SAFETY ANALYSIS REPORT

IR-100 EXPOSURE DEVICE

Docket No. 71-9157
Revision 4
June 2015

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1.0 GENERAL INFORMATION

This chapter of the IR-100 Exposure Device Safety Analysis Report presents a general introduction and description of the IR-100 Exposure Device. 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 IR-100 Exposure Device (hereto referred to as the IR-100) is a transportation system designed to transport a single, special form iridium-192 (Ir-192) or selinium-75 (Se-75) source capsule. The design is optimized to provide maximum safety during both operations and transport conditions. The packaging consists of a rectangular housing, lifting handle, a Safety Plug, a Lock Box assembly, interior polyurethane foam, and a depleted uranium (DU) gamma shield.

Authorization is sought for shipment of a single, special form Ir-192 or Se-75 source capsule (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 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 IR-100, 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 53 pounds and its primary components of construction are identified in Figure 1-1. The payload is a special form capsule 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 shielding, which is composed of 0.23% U-235, 99.77% U-238, and illustrated in Figure 1-1, is a solid form casting. The shield contains 0.0042 Ci (0.00016 TBq) of DU. Detailed drawings of the IR-100 are provided in Appendix 1.3.1, *General Arrangement Drawings*.

1.2.2 Contents of Packaging

The IR-100 is designed to transport a maximum of 120 Ci (4.44 TBq) of Ir-192 or Se-75 within a single, special form capsule. The capsule is attached to a pigtail assembly that, along with the Lock Box and lockball, secures the capsule within the center of the DU shield.

1.2.3 Special Requirements for Plutonium

This section does not apply, since plutonium is not shipped in the IR-100.

[1] Title 10, Code of Federal Regulations, Part 71 (10 CFR 71), *Packaging and Transportation of Radioactive Material*, 1-1-15 Edition.

1.2.4 Operational Features

There are no operationally complex features of the IR-100. The contents (described in the following section) are confined within the housing, lockbody, and DU, as shown in Figure 1-1. Integral to the housing and DU gamma shielding, the lockbody prevents unauthorized removal or unshielded exposure or the contents. The Lock Box assembly, which allows access to the contents, conforms to the requirements of 10 CFR §34.22[2]. Attached to the housing is a handle to facilitate both tie-down and handling. Sequential steps of operation are provided in Chapter 7.

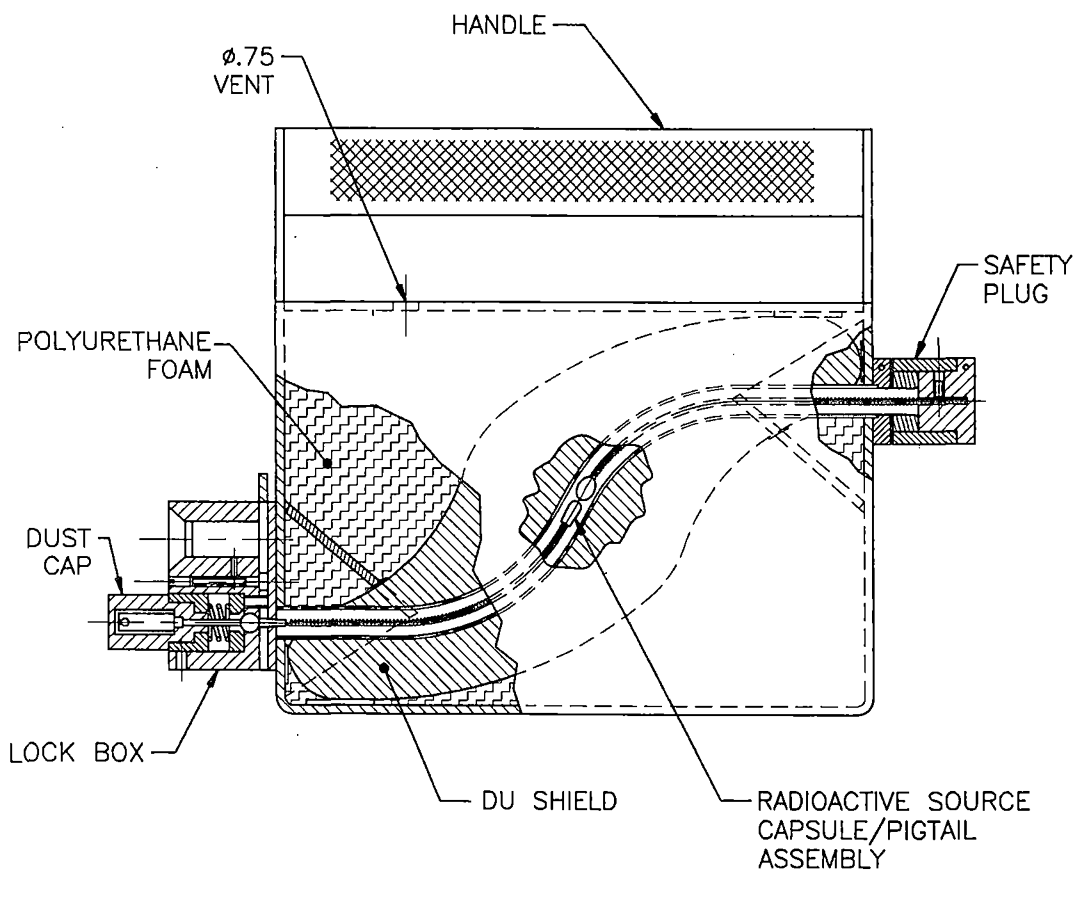

Figure 1-1 - Sectional View of the IR-100 Packaging

[2] Title 10, Code of Federal Regulations, Part 34 (10 CFR 34), *Licenses for Radiography and Radiation Safety Requirements for Radiographic Operations*, 1-1-15 Edition.

1.3 Appendices

1.3.1 General Arrangement Drawings

Content 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 which demonstrate that the IR-100 Exposure Device meet all applicable structural criteria for transportation as defined in 10 CFR 71[3].

2.1 Description of Structural Design

The primary evaluation of the IR-100 is performed with various tests. The results of the tests are provided in the following sections. Supporting analyses and analyses of non-tested structural aspects are also provided.

The IR-100 consists of three major fabricated components: 1) a stainless steel housing and lock assembly that enclose and secure the contents, 2) polyurethane foam that provides protection of the DU from moisture, and 3) DU gamma shielding that provides shielding.

2.1.1 Discussion

The IR-100 is designed to transport a maximum of 120 Ci (4.44 TBq) of Ir-192 or Se-75 in a special form capsule. Since the payload is designated as special form, the IR-100 is defined as a confinement system. As shown in the section view in Figure 2-1, the primary components of the package are a stainless steel housing (outer shell, including a Lock Box), internal polyurethane foam, and DU gamma shielding. The housing is constructed of Type 304 austenitic stainless steel. The polyurethane foam is closed cell. The DU gamma shielding is a casting of solid form and optimally designed to provide efficient shielding. The DU shield is secured in the housing by welded brackets that capture the shield between the bracket and the housing.

The housing is a rectangular shell structure with 12-gauge (0.105-inch) thick walls, and outer dimensions of approximately 12 inch × 4½ inch × 8½ inch. The housing is constructed entirely of Type 304 stainless steel sheet that completely encloses the foam and DU gamma shielding. As shown in Figure 2-1, a handle for lifting is provided to facilitate operations. Welded to opposite sides of the housing are the lockbody and outlet/safety block assemblies. These assemblies provide the operationally capability during use and secure the location of the Ir-192, or Se-75 capsule during transportation. The lockbody, which allows access to the contents, conforms to the requirements of 10 CFR §34.22[4].

Polyurethane foam within the housing fills the void between the DU gamma shielding and the housing. The foam provides moisture protection of the DU during normal operations.

[3] Title 10, Code of Federal Regulations, Part 71 (10 CFR 71), *Packaging and Transportation of Radioactive Material*, 1-1-15 Edition.

[4] Title 10, Code of Federal Regulations, Part 34 (10 CFR 34), *Licenses for Radiography and Radiation Safety Requirements for Radiographic Operations*, 1-1-15 Edition.

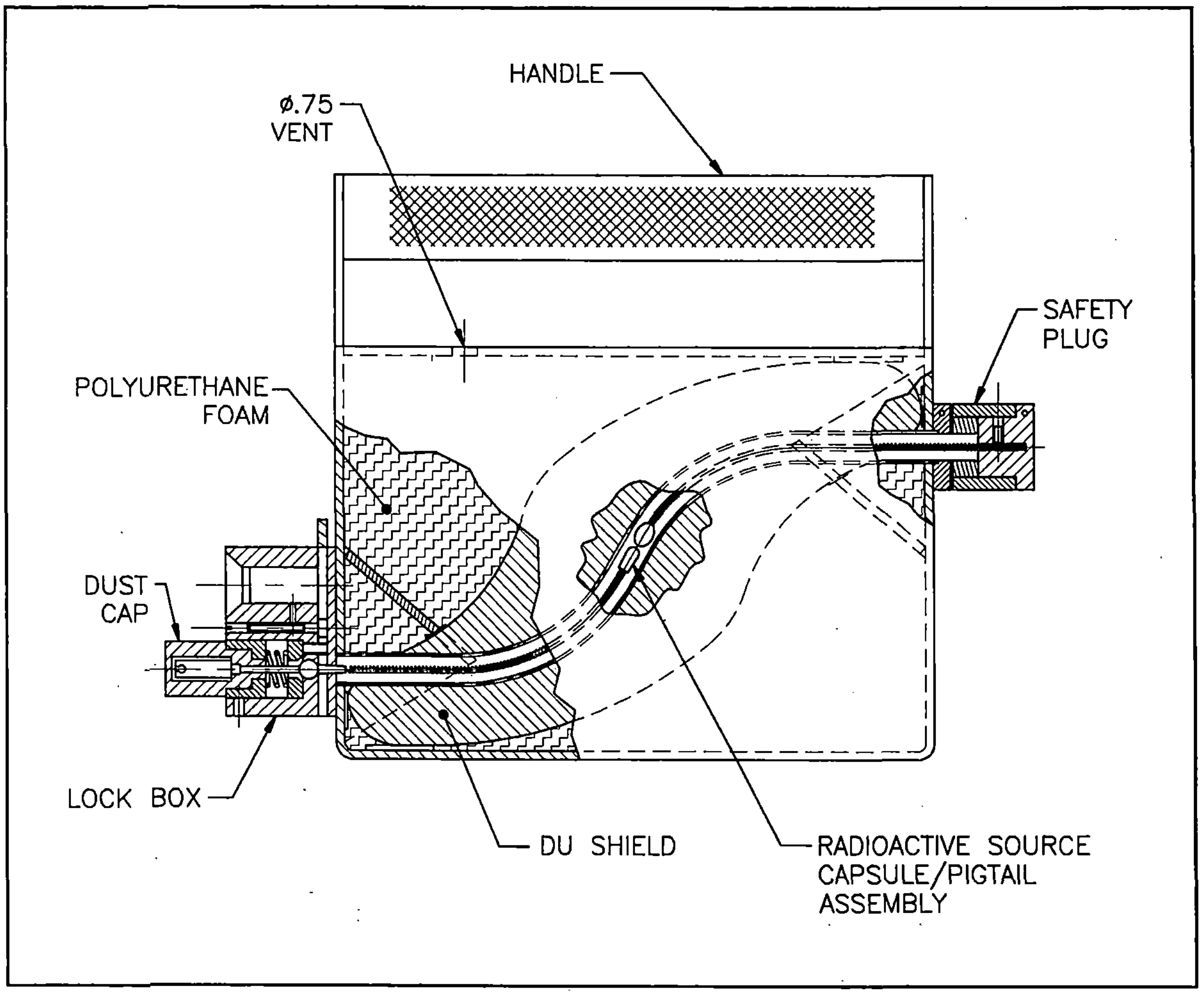

Figure 2-1 - Sectional View of the IR-100 Packaging

2.1.2 Design Criteria

2.1.2.1 Basic Design Criteria

The IR-100 is primarily demonstrated to satisfy the requirements of 10 CFR 71 via full-scale tests. For evaluation of tie-down devices, the design criteria is that the structural tie-down members do not exceed the material's yield strength when subjected to the requirements of 10 CFR §71.45(b).

2.1.2.2 Miscellaneous Structural Failure Modes

2.1.2.2.1 Brittle Fracture

The structural materials of the IR-100 packaging include stainless steel and DU. Each material is not susceptible to brittle fracture at temperatures as low as -20 °F (-29 °C) as described below.

The housing and Lock Box of the IR-100 are fabricated from austenitic stainless steel sheet and bar respectively. 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 DU shield material, which is enclosed by the stainless steel housing, has been previously drop and puncture tested 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[5], the IR-100 passed all the tests, which included cumulative damage effects, with no loss of shielding or confinement capability. Based on the low temperature testing of the OP-100, the brittle fracture of the DU shield component is not of concern.

2.1.2.2.2 Fatigue

Because the IR-100 is an essentially a rigid body, no structural failures of the confinement boundary due to fatigue will occur.

2.1.2.2.3 Buckling

The IR-100 provides only a confinement boundary. For normal condition and hypothetical accident conditions, the confinement boundary (i.e., the DU shield) will not buckled due to free or puncture drops. This conclusion has been demonstrated via full-scale test of the IR-100.

2.1.3 Weights and Center of Gravity

The maximum gross weight of the IR-100 is 53 pounds. The center of gravity is approximately at the geometric center of the DU casting.

2.1.4 Identification of Codes and Standards for Package Design

Since the IR-100 contains small quantities of Ir-192 or Se-75 radioactive material, and does not contain a pressure boundary, the package is designed to industrial metal fabrication standards.

2.2 Materials

2.2.1 Material Properties and Specifications

Mechanical properties for the materials used for the structural components of the IR-100 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 IR-100 is primarily via test, 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 used in the device.

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

[6] American Society of Engineers (ASME) Boiler and Pressure Vessel Code, Section II, *Materials, Part A – Ferrous Material Specifications*, and *Materials, Part D – Properties*, 1995 edition, 1997 Addenda.

Table 2.2-1 - Type 304 Stainless Steel Material Properties

Material Specification	Temperature, °F	Yield Strength (S_y), psi	Ultimate Strength (S_u), psi	Design Stress Intensity (S_m), psi	Elastic Modulus, x10^6 psi	Coefficient of Thermal Expansion, x10^6, in/in/°F
Type 304 Stainless Steel	-40	**30,000**	**75,000**	**20,000**	**28.8**	**8.21**
	-20	30,000	75,000	20,000	**28.7**	**8.26**
	70	30,000	75,000	20,000	28.3	...
	100	30,000	75,000	20,000	**28.1**	8.55
	200	25,000	71,000	20,000	27.6	8.79
	300	22,500	66,000	20,000	27.0	9.00

Notes:
① ASME B&PV Code, Section II, Part D, Table Y-1
② ASME B&PV Code, Section II, Part D, Table Y-1
③ ASME B&PV Code, Section II, Part D, Table Y-1
④ ASME B&PV Code, Section II, Part D, Table Y-1
⑤ ASME B&PV Code, Section II, Part D, Table Y-1
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 0.290 lb/in^3 and 0.29, respectively

2.2.2 Chemical, Galvanic, or Other Reactions

The housing that contains the DU shield casting is fabricated from Type 304 stainless steel. The stainless steel housing does not have significant reactions with the interfacing components, air, or water. The DU casting, which is coated with epoxy paint, is further encased by polyurethane foam. Copper shims are placed between the interface between the DU and stainless steel to prevent a eutectic reaction. The "S" tube (made of either titanium or Zircaloy) does not react or form a galvanic corrosion cell between the DU shield material and the stainless steel.

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 and depleted uranium (DU) comprising the structural materials of the IR-100. As discussed in Section 2.1.1, *Discussion*, the interior polyurethane foam provides moisture protection of the DU gamma shield. The effect of the radiation on the polyurethane foam to provide this function is negligible.

2.3 Fabrication and Examination

2.3.1 Fabrication

The IR-100 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 IR-100 is to provide gamma shielding of the special forma radioactive material. To verify this function, each DU shield is examined by performing a shielding test, as delineated in Section 8.1.6, *Shielding Tests*, prior to being used in the fabrication of an IR-100 packaging. In addition, all welds are visually inspected in accordance with the notes identified in Appendix 1.3.1, *General Arrangement Drawings*.

2.4 General Requirements for All Packages

The IR-100 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 IR-100 Exposure Device package is 4.5 inches. This dimension is greater than the minimum dimension of 4 inches specified in 10 CFR §71.43(a). Therefore, the requirements of 10 CFR §71.43(a) are satisfied by the IR-100.

2.4.2 Tamper Indicating Device

Tamper indicating seals (wire/lead security seals) are attached to the dust cap and Safety Plug (refer to Figure 2-1), which provide visual evidence that the closures were not tampered. Thus, the requirements of 10 CFR §71.43(b) are satisfied.

2.4.3 Positive Closure

The IR-100 cannot be opened inadvertently. Positive closure of the IR-100 is provided by the Lock Box assembly that secures the source pigtail assembly in its proper shielded position. The Lock Box assembly, which permits access to the contents, conforms to the requirements of 10 CFR §34.22[2]. Thus, the requirements of 10 CFR §71.43(c) are satisfied.

2.4.4 Valves

Because the IR-100 is a confinement system and designed to transport only a special form radioactive material, 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, 3.4, and 5.6, the IR-100 design satisfies the requirements of 10 CFR §71.71. Thus, the requirements of 10 CFR §71.43(f) 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*, 1995 edition, 1997 Addenda.

2.4.6 External Temperatures

The decay heat load of the Ir-192 or Se-75 special form capsule is negligible. Therefore, the surface temperature does not exceed 185 °F (85 °C) in still air and shade during transport. Thus, the requirements of 10 CFR §71.43(g) are satisfied by the IR-100.

2.4.7 Venting

With an Ir-192 or Se-75 special form source capsule encapsulating the radioactive material, the package does not incorporate any feature that would permit continuous venting during transport. Thus, the requirements of 10 CFR §71.43(h) are satisfied by the IR-100.

2.5 Lifting and Tie-down Devices for All Packages

2.5.1 Lifting Devices

The IR-100 is manually lifted by the handle (refer to Figure 2-1). A force of 450 pounds was applied to the handle without any measurable distortion or damage. Therefore the handle can support three times the package weight and the requirements of 10 CFR §71.45(a) are met.

2.5.2 Tie-Down Devices

The IR-100 is secured to a transport vehicle via tie-down rope, cable, or other suitable system as illustrated in Figure 2-2. A nominal angle of 60° in the longitudinal and lateral directions will result in the highest tie-down force within each tie-down device. Because the IR-100 can be orientated in any direction within the transportation vehicle, the 10g longitudinal force and 5g lateral force will be assumed to apply laterally and longitudinal respectively to the IR-100. For this configuration, the force in a tie-down device due to the 10g lateral force is:

$$F_{10g} = \frac{10(53)}{2(\cos 60°)(\cos 60°)} = 1{,}060 \text{ lbs.}$$

The force in the tie-down device due to the 5g longitudinal force is:

$$F_{5g} = \frac{5(53)}{2(\cos 60°)(\cos 60°)} = 530 \text{ lbs.}$$

The force in a tie-down device due to the 2g vertical force is:

$$F_{2g} = \frac{2(53)}{4(\sin 60°)(\sin 60°)} = 35 \text{ lbs.}$$

The resultant force in any tie-down device is the sum of these individual forces or 1,625 pounds. If this maximum force is conservatively assumed to react in shear by only the 12-gauge stainless steel sheet, then maximum stress in the sheet is:

$$\tau_{tiedown} = \frac{1{,}625}{0.105(4.5)} = 3{,}439 \text{ psi}$$

From Chapter 3.0, the maximum package temperature is 190 °F. At this temperature, the minimum tensile yield strength of the Type 304 stainless steel sheet is 25,000 psi (from Table

2.3-1). The shear allowable is taken as 0.6 of the tensile allowable, or 0.6 (25,000) = 15,000 psi. Therefore, the minimum margin of safety (M.S.) is:

$$M.S. = \frac{15,000}{3,439} - 1.0 = +3.36$$

Therefore, the requirements of 10 CFR §71.45(b) are met.

