71-9185

July 21, 2015

INDUSTRIAL NUCLEAR CO., INC.

M. Sampson, Branch Chief,
Spent Fuel Licensing Branch
Division of Spent Fuel Management
Office of Nuclear Material Safety and Safeguards
Two White Flint North – Mail Stop T4-B34
11545 Rockville Pike
Rockville, MD 20852-2738

Subject: Certificate of Compliance Amendment Request, Docket 71-9185

Dear Ms. Sampson,

Enclosed please find one hardcopy and five (5) Compact Discs containing Industrial Nuclear Company's amendment request to Certificate of Compliance 71-9185 for the addition of Selenium-75 isotope to the OP100 Type B shipping container. The enclosed Safety Analysis Report, OP100 Package, Docket 71-9185, Revision 4, includes all required analyses for use of Selenium-75 in this exposure device.

Please note that the SAR was updated to the format and content of NRC Reg Guide 7.9, Rev. 2.

Please contact Mike Rose at 510.352.6766 if you have any questions.

Sincerely,

Mike Rose, QA Manager/ARSO
Industrial Nuclear Company

NMSS01

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SAFETY ANALYSIS REPORT

OP100 PACKAGE

Docket Number 71-9185

Revision 4

June 2015

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San Leandro, California 94577
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TABLE OF CONTENTS

1.0 GENERAL INFORMATION

This chapter of the OP-100 Package Safety Analysis Report presents a general introduction and description of the OP-100 Package. A detailed description of the major packaging and payload components is presented in the following sections. Detailed drawings are presented in Appendix 1.3.1, *General Arrangement Drawings.*

1.1 Introduction

The Industrial Nuclear Co. (INC) Model OP-100 package consists of a 10-gallon steel drum, which houses a plywood support structure and either an INC Model IR-100 Exposure Device (NRC Docket No. 71-9157) or an INC Model IR-50 Source Changer. The drum is certified to comply with DOT/UN Standard No. 1A2/X150/S (steel drum w/ removable head, satisfies Packaging Groups I, II, & III Tests, intended for solids [Specific Gravity = 1.5] or inner packagings). The plywood support structure centrally locates the Model IR-100 or the Model IR-50 within the steel drum overpack. The steel drum lid is secured by a 12-gauge, ASTM A366 carbon steel closure ring which is secured with a 5/8-inch diameter × 4 inch long carbon steel hex bolt. Although the bolt threads into the closure ring lug, a hex nut is added for additional security. The drum lid and body are fabricated using 20-gauge, ASTM A366 carbon steel. An overall view of the OP-100 package is shown in Figure 1-1.

Authorization is sought for shipment of a single, special form iridium-192 (Ir-192) or selenium-75 (Se-75) source capsule (per package) as a Type B(U), 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 OP-100 package is a Type B(U) package designed for the transportation of an Ir-192 or Se-75 special form capsule. The maximum gross weight of the package is 77 pounds and its primary components of construction are identified in Figures 1-1 and 1-2. The two payloads, the IR-100 Exposure Device and the IR-50 Source Changer, are illustrated in Figures 1-3 and 1-4 respectively. The radioactive source contained by either payload is a special form capsule containing a maximum of 120 curies (Ci) (4.44 terabecquerels (TBq)) of Ir-192 or Se-75, and is described in Section 1.2.2, *Contents of Packaging.* Primary shielding is provided by depleted uranium (DU). The DU shielding, which is composed of 0.23% U-235, 99.77% U-238, and illustrated in Figure 1-3 and Figure 1-4, is a solid form casting. The shield contains 0.0042 Ci (0.00016 TBq) of DU. Detailed drawings of the OP-100 package are provided in Appendix 1.3.1, General Arrangement Drawings, *OP-100 Package.*

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

1.2.2 Contents of Packaging

The OP-100 package is designed to transport either an IR-100 Exposure Device or an IR-50 Source Changer, which are illustrated in Figure 1-3 and Figure 1-4 respectively. Either payload may contain 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 of the IR-100 or IR-50 device.

1.2.3 Special Requirements for Plutonium

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

1.2.4 Operational Features

There are no operationally complex features of the OP-100 package. The contents (described in the following section) are confined within the steel drum that provides the overall protection of the payload. In addition to the secured steel drum closure, the Lock Box, which is integral to the IR-100/IR-50 stainless steel housing and DU gamma shielding, prevents unauthorized removal or unshielded exposure or the contents. The Lock Box assembly, which allows access to the contents, also conforms to the requirements of 10 CFR §34.22[2]. Each housing incorporates a handle to facilitate manual handling of the payload. Sequential steps of operation are provided in Chapter 7.

