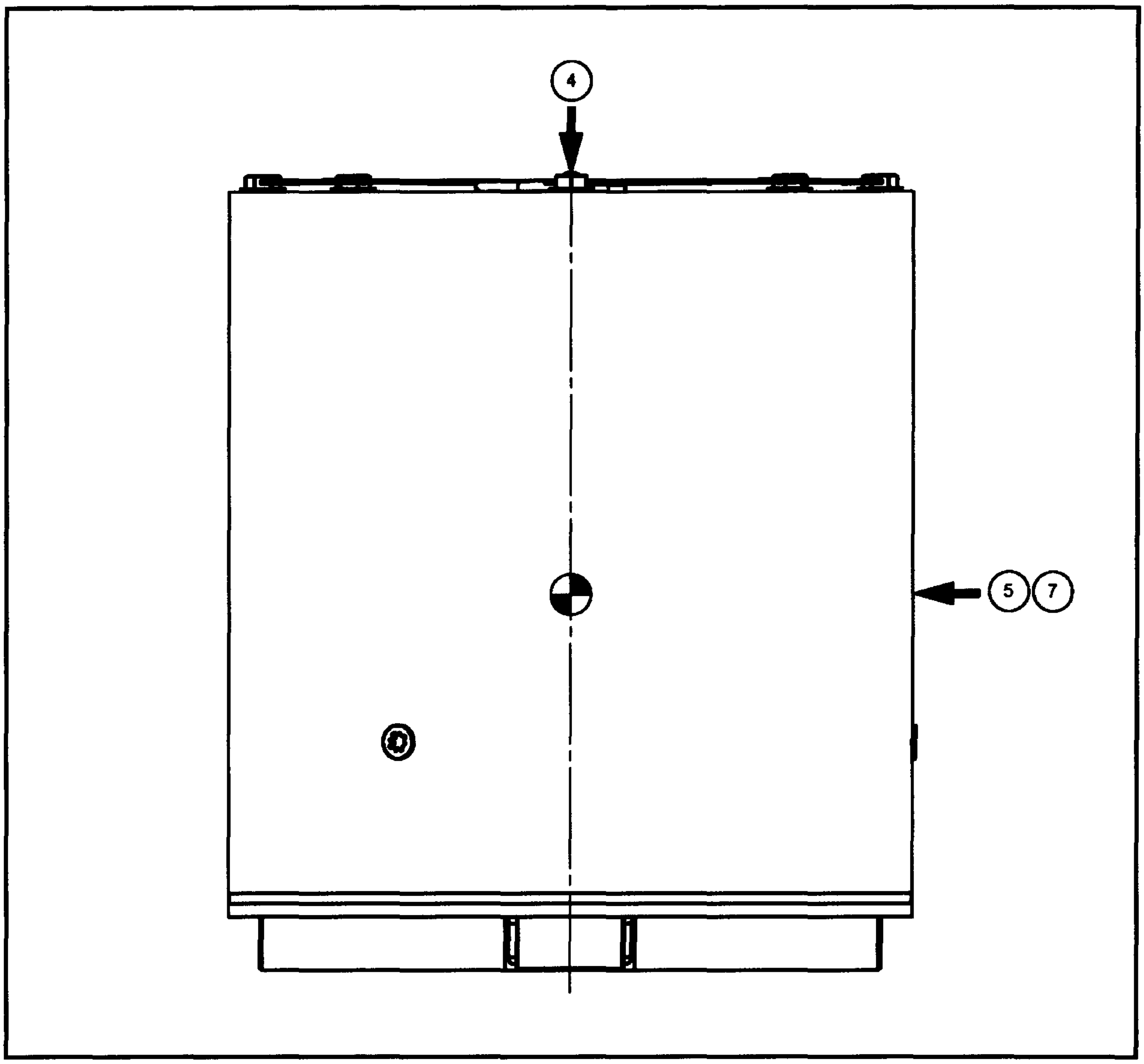


Figure 2.12.1-2 – Schematic Summary of CTU-2 Testing

Figure 2.12.1-3 – CTU-1 Free Drop Test No. 1

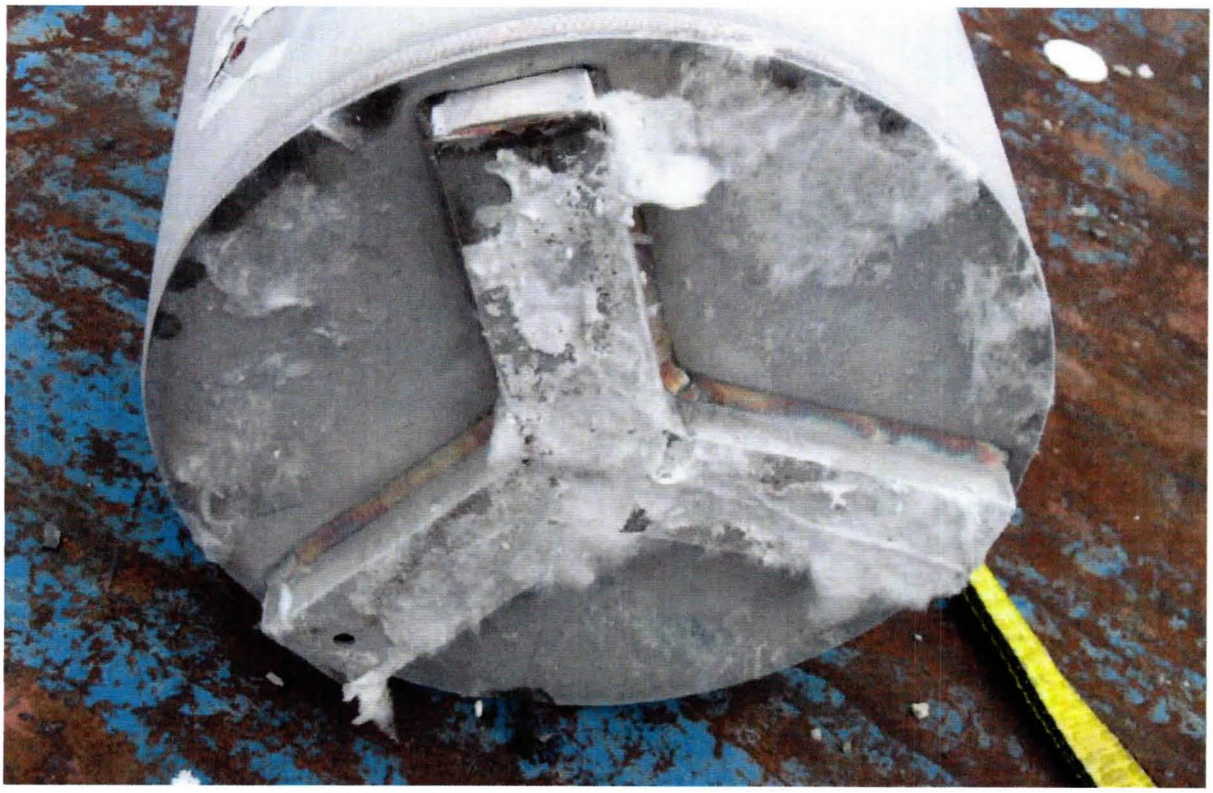


Figure 2.12.1-4 – CTU-1 Free Drop Test No. 1; Close-up View of Bottom Damage

Figure 2.12.1-5 – CTU-1 Free Drop Test No. 2; View of Test Setup

Figure 2.12.1-6 – CTU-1 Free Drop Test No.2; View of Test Unit Bottom