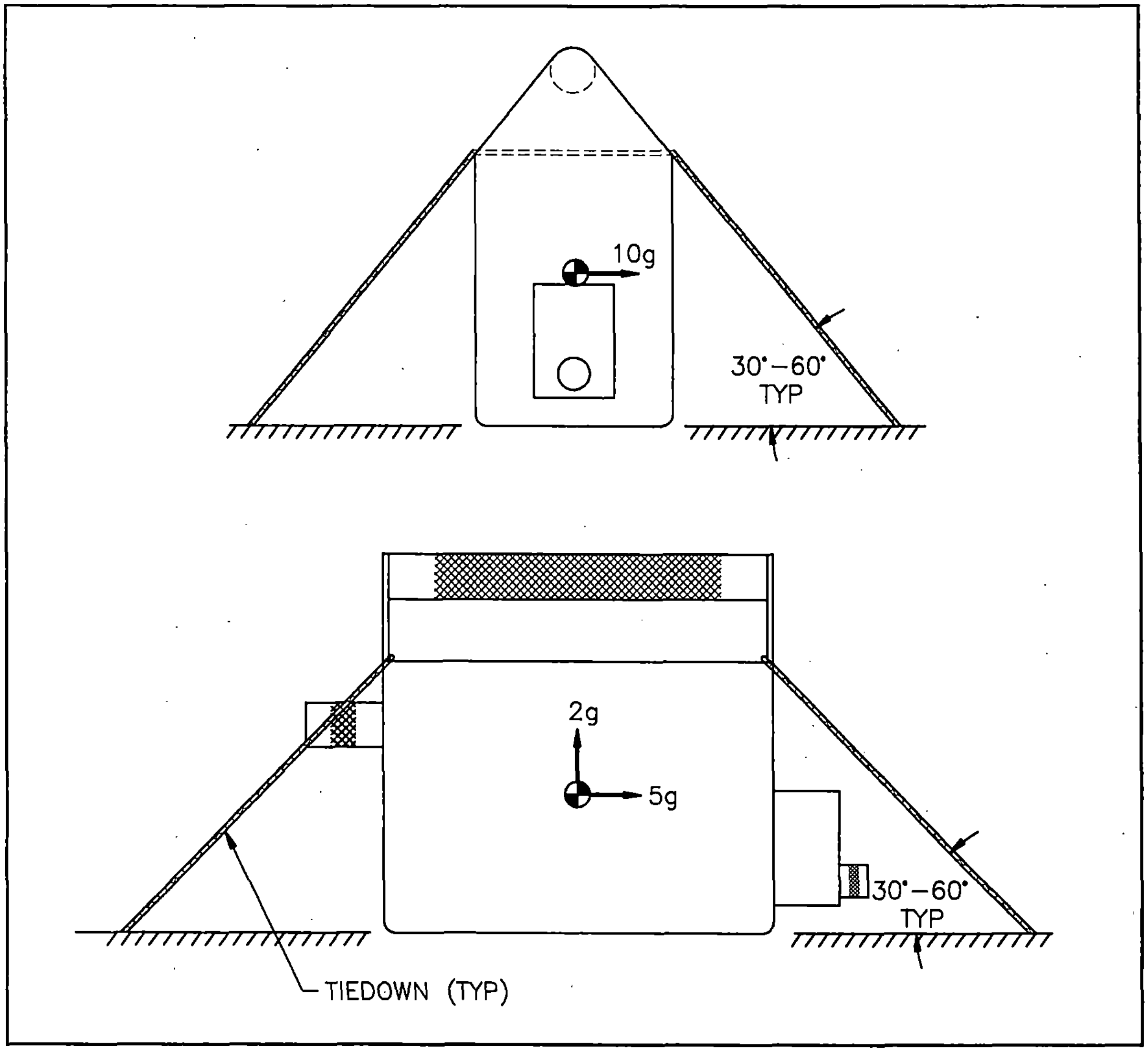


Figure 2-2 IR-100 Tie-down Loading Configuration

2.6 Normal Conditions of Transport

2.6.1 Heat

The IR-100 was exposed to a maximum temperature of 250 °F over 3 hours during the foam cure. No loss in operational capability or damage occurred. The maximum steady state temperature of any component in an ambient environment of 100 °F and full insolation is 190 °F.

2.6.2 Cold

The IR-100 was exposed to -40 °F (-40 °C) for two hours in an environmental chamber without negative effects.

2.6.3 Reduced External Pressure

The IR-100 is a confinement boundary for a special form payload and does not have a pressure boundary. Therefore, the effect of reduced external pressure is not applicable.

2.6.4 Increased External Pressure

The IR-100 is a confinement boundary for special form payload and does not have a pressure boundary. Therefore, the effect of increased external pressure is not applicable.

2.6.5 Vibration

The package has been subjected to both normal conditions of transport as well as rugged field use over an extended period of time (1982 to present). The packages have not experienced any damage or effects due to the vibrations induced by normal conditions of transport.

2.6.6 Water Spray

The materials of construction utilized for the IR-100 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 IR-100 is less than 11,000 pounds, a four-foot free drop is required per 10 CFR §71.71.(c)(7). As discussed in Appendix 2.12.1, *Certification Tests*, a NCT, four foot drop, aligned the center-of-gravity (CG) over the Lock Box lower edge, was performed on a IR-100 certification test unit (CTU) as an initial condition for subsequent hypothetical accident condition (HAC) tests. A radiation survey following certification testing demonstrated the ability of the IR-100 packaging to maintain its shielding 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 265-pound force, which is equal to five times the gross package weight, was applied to the IR-100 handle while sitting in its normal upright position. No observable deformation and damage was detected. Therefore, the requirements of 10 CFR §71.71(c)(9) are satisfied.

2.6.10 Penetration

A 1¼ inch diameter, 13 pound, hemispherical end steel rod was dropped from a height of one meter (40 inches) onto the package in an effort to pierce the housing, and possibly bend the lock assembly. These orientations were an effort to shift the source out of the "safe" area of the DU gamma shielding. Three drop tests were performed. The first two drop tests were onto the outlet

end (safety plug end) and a side. Both drops resulted in a 3/16-inch spherical dent in the impacted surface. The third drop test was onto the side of the lock body in an effort to shear or bend the lock assembly away from the housing. The result of the third drop was a 3-degree angular shift of the lock assembly relative to the housing. The weld integrity was not compromised, there was no damage to the pigtail assembly, and there was no lose in operational capability of the IR-100. Therefore, the requirements of 10 CFR §71.71(c)(10) are satisfied.

2.7 Hypothetical Accident Conditions

When subjected to the hypothetical accident conditions as specified in 10 CFR §71.73, the IR-100 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 loads 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 that a 30-foot free drop to be considered for the IR-100. The free drop is to occur onto a flat, essentially unyielding, horizontal surface, and the package is to strike the surface in an orientation for which the maximum damage is expected. The free drop is addressed by test, in which several orientations are used. The free drop proceeds both the puncture and fire tests.

2.7.1.1 Technical Basis for the Free Drop Tests

To properly select a worst case package orientation for the 30 foot free drop event, items that could potentially compromise shielding integrity and/or the special form source of the IR-100 must be clearly identified. For the IR-100 design, the foremost item to be addressed is the shielding integrity.

The shielding integrity may be compromise by two methods: 1) movement of the special form source relative to the DU shield, and/or 2) as a result of thermal degradation of the DU shield itself by excessive oxidation in a subsequent fire event. Importantly, these methods require significant damage to the stainless steel housing and/or Lock Box that secures the special form source.

For the above reasons, testing must include orientations that affect the Lock Box, which secures the special form source, and/or the Safety Plug outlet end, which may result in an excessive opening into the housing cavity for a subsequent fire event. Therefore, an orientation that places the center-of-gravity (CG) over each of these two items was included in the test sequence.

2.7.1.2 Test Sequence for the Selected Tests

Based on the above discussions, the IR-100 was tested for three specific, HAC 30 foot free drop conditions: 1) CG over the Lock Box lower edge, 2) an impact on the Lock Box lower edge which resulted in a slapdown impact on the opposite edge, and 3) CG over the Safety Plug. Although only a single "worst case" 30 foot drop is required by 10 CFR §71.73(c)(1), multiple 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 IR-100 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 IR-100 design features are adequately designed to withstand the HAC 30 foot free drop event. The most important result of the testing program was the demonstrated ability of the IR-100 to maintain its shielding integrity. Significant results of the free drop testing are as follows:

- No evidence of excessive distortion of the Lock Box occurred that would have significantly displaced the special form source from its desired shielded position.
- There was no evidence of excessive rupturing of the stainless steel housing that could have resulted in thermal degradation of the DU shield by excessive oxidation in a subsequent fire event.
- The most significant damage from the free drop tests was a failure of one of the fillet welds joining one side stainless steel sheet to the bottom stainless steel sheet. The resulting gap was 3/16 inches at its widest point. This failure was due to poor fusion/penetration of the weld rather than a design flaw.

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

2.7.2 Crush

The crush test specified in 10 CFR §71.73(c)(2) 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. The IR-100 density is greater than 62.4 lb_m/ft^3 (1,000 kg/m^3) and the payload is special form. Therefore, the dynamic crush test of 10 CFR §71.73(c)(2) is not applicable to the IR-100.

2.7.3 Puncture

Subpart F of 10 CFR 71 requires performing a puncture test in accordance with the requirements of 10 CFR §71.71(c)(3). The puncture test involves a 40 inch drop onto the upper end of a solid, vertical, cylindrical, mild steel bar mounting on an essentially unyielding, horizontal surface. The bar must be six inches in diameter, with the top surface horizontal and its edge rounded to a radius of not more than 1/4 inch. The minimum length of the bar is to be eight inches. The ability of the IR-100 to adequately withstand this specified drop condition is demonstrated via testing of two full-scale, IR-100 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 source of the IR-100 must be clearly identified. For the IR-100 design, the foremost item to be addressed is the shielding integrity.

The shielding integrity may be compromise by two methods: 1) movement of the special form source relative to the DU shield, and/or 2) as a result of thermal degradation of the DU shield itself

by excessive oxidation in a subsequent fire event. Importantly, these methods require significant damage to the stainless steel housing and/or Lock Box that secures the special form source.

For the above reasons, testing must include orientations that affect the Lock Box, which secures the special form source, and/or the Safety Plug outlet end, which may result in an excessive opening into the housing cavity for a subsequent fire event. Therefore, an orientation that places the CG over each of these two items was included in the test sequence. These orientations were also utilized for the HAC 30 foot free drops and hence, would expect to produce the worst case cumulative damage to the package.

2.7.3.2 Test Sequence for the Selected Tests

Based on the above general discussions, the CTUs were specifically tested for three 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 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 IR-100 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 various IR-100 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 IR-100 to maintain its shielding integrity. Significant results of the puncture drop testing are as follows:

- No evidence of excessive distortion of the Lock Box occurred that would have significantly displaced the special form source from its desired shielded position.
- There was no evidence of excessive rupturing of the stainless steel housing that could have resulted in thermal degradation of the DU shield by excessive oxidation in a subsequent fire event.
- The worst case damage from the free drop tests (i.e., failed fillet weld on housing) was a slight increase in the gap. The resulting gap increased by 1/16 inch, to a maximum of 1/4 inch at its widest point.

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

Table 2.7-1 - Summary of IR-100 Certification Test Unit (CTU) Tests and Results

Test No.	Test Description (Certification Test Unit No.)	Test Unit Angular Orientation		Remarks
		Longitudinal Axis (0° = horizontal)	Rotational Axis (0° = upright)	
1	4 foot, CG over Lock Box lower edge (CTU-1)	68°	0°	NCT impact on most probable orientation in field to cause damage.
2	30 foot, CG over Lock Box lower edge (CTU-1)	68°	0°	HAC impact on most probable orientation in field to cause damage.
3	30 foot slapdown on Lock Box lower edge (CTU-2)	25°	0°	HAC impact producing maximum load on Lock Box.
4	30 foot, CG over Safety Plug (CTU-1)	240°	0°	HAC impact to attack the Safety Plug opposite the Lock Box.
5	Puncture drop, CG over Lock Box lower edge (CTU-1)	69°	0°	HAC impact producing maximum load on Lock Box.
6	Puncture drop on housing lower edge (CTU-2)	68°	0°	Puncture in area expected to produce worst case cumulative damage to failed weld joint.
7	Puncture drop, CG over Safety Plug (CTU-1 or CTU-2)	250°	0°	Puncture in area expected to produce worst case cumulative damage to Safety Plug.
8	HAC Thermal Test (CTU-2)	120°	0°	Rotational orientation placed the damaged stainless steel housing at the highest point in the thermal test.

2.7.4 Thermal

Subpart F of 10 CFR 71 requires performing a thermal test in accordance with the requirements of 10 CFR §71.71(c)(4). To demonstrate the performance capabilities of the IR-100 when subjected to the HAC thermal test specified in 10 CFR §71.71(c)(4), a full scale CTU was exposed to a minimum of 1,475 °F (800 °C) for 30 minutes in a vented electric oven. The selected CTU was subjected to a number of 30-foot free drop and puncture tests prior to being placed in the oven, as discussed in Section 2.71, *Free Drop*, and Section 2.7.3, *Puncture*.

To ensure that there was adequate oxygen available for combustion of the flammable material in the packaging (i.e., polyurethane foam), a source of air was supplied into the furnace. Two K type thermocouples were installed on the surface of each side of the packaging to monitor the package's temperature during the test.

The packaging was orientated such that the gap in the stainless steel housing was at the highest point of the package. This orientation would result in the possible formation of a chimney and thus, result in complete combustion of the interior foam and possibly the DU material.

The thermal test was initiated when the temperature of the packaging was a minimum of 1,475 °F (800 °C) after the forced introduction of air. This test condition conservatively addressed the effects of the convective heat transfer that would naturally occur in a fully engulfing fire test. Following 30 minutes, the CTU was removed from the oven and allowed to naturally cool in air, without any active cooling systems.

Successful HAC thermal testing of the CTU indicates that the various IR-100 design features are adequately designed to withstand the HAC thermal test event. The most significant result of the testing program was the demonstrated ability of the IR-100 packaging to maintain its shielding integrity, as demonstrated by an actual radiation post-test survey.

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

2.7.5 Immersion – Fissile

The IR-100 does not carry fissile material, and therefore, this section does not apply.

2.7.6 Immersion – All Packages

The IR-100 is a confinement boundary for special form payload and does not have a pressure boundary. Therefore, the effect of pressure is not applicable.

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

The IR-100 contains a maximum of 120 Ci (4.44 TBq) of Ir-192 or Se-75, which have A_2 values of 16 Ci (0.6 TBq) and 81 Ci (3.0 TBq), respectively. Since the IR-100 does not contain more than 10^5 A_2 quantities of radioactive material, this section does not apply.

2.7.8 Summary of Damage

As discussed in the previous sections, the cumulative damaging effects of free drop, puncture drop, and thermal tests were satisfactorily withstood by the IR-100 certification testing. Subsequent radiation post-test survey and destructive examinations of the CTUs confirmed that

shielding integrity was maintained throughout the test series. Therefore, the requirements of 10 CFR §71.73 have been adequately satisfied.

2.8 Accident Conditions for Air Transport of Plutonium

This section does not apply, since plutonium is not shipped in the IR-100.

2.9 Accident Conditions for Fissile Material Packages for Air Transport

This section does not apply, since fissile material is not shipped in the IR-100.

2.10 Special Form Certification

The contents of the IR-100 are a special form Ir-192 or Se-75 source capsule. All source capsules are limited to a maximum of 120 curries. The special form certifications for the Ir-192 or Se-75 capsules are as follows:

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

* Note: Source capsule is limited to a maximum of 120 Ci of Se-75 material.

2.11 Fuel Rods

This section does not apply, since fuel rods are not shipped in the IR-100.

2.12 Appendix

2.12.1 Certification Tests

2.12.1 Certification Tests

Presented herein are the results of normal conditions of transport (NCT) and hypothetical accident condition (HAC) test that address free drop, puncture, and thermal test performance requirements of 10 CFR 71[8].

2.12.1.1 Introduction

The IR-100, 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, puncture, and thermal testing of IR-100 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 IR-100 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 IR-100 packaging to maintain its shielding integrity.

Significant results of the free drop tests are as follows:

- No evidence of excessive distortion of the Lock Box occurred that would have significantly displaced the special form source from its desired shielded position.
- There was no evidence of excessive rupturing of the stainless steel housing that could have resulted in thermal degradation of the DU shield by excessive oxidation in a subsequent fire event.
- The most significant damage from the free drop tests was a failure of one of the fillet welds joining one side stainless steel sheet to the bottom stainless steel sheet. The resulting gap was 3/16 inches at its widest point. This failure was due to poor fusion/penetration of the weld rather than a design flaw.

Significant results of the puncture drop testing are as follows:

- No evidence of excessive distortion of the Lock Box occurred that would have significantly displaced the special form source from its desired shielded position.
- There was no evidence of excessive rupturing of the stainless steel housing that could have resulted in thermal degradation of the DU shield by excessive oxidation in a subsequent fire event.
- The worst case damage from the free drop tests (i.e., failed fillet weld on housing) was a slight increase in the gap. The resulting gap increased by 1/16 inch, to a maximum of 1/4 inch at its widest point.

Significant results of the thermal testing are as follows:

[8] Title 10, Code of Federal Regulations, Part 71 (10 CFR 71) *Packaging and Transportation of Radioactive Material*, 1-1-15 Edition.

- No evidence of excessive oxidation of the DU shield and subsequent loss of shielding.
- Gases formed by thermal degradation of the polyurethane foam were safely vented out of the stainless steel housing.
- The polyurethane foam was completely consumed in the test without any effect on the DU shield material.
- None of the components that are important to safety (i.e., stainless steel housing, Lock Box, DU shield) sustained any degradation due to excessive temperatures.

2.12.1.3 Test Facilities

The drop testing is being performed using a horizontal concrete slab, which is approximately 20 inches × 4 feet × 8 feet. A 2 inch × 46 inch × 60 inch steel plate is placed on top of the concrete slab and welded to two 8-inch wide steel channels that are embedded in the concrete. The estimated mass of the drop pad is 9,295 lb_m, which is more than 175 times the mass of the IR-100 CTU. Based on these characteristics, the drop pad satisfies the requirement of 10 CFR §71.71 and 10 CFR §71.73 for an essentially unyielding, horizontal surface.

The puncture bar for the puncture tests is a 6 inch diameter × 13 inch long solid bar which is orthogonally socket welded through a 1 inch × 18 inch × 18 inch steel plate. The top circumferential edge of the bar has a 1/4-inch radius. The free length of the bar is 12 inches (i.e., 13 inches minus the 1 inch thick plate), thus ensuring an adequate length to potentially cause maximum damage to the CTU as required by 10 CFR §71.73(c)(3). Following the thirty foot free drop tests, the 1 inch plate of the puncture bar assembly will then be welded to the 2-inch thick plate on the drop pad to ensure that the puncture bar is restrained for the puncture drop tests.

The oven that was utilized for the IR-100 thermal testing is located at Manufacturing Sciences Corporation's Oak Ridge, TN facility. The MSC oven is a General Electric, 60 Kw resistance heated box furnace with interior dimensions of 87 inch (L) × 42 inch (W) × 25 inch (H). The oven is capable of temperatures up to 2,000 °F, controlled within ±10 °F.

2.12.1.4 Certification Test Unit Description

The IR-100 consists of a Zircaloy or titanium source tube surrounded by an epoxy-coated, depleted uranium (DU) shield. The DU shield assembly is encased within a welded, Type 304 stainless steel housing. Stainless steel support brackets, welded to the inner housing surface, capture the DU shield between the support bracket and the inner surface of the stainless steel housing. Copper shim stock is installed between the DU-stainless steel interfaces to preclude a reaction between the two dissimilar metals. The void space between the DU shield assembly and the inner stainless steel housing is filled with approximately 2 pounds of rigid polyurethane foam that prevents moisture from contacting the DU material. The maximum gross weight of the IR-100 Exposure Device is 53 pounds.