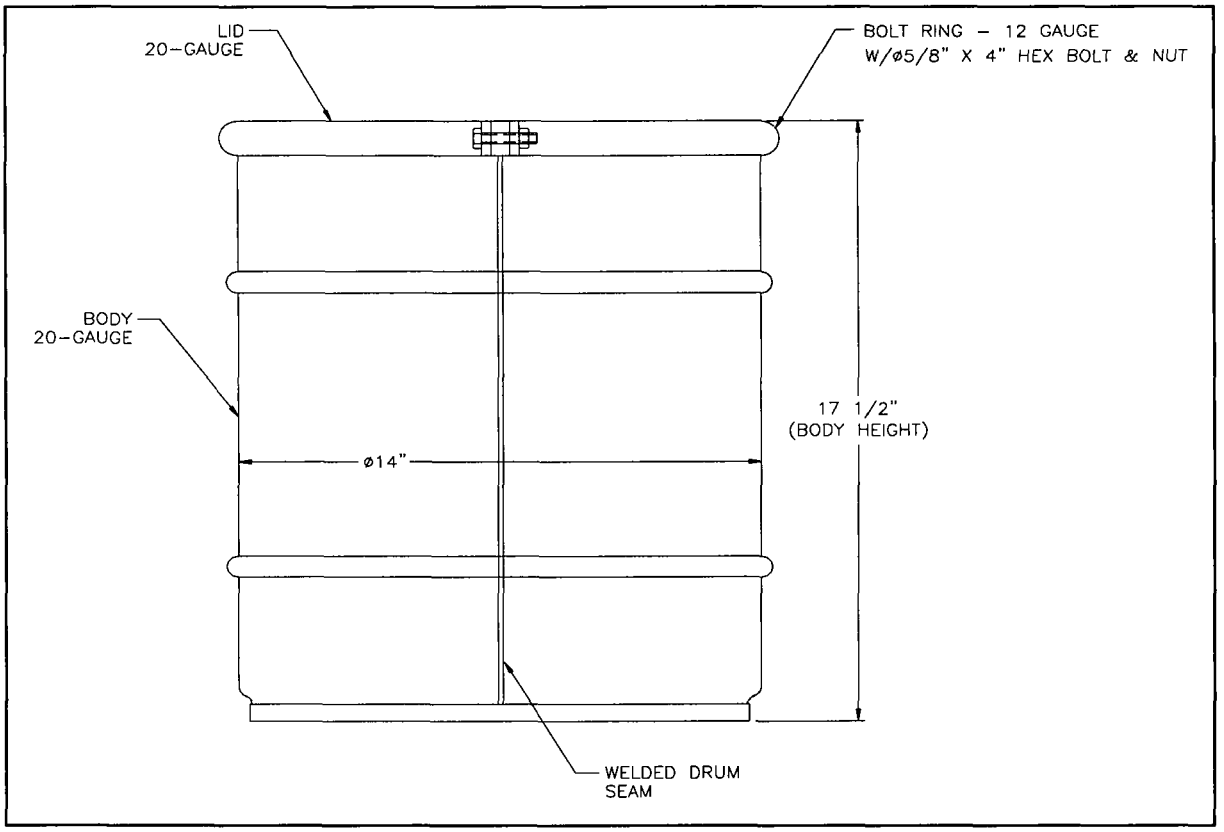

Figure 1-1 - INC OP-100 Packaging

[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.