Figure 2.12.1-7 – CTU-1 Free Drop Test No. 3; View of Test Setup

Figure 2.12.1-8 – CTU-1 Free Drop Test No. 3; View of Impact Damage

Figure 2.12.1-9 – CTU-1 Puncture Drop Test No. 6 Immediately Prior to Impact

Figure 2.12.1-10 – CTU-1 Puncture Drop Test No. 6; Close-up View of Impact Area

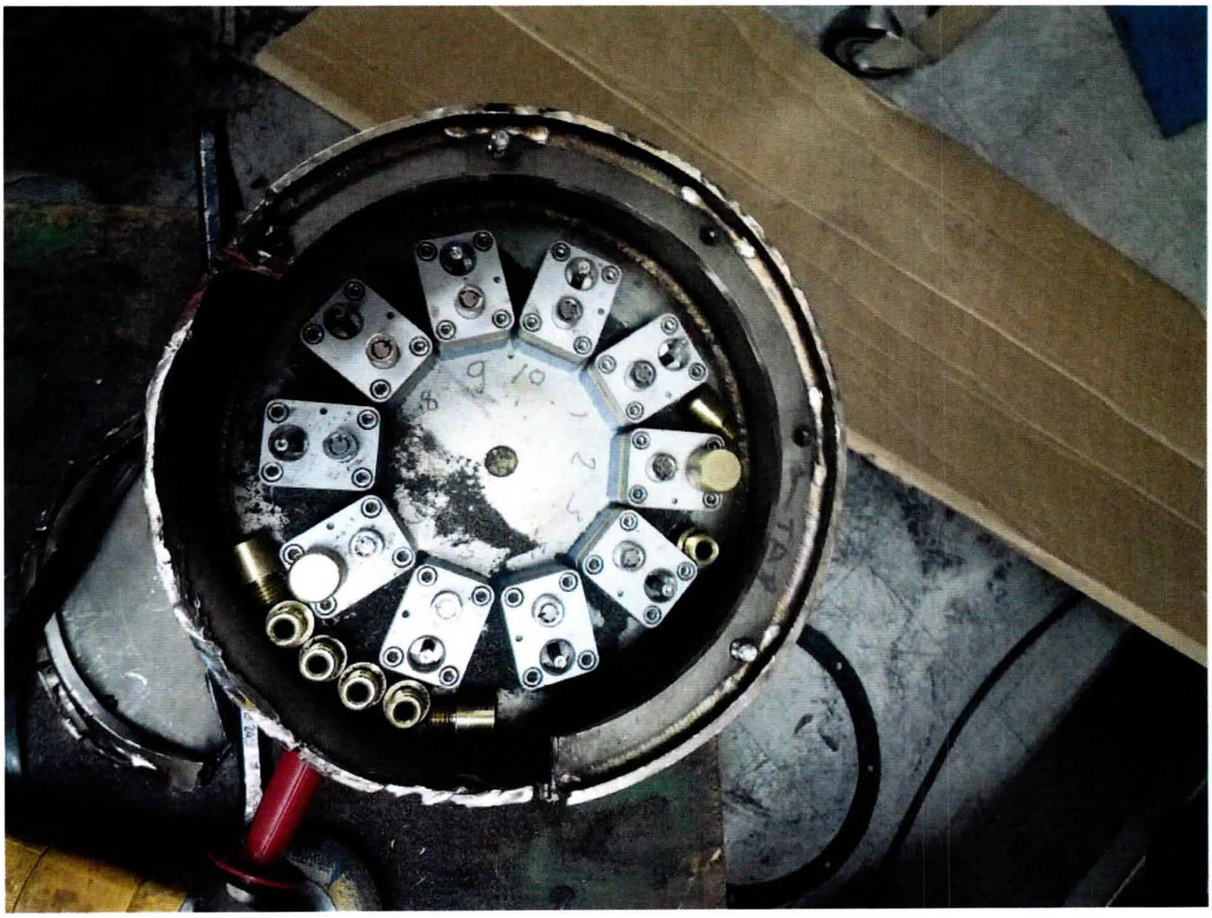


Figure 2.12.1-11 – CTU-1 Post-Test Disassembly; View of Mounting Plate/Lock Boxes