Prior to free drop, puncture, and thermal testing, two IR-100 CTUs were loaded with a dummy source capsule assembly to simulate the special form capsule. The actual weight of the CTUs was 51 pounds/shield weight 36 pounds for each unit. Aside from the dummy source capsule assembly, the CTUs were identical to the IR-100 packaging design depicted in Appendix 1.3.1, *General Arrangement Drawings*.

2.12.1.5 Technical Basis for Tests

For the confinement system to fail, the IR-100 would need to move or separate the radioactive source from the central location within the DU shield assembly. This potential failure mode may only occur if either or both of the following conditions occur:

1. The Lock Box of the IR-100 is broken free of the stainless steel housing or damaged such that the source is significantly moved from its stored position.
2. The DU shield assembly translates away from the lock box/pigtail assembly and the source is significantly moved from its stored position.

For either of these potential conditions to be initiated, the IR-100 would need to sustain significant damage due to the normal and hypothetical accident condition free drops and then sustain further damage due to the 1-meter (40-inch) drop onto a 6-inch diameter vertical steel bar. Therefore, the primary objective of the 1.2-meter (4 ft) normal condition and 9-meter (30 ft) hypothetical accident condition (HAC) free drops is to damage the lock box or cause significant movement of the special form source within the DU shield of the IR-100 packaging. A secondary objective of the 9-meter (30 ft.) HAC free drops is to attempt to damage the safety plug fitting such that a potential air pathway into the interior would form. Such a pathway could potential result in a self-sustaining oxidation reaction of the DU and hence, result in a loss of shielding.

The following sections provide the technical basis for the chosen test orientations and sequences for the IR-100 CTUs as presented in Appendix 2.12.3.6, *Test Sequence for Selected Free Drop, Puncture Drop, and Thermal Tests*.

2.12.1.5.1 Temperature

Ambient temperature was utilized at the time of IR-100 certification testing. Previous certification testing of a related INC package, Model OP-100 (NRC Docket No. 71-9185) that includes the IR-100 as one of its authorized payloads, was performed at temperatures below -20 °F and as high as 125 °F. The results of the OP-100 package testing[9] demonstrated that extreme temperatures had no effect on the shielding integrity of the IR-100. 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*.

2.12.1.5.2 Free Drop Tests

The IR-100 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 Model IR-100 and potentially separating the radioactive source, three orientations have been selected for the free drop testing:

1. <u>CG-Over-Lock Box Lower Edge:</u> This orientation targets the Lock Box that secures the position of the special form source in the DU shield. Should this impact be sufficiently

[9] Packaging Technology, Inc (PacTec), Document No. TR-002, *Certification Test Report for the OP-100 Package*, Revision 1, March 1998.

severe, the Lock Box potentially may be dislodged and/or broken and allow the special form source to separate from the IR-100 body. The intent of this drop orientation is also to simulate a probable orientation that could occur in actual use in the field.

2. Slapdown on Lock Box Lower Edge: This orientation again targets the Lock Box, but at a shallower angle. The intent of this orientation is to attempt to apply the maximum shearing force on the Lock Box attachment welds. Should this impact be sufficiently severe, the Lock Box potentially may be dislodged and/or broken and allow the special form source to separate from the IR-100 body.

3. CG-Over-Safety Plug: This orientation targets the Safety Plug. Should this impact be sufficiently severe, the Safety Plug adapter potentially may be dislodged and/or broken and allow a passageway for air (i.e., oxygen) into the interior of the IR-100 body. Excessive exposure of the DU to the hypothetical accident condition thermal event has been shown to be a possible failure of the DU shield.

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 onto a puncture bar "in a position for which maximum damage is expected." As 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 the Lock Box body and/or broken and allow the special form source to separate from the IR-100 body.

All puncture orientations are oblique per the orientations identified above in Section 2.12.1.5.2, *Free Drop Tests*. Should a condition surface during the certification testing that results in unanticipated damage, then a new evaluation and assessment to determine most-damaging orientation(s) for the puncture drop test will be performed.

2.12.1.5.4 Thermal Test

Depending on the results of the normal and hypothetical accident condition free drop and puncture tests, the IR-100 may be subjected to a 30-minute, 1,475 °F thermal test in accordance with 10 CFR §71.73(c)(4). The criteria for whether this test will be performed or not is dependent on the presence of a cracked and/or opening of the stainless steel housing.

Because CTU-2 experienced a weld failure during the free drop testing, a thermal test of that unit was performed in the thermal test facility described in Section 2.12.1.3, *Test Facilities*. The IR-100 CTU was oriented

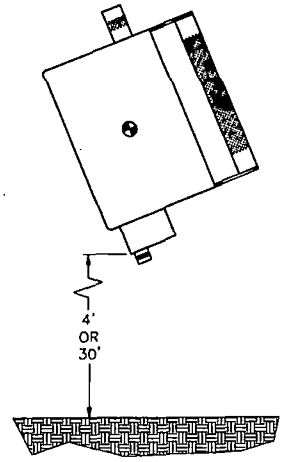
2.12.1.6 Test Sequence for Selected Free Drop, Puncture Drop and Thermal Tests

The following sections establish the selected free drop, puncture drop, and thermal test sequence for the IR-100 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.

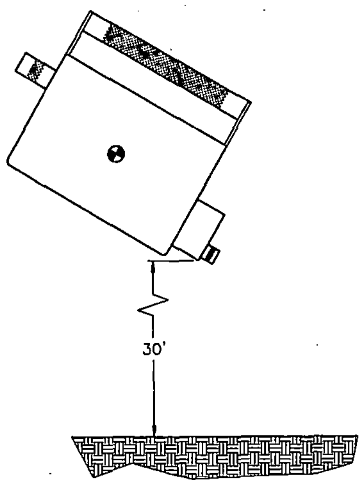
2.12.1.6.1 Certification Test Unit No. 1 (CTU-1)

Free Drop No. 1 is a NCT free drop from a height of four feet, impacting the lower edge of the Lock Box. The four foot drop height is based on the requirements of 10 CFR §71.71(c)(7) for a package weight note exceeding 11,000 pounds. The purpose of this test was to cause maximum damage to the most vulnerable feature (Lock Box) on the packaging.

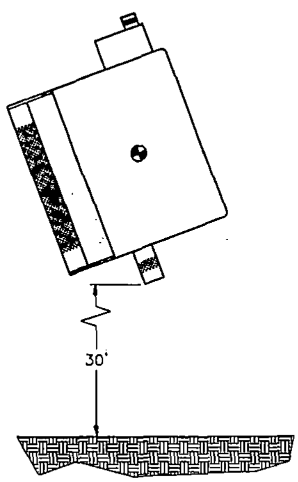
Free Drop No. 2 is a HAC free drop from a height of 30 feet, impacting the lower edge of the Lock Box, which is the same impact pint as the NCT Free Drop No. 1. In this way, NCT and HAC free drop damage is cumulative. The 30 foot drop height is based on the requirements of 10 CFR §71.73(c)(1). The purpose of this test is to cause maximum damage to the most vulnerable feature (Lock Box) on the packaging.



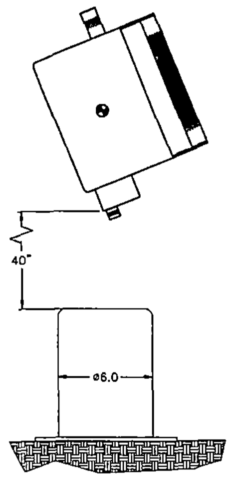
Free Drop No. 3 is a HAC free drop from a height of 30 feet, impacting the lower edge of the Lock Box at a shallower angle than Free Drop No. 2. The 30 foot drop height is based on the requirements of 10 CFR §71.73(c)(1). The purpose of this test was intended to cause maximum damage to the Lock Box in an attempt to shear the box off the housing and pull the special form capsule out of its shielded position.



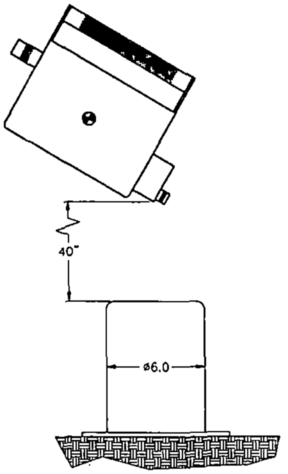
Free Drop No. 4 is a HAC free drop from a height of 30 feet, impacting the Safety Plug. The 30 foot drop height is based on the requirements of 10 CFR §71.73(c)(1). The purpose of this test was to cause maximum damage to the Safety Plug and possibly cause a breach in the stainless steel housing.



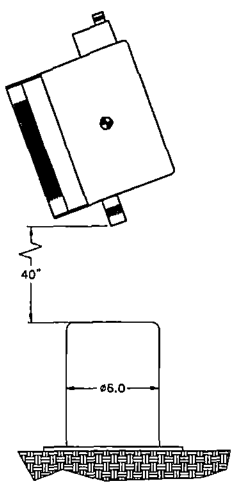
Puncture Drop No. 5 impacts directly onto the damage created by Free Drop Tests 1 and 2, directly on the lower edge of the Lock Box. The puncture drop height is based on the requirements of 10 CFR §71.73(c)(3). The purpose of Puncture Drop No. 5 is to cause maximum damage to the most vulnerable feature (Lock Box) on the packaging.



Puncture Drop No. 6 impacts directly onto the damage created by Free Drop Test No. 3, directly impacting the lower edge of the Lock Box at a shallower angle than Puncture Drop No. 5. 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 Lock Box in an attempt to shear the box off the housing and pull the special form capsule out of its shielded position.



Puncture Drop No. 7 impacts directly onto the damage created by Free Drop Test No. 4, directly on the Safety Plug. 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 Safety Plug and possibly cause a breach in the stainless steel housing.



Thermal Test No. 8 is intended to be performed if a breach in the stainless steel housing occurs due to the cumulative effects of the free drop and puncture drop tests. Orientation of the packaging would be based on the observed damaged should the housing breach condition occur.

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 Figure 2.12.1-1 and Figure 2.12.1-2).

Figure 2.12.1-3 through Figure 2.12.1-25 sequentially photo-document the certification testing process for the IR-100 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 lower edge of the Lock Box. As shown in Figure 2.12.1-3, the CTU was oriented 68° with respect to the horizontal impact surface (longitudinal angle 68°, rotational angle 0°). The following list summarizes the test parameters:

- verified longitudinal angle as 68° ±1°
- verified rotational angle as 0° ±1°
- verified drop height as 4 feet, +3/-0 inches (actual drop height 4 feet)
- measured ambient and package temperatures as 49 °F and 48 °F respectively
- conducted test at 9:07 a.m. on Monday, 4/26/99

The packaging rebounded upon impact. The measured deformation of the lower edge of the brass dust cap was approximately 3/16 inches. The dust cap was also deformed slightly upward. The impact damage is shown in Figure 2.12.1-4.

2.12.1.7.1.2 CTU-1Free Drop Test No. 2

Free Drop No. 2 is a HAC free drop from a height of 30 feet, impacting the lower edge of the Lock Box. As shown in Figure 2.12.1-5, the CTU was oriented 68° with respect to the horizontal impact surface (longitudinal angle 68°, rotational angle 0°). The following list summarizes the test parameters:

- verified longitudinal angle as 68° ±1°
- verified rotational angle as 0° ±1°
- verified drop height as 30 feet, +3/-0 inches (actual drop height 30 feet)
- measured ambient and package temperatures as 46 °F and 42 - 44 °F respectively
- conducted test at 9:30 a.m. on Monday, 4/26/99

The packaging rebounded upon impact. The brass dust cap was sheared off the Lock Box and the lower edge of the Lock Box was deformed approximately 1/16 inch deep × 5/16 inch wide × 1-5/16 inch long. The spring of the special form source capsule assembly was also exposed. The dust cap was also deformed slightly upward. The impact damaged is shown in Figure 2.12.1-6.

2.12.1.7.1.3 CTU-1 Free Drop Test No. 4

Free Drop No. 4 is a HAC free drop from a height of 30 feet, impacting the Safety Plug. As shown in Figure 2.12.1-7, the CTU was oriented 240° with respect to the horizontal impact surface (longitudinal angle 240°, rotational angle 0°). The following list summarizes the test parameters:

- verified longitudinal angle as 240° ±1°
- verified rotational angle as 0° ±1°
- verified drop height as 30 feet, +3/-0 inches (actual drop height 30 feet)
- measured ambient and package temperatures as 52 °F and 48 - 51 °F respectively
- conducted test at 10:14 a.m. on Monday, 4/26/99

The packaging rebounded upon impact. The brass Safety Plug was broken and deformed towards the bottom of the packaging. The stainless steel housing near the Safety Plug welded attachment was deformed by the rotation of the plug. The handle was also deformed approximately 1/2 inch towards the opposite end (i.e., Lock Box). The impact damaged is shown in Figure 2.12.1-8.

2.12.1.7.1.4 CTU-1 Puncture Drop Test No. 5

Puncture Drop No. 5 impacted directly onto the damage created by Free Drop Tests 1 and 2, directly on the lower edge of the Lock Box. As shown in Figure 2.12.1-9, the CTU was oriented 68° with respect to the horizontal impact surface (longitudinal angle 68°, rotational angle 0°). The following list summarizes the test parameters:

- verified longitudinal angle as 68° ±1°
- verified rotational angle as 0° ±1°
- verified drop height as 40 inches, +1/-0 inches (actual drop height 40.75 inches)
- measured ambient and package temperatures as 61 °F and 60 - 62 °F respectively
- conducted test at 11:03 a.m. on Monday, 4/26/99

The packaging rebounded upon impact. The lower edge of the Lock Box was slightly deformed. The impact also knocked out the brass Safety Plug that was damaged by Free Drop Test No. 4.

2.12.1.7.1.5 CTU-1 Puncture Drop Test No. 7

Puncture Drop No. 7 impacted directly onto the damage created by Free Drop Test 4, directly on the Safety Plug. As shown in Figure 2.12.1-10, the CTU was oriented 250° with respect to the horizontal impact surface (longitudinal angle 250°, rotational angle 0°). The following list summarizes the test parameters:

- verified longitudinal angle as 250° ±1°

- verified rotational angle as 0° ±1°
- verified drop height as 40 inches, +1/-0 inches (actual drop height 40 inches)
- measured ambient and package temperatures as 55 °F and 47 - 48 °F respectively
- conducted test at 11:35 a.m. on Monday, 4/26/99

The packaging rebounded upon impact. The Safety Plug Assembly was knocked out approximately 2-3/4 inches from the stainless steel housing. The threaded swivel fitting split and separated from the packaging.

2.12.1.7.1.6 CTU-1 Post-Test Radiation Survey

Due to the severe damage to the Safety Plug outlet end, a radioactive special form capsule assembly could not be installed into CTU-1 and perform a post-test radiation survey.

2.12.1.7.1.7 CTU-1 Post-Test Disassembly

Post-test disassembly of CTU-1 was performed on Wednesday, 5/26/99. An abrasive cutting wheel was utilized to cut and remove one side of the stainless steel housing sheet.

Upon removal of the stainless steel sheet, the polyurethane foam was essentially undamaged from any of the free drop and puncture drop tests. A single longitudinal crack in the polyurethane foam formed that ran essentially between the Safety Plug and the Lock Box, as shown in Figure 2.12.1-12. The foam adjacent to the DU shield support brackets and around the DU shield was removed. No noticeable damage was detected in either the DU shield or the attachment shield bracket welds, as shown in Figure 2.12.1-13.

Based on the post-test structural condition of the DU shield and the stainless steel housing, it was concluded that the IR-100 CTU-1 successfully demonstrated its ability to retain its shielding integrity.

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

2.12.1.7.2.1 CTU-2 Free Drop Test No. 3

Free Drop No. 3 is a HAC free drop from a height of 30 feet, impacting the lower edge of the Lock Box at a shallower angle than Free Drop Test No. 2. As shown in Figure 2.12.1-14, the CTU was oriented 25° with respect to the horizontal impact surface (longitudinal angle 25°, rotational angle 0°). The following list summarizes the test parameters:

- verified longitudinal angle as 25° ±1°
- verified rotational angle as 0° ±1°
- verified drop height as 30 feet, +3/-0 inches (actual drop height 30 feet)
- measured ambient and package temperatures as 45 - 47 °F and 44 - 46 °F respectively
- conducted test at 9:45 a.m. on Monday, 4/26/99

The packaging rebounded upon impact. One fillet seam weld along the lower edge of the stainless steel housing failed and exposed the interior cavity. The maximum gap was measured as 3/16 inch at its widest point. The weld failure was visually determined to be caused by a lack of fusion in the

weldment. In addition, the DU shield moved downward (i.e., towards the impact plane), which resulted in a small bulge of approximately 1/4 inch in the bottom plate. The impact event and damage are shown in Figure 2.12.1-15, and Figures 2.12.1-16 and 2.12.1-17 respectively.

2.12.1.7.2.2 CTU-2 Puncture Drop Test No. 6

Puncture Drop No. 6 was intended to impact directly onto the damage created by Free Drop Test 3, directly impacting the lower edge of the Lock Box at a shallower angle than Puncture Drop No. 5. However, the orientation was modified to impact the lower edge of the stainless steel housing due to the failed fillet weld. This orientation was an attempt to increase the existing opening in the housing and thus, provide more exposure of the DU shield for the subsequent thermal test. As shown in Figure 2.12.1-18, the CTU was oriented 68° with respect to the horizontal impact surface (longitudinal angle 68°, rotational angle 0°). The following list summarizes the test parameters:

- verified longitudinal angle as 68° ±1°
- verified rotational angle as 0° ±1°
- verified drop height as 40 inches, +1/-0 inches (actual drop height 40 inches)
- measured ambient and package temperatures as 68 °F and 59 °F respectively
- conducted test at 1:02 p.m. on Monday, 4/26/99

The packaging rebounded upon impact. The impact resulted in a slight increase (approximately 1/16 inch) of the opening in the stainless steel housing. Additionally, the brass dust cap was completely sheared off the Lock Box. This was due to the secondary impact of the CTU with the drop pad. The impact event and damage are shown in Figure 2.12.1-19 and Figure 2.12.1-20 respectively.

2.12.1.7.2.3 CTU-2 Thermal Test

Since a breach in the stainless steel housing occurred, Thermal Test No. 8 was performed to demonstrate compliance with 10 CFR 71. The following list summarizes the test parameters:

- The IR-100 CTU-2 was orientated with the failed weld joint at the highest elevation point (longitudinal angle 0°, rotational angle 120°). The CTU was placed on fire bricks to provide as much surface area as possible for heat transfer during the test (refer to Figure 2.12.1-21).
- A Type K thermocouple was installed on each side of the packaging to monitor the temperature of the package throughout the test.
- Consistent with discussions with the NRC Storage and Transportation Package Section, pressurized air was introduced into the oven near the test article once the minimum package temperature reached 1,475 °F. After re-establishing a minimum of 1,475 °F, the test was started.
- Commenced thermal testing (minimum 1,475 °F package temperature after air introduction) at 11:46 a.m. on Friday, 5/7/99.
- Completion of thermal test at 12:16 p.m. on Friday, 5/7/99 (refer to Figure 2.12.1-22).

2.12.1.7.2.4 CTU-2 Post-Test Radiation Survey

Post-test radiation survey of the IR-100 CTU-2 was performed on Wednesday, 5/26/99. The post-test radiation survey was performed using an Ir-192 special form source. During the repair of the lock assembly to permit post-test operation, it was determined that the DU shield S-tube had been severed at the interface with the Lock Box. With the S-tube severed, the DU shield was free to travel between the deformed bottom and the support bracket on the Lock Box end.

Prior to removing the dummy pigtail source assembly, the position of the dummy source was measured relative to the portal outlet end. The dummy source was found to have moved approximately 1/4 inch from its pre-test position (later attributable to the free movement of the DU shield during disassembly). With this known position, the dummy source pigtail assembly was removed and the active Ir-192 radioactive source was re-installed. The strength of the source on the day of the survey was 108 Ci (4 TBq). To account for the maximum allowable payload of 120 Ci (4.44 TBq) of Ir-192, the measured values were adjusted upward by the ratio of 120/108 or 1.1111. The results of the post-test radiation survey are follows:

Source Position (in)*	Maximum Dose Rate [Top/Bottom/Side/End] (mrem/hr)											
	Surface				1-meter				2-meter			
6-5/8	63	59	106	88	0	0.6	0.9	1.1	0	0	0.3	0.1

* Measured from the source portal exit end

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.