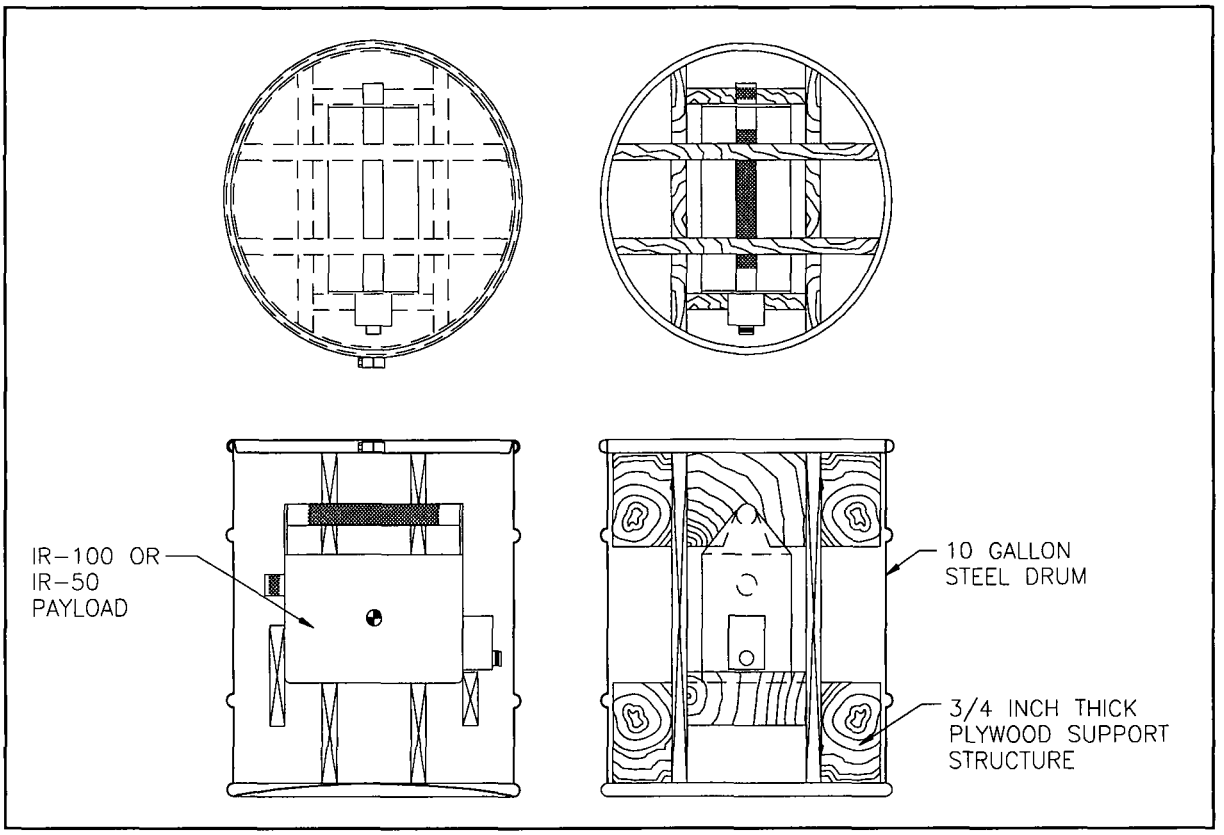

Figure 1-2 - Sectional View of the OP-100 Packaging

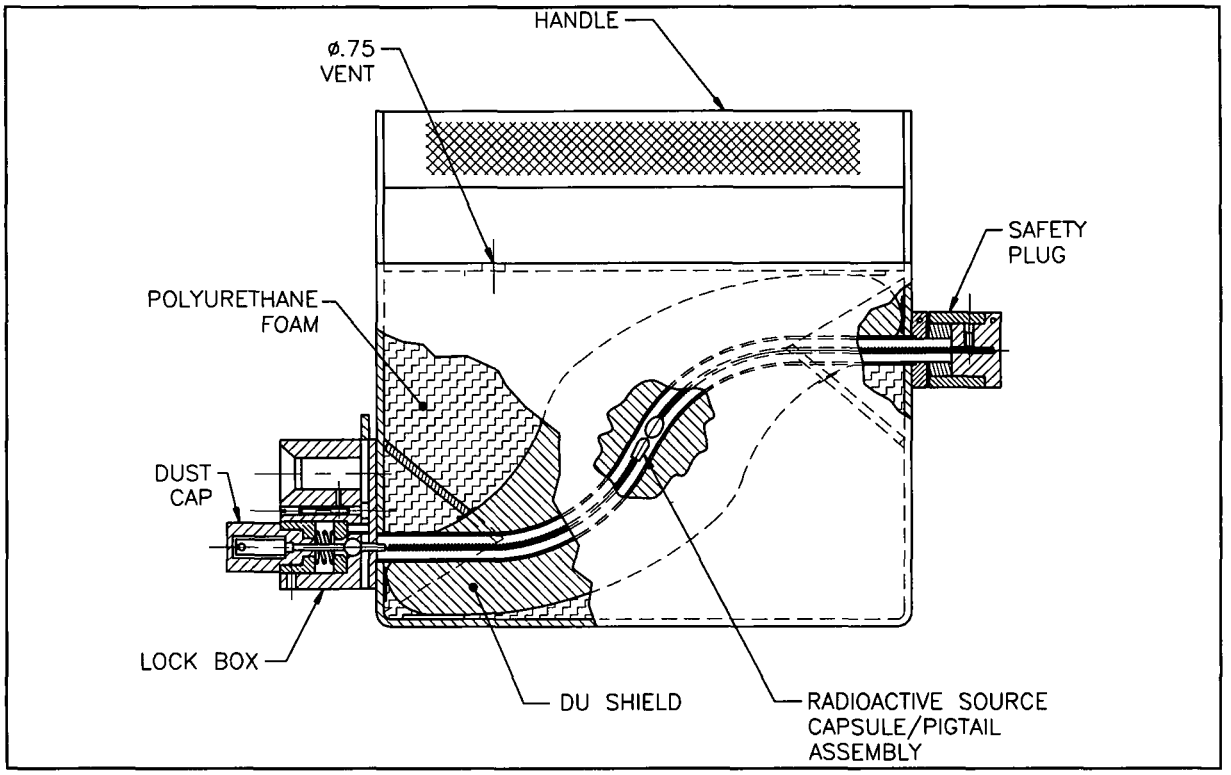

Figure 1-3 - Sectional View of the IR-100 Exposure Device

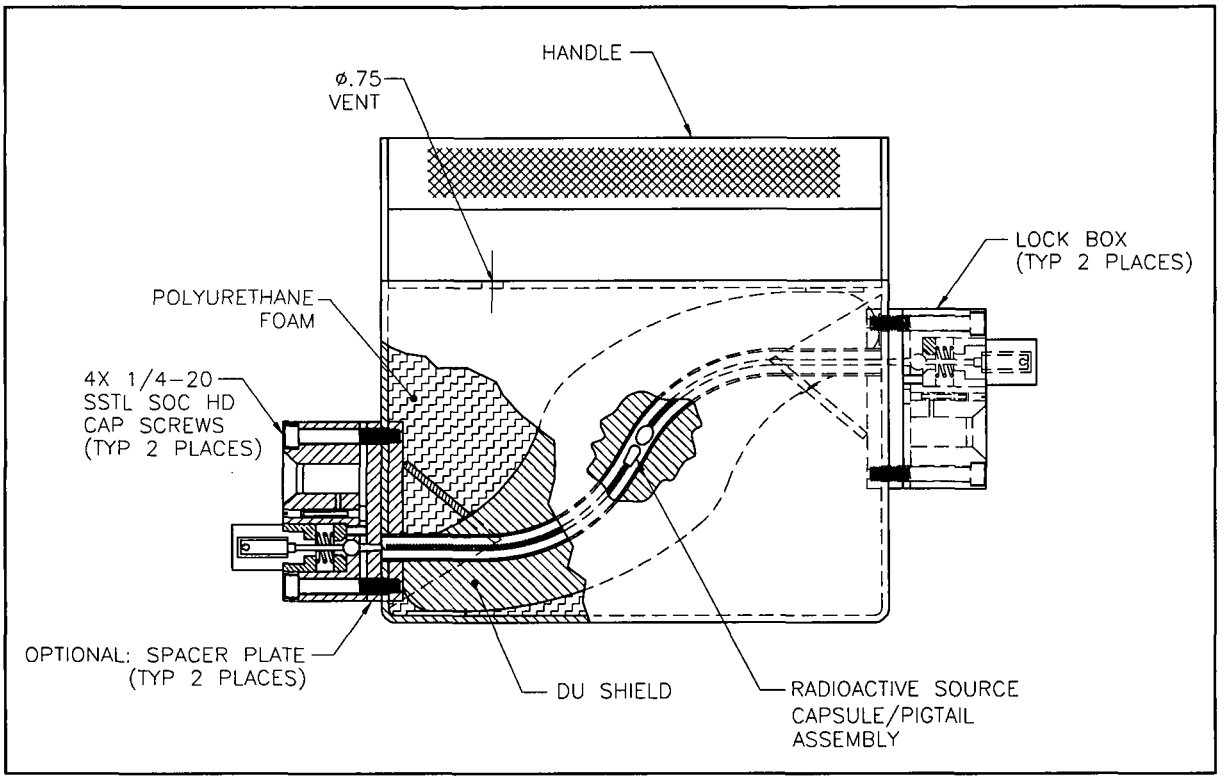