Figure 2.12.1-12 – CTU-2 Free Drop Test No. 4; View of Test Setup

Figure 2.12.1-13 – CTU-2 Free Drop Test No. 4; Close-up View of Impact Area

Figure 2.12.1-14 – CTU-2 Free Drop Test No. 5; View of Test Setup

Figure 2.12.1-15 – CTU-2 Free Drop Test No. 5; Close-up View of Impact Area

Figure 2.12.1-16 – CTU-2 Puncture Drop Test No. 7; View of Test Setup

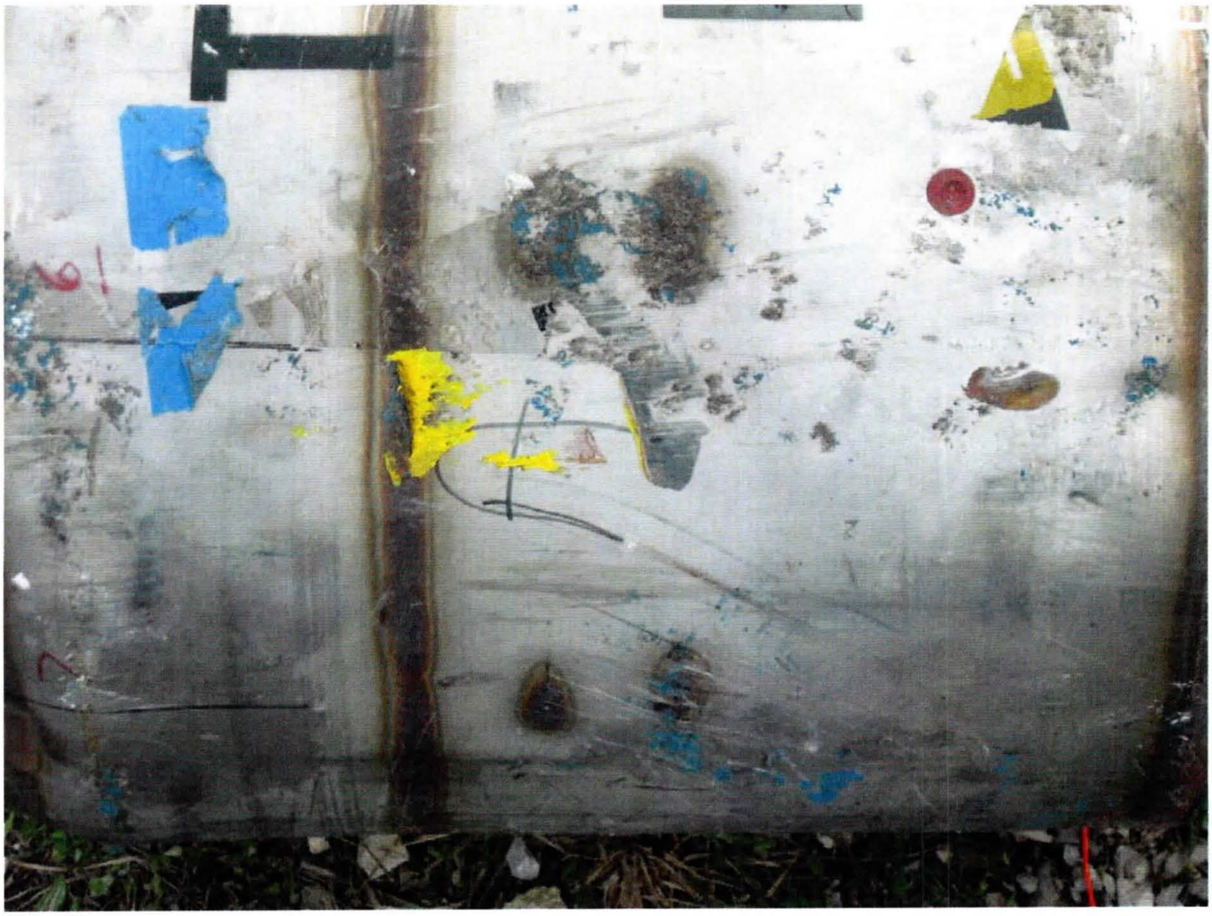


Figure 2.12.1-17 – CTU-2 Puncture Drop Test No. 7; Close-up View of Impact Area

Figure 2.12.1-18 – CTU-2 Post-Test Disassembly; View of Mounting Plate/Lock Boxes

3.0 THERMAL EVALUATION

This chapter establishes the compliance of the THSC transporting a payload of up to 1,500 Ci (55.5 TBq) of Ir-192 or Se-75 in special form with the thermal requirements of 10 CFR 71[13].

3.1 Description of Thermal Design

3.1.1 Design Features

The THSC does not contain any specific thermal design features. The thermal performance of the package is demonstrated by test. Therefore, this section does not apply.

3.1.2 Content's Decay Heat

The THSC may contain up to 1,500 Ci (55.5 TBq) of Ir-192 or Se-75 in special form. The radiolytic decay heat of Ir-192 is 7.03×10^{-3} W/Ci[14]. The radiolytic decay heat of Se-75 is 2.41×10^{-3} W/Ci[12]. Since the radiolytic decay heat per Curie of Ir-192 is 2.92 times greater than the radiolytic decay heat of Se-75, the heatload for Ir-192 payload bounds the Se-75 payload. Therefore, the maximum decay heat load for the THSC package is 10.55 W (36 Btu/hr), which is minimal, for the maximum radioactive content of 1,500 Ci (55.5 TBq).