2.12.1.7.2.5 CTU-2 Post-Test Disassembly

Post-test disassembly of IR-100 CTU-2 was performed on Wednesday, 5/26/99. An abrasive cutting wheel was utilized to cut and remove one side of the stainless steel housing sheet.

Upon removal of the stainless steel sheet, the presence of foam char that demonstrated the intumescent behavior of the polyurethane foam, as shown in Figure 2.12.1-23. Following removal of the foam char, visual examination of the DU shield and the DU shield support brackets was performed. As shown in Figure 2.12.1-24, there was no indication of any weld/structural failure or deterioration of the DU shield material. In examining the Lock Box end, the free travel of DU shield was measured to be between 1/8 and 3/16 inches (refer to Figure 2.12.1-25.

In conclusion, the IR-100 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 IR-100 Certification Tests in Sequential Order[1]

Test No.	Test Description (Certification Test Unit No.)	Orientation		Remarks
		θ^2	ϕ^3	
1	4 foot, CG over Lock Box lower edge (CTU-1)	68°	0°	NCT impact on most probable orientation in field to cause damage.
2	30 foot, CG over Lock Box lower edge (CTU-1)	68°	0°	HAC impact on most probable orientation in field to cause damage.
3	30 foot slapdown on Lock Box lower edge (CTU-2)	25°	0°	HAC impact producing maximum load on Lock Box.
4	30 foot, CG over Safety Plug (CTU-1)	240°	0°	HAC impact to attack the Safety Plug opposite the Lock Box.
5	Puncture drop, CG over Lock Box lower edge (CTU-1)	69°	0°	HAC impact producing maximum load on Lock Box.
6	Puncture drop on housing lower edge (CTU-2)	68°	0°	Puncture in area expected to produce worst case cumulative damage to failed weld joint.
7	Puncture drop, CG over Safety Plug (CTU-1)	250°	0°	Puncture in area expected to produce worst case cumulative damage to Safety Plug.
8	HAC Thermal Test (CTU-2)	120°	0°	Rotational orientation placed the damaged stainless steel housing at the highest point in the thermal test.

Notes:
1. Tested 4/26/99 and 5/7/99.
2. Longitudinal angle, θ, is relative to long axis of packaging (i.e., 0° is horizontal).
3. Rotational angle, ϕ, is relative to rotation of package around longitudinal axis (i.e., 0° is upright).

Table 2.12.1-2 - Summary of IR-100 Certification Test Results in Sequential Order

Test No.	Test Description (Certification Test Unit No.)	Orientation		Results
		θ^2	ϕ^3	
1	4 foot, CG over Lock Box lower edge (CTU-1)	68°	0°	Slightly deformed brass dust cap, approximately 3/16 inch deep.
2	30 foot, CG over Lock Box lower edge (CTU-1)	68°	0°	Brass dust cap was sheared off Lock Box, lower edge of Lock Box was indented 1/16" D × 5/16" W × 1-5/16" L.
3	30 foot slapdown on Lock Box lower edge (CTU-2)	25°	0°	Failure of weld along housing right side. DU shield moved downward and deformed bottom housing plate (~1/4 inch).
4	30 foot, CG over Safety Plug (CTU-1)	240°	0°	Safety Plug broken, assembly deformed towards bottom, housing deformed by rotation of plug assembly, handle deformed ½ inch towards Lock Box.
5	Puncture drop, CG over Lock Box lower edge (CTU-1)	69°	0°	Lock Box lower edge deformed slightly. Impact knocked out damaged Safety Plug assembly on portal outlet end..
6	Puncture drop on housing lower edge (CTU-2)	68°	0°	Impact increased gap in housing by ~1/16 inch, maximum gap ~1/4 inch at its widest point.
7	Puncture drop, CG over Safety Plug (CTU-1)	250°	0°	Safety Plug assembly was pulled out of housing ~2-3/4 inches, brass threaded swivel fitting split and separated from package.
8	HAC Thermal Test (CTU-2)	120°	0°	Rotational orientation placed the damaged stainless steel housing at the highest point in the thermal test.

Notes:

1. Tested 4/26/99 and 5/7/99.
2. Longitudinal angle, θ, is relative to long axis of packaging (i.e., 0° is horizontal).
3. Rotational angle, ϕ, is relative to rotation of package around longitudinal axis (i.e., 0° is upright).

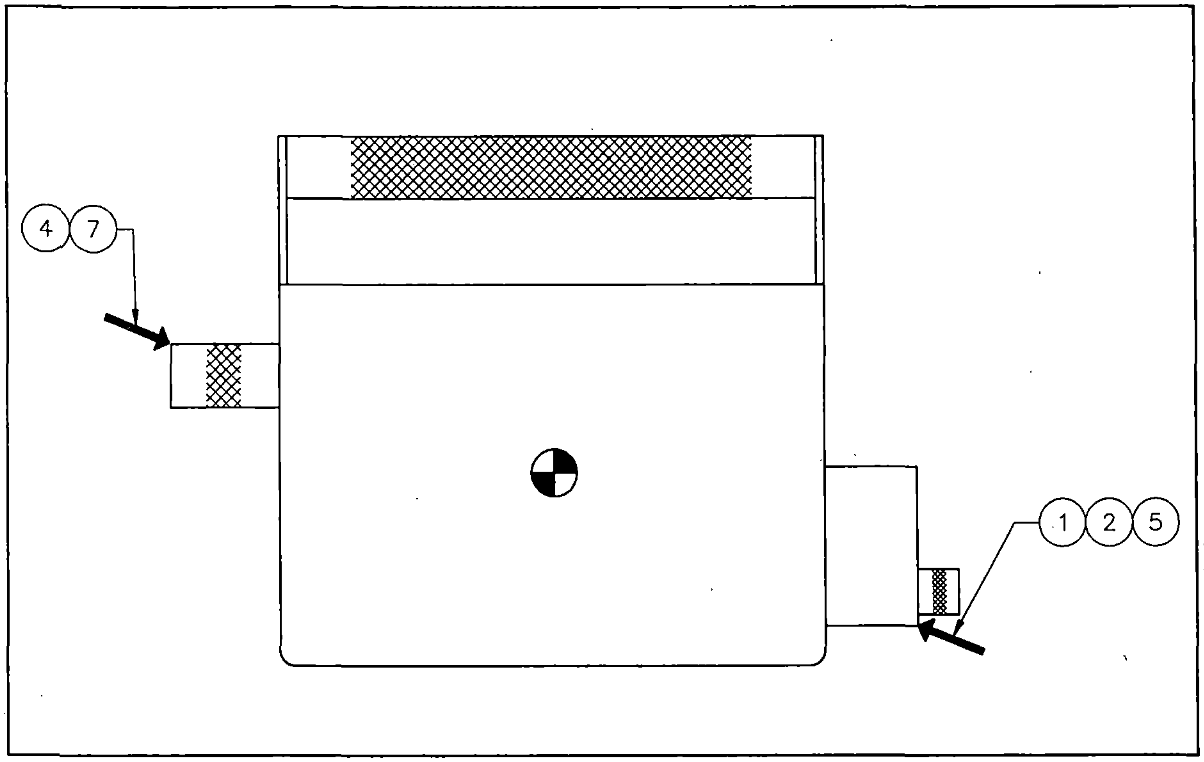


Figure 2.12.1-1 – Schematic Summary of CTU-1 Testing

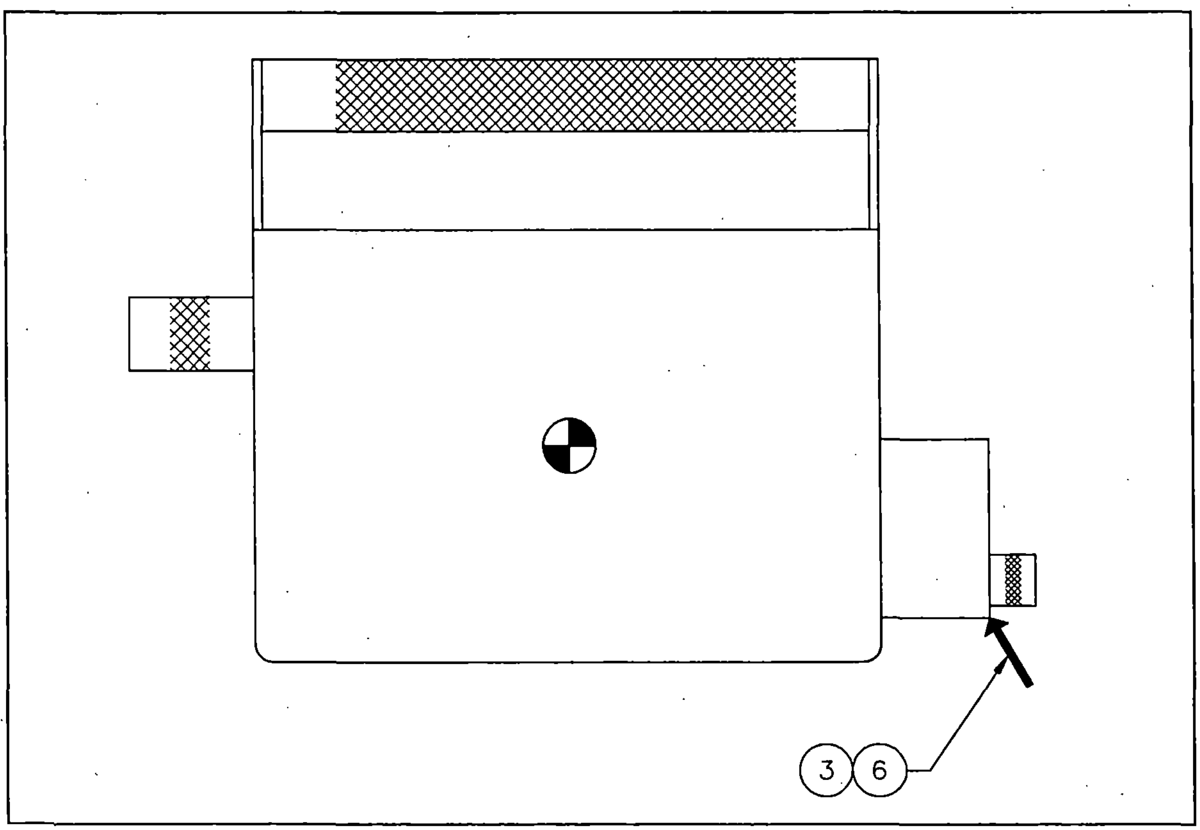


Figure 2.12.1-2 – Schematic Summary of CTU-2 Testing

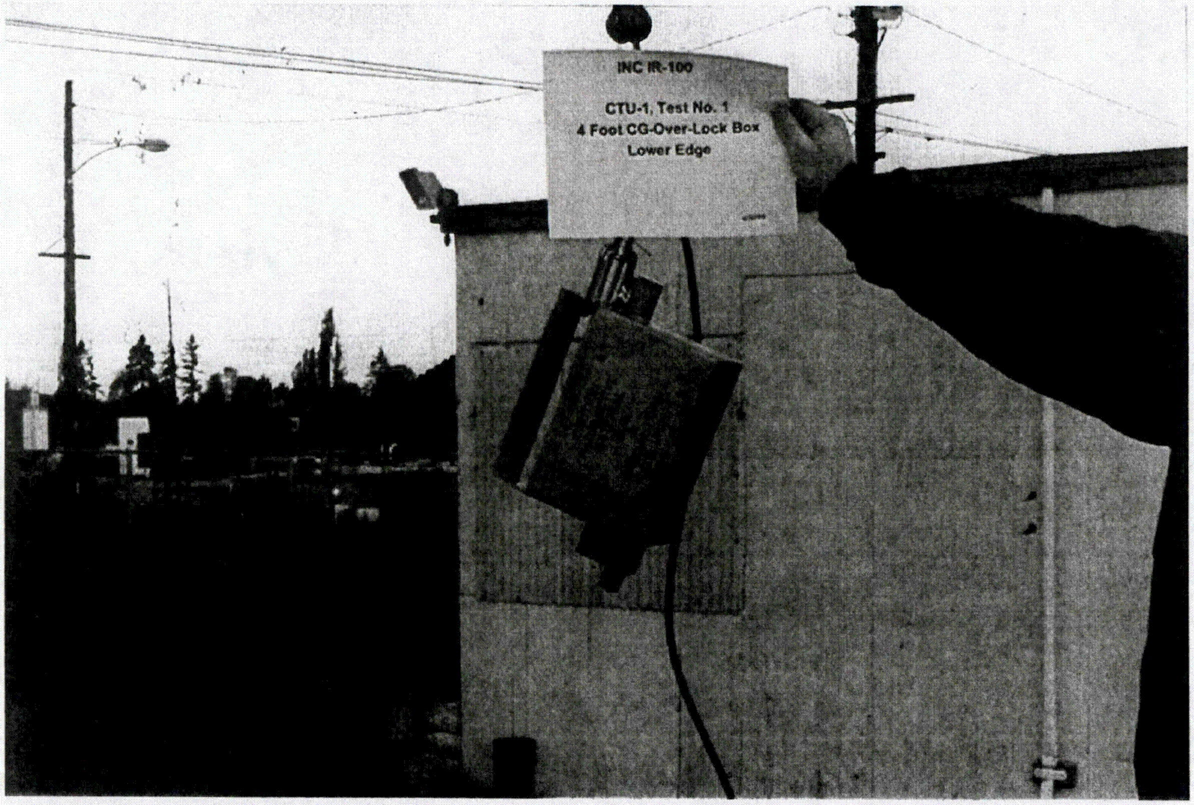


Figure 2.12.1-3 – CTU-1 Free Drop Test No. 1

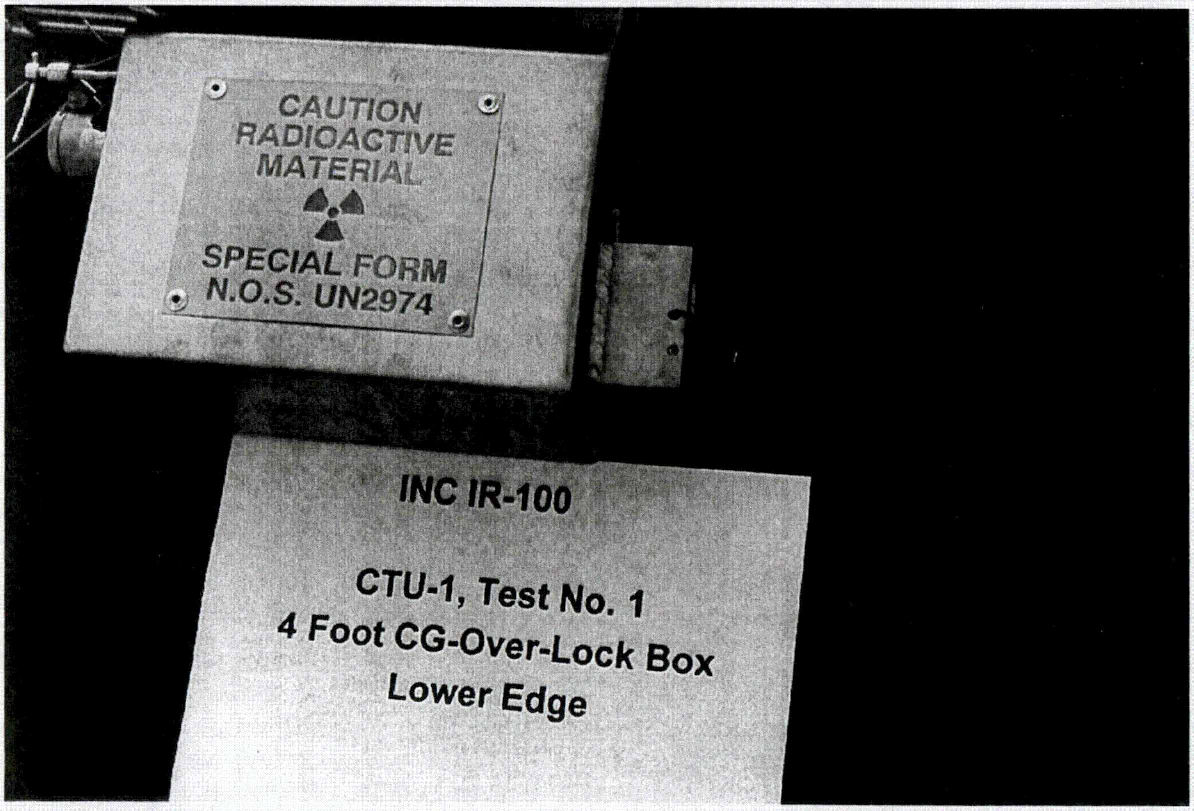


Figure 2.12.1-4 – CTU-1 Free Drop Test No. 1; Dust Cap Damage

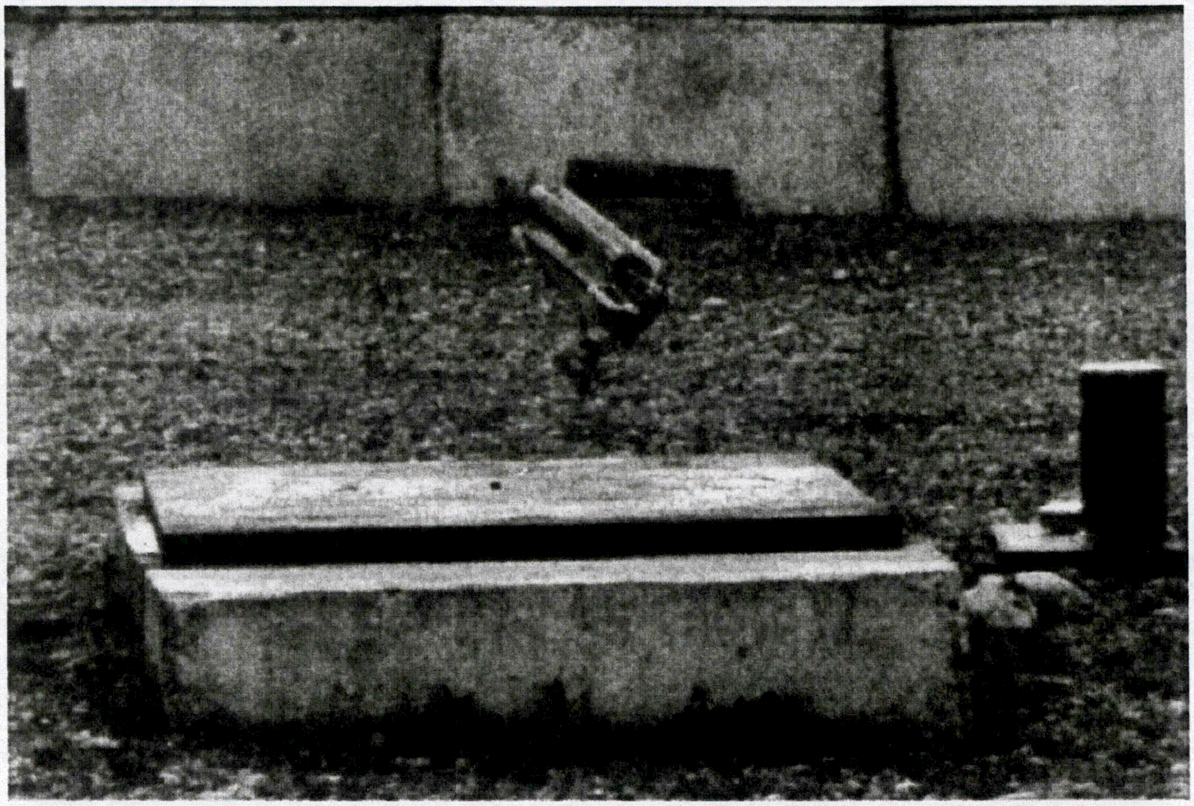


Figure 2.12.1-5 - CTU-1 Free Drop Test No. 2; Rebound of Package Following Impact