Figure 1-4 - *Sectional View of the IR-50 Source Changer*

1.3 Appendices

1.3.1 General Arrangement Drawings

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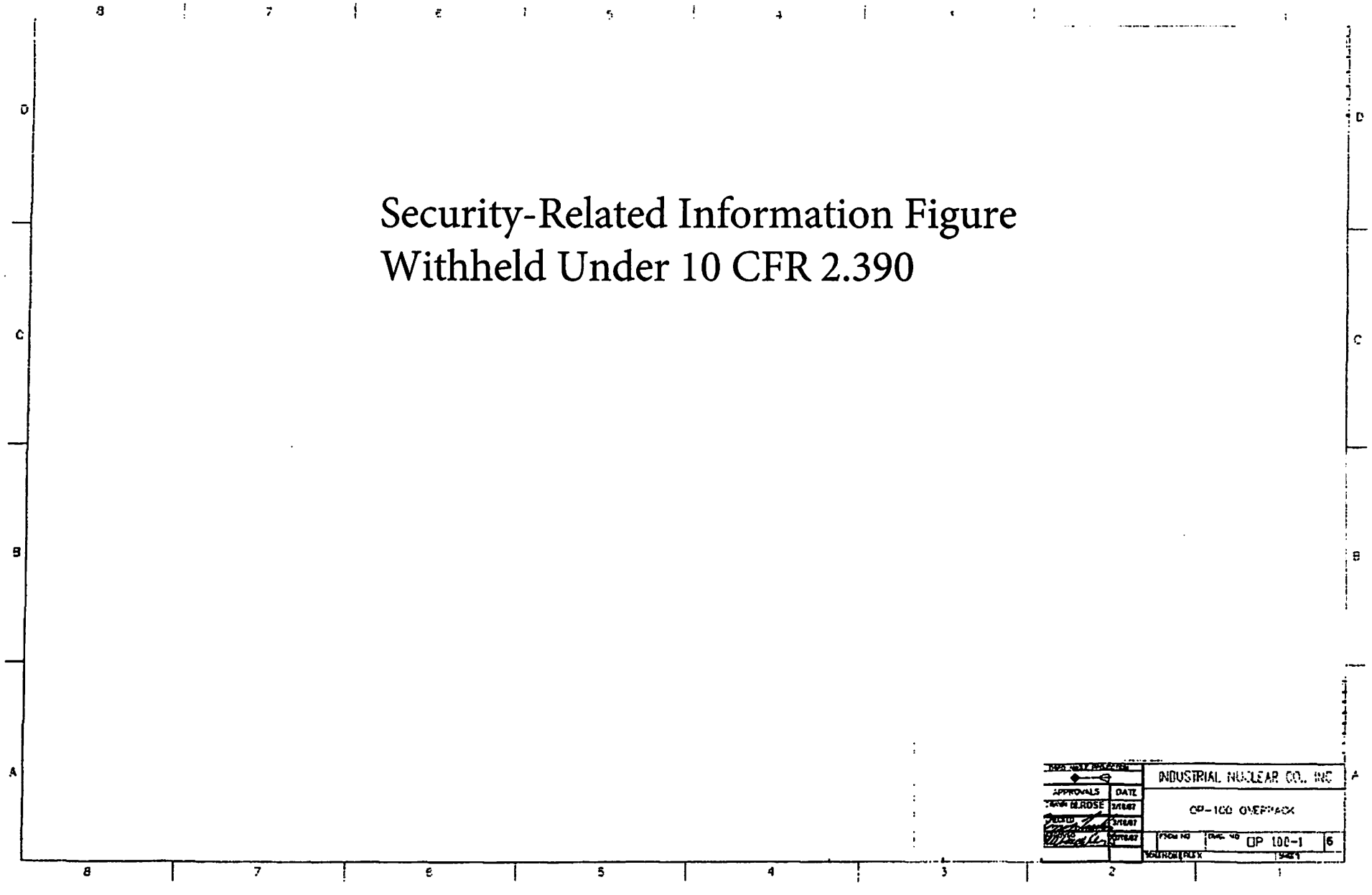