3.1.3 Summary Tables of Temperatures

The maximum surface temperature of the THSC is 190 °F (88 °C), as documented in Section 3.3, *Thermal Evaluation under Normal Conditions of Transport*, in full sunlight.

3.1.4 Summary Tables of Maximum Pressures

The containment of the THSC is provided by the special form payload. Gas can freely move from the internal cavity to the environment during all phases of operation. Therefore, there are no internal pressures to be determined, since the THSC does not contain any pressure boundaries.

3.2 Material Properties and Component Specifications

3.2.1 Material Properties

The THSC is constructed primarily of Type 304 stainless steel pipes and plates that are welded into assembly, which surrounds a DU gamma shield. Since the structural integrity of the package is established by testing, the only pertinent temperature limits on the components is established by their melting temperatures for the fire-based Hypothetical Accident Condition (HAC). The melting temperatures for DU and Type 304 stainless steel are 2,071 °F (1,133 °C) and 2,550 – 2,640 °F (1,400 – 1,450 °C), respectively.

The payload was qualified per *Qualification of Special Form Radioactive Material,* in 10 CFR §71.75(b)(4).

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[13] Title 10, Code of Federal Regulations, Part 71 (10 CFR 71), *Packaging and Transportation of Radioactive Material*, 1-1-18 Edition.

[14] *ORIGEN-S Decay Data Library and Half-Life Uncertainties*, O. W. Hermann, P. R. Daniel, and J. C. Ryman, Oak Ridge National Laboratory, ORNL/TM-13624, September 1998.

3.2.2 Component Specifications

The THSC does not contain any component or material that is important to the thermal performance of the package. The two primary structural materials are austenitic stainless steel and the DU gamma shield. As noted in Section 2.1.2.2.1, *Brittle Fracture*, both materials have been tested to temperatures below -20 °F (-29 °C) with no loss of structural or shielding capability.

3.3 Thermal Evaluation under Normal Conditions of Transport

This section presents the thermal evaluation of the THSC under the normal conditions of transport (NCT) per 10 CFR §71.71.

3.3.1 Heat and Cold

Since the total decay heat load of the THSC is 10.55 W (36 Btu/hr), a very detailed thermal analysis of the package and internals is unnecessary. The internal temperatures will very closely match those on the surface of the package. To determine the NCT maximum package temperatures with and without insolation, a 3-D, quarter-symmetry thermal model was created utilizing ANSYS® finite element analysis (FEA) program[15]. Per 10 CFR §71.71(c)(1), the worst-case high temperature condition for the package consists of an ambient temperature of 100 °F (38 °C) with maximum insolation. For this condition, the maximum peak surface temperature of the THSC is 190 °F (88 °C), which occurs on the flat closure lid. The maximum surface temperature of the THSC in shade with an ambient temperature of 100 °F (38 °C) is 112 °F (44 °C). This temperature is lower than the maximum acceptable surface temperature of 122 °F (50 °C) for non-exclusive use shipments, as stipulated in 10 CFR §71.43(g).

The ANSYS® NCT thermal model results are illustrated in Figure 3.3-1 and Figure 3.3-2 with and without insolation, respectively.

For the cold condition, the package surface temperature will be equal to the low temperature ambient conditions of -20 °F (-29 °C) and -40 °F (-40 °C).

3.3.2 Maximum Normal Operating Pressure

This section does not apply, since the THSC does not contain any pressure boundaries. Therefore, there is no maximum normal operating pressure (MNOP) for the THSC.

[15] *ANSYS® Finite Element Analysis Program*, Version 17.1, ANSYS Inc.