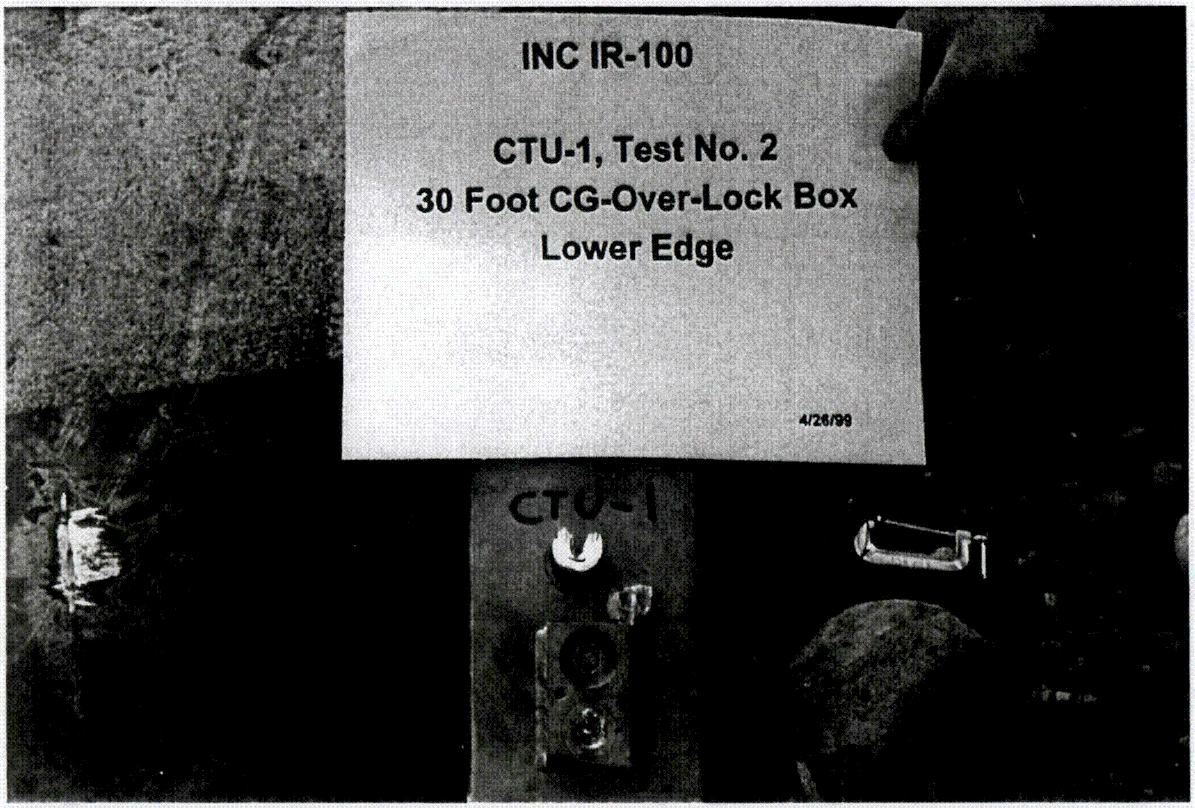


Figure 2.12.1-6 - CTU-1 Free Drop Test No.2; Dust Cap/Lock Box Damage

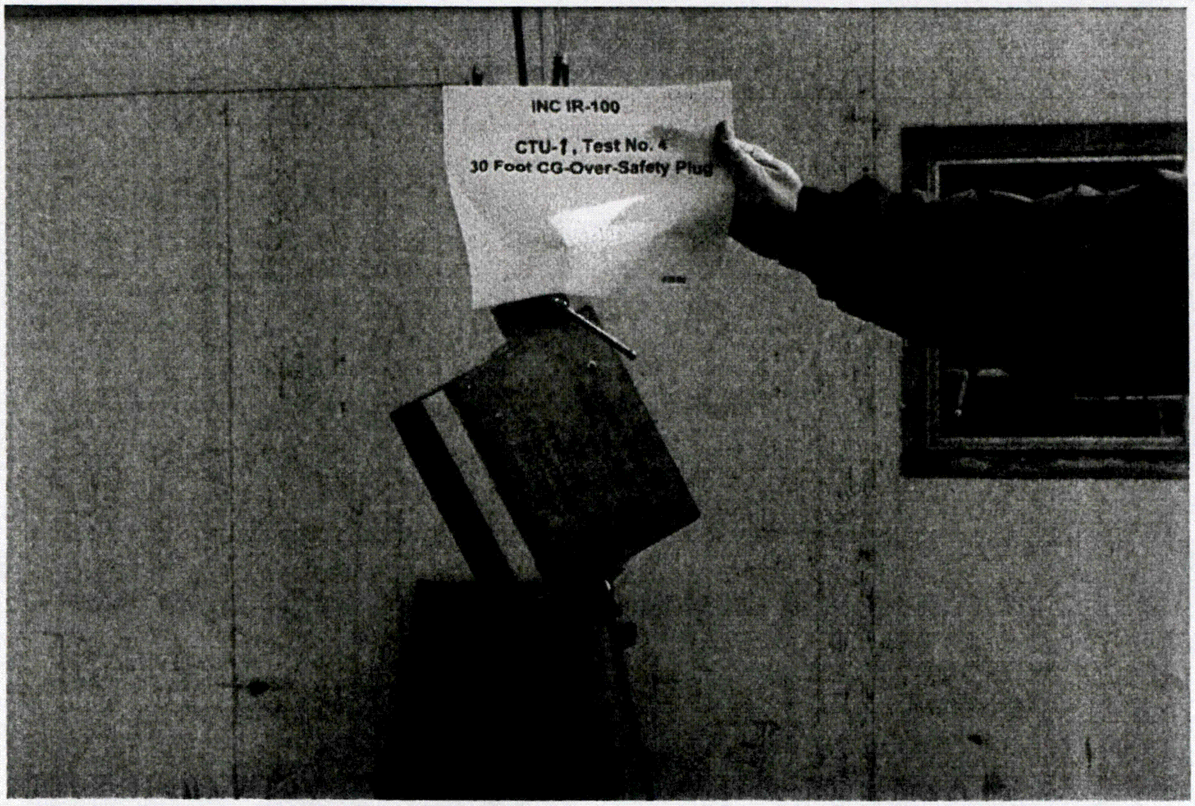


Figure 2.12.1-7 – CTU-1 Free Drop Test No. 3

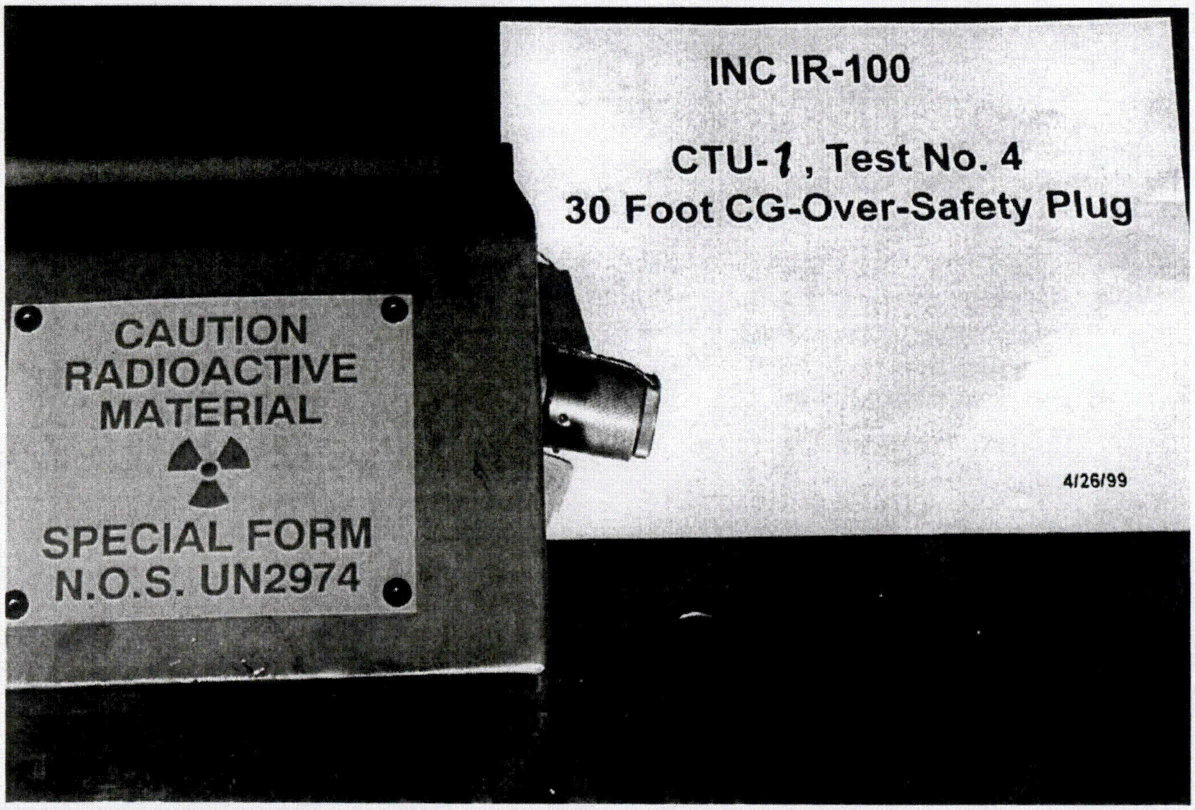


Figure 2.12.1-8 – CTU-1 Free Drop Test No. 3; Safety Plug Damage

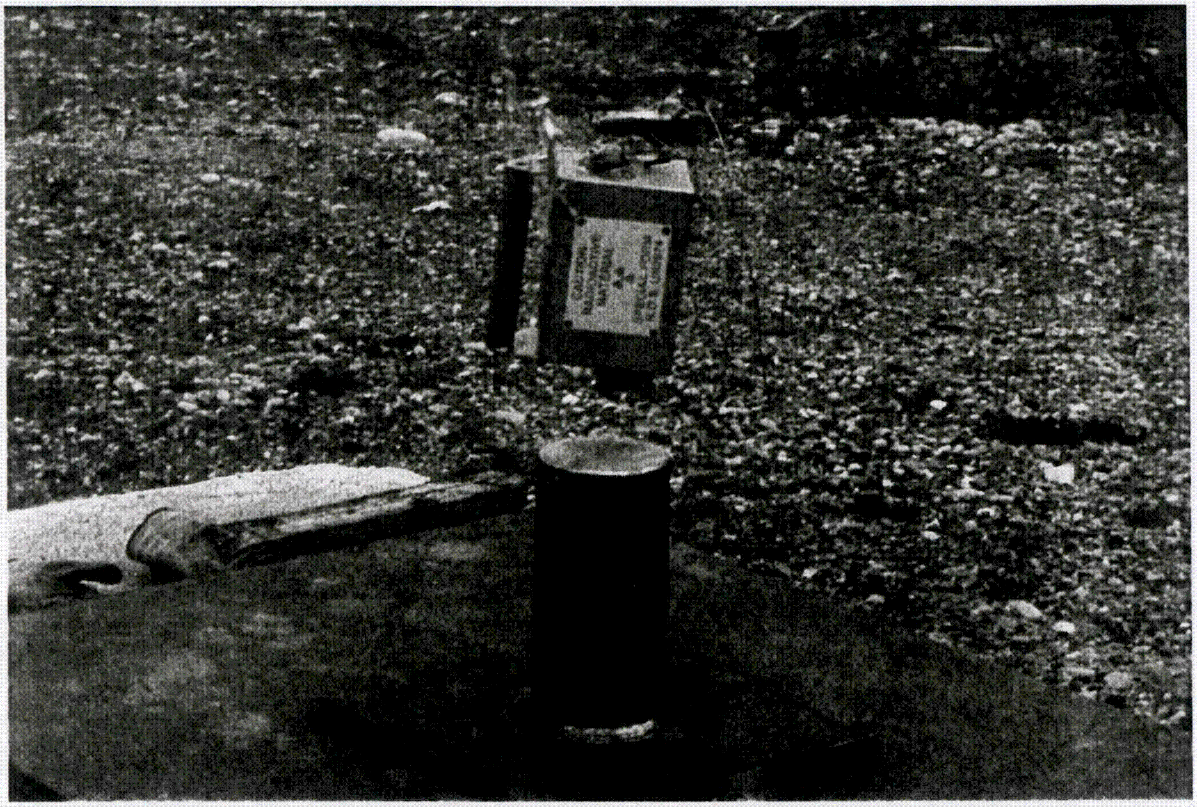


Figure 2.12.1-9 – CTU-1 Puncture Drop Test No. 5 Immediately Prior to Impact

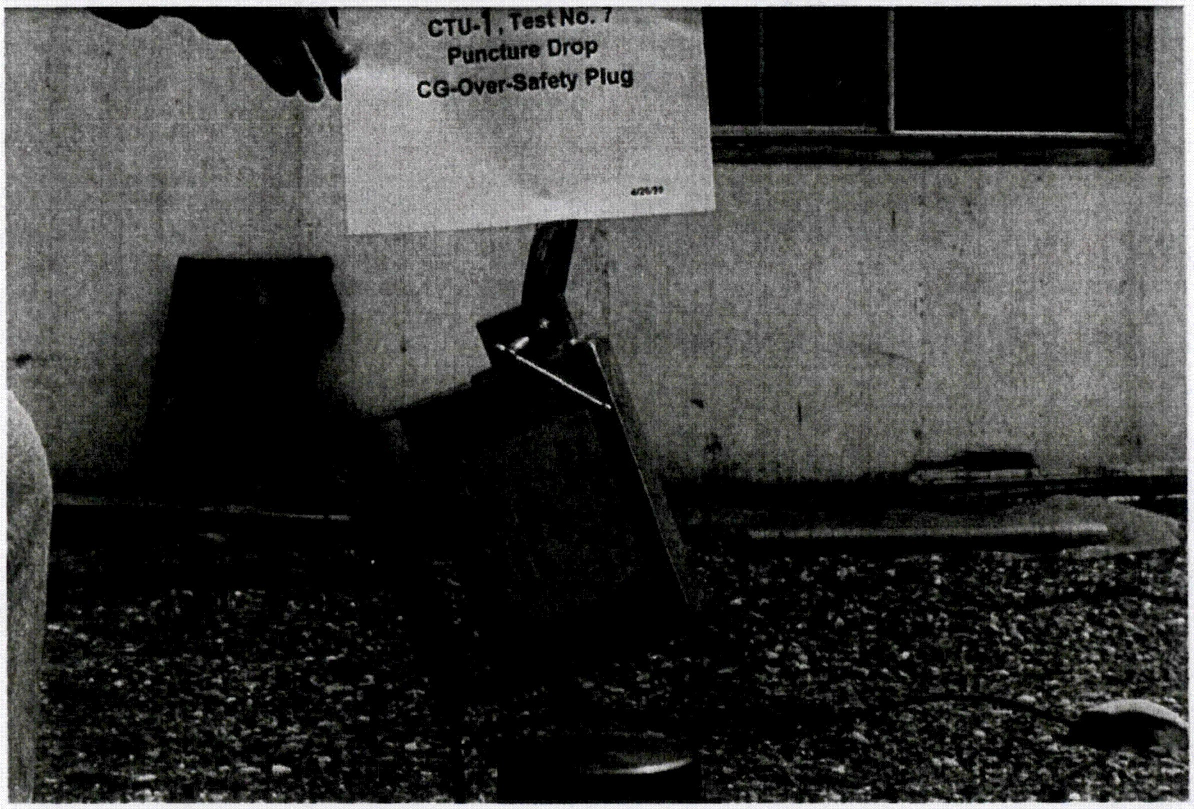


Figure 2.12.1-10 – CTU-1 Puncture Drop Test No. 7

Figure 2.12.1-11 – CTU-1 Free Drop Test No. 7 at Impact

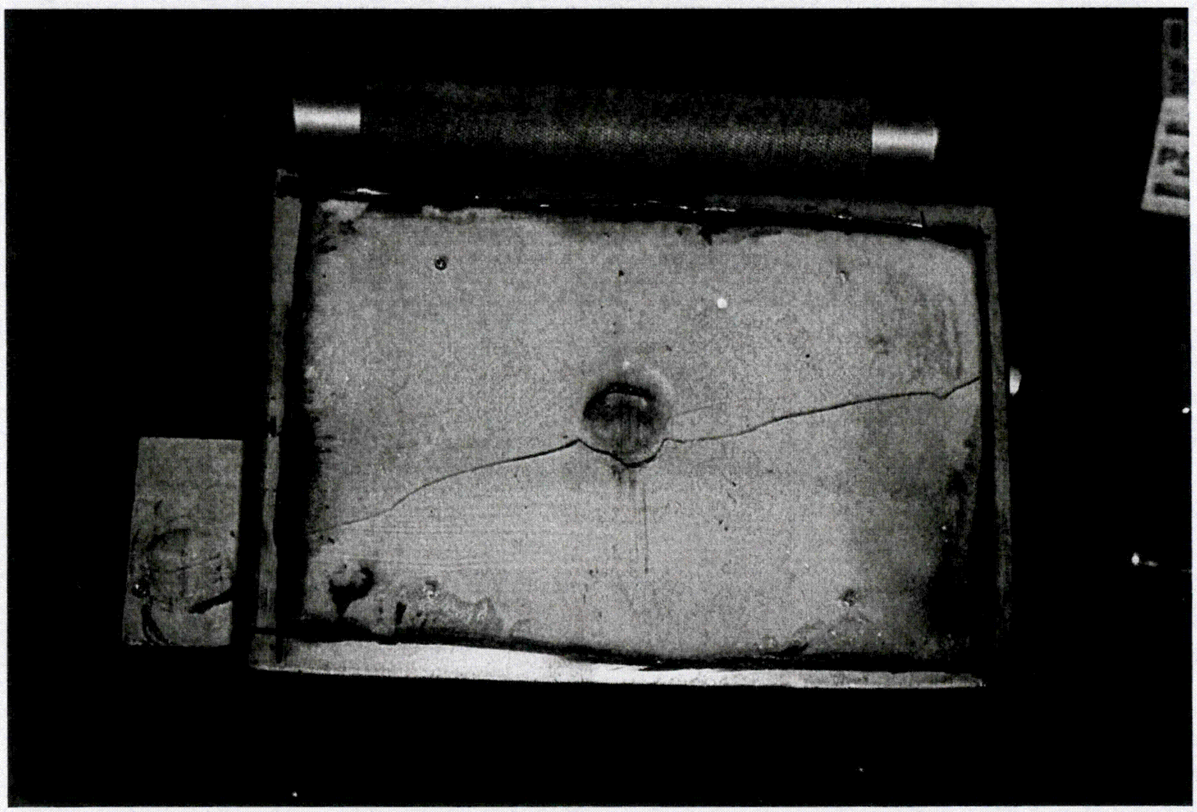


Figure 2.12.1-12 – CTU-1 Post-Test Disassembly: Condition of Foam

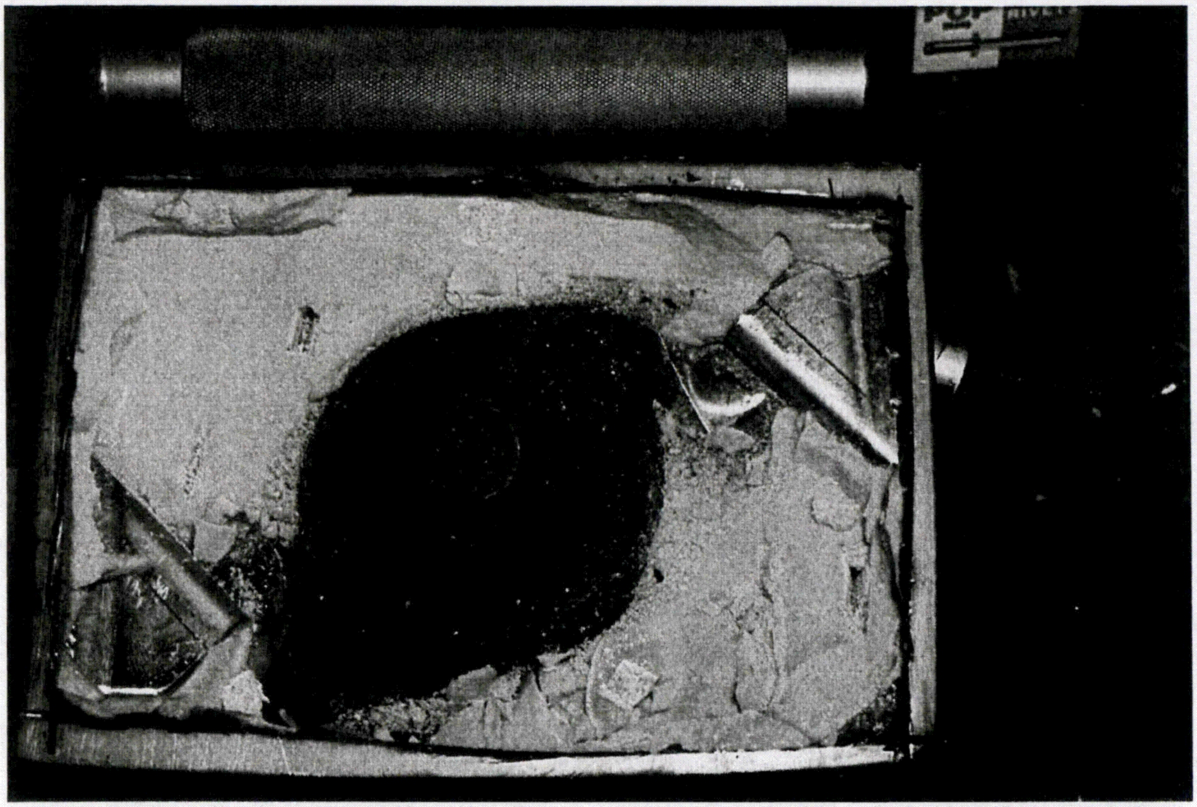


Figure 2.12.1-13 – CTU-1 Post-Test Disassembly; View of DU Shield/Support Brackets