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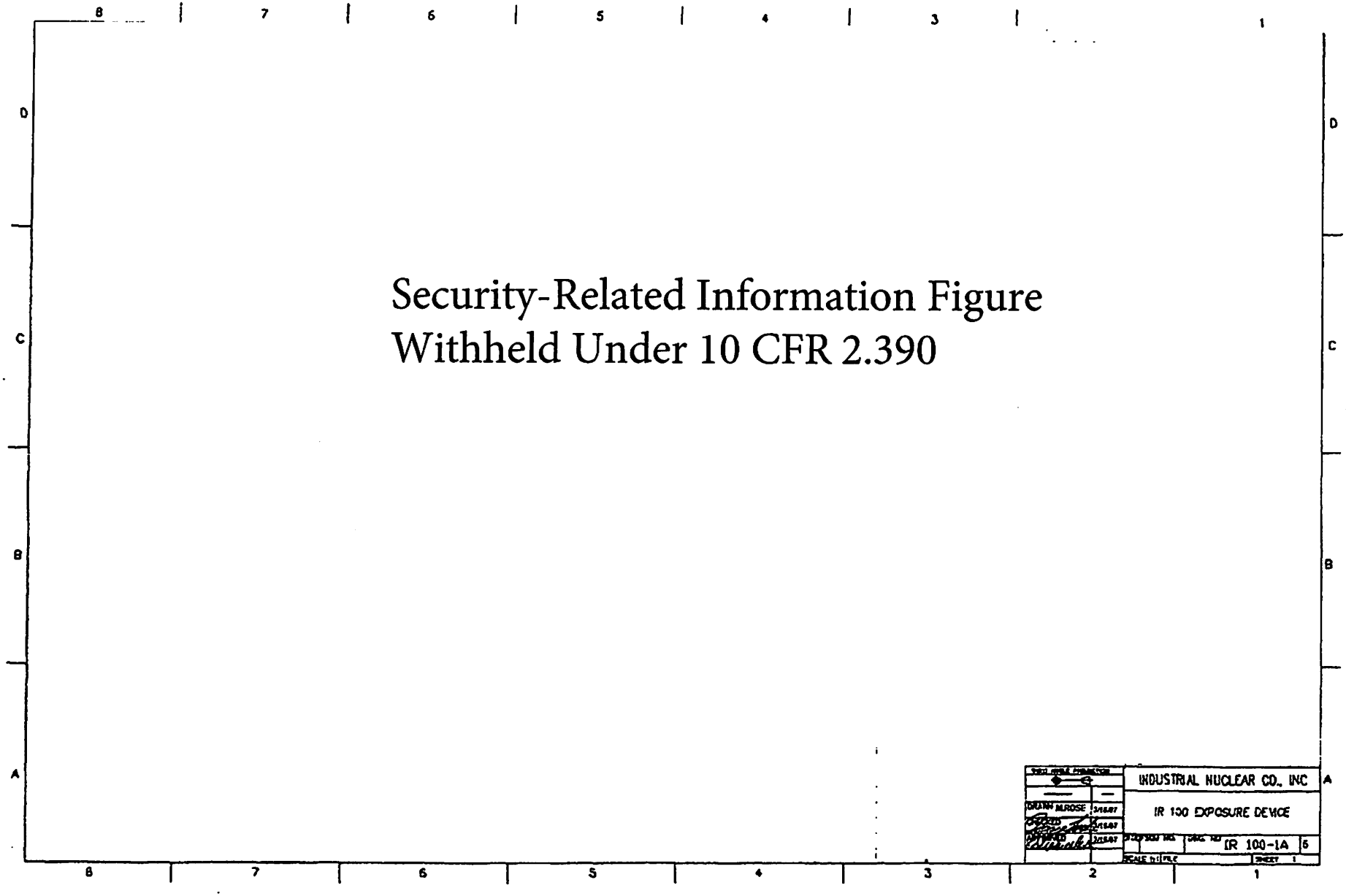