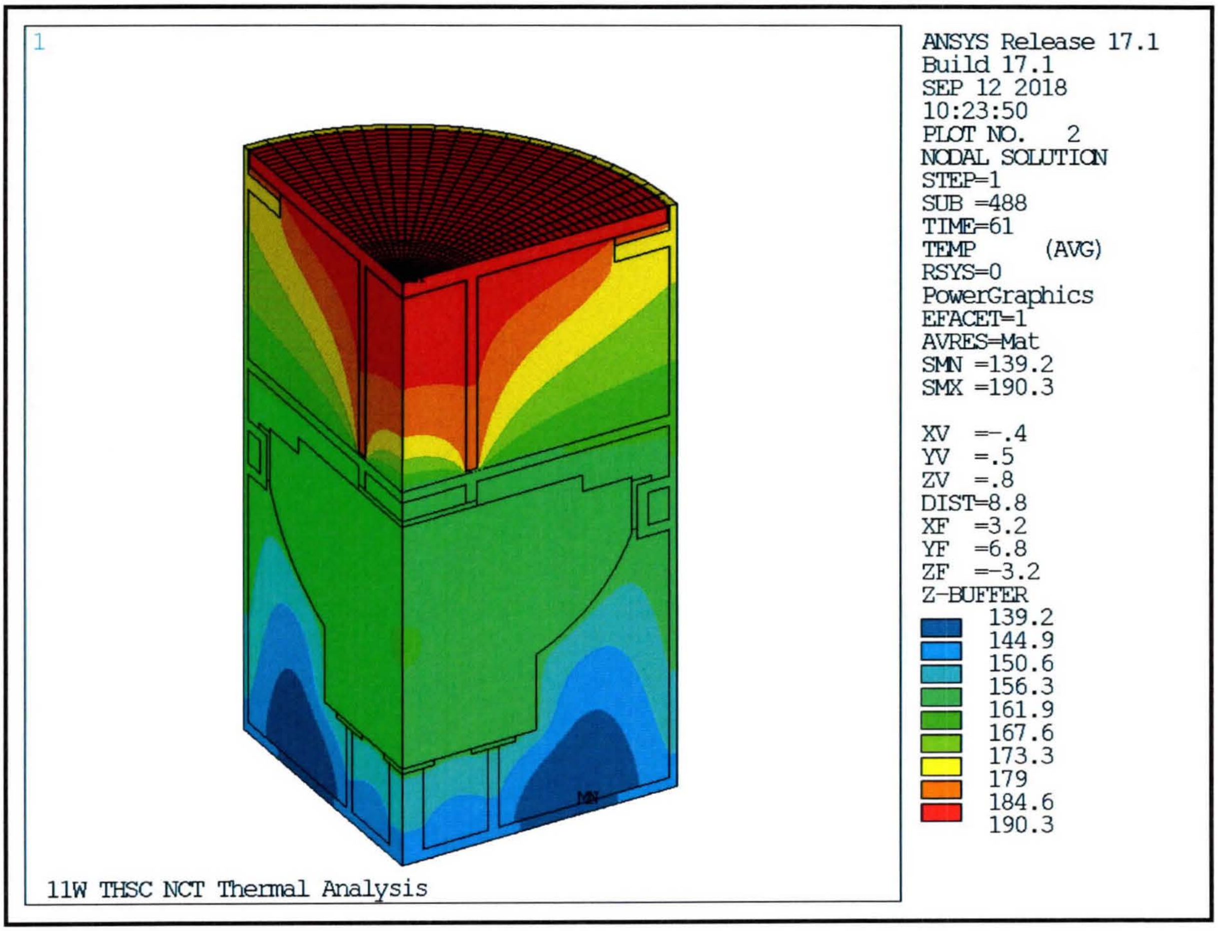

Figure 3.3-1 – THSC NCT Temperature Profile with Insolation

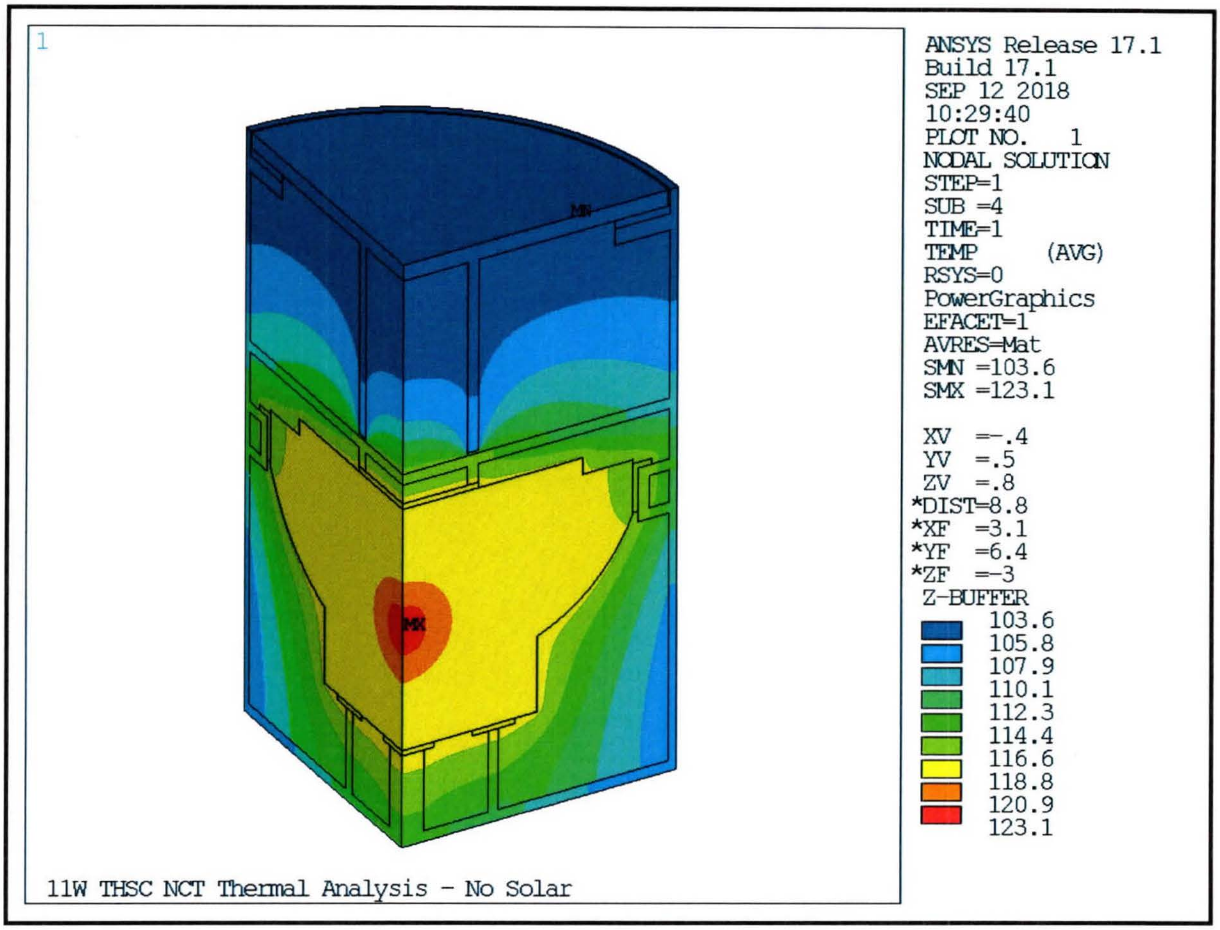

Figure 3.3-2 – THSC NCT Temperature Profile without Insolation

3.4 Thermal Evaluation under Hypothetical Accident Conditions

The thermal performance of the THSC under hypothetical accident conditions (HAC) in accordance with 10 CFR §71.73(c)(4) requires that a test specimen must be exposed to a fully engulfed in a hydrocarbon fuel/air fire with an average flame temperature of 1,475 °F (800 °C) for a period of 30 minutes. The only combustible materials in the THSC packaging are the polyurethane foam and the neoprene rubber lid gasket, which are not structural or shielding materials. Since all of the structural and shielding materials (Type 304 stainless steel and DU) have melting temperatures of 2,550 – 2,640 °F (1,400 – 1,450 °C) and 2,071 °F (1,133 °C), respectively, the THSC is unaffected by the lower temperature 1,475 °F (800 °C) HAC fire event.