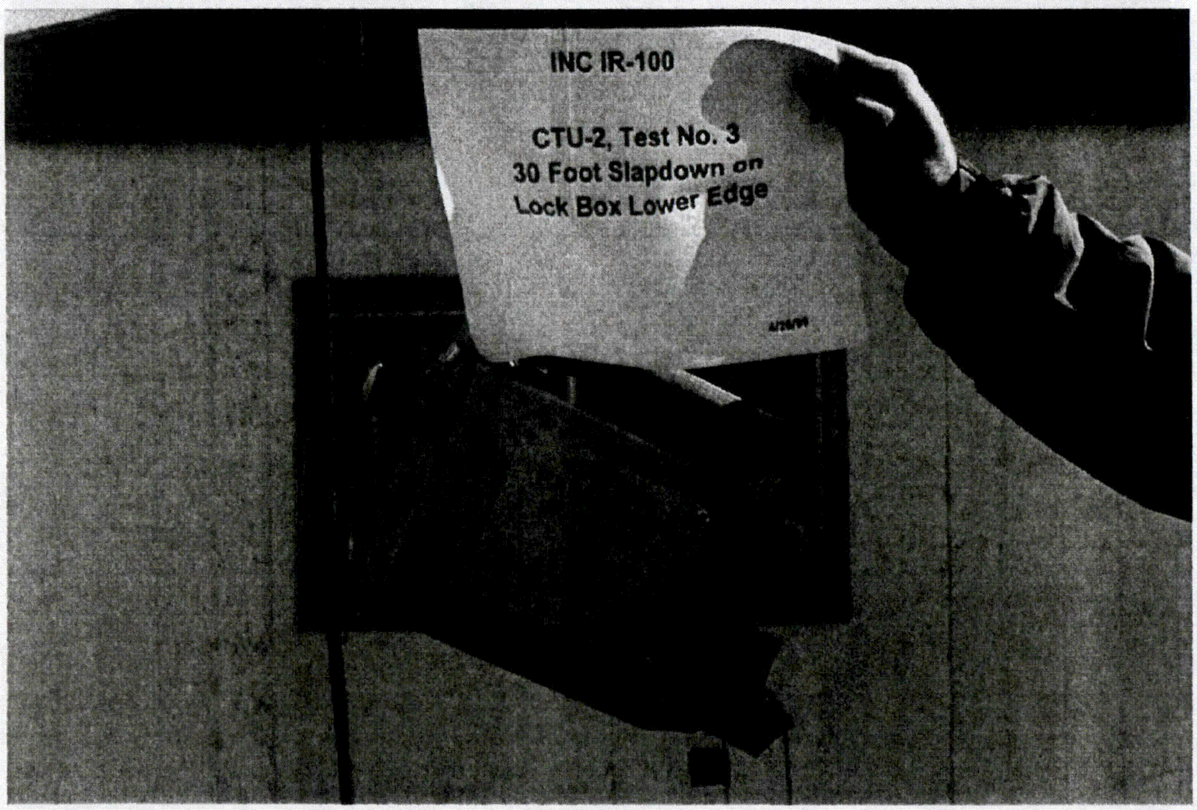


Figure 2.12.1-14 – CTU-2 Free Drop Test No. 3

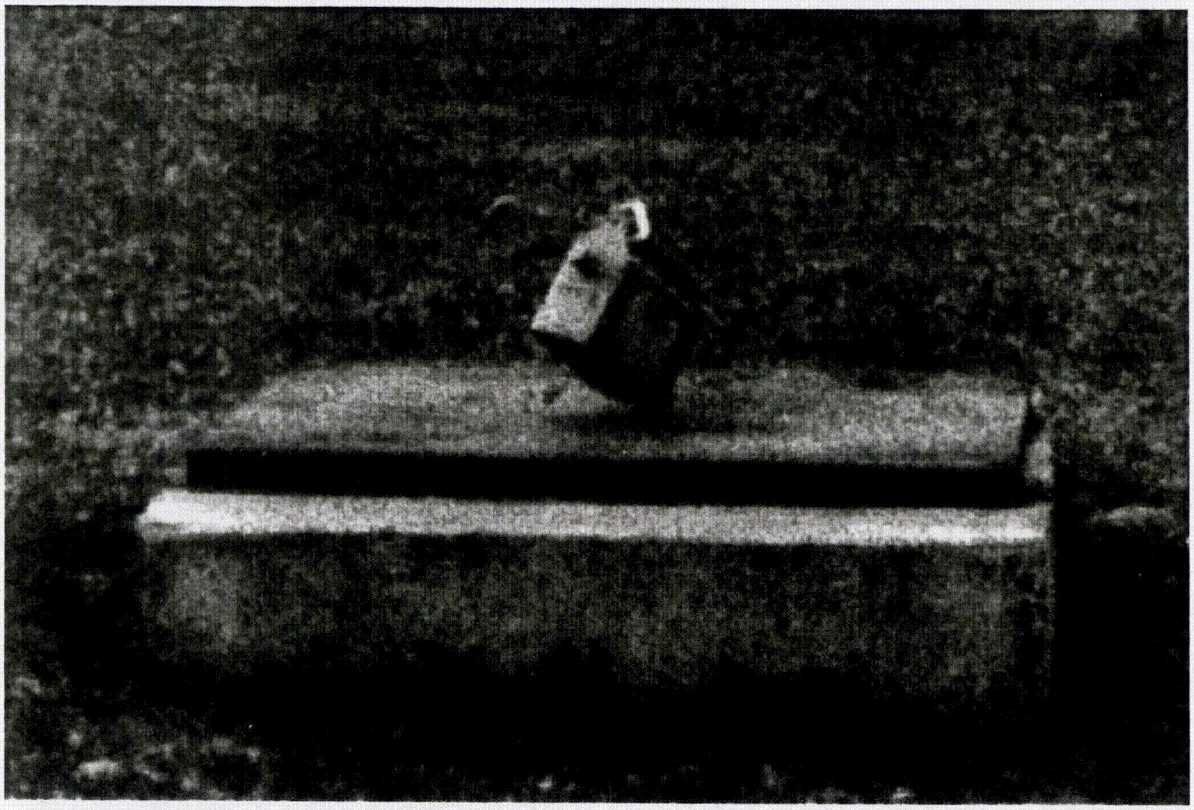


Figure 2.12.1-15 – CTU-2 Free Drop Test No. 3 at Impact

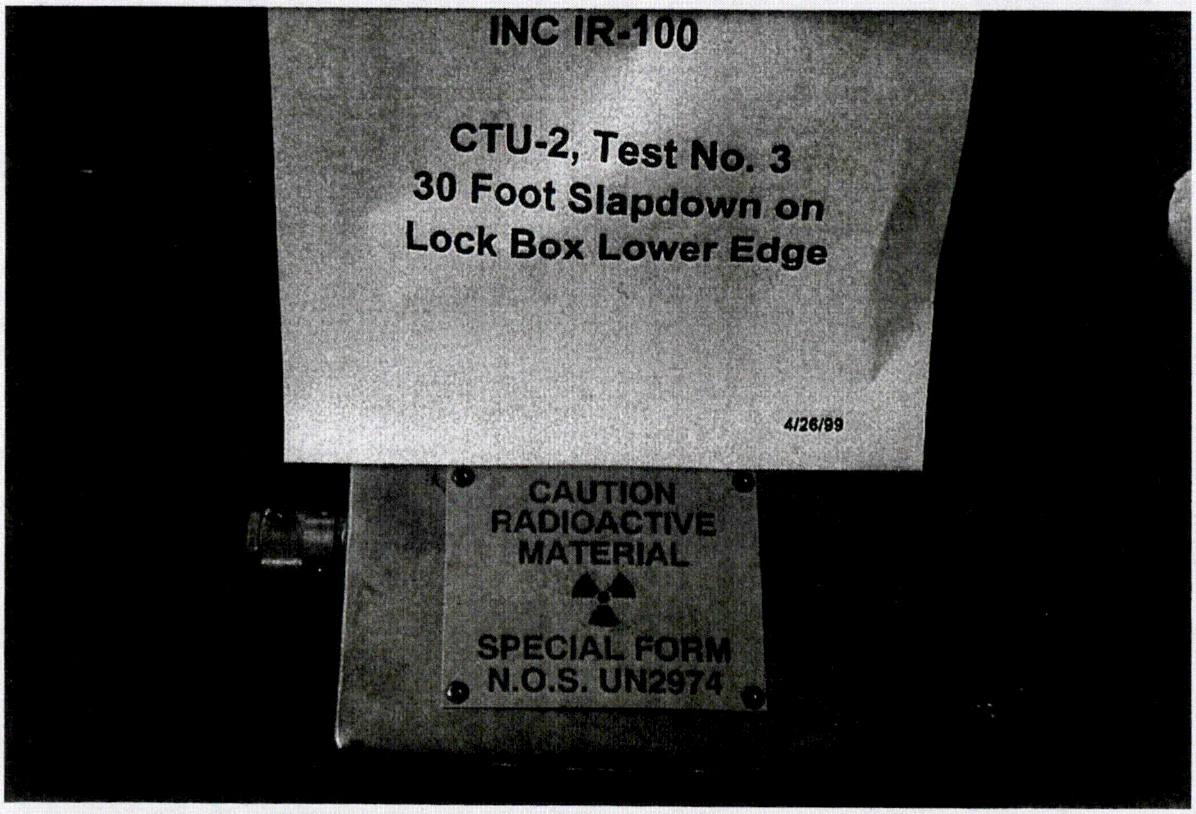


Figure 2.12.1-16 – CTU-2 Free Drop Test No. 3; Failed Seam Weld on Housing

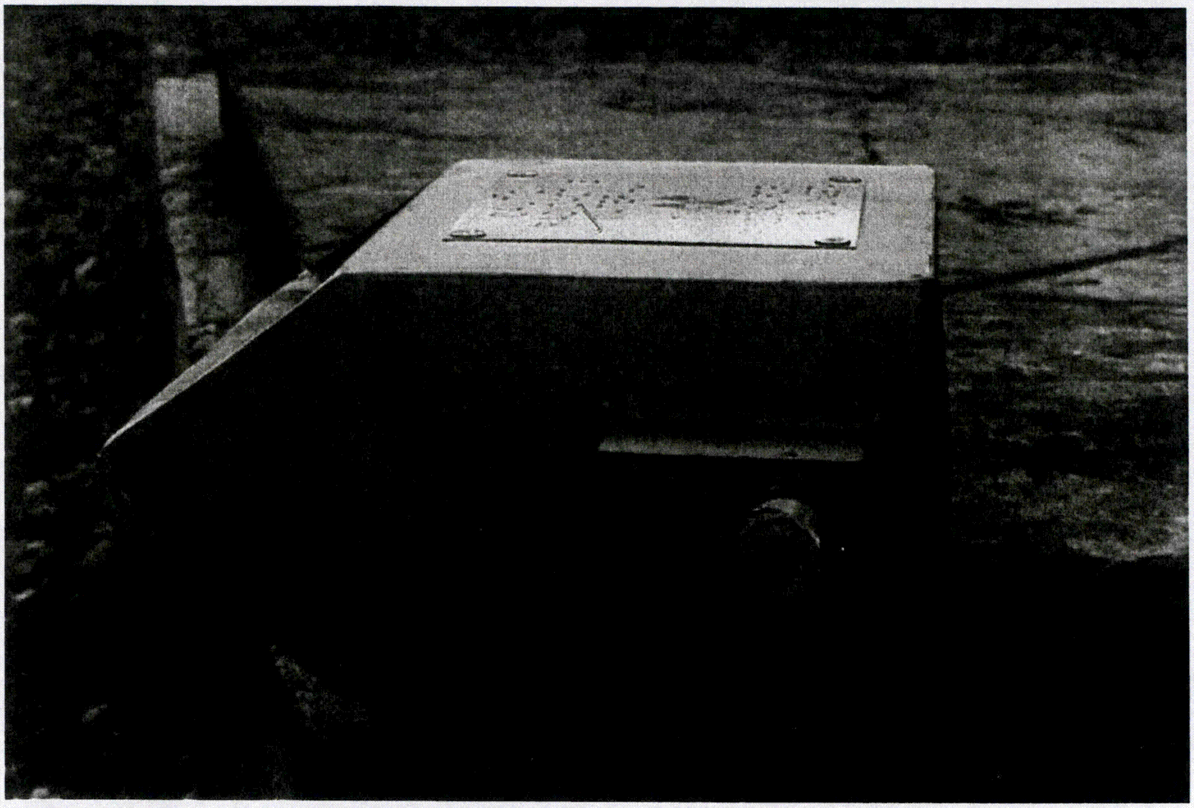


Figure 2.12.1-17 – CTU-2 Free Drop Test No. 3; Bulge of Bottom Housing Plate

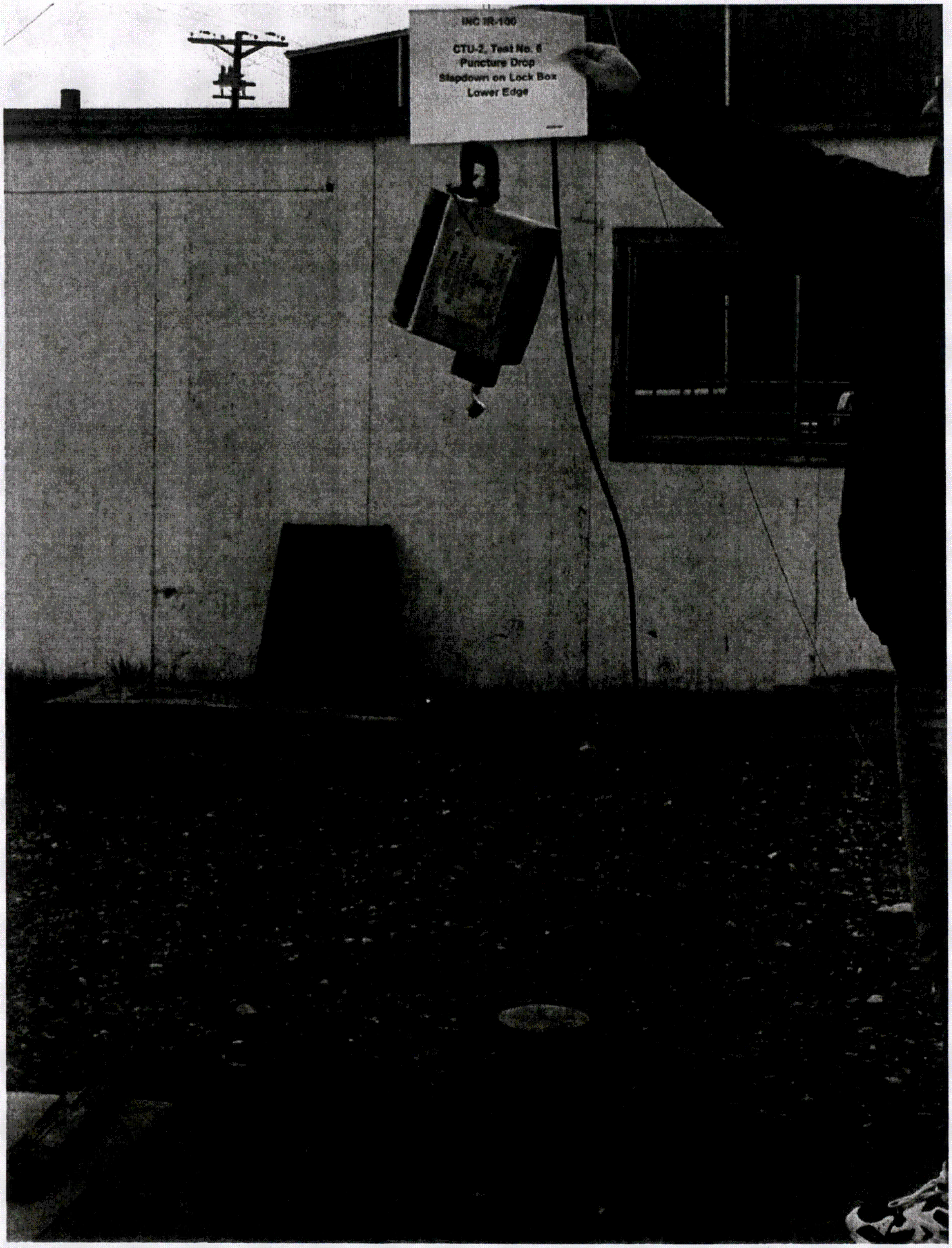


Figure 2.12.1-18 – CTU-2 Puncture Drop Test No. 6

Figure 2.12.1-19 – CTU-2 Puncture Drop Test No. 6 Immediately Prior to Impact

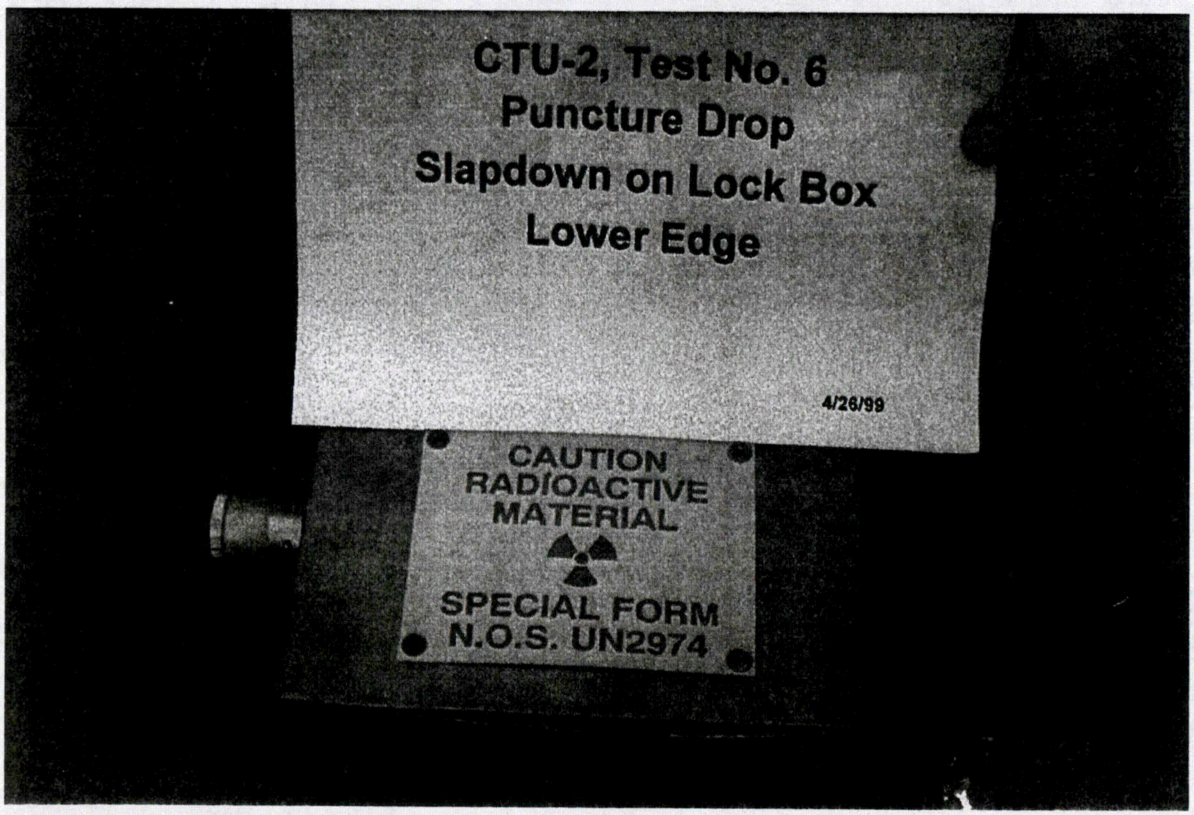


Figure 2.12.1-20 – CTU-2 Puncture Drop Test No. 6; Gap in Housing

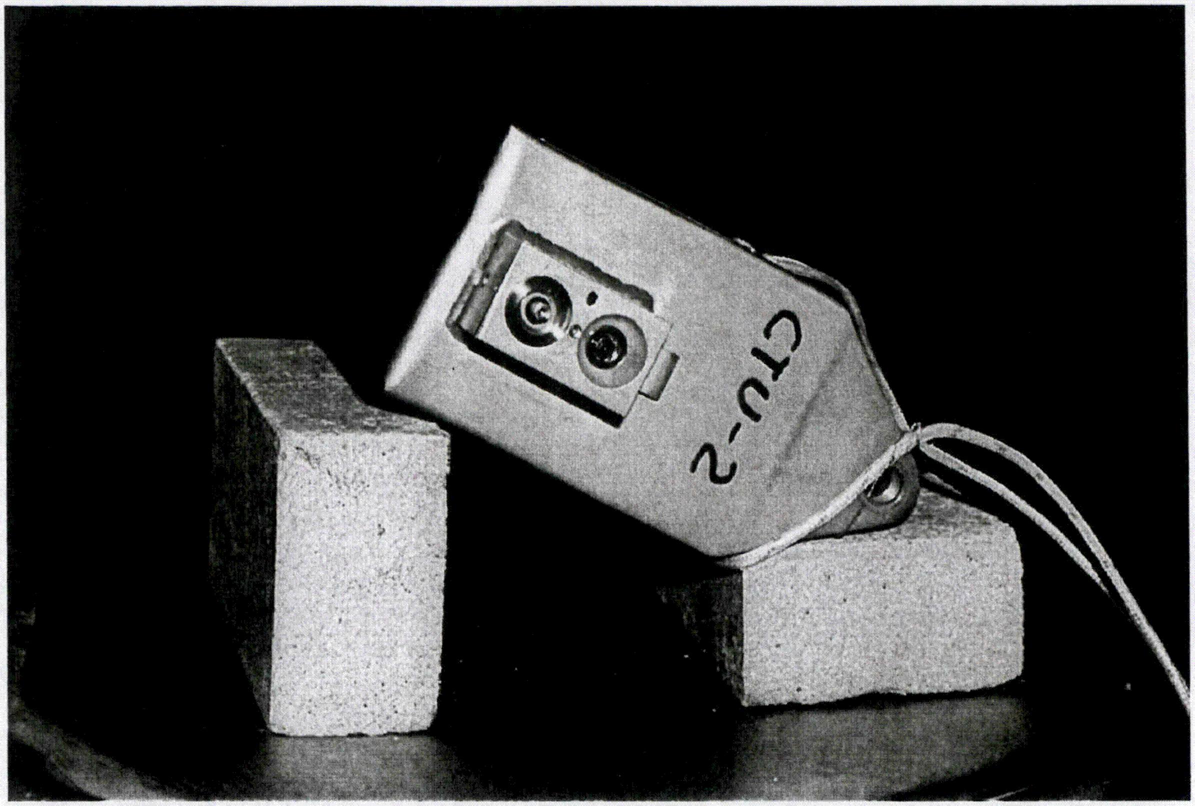


Figure 2.12.1-21 – CTU-2 Thermal Test No. 8 Setup

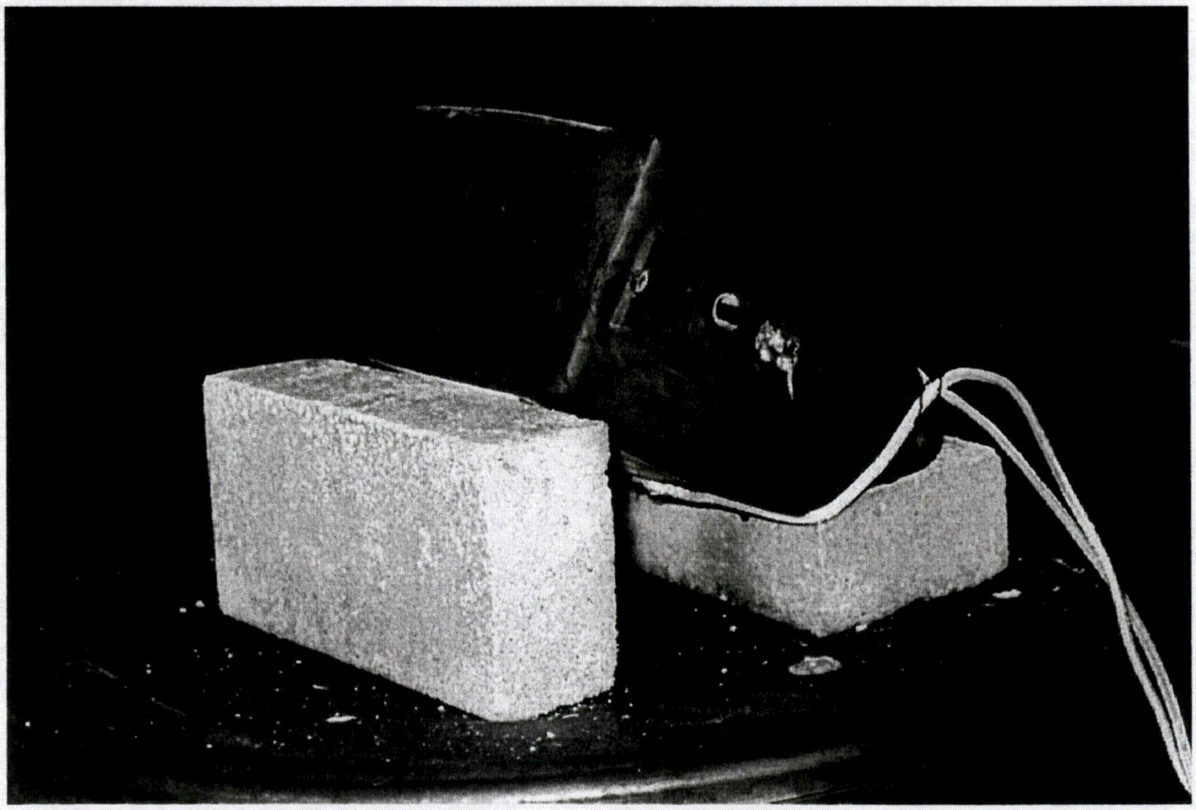


Figure 2.12.1-22 – CTU-2 Thermal Test No. 8 Immediately Upon Removal from Oven

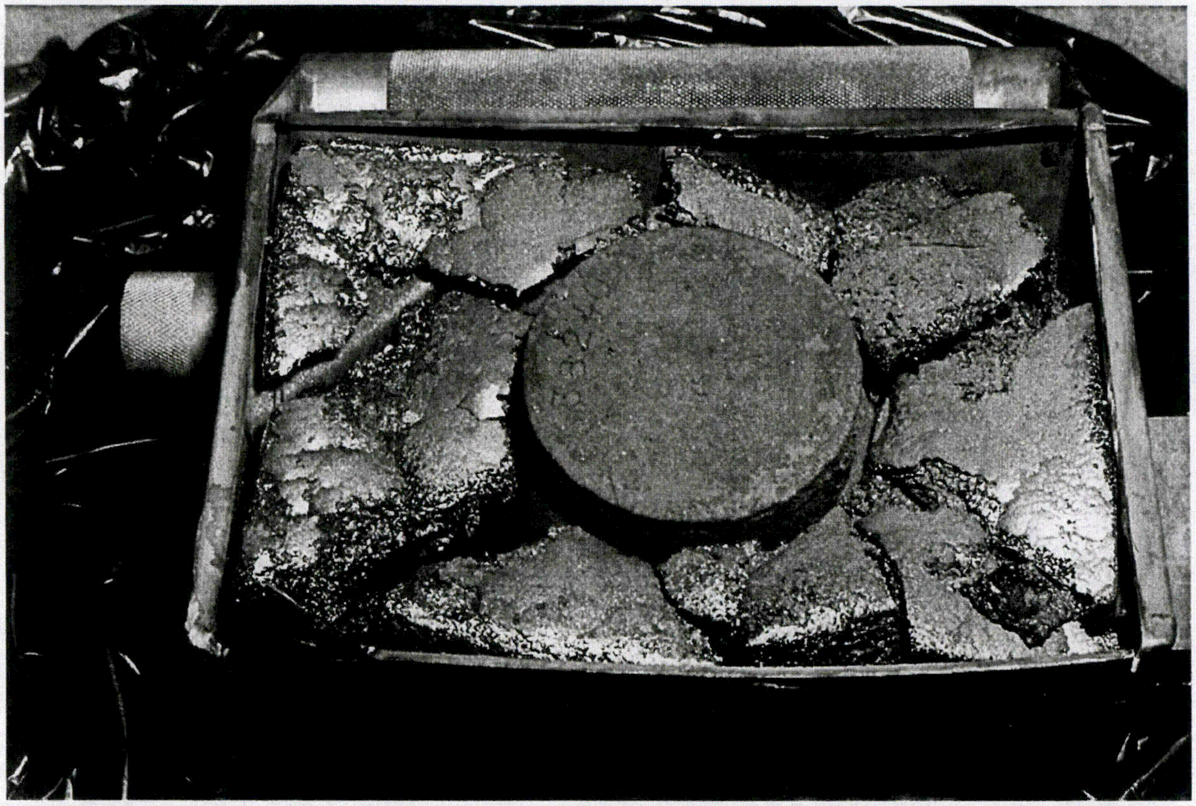


Figure 2.12.1-23 – CTU-2 Post-Test Disassembly; View of Interior Cavity/Foam Char

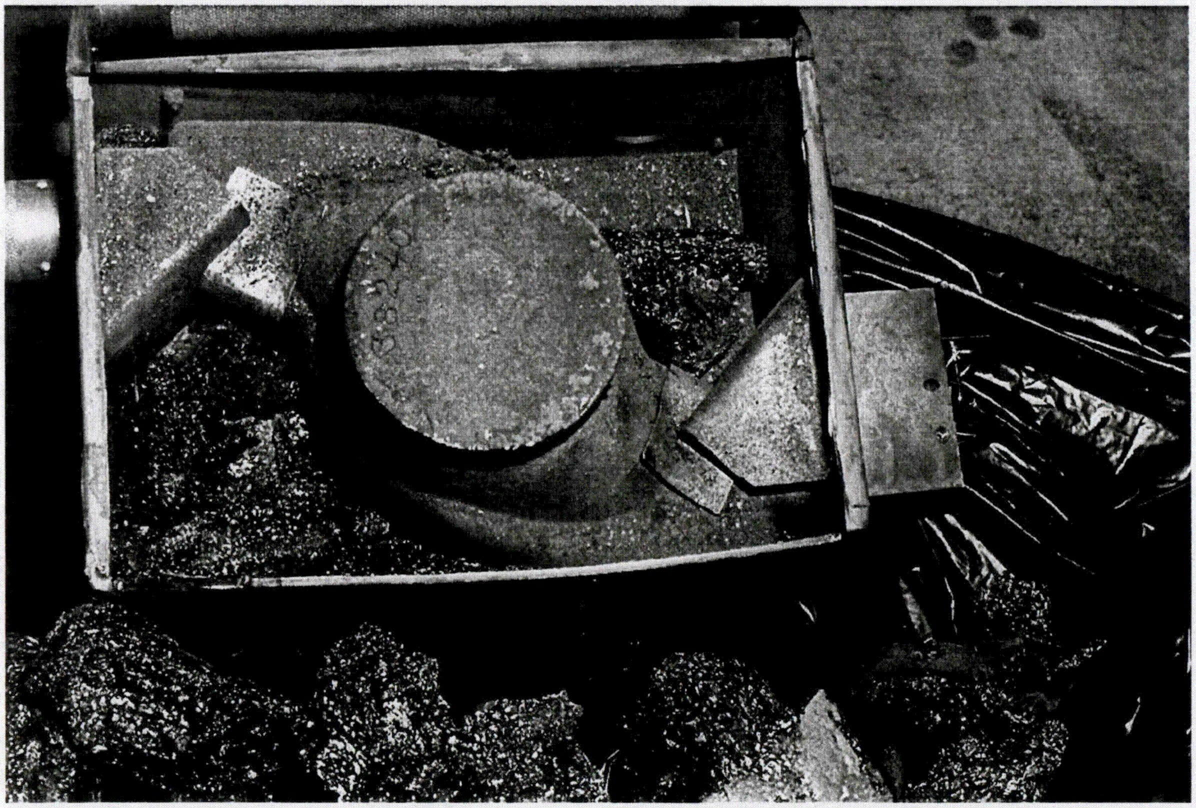


Figure 2.12.1-24 – CTU-2 Post-Test Disassembly; Interior Cavity w/ Foam Char Removed

Figure 2.12.1-25 – CTU-2 Post-Test Disassembly; Gap Between DU Shield & Support Bracket

3.0 THERMAL EVALUATION

This chapter establishes the compliance of the IR-100 transporting a payload of up to 120 Ci (4.44 TBq) of Ir-192 or Se-75 in special form with the thermal requirements of 10 CFR 71[10].

3.1 Description of Thermal Design

3.1.1 Design Features

The IR-100 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 IR-100 may contain up to 120 Ci (4.44 TBq) of Ir-192 or Se-75 in special form. The radiolytic decay heat of Ir-192 is 7.03×10^{-3} W/Ci[12]. The radiolytic decay heat of Se-75 is 2.41×10^{-3} W/Ci[12]. Since the radiolytic decay heat of Ir-192 is greater than the radiolytic decay heat of Se-75, the heatload of Ir-192 payload bounds the Se-75 payload. Therefore, the maximum decay heat load for the IR-100 package is 0.84 W (2.87 Btu/hr), which is negligible.

3.1.3 Summary Tables of Temperatures

The maximum surface temperature of the IR-100 is 189.9 °F, as documented in Appendix 3.6.1, *Determination of Maximum Surface Temperature for IR-100 Package*, in full sunlight.

3.1.4 Summary Tables of Maximum Pressures

The containment of the IR-100 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 IR-100 does not contain any pressure boundaries.

3.2 Material Properties and Component Specifications

3.2.1 Material Properties

The IR-100 is constructed of a 12-gauge (0.105 inch) thick stainless steel outer skin surrounding polyurethane foam and a depleted uranium 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 uranium and stainless steel are 2,071 °F and 2,800 °F, respectively.

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

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[10] Title 10, Code of Federal Regulations, Part 71 (10 CFR 71), *Packaging and Transportation of Radioactive Material*, 1-1-15 Edition.

[12] *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 IR-100 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 shield. As noted in Section 2.1.2.2.1, *Brittle Fracture*, both materials have been tested to temperatures below -20 °F 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 IR-100 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 IR-100 is less than 1 W (3 Btu/hr), a detailed thermal analysis of the package and internals is unnecessary. The peak internal temperatures will very closely match those on the surface of the package.

Per 10 CFR §71.71(c)(1), the worst-case high temperature conditions for the package consist of an ambient temperature of 100 °F and maximum insolation. Under those conditions, the worst case surface temperature for the IR-100 would be 189.9 °F, as documented in Appendix 3.6.1, *Determination of Maximum Surface Temperature for IR-100.*