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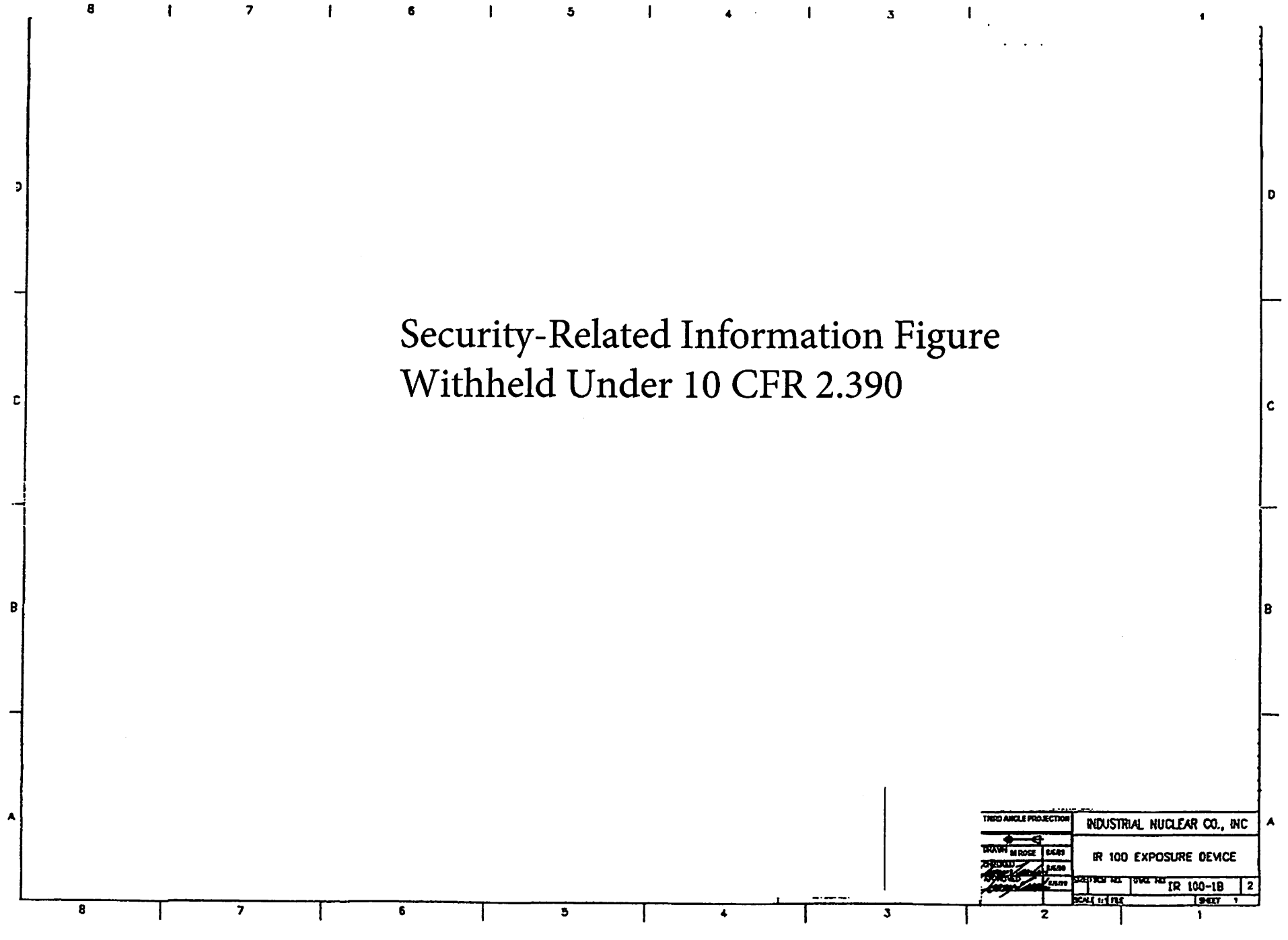