3.4.1 Initial Conditions

As noted in Appendix 2.12.1, *Certification Tests*, THSC certification test units (CTUs) were heated above 150 °F (66 °C) as an initial condition for the 30-foot (9-meter) free drop. There was no rupturing of the stainless steel body to expose the DU gamma shield. Therefore, the limiting temperature for the THSC package is the melting temperatures of the structural and shielding materials, which significantly exceed the HAC fire event temperature.

3.4.2 Fire Test Conditions

As noted above, there was no failure of the THSC stainless steel structure that exposed the DU gamma shield. Therefore, the peak temperatures package temperatures would not exceed the

1,475 °F (800 °C) fire temperature, which is well below the melting temperatures of both Type 304 stainless steel (2,550 – 2,640 °F [1,400 – 1,450 °C]) and DU (2,071 °F [1,133 °C]).

Per 10 CFR §71.75(b)(4), the special form qualification of the payload capsules demonstrates that they could withstand the fire test without degradation.

3.4.3 Maximum Temperatures and Pressures

Based the thermal tests performed on the THSC, none of the components exceeds its temperature limit as described in Section 3.2.1, *Material Properties*. Specifically, the maximum package temperatures fall more than 500 °F (260 °C) below the lowest melting point of the stainless steel or the DU materials. Additionally, the special form payload does not exceed the temperatures for the special form certification tests.

The containment of the THSC is provided by the special form payload. Gas can freely move from the internal cavity to the environment during all phases of operation, so determination of internal pressures is not required.

Therefore, the THSC satisfies the HAC thermal requirements set forth in 10 CFR §71.73(c)(4).

3.4.4 Maximum Thermal Stresses

The effects of HAC thermal stresses on the THSC package are minimal for the single event of the HAC fire. The THSC package is a welded, austenitic stainless steel package, which will thermally expand uniformly, resulting in no significant thermal stresses. The DU gamma shield is not rigidly restrained in the THSC stainless steel structure. The DU gamma shield is supported in the welded body of the package at (11) eleven separate points (one on top, two on bottom, and eight on the side). At each DU shield support point in the package, a 1/8-inch thick copper shim is installed between the DU and the stainless steel. These copper shims are ASTM B152, Type 110 copper, which as a specified Rockwell F hardness of 43-57. The Type 304 stainless steel structural packaging material that restrains the DU gamma shield has a Rockwell B hardness of 92. Additionally, depleted uranium metal is extremely hard, with a Brinell hardness of 187 (equivalent to a Rockwell B hardness value of 90.7) for cast DU. Since the copper shim material is softer than either the DU or the stainless steel, the copper shims will plastically deform under any differential thermal expansion that may occur between the stainless steel and the DU gamma shield, and thus, preclude the formation of any excessive thermal stresses in the THSC package from the single HAC fire event. Additionally, the stresses developed in the package from the multiple 30-foot free drop tests of the full-scale prototypic test units produced plastic deformation of the package stainless steel structural that exceeded any potential thermal stresses from any differential thermal expansion that may occur during the single HAC fire event. Therefore, the maximum fire temperature for the welded package would not result in any metal fatigue or detrimental stress condition that affects the shielding or confinement safety functions of the package.

3.4.5 Accident Conditions for Fissile Material Packages for Air Transport

This section does not apply, since the THSC does not contain fissile material.

4.0 CONTAINMENT

The THSC is designed as a confinement boundary for special form Ir-192 or Se-75 source capsules. Containment of radioactive material is provided by the special form construction of the payloads. The source capsules and their respective special form certification are as follows:

Manufacture	Model Number	Certification Number
Industrial Nuclear Co., Inc.	A[1]	USA/0297/S-96
	791[1]	USA/0393/S-96
Source Production & Equipment Co., Inc.	VSe Source Capsule[2]	USA/0785/S-96

Notes: 1. Source capsule is limited to a maximum of 150 Ci (5.55 TBq) of Ir-192 material
2. Source capsule is limited to a maximum of 150 Ci (5.55 TBq) of Ir-192 or Se-75 material.

Since the THSC does not provide containment, subsequent sections of this chapter are not applicable.

5.0 SHIELDING EVALUATION

This section demonstrates the shielding capability of the THSC design for the authorized special form contents. The shielding evaluation is demonstrated via prototypic testing of full-scale packages in lieu of an analytical evaluation.

5.1 Description of Shielding Design

5.1.1 Design Features

The THSC is a welded stainless steel structure that contains a depleted uranium (DU) gamma shield, which surrounds a titanium source tubes/hub assembly. Stainless steel special form capsules, each containing a maximum of 150 Ci (5.55 TBq) of Ir-192 or Se-75 isotope, are inserted into each source tube in the titanium source tube/hub assembly via a pigtail assembly. The radioactive sources are positioned and retained against or near the titanium hub in the DU gamma shield by the lock box assemblies. This position provides the maximum attenuation of the gamma radiation.

5.1.2 Summary Table of Maximum Radiation Levels

Table 5.1-1 provides the maximum measured external radiation levels for the THSC with the maximum bounding payload content (1,500 Ci [55.5 TBq] Ir-192) for a non–exclusive use shipment.