Given the negligible decay heat, the maximum temperature for all surfaces of the IR-100 in shade with an ambient temperature of 100 °F (560 °R) is 100 °F (560 °R). This temperature is below the maximum acceptable surface temperature of 122 °F for non-exclusive use shipments as stipulated in 10 CFR §71.43(g). Similarly, the package temperature will be equal to ambient under the low temperature conditions of -20 °F and -40 °F

3.3.2 Maximum Normal Operating Pressure

This section does not apply, since the IR-100 does not contain any pressure boundaries. Therefore, there is no maximum normal operating pressure (MNOP) for the IR-100.

3.4 Thermal Evaluation under Hypothetical Accident Conditions

The thermal performance of the IR-100 under Hypothetical Accident Conditions (HAC) was determined via testing in accordance with 10 CFR §71.73. Additional details are provided in the following sections.

3.4.1 Initial Conditions

A previously free and puncture dropped IR-100 certification test unit (CTU) package was placed into an oven and exposed to a forced convective environment that resulted in the average surface temperature of the package to at least 1,475 °F.

3.4.2 Fire Test Conditions

Following the introduction of air and indication of the package surface was at a minimum of 1,475 °F, the package was maintained in the oven for 30 minutes. During the 30-minute test, the surface temperature varied between 1,481 and 1,530 °F. During heat-up, burning of the polyurethane foam

was observed. Following the 30-minute test, the package was removed from the oven and allowed to cool in air.

A post-test examination of the package indicated that the polyurethane foam was completely consumed by the fire, adding its combustion energy to that of the forced convection from the oven. The depleted uranium shielding, and the outer skin of the package were not compromised or appreciably oxidized. Additionally, the peak temperatures recorded in the test were well below the melting temperatures of both stainless steel (2,800 °F) and uranium (2,071 °F).

A post-test radiation survey conducted subsequent to the fire test indicated little, if any, degradation in shielding capability.

The special form qualification of the payload certifies that it could withstand the fire test without degradation.

3.4.3 Maximum Temperatures and Pressures

Based the thermal tests performed on the IR-100, none of the components exceeds its temperature limit as described in Section 3.2.1, *Material Properties*. Specifically, the maximum recorded package temperatures fall more than 500 °F below the melting point of steel and uranium. Additionally, the special form payload does not exceed the temperatures for the special form certification tests.

The containment of the IR-100 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.

This verifies that the IR-100 satisfies the HAC thermal requirements set forth by 10 CFR §71.73(c).

3.4.4 Maximum Thermal Stresses

The effects of HAC thermal stresses were addressed by the fire test. No damage due to thermal stresses was found during post-test examination of the IR-100 CTU.

3.4.5 Accident Conditions for Fissile Material Packages for Air Transport

This section does not apply, since the IR-100 does not contain fissile material.

3.5 Appendix

3.5.1 Determination of Maximum Surface Temperature for IR-100

PACTEC
Packaging Technology, Inc.

Prepared	Paul F. Stevens PFS	Date 06/08/99	Revision 1
Reviewed	Phil W. Noss PWN	Date 6/8/99	Page 1 of 7
Approved	Gary L. Clark G L Clark	Date 6/8/99	Project 98005

Title Surface Temperature Calculation for INC IR-100 Exposure Device

TABLE OF CONTENTS

REVISION LOG

Revision	Date	Item Revised	Reason for Revision
1	06/08/99	pp. 2 – 7	Drawing references updated, package name corrected to "IR-100 Exposure Device"

1.0 OBJECTIVE

The purpose of this calculation is to determine the peak surface temperatures on the Industrial Nuclear Company IR-100 Exposure Device due to solar radiation per the regulations of 10 CFR 71.71(c)(1).

2.0 REFERENCES

1) Code of Federal Regulations, Title 10, Part 71, Packaging and Transportation of Radioactive Materials, 1/1/98.

2) *Engineering Heat Transfer*, James R. Welty, John Wiley and Sons Publishing, New York, 1974.