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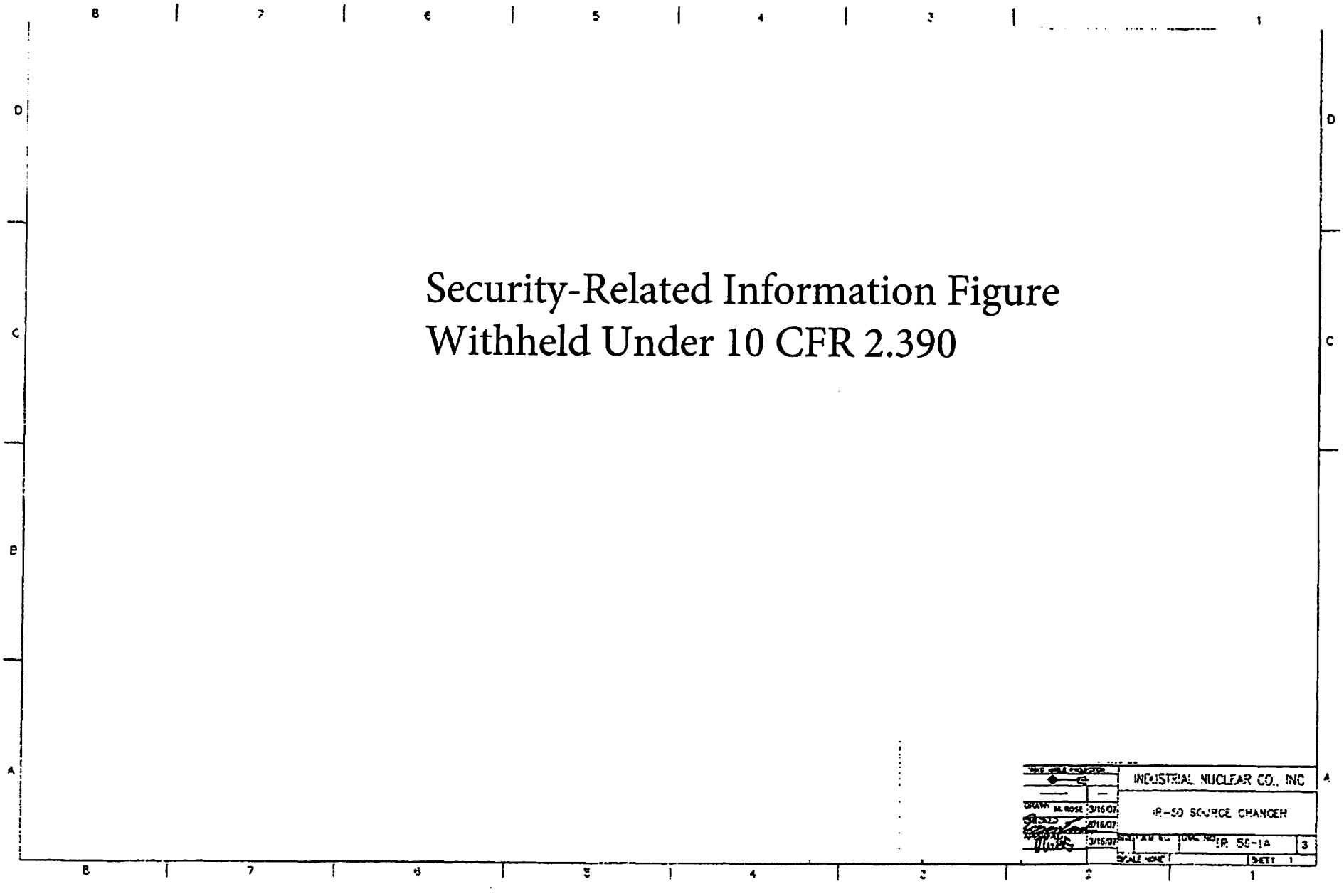

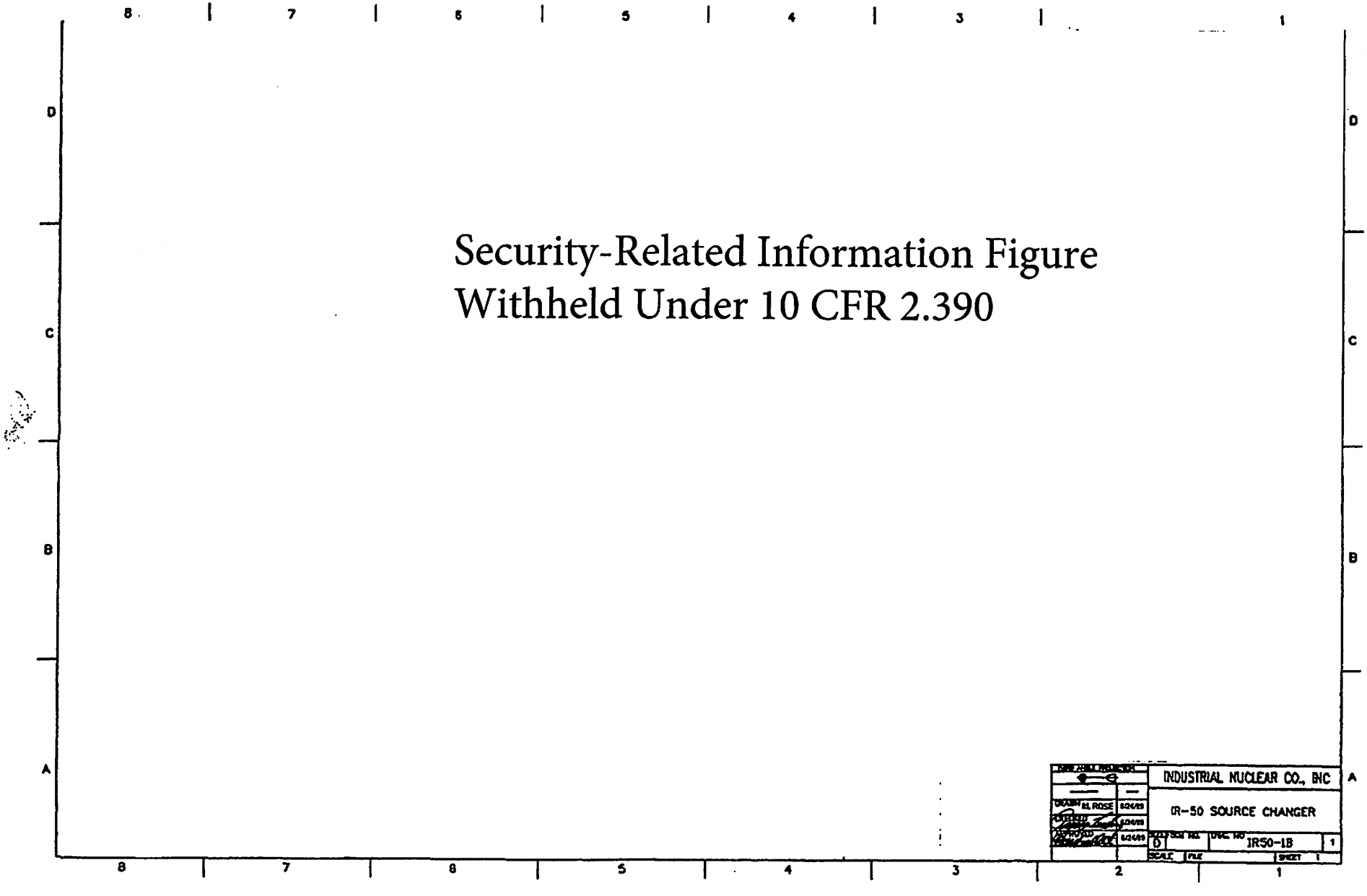
Security-Related Information Figure
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INDUSTRIAL NUCLEAR CO., INC
IR-50 SOURCE CHANGER
IR50-1B