Table 5.1-1 – Maximum Measured External Radiation Levels (Non–Exclusive Use)

Measurement Location	Normal Conditions of Transport[1]		Hypothetical Accident Conditions	
	Measured* mrem/hr (mSv/hr)	10 CFR §71.47(a) Limit mrem/hr (mSv/hr)	Measured mrem/hr (mSv/hr)	10 CFR §71.51(c)(2) Limit mrem/hr (mSv/hr)
Surface	180 (1.8)	200 (2)	N/A	N/A
40 inches (1 Meter) from Surface	0.0 (0.0)	10 (0.1)	0.0 (0.0)	1000 (10)

* Note: Normal condition maximum measured values are for CTU-2 and are adjusted to account for the maximum 1,500 Ci (55.5 TBq) radioactive content. Measurements were performed post-test following the hypothetical accident conditions tests per 10 CFR §71.73.

5.2 Source Specification

5.2.1 Gamma Source

The radioactive content of the THSC is limited to 1,500 Ci (55.5 TBq) of either Ir-192 or Se-75 isotopes. As shown in Table 5.2-1, Ir-192 results in a higher unit dose than Se-75 per curie of activity. In addition, the photon energies of Ir-192 (0.380 MeV average) are higher than Se-75 (0.280 MeV average). Therefore, the Ir-192 payload will bound the Se-75 payload for the maximum 1,500 Ci (55.5TBq) content. Since actual Ir-192 special form capsules are utilized to determine the acceptance of the DU gamma shield, the tabulation of gamma decay source strengths for the special form capsules is not required for the THSC.

Table 5.2-1 – Specific Gamma Ray Constants for Iridium and Selenium Isotopes[16]

Radionuclide	Specific Gamma Ray Constant ($R\text{-}m^2/hr\text{-}Ci$)
Iridium-192	0.460
Selenium-75	0.203

5.2.2 Neutron Source

This section does not apply, since the THSC does not contain fissile material.

5.3 Shielding Model

The shielding capability of the THSC design is demonstrated by physical tests of prototypic packages. Therefore, no analytical shielding model of the package is performed.

5.4 Shielding Evaluation

5.4.1 Methods

The method utilized to demonstrate the shielding performance of the THSC is via prototypic testing utilizing special form capsules containing Ir-192 radioactive material.

5.4.2 Input and Output Data

This section does not apply, since the shielding performance of the THSC is not performed analytically.

5.4.3 Flux-to-Dose-Rate Conversions

This section does not apply, since the shielding performance of the THSC is not performed analytically.

5.4.4 External Radiation Levels

Following the specified tests of a prototypic package with 1,500 Ci (55.5 TBq) of Ir-192 payload per 2.6, *Normal Conditions of Transport*, and 2.7, *Hypothetical Accident Conditions*, the adjusted maximum radiation level measured on the surface and at 1-meter of the THSC is 180 mrem/hr (1.80 mSv/hr) and 0.0 mrem/hr (0.0 mSv/hr), respectively. As noted in Table 5-1, these levels are significantly below the regulatory limits of 10 CFR §71.47(a) and 10 CFR §71.51(a)(2).

[16] "Exposure Rate Constants and Lead Shielding Values for Over 1,100 Radionuclides", David S. Smith and Michael G. Stabin, Department of Radiology and Radiological Sciences, Vanderbilt University, Nashville, TN, Health Physics Society Journal, March 2012 issue.

6.0 CRITICALITY EVALUATION

The THSC does not transport fissile material; therefore, this section does not apply.

7.0 PACKAGE OPERATIONS

7.1 Package Loading

This section delineates the procedures for loading a payload into the THSC. Hereafter, reference to specific THSC components may be found in Appendix 1.3.1, *General Arrangement Drawings*.

7.1.1 Preparation of the THSC for Loading

1) Visually inspect the THSC for damage and/or missing parts.
2) Remove the hex bolts/washers and the closure lid from the THSC body.
3) Remove the brass dust cover from each lock box. Check the threads for wear or damage.
4) Inspect the lock boxes for damage or missing fasteners. Replace any damaged or missing fasteners.
5) Prior to loading active Ir-192 or Se-75 source into the package, insert a dummy source pigtail and functionally test the locking device on the lock box to ensure that all components are operating properly.
6) Push (extend) the dummy pigtail into the lock box, and rotate the key to the locked position. Remove the key.
7) Insert the key into the lock box, and rotate it to the unlocked position. Retract the dummy pigtail.
8) Repeat Steps 5 thru 7 for the remaining lock boxes.

7.1.2 Loading the Special Form Contents into the THSC

1) Place the special form Ir-192 or Se-75 source pigtail assembly into a source changer.
2) Connect the drive cable housing and the guide tube to one of the THSC lock boxes.
3) Crank the drive cable out through the guide tube and connect it to the Ir-192 or Se-75 source pigtail assembly. Connect the guide tube to the source changer.
4) Unlock the source changer or camera and push the Ir-192 or Se-75 source pigtail assembly into the THSC.
5) Survey the package to ensure that the source is in the stored position. Rotate key to locked position and remove the key.
6) Disconnect drive cable, and install the brass dust cap.
7) Repeat Steps 1 thru 6 for the remaining THSC lock boxes.
8) Install the Ir-192 or Se-75 source identification plates on the top of the lock boxes.

7.1.3 Preparation for Transport

1) Install the closure lid and the eight (8) closure lid bolts/washers to the THSC body. Tighten the closure lid bolts to 40 ±5 lb_f-ft.
2) Install a tamper-indicating seal (security wire/lead seals) to one pair of the closure lid bolts.

3) Load the THSC onto the transport conveyance and secure the package utilizing nylon straps or other securement system.
4) Monitor external radiation per the guidelines of 49 CFR §173.441[17].
5) Determine the shielding transport index for the loaded THSC per the guidelines of 49 CFR §173.403.
6) Complete all necessary shipping papers in accordance with Subpart C of 49 CFR 172[18].
7) THSC marking shall be in accordance with 10 CFR §71.85(c) and Subpart D of 49 CFR 172. Package labeling shall be in accordance with Subpart E of 49 CFR 172. Packaging placarding shall be in accordance with Subpart F of 49 CFR 172.