3) Industrial Nuclear Company, *IR-100 Exposure Device*, Drawings IR-100-1A, IR-100-1B.

4) *Thermal Radiation Properties of Selected Materials*, Volume 1, W. D. Wood, Editor.

3.0 CALCULATION ASSUMPTIONS

- Package self shading (such as the handle shading the top of the package) is considered to be negligible for the purposes of this calculation.
- Conductance along the stainless steel outer skin of the package is conservatively assumed to be negligible.
- Solar radiation is assumed to be at a constant value that is 1/12th of the maximum solar radiation value as prescribed by 10 CFR 71.71(c)(1) (Reference 1).
- Ambient temperature is assumed to be at a constant temperature of 100°F (560 °R) per Reference 1.
- All surfaces, excepting the base, of the IR-100, experience turbulent free convection.

4.0 MATERIAL PROPERTIES

Since conduction is conservatively neglected for the purposes of this calculation, the only pertinent material properties are the emissivity and solar absorptivity of the stainless steel skin.

From Reference 4, page 56, the emissivity of cleaned stainless steel is bounded by a lower value of ε_{ss}=0.25, and a solar absorptivity, α_{ss}=0.50.

Conductivity and kinematic viscosity of air affect convective heat transfer from the IR-100. These material properties are addressed by using simplified heat transfer equations for air as documented in Section 6.0.

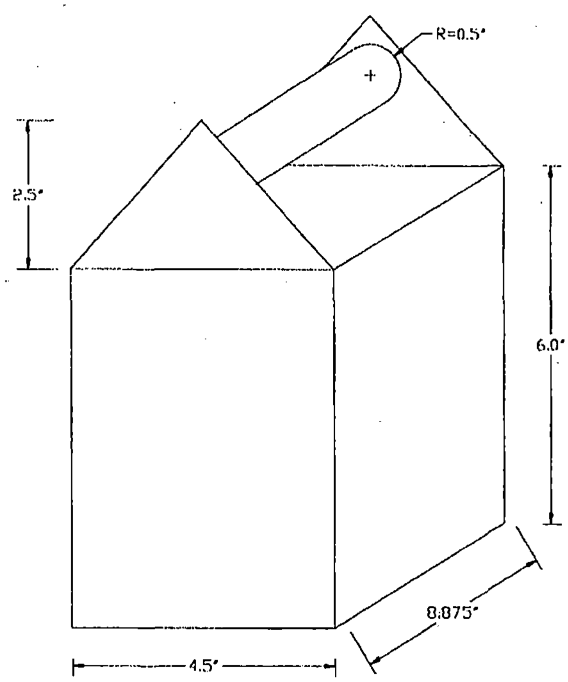
5.0 THERMAL LOADS

Since the decay heat source term of the IR-100 is negligible, the only pertinent thermal load is solar radiation (insolation). Per 10 CFR 71.71(c)(1) (Reference 1), the maximum insolation is as follows:

Surface Orientation	Total Insolation for 12 Hour Period (gcal/cm^2)	Average Heat Flux (Btu/hr-ft^2)
Flat, horizontal (not base)	800	245.7
Flat, horizontal (base)	0	0.0
Flat, non-horizontal	200	61.4
Curved	400	122.9

6.0 ANALYTICAL CALCULATIONS

The simplified dimensions of the IR-100 used in the analytical calculations are shown in the figure below and are derived from Reference 3.



Determining the surface temperature of the IR-100 in the shade with an ambient temperature of 100 °F (560 °R) in accordance with 10 CFR 71.43(g) (Reference 1), which stipulates a maximum accessible surface temperature of 122 °F for non-exclusive use shipments is a trivial exercise. Without a significant decay heat load, the IR-100 will have a surface temperature of 100 °F (560 °F), and thereby meets the requirements of 10 CFR 71.43(g).

The temperature for the curved, horizontal and vertical surfaces with maximum insolation can be found by solving the following heat balance equation for each of the three geometries:

$$\dot{Q}_{solar} = \dot{Q}_{radition} + \dot{Q}_{convection}$$

where

Q_{solar} = Insolation value for the particular geometry $\cdot \alpha_{ss} \cdot$ Area

$Q_{radiation} = \sigma \cdot \varepsilon_{ss} \cdot \text{Area} \cdot (T^4_{surface} - T^4_{ambient})$, $\sigma = 0.1714 \times 10^{-8}$ Btu/hr-ft^2-°R^4

$Q_{convection} = h \cdot \text{Area}(T_{surface} - T_{ambient})$, h = free convection heat transfer coefficient

From Reference 2, pp. 252-3, the general form of h at one atmosphere and moderate temperatures is:

$$h = a\left(\frac{T_{surface} - T_{ambient}}{L}\right)^b$$

Where a, b and L vary based on surface geometry, orientation and whether the free convection is turbulent or laminar. Since turbulent free convection is less efficient, it is conservatively assumed for this analysis that all surfaces on the IR-100 will experience turbulent natural convection. The values for a, b and L for each orientation is presented below:

Simplied Turbulent Free Convection Equation Coefficients

	Flat Vertical	Flat Horizontal	Curved
a	0.19	0.22	0.18
b	1/3	1/3	1/3
L	1.0	1.0	1.0
h=	$0.19\Delta T^{1/3}$	$0.22\Delta T^{1/3}$	$0.18\Delta T^{1/3}$

For a unit area, the energy balance equations for each of the orientation is:

Flat Horizontal (non base)

$$\dot{Q}_{solar} = 245.7 \cdot 0.5 = 122.9 \frac{Btu}{hr}$$

$$\dot{Q}_{radiation} = 0.1714 x 10^{-8} \cdot 0.25 \cdot (T^4_{surface} - 560^4) = 4.29 x 10^{-10} \cdot (T^4_{surface} - 560^4)$$

$$\dot{Q}_{convection} = 0.22 \cdot (T_{surface} - 560)^{1/3} \cdot (T_{surface} - 560) = 0.22 \cdot (T_{surface} - 560)^{4/3}$$

$T_{surface}$ = 649.9 °R or 189.9 °F

Flat Vertical

$$\dot{Q}_{solar} = 61.4 \cdot 0.5 = 30.7 \frac{Btu}{hr}$$

$$\dot{Q}_{radiation} = 0.1714x10^{-8} \cdot 0.25 \cdot (T^4_{surface} - 560^4) = 4.29x10^{-10} \cdot (T^4_{surface} - 560^4)$$

$$\dot{Q}_{convection} = 0.19 \cdot (T_{surface} - 560)^{1/3} \cdot (T_{surface} - 560) = 0.19 \cdot (T_{surface} - 560)^{4/3}$$

$T_{surface}$ = 592.8 °R or 132.8 °F

Curved

$$\dot{Q}_{solar} = 122.9 \cdot 0.5 = 61.5 \frac{Btu}{hr}$$

$$\dot{Q}_{radiation} = 0.1714x10^{-8} \cdot 0.25 \cdot (T^4_{surface} - 560^4) = 4.29x10^{-10} \cdot (T^4_{surface} - 560^4)$$

$$\dot{Q}_{convection} = 0.18 \cdot (T_{surface} - 560)^{1/3} \cdot (T_{surface} - 560) = 0.18 \cdot (T_{surface} - 560)^{4/3}$$

$T_{surface}$ = 618.5 °R or 158.5 °F

7.0 SUMMARY OF RESULTS

The maximum temperature for all surfaces of the IR-100 in shade and an ambient temperature of 100 °F (560 °R) is 100 °F (560 °R), which satisfies the requirements of 10 CFR 71.43(g). Under peak insolation, the maximum predicted surface temperature of the sides of the IR-100, flat vertical surfaces, would be 132.8 °F (598.8 °R), the maximum predicted temperature of the handle, a horizontal curved surface, would be 158.8 °F (618.5 °R), and the maximum predicted temperature of the top of the IR-100, a horizontal flat

surface, is 189.9 °F (649.9 °R). Note, however, that self shading has been neglected for this calculation, so in reality the peak temperature of the top of the IR-100 is expected to be much less than this value.

4.0 CONTAINMENT

The IR-100 is designed as a means of confinement for a special form Ir-192 or Se-75 source capsule. Containment of radioactive material is provided by the special form construction of the payload. The source capsules and their respective special form certification are as follows:

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

* Note: Source capsule is limited to a maximum of 120 Ci of Se-75 material.

Since the IR-100 does not provide containment, subsequent sections of this chapter are not applicable.

5.0 SHIELDING EVALUATION

This section demonstrates the shielding capability of the IR-100 design for the authorized special form contents. The shielding evaluation is demonstrated via prototypic testing in lieu of an analytical evaluation.

5.1 Description of Shielding Design

5.1.1 Design Features

The IR-100 is a welded structure that contains a depleted uranium (DU) gamma shield, which surrounds a titanium S–tube. A stainless steel special form capsule, which contains either 120 Ci (4.44 TBq) of Ir-192 or Se-75 isotope, is inserted into the S–tube via a pigtail assembly. The radioactive source is positioned at the center of the DU gamma shield to provide the maximum attenuation of the gamma radiation.

5.1.2 Summary Table of Maximum Radiation Levels

Table 5-1 provides the maximum measured external radiation levels for the IR-100 with the maximum bounding payload content (120 Ci (4.44 TBq) Ir-192) for a non–exclusive use shipment.

Table 5-1 - Maximum Measured External Radiation Levels (Non–Exclusive Use)

Package Measurement Location	Normal Conditions of Transport		Hypothetical Accident Conditions	
	Measured[1] 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	106 (1.06)	200 (2)	N/A	N/A
1 Meter from Surface	0.9 (0.009)	10 (0.1)	0.9 (0.009)	1000 (10)

Note: 1. Normal condition measured values are for a test unit that was post-test for the hypothetical accident conditions tests per 10 CFR §71.73.

5.2 Source Specification

5.2.1 Gamma Source

The radioactive content of the IR-100 is limited to 120 Ci (4.44 TBq) of either Ir-192 or Se-75 isotopes. As shown in Table 5-2, 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 120 Ci (4.44 TBq) content. Since actual Ir-192 special form capsules are utilized to determine the acceptance of the DU gamma shielding, the tabulation of gamma decay source strengths for the special form capsules is not required for the IR-100.

5.2.2 Neutron Source

This section does not apply, since the IR-100 does not contain fissile material.

Table 5-2 – Specific Gamma Ray Constants for Iridium and Selenium Isotopes[13]

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

5.3 Shielding Model

The shielding capability of the IR-100 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 IR-100 is via prototypic testing utilizing a special form capsule containing radioactive Ir-192 material.

5.4.2 Input and Output Data

This section does not apply, since the shielding performance of the IR-100 is not performed analytically.

5.4.3 Flux-to-Dose-Rate Conversions

This section does not apply, since the shielding performance of the IR-100 is not performed analytically.

5.4.4 External Radiation Levels

Following the specified tests of a prototypic package with a 120 Ci (4.44 TBq) of Ir-192 payload per 2.6, *Normal Conditions of Transport*, and 2.7, *Hypothetical Accident Conditions*, the maximum radiation level measured on the surface and at 1-meter of the IR-100 is 106 mrem/hr (1.06 mSv/hr) and 0.9 mrem/hr (0.009 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).

[13] "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 IR-100 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 IR-100. Hereafter, reference to specific IR-100 components may be found in Appendix 1.3.1, *General Arrangement Drawings*.

7.1.1 Preparation of the IR-100 for Loading

1) Visually inspect the IR-100 for damage and/or missing parts.
2) Remove the Safety Plug and the dust cover. Check the threads for wear or damage.
3) Inspect the Lock Box for damage or missing set screws. Replace any damaged or missing set screws.
4) Prior to loading an active Ir-192 or Se-75 source into the package, insert a dummy source pigtail and functionally test the automatic locking device to ensure that all components are operating properly.
5) Pull (retract) the dummy pigtail. The Safety Latch Plate will pop-up and lock the dummy source in the stored position. Rotate the key to the locked position and remove the key.
6) Insert the key into the lock, retract (pull) the dummy source pigtail and rotate the key to the unlocked position. Manually depressed the Safety Latch Plate to the operate position and remove the dummy source pigtail.

7.1.2 Loading the Special Form Payload into the IR-100

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 the package.
3) Crank the drive cable out through the guide tube and connect it to the Ir-192 source pigtail assembly. Connect the guide tube to the source changer.
4) Unlock the source changer and retract the Ir-192 or Se-75 source pigtail assembly into the package.
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 Safety Plug and dust cap.
7) Install the Ir-192 or Se-75 source identification plate on the top of the IR-100.

7.1.3 Preparation for Transport

1) Install the two tamper-indicating seals (security wire/lead seals). One tamper-indicating seal is located at the lock assembly; the second is located at the safety plug and has the lock keys attached.
2) Load the IR-100 onto the transport and secure using tie-down rope or straps, as shown in Figure 7-1. (In lieu of using tie-down rope or straps, the IR-100 may be optionally placed within a shielded lock box that secured within a transport vehicle.)

3) Monitor external radiation per the guidelines of 49 CFR §173.441[14].
4) Determine the shielding transport index for the loaded IR-100 per the guidelines of 49 CFR §173.403.
5) Complete all necessary shipping papers in accordance with Subpart C of 49 CFR 172[15].
6) IR-100 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.

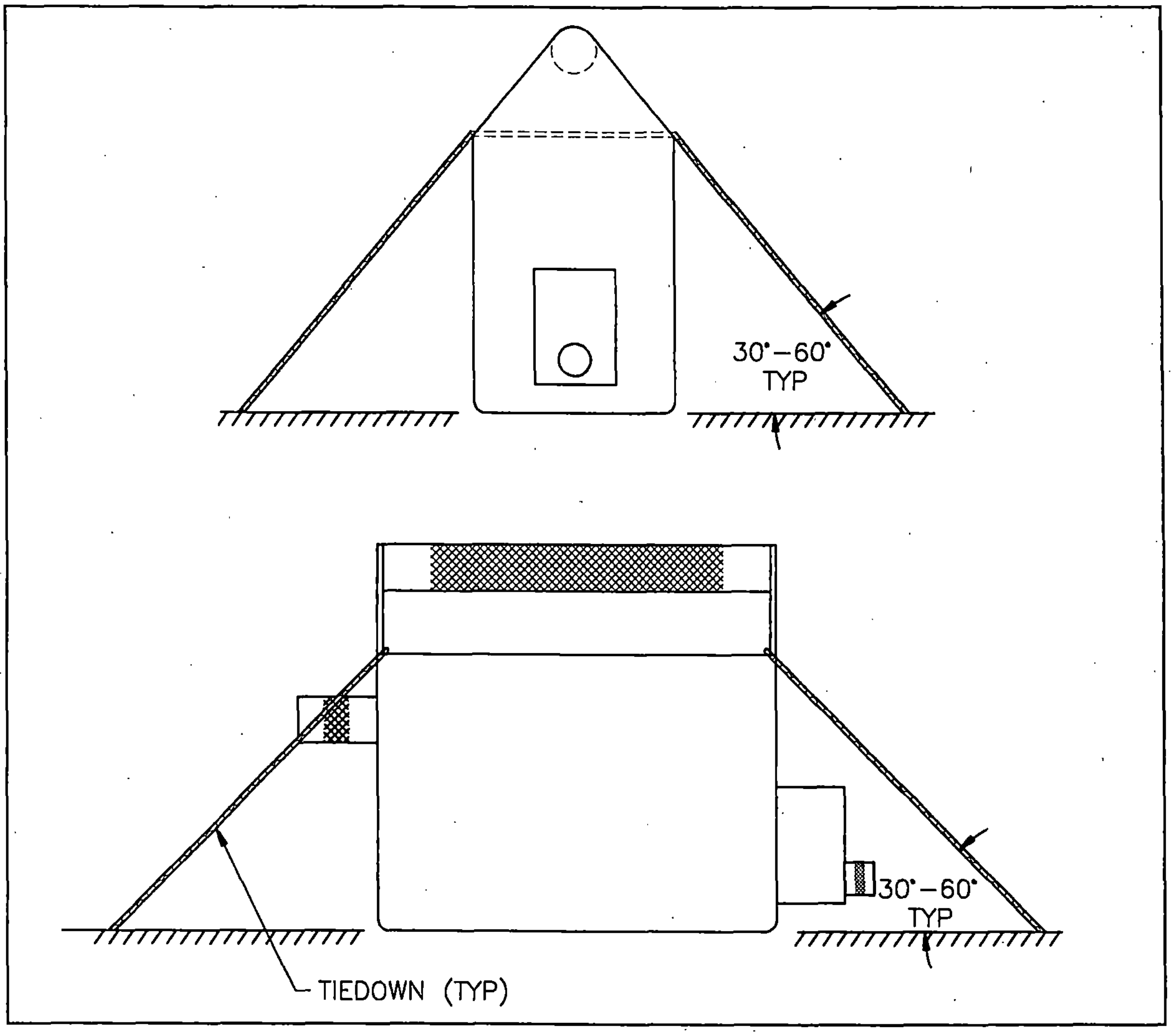


Figure 7-1 IR-100 Tie-down Configuration

7.2 Package Unloading

This section delineates the procedures for unloading a payload into the IR-100. Hereafter, reference to specific IR-100 components may be found in Appendix 1.3.1, *General Arrangement Drawings*.

[14] Title 49, Code of Federal Regulations, Part 173 (49 CFR 173), *Shippers-General Requirements for Shipments and Packagings*, 10-1-14 Edition.

[15] Title 49, Code of Federal Regulations, Part 172 (49 CFR 172), *Hazardous Materials Tables and Hazardous Communications Regulations*, 10-1-14 Edition.

7.2.1 Receipt of Package from Carrier

1) Remove the tie-down devices that secure the IR-100 to the transport vehicle. If optionally transported within a shielded lock box, remove the IR-100 from the lock box.
2) Monitor the external radiation to ensure that the IR-100 was not damaged during shipment.

7.2.2 Removal of Contents from the IR-100 Package

1) Remove the tamper indicating wire seals.
2) Remove the Safety Plug and the dust cover.
3) Connect the drive cable housing and the guide tube to the package. Connect the guide tube to a source changer.
4) Unlock the IR-100 and extend the Ir-192 or Se-75 source pigtail assembly into the source changer.
5) Secure the Ir-192 or Se-75 source pigtail assembly in the source changer, lock, and remove the key.
6) Disconnect the drive cable from the source changer and retract it.
7) Disconnect the guide tube from the source changer and the IR-100. Install the Safety Plug and dust seal on the IR-100.
8) Complete all required shipping papers in accordance with Subpart C of 49 CFR 172.
9) IR-100 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 an Empty Package for Transport

Previously used and empty IR-100s 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 IR-100.

8.1.1 Visual Inspections and Measurements

All IR-100 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 IR-100 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 IR-100 does not contain any lifting/tie-down devices or pressure boundaries that require testing.

8.1.4 Leakage Tests

The IR-100 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 IR-100 does not contain any additional components or materials that require acceptance testing.

8.1.6 Shielding Tests

A radiation profile is performed on each depleted uranium (DU) shield prior to being used in the fabrication of an IR-100. These measured survey results are ratioed to determine the expected radiation levels for the maximum authorize source strength of 120 Ci (4.44 TBq) for either Ir-192 or Se-75 isotopes. Any radiation profile of a DU shield that results in a dose rate that exceeds the requirements of 49 CFR §173.441 with the maximum authorized payload shall not be utilized in the manufacture of an IR-100.

8.1.7 Thermal Tests

The IR-100 does not contain any thermal features or systems that require testing. Therefore, this section does not apply.

8.1.8 Miscellaneous Tests

There are no additional acceptance tests required for the IR-100.

8.2 Maintenance Program

This section describes the maintenance program used to ensure continued performance of the IR-100.

8.2.1 Structural and Pressure Tests

The IR-100 does not contain any lifting/tie-down devices or pressure boundaries that require load testing.

8.2.2 Leakage Tests

The IR-100 does not contain any seals or containment boundaries that require testing.

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 Assembly

Prior to each use, inspect the lock assembly for restrained motion. Any motion or operational impairing shall be corrected prior to further use.

8.2.4 Thermal Tests

No thermal tests are necessary to ensure continued performance of the IR-100.

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 shield has maintained its shielding function.