2.0 STRUCTURAL EVALUATION

This chapter presents the structural design criteria, weights, mechanical properties of material, and structural evaluations which demonstrate that the OP-100 package meets all applicable structural criteria for transportation as defined in 10 CFR 71[3].

2.1 Description of Structural Design

The primary evaluation of the OP-100 package 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 OP-100 package consists of five major fabricated components: 1) a standard, DOT/UN Standard No. 1A2/X150/S 10-gallon drum, 2) plywood dunnage for positioning the payload in the drum, 3) a stainless steel housing and lock assembly which enclose and secure the radioactive contents, 4) polyurethane foam which provides protection of the DU from moisture, and 5) DU gamma shielding which provides shielding.

2.1.1 Discussion

2.1.1.1 OP-100 Packaging

The OP-100 package consists of a 10-gallon steel drum that houses a plywood support structure and either a Model IR-100 Exposure Device or a Model IR-50 Source Changer. The drum is certified to comply with DOT/UN Standard No. 1A2/X150/S (steel drum w/ removable head, satisfies Packaging Groups I, II, & III Tests, intended for solids [Specific Gravity = 1.5] or inner packagings). The plywood support structure centrally locates the Model IR-100 or the Model IR-50 within the steel drum overpack. The steel drum lid is secured by a 12-gauge, ASTM A366 carbon steel closure ring, which is secured with a 5/8-inch diameter × 4 inch long carbon steel hex bolt. Although the bolt threads into the closure ring lug, a hex nut is added for additional security. The drum lid and body are fabricated using 20-gauge, ASTM A366 carbon steel. The gross weight of the OP-100 package overpack is 77 pounds, and is illustrated in Figure 2-1.

2.1.1.2 IR-100 Exposure Device

The Model IR-100 Exposure Device 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 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 in 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, which prevents moisture from contacting the DU material. The Model IR-100 Exposure Device is illustrated in Figure 2-2.

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

The stainless steel housing is fabricated from 11-gauge (0.120 inch) thick Type 304 stainless steel sheet. The stainless steel sheet joints are continuously welded so that the DU shield assembly is fully encased in stainless steel.

The radioactive source is a Special-Form, encapsulated capsule assembly that is attached to a source wire or "pigtail" assembly. The pigtail assembly is secured in the package by the stainless steel Lock Box that is welded to the rear end plate. The pigtail assembly maintains the radioactive source in a central location within the DU shield, which provides maximum shielding to the public. Maintaining the location of the radioactive source is an important safety requirement since significant displacement of the source from the stored position would elevate the surface and 1-meter dose rates.

2.1.1.3 IR-50 Source Changer

The Model IR-50 Source Changer utilizes the same DU shield assembly and welded stainless steel housing as the Model IR-100 Exposure Device. The difference between the two units is that the Model IR-50 Source Changer has a bolted lock box on each end of the housing. Each lock box is attached to the stainless steel housing by (4) 1/4 - 20 UNC × 2 inch stainless steel socket head cap screws, which thread into a 1/4 inch thick stainless steel plate that is welded on the inner surface of the housing. The Model IR-50 Source Changer is illustrated in Figure 2-3.

The radioactive source is a Special-Form, encapsulated capsule assembly that is attached to a source wire or "pigtail" assembly. The pigtail assembly is secured in the package by one of the stainless steel Lock