7.2 Package Unloading

This section delineates the procedures for unloading the payload from the THSC. Hereafter, reference to specific THSC components may be found in Appendix 1.3.1, *General Arrangement Drawings*.

7.2.1 Receipt of THSC Package from Carrier

1) Remove the straps or system that secures the THSC to the transport conveyance.
2) Monitor the external radiation to ensure that the THSC was not damaged during shipment.
3) Utilizing appropriate rigging equipment, lift the THSC package from the transport conveyance, and place in a secure position for unloading the special form capsule payload.

7.2.2 Removal of Special Form Contents from the THSC Package

1) Remove the tamper-indicating seals from the closure lid bolts.
2) Remove the closure lid bolts/washers and the closure lid.
3) Remove the brass dust cap from each of the lock boxes.
4) Connect the drive cable housing and the guide tube to one of the lock boxes. Connect the guide tube to a source changer or camera.
5) Unlock the lock box and retract the Ir-192 or Se-75 source pigtail assembly into the source changer or camera.
6) Secure the Ir-192 or Se-75 source pigtail assembly into the source changer or camera, lock, and remove the key.
7) Disconnect the drive cable from the source changer or camera, and retract it.
8) Disconnect the guide tube from the source changer or camera and the THSC.
9) Repeat Steps 4 thru 8 for the remaining lock boxes.
10) Re-install the brass dust cap on each of the lock boxes.

[17] Title 49, Code of Federal Regulations, Part 173 (49 CFR 173), *Shippers-General Requirements for Shipments and Packagings*, 10-1-17 Edition.

[18] Title 49, Code of Federal Regulations, Part 172 (49 CFR 172), *Hazardous Materials Tables and Hazardous Communications Regulations*, 10-1-17 Edition.

11) Re-install the closure lid and closure lid bolts/washers. Tighten the closure lid bolts to a snug-tight condition.
12) Complete all required shipping papers in accordance with Subpart C of 49 CFR 172.
13) THSC package marking shall be in accordance with 10 CFR §71.85(c) and Subpart D of 49 CFR 172. Package labeling shall be in accordance with Subpart E of 49 CFR 172. Packaging placarding shall be in accordance with Subpart F of 49 CFR 172.

7.3 Preparation of Empty THSC Package for Transport

Previously used and empty THSC packages shall be prepared and transported per the requirements of 49 CFR §173.426, Subpart I.

8.0 ACCEPTANCE TESTS AND MAINTENANCE PROGRAM

8.1 Acceptance Tests

Per the requirements of 10 CFR §71.85(c), this section discusses the inspections and tests to be performed prior to first use of the THSC package.

8.1.1 Visual Inspections and Measurements

All THSC materials of construction shall be examined in accordance with the requirements delineated on the drawings in Appendix 1.3.1, *General Arrangement Drawings*, per the requirements of 10 CFR §71.85(a).

8.1.2 Weld Examinations

All THSC welds shall be examined in accordance with the requirements delineated on the drawings in Appendix 1.3.1, *General Arrangement Drawings*, per the requirements of 10 CFR §71.85(a).

8.1.3 Structural and Pressure Tests

The THSC package does not contain any lifting/tie-down devices or pressure boundaries that require testing. Therefore, this section does not apply.

8.1.4 Leakage Tests

The THSC does not contain any seals or containment boundaries that require leakage testing. Therefore, this section does not apply.

8.1.5 Component and Material Tests

The THSC does not contain any additional components or materials that require acceptance testing. Therefore, this section does not apply.

8.1.6 Shielding Tests

A radiation profile shall be performed on each depleted uranium (DU) gamma shield prior to being used in the fabrication of a THSC package. These measured survey results are adjusted to determine the expected radiation levels for the maximum authorize source strength of 1,500 Ci (55.5 TBq) for Ir-192 isotope. Any radiation profile of a DU gamma shield with the maximum authorized payload that results in a dose rate that exceeds the requirements of 49 CFR §173.441 shall not be utilized in the manufacture of a THSC package.

8.1.7 Thermal Tests

The THSC does not contain any thermal features or systems that require testing; therefore, this section does not apply.

8.1.8 Miscellaneous Tests – Ultrasonic Examination

In addition to the shielding test per 8.1.6, *Shielding Tests*, each DU gamma shield shall be ultrasonically examined to ensure there are no significant voids or defects in the shield. This examination will be performed at the supplier's facility prior to releasing the DU gamma shield for the shielding test per 8.1.6, *Shielding Tests*.

8.2 Maintenance Program

This section describes the maintenance program used to ensure continued performance of the THSC.

8.2.1 Structural and Pressure Tests

The THSC does not contain any lifting/tie-down devices or pressure boundaries that require load testing. Therefore, this section does not apply.

8.2.2 Leakage Tests

The THSC does not contain any seals or containment boundaries that require testing. Therefore, this section does not apply.

8.2.3 Component and Material Tests

8.2.3.1 Fasteners

All threaded components shall be inspected quarterly for deformed or stripped threads. Damaged components shall be repaired or replaced prior to further use.

8.2.3.2 Lock Box Assemblies

Prior to each use, inspect each lock box assembly for restricted motion or damage. Any motion or operational impairment shall be corrected prior to further use.

8.2.4 Thermal Tests

No thermal tests are necessary to ensure continued performance of the THSC package.

8.2.5 Miscellaneous Tests – Shielding

Prior to each shipment, a radiation survey is performed to ensure that the radiation dose levels do not exceed the requirements of 49 CFR §173.441. This survey confirms that the DU gamma shield has maintained its shielding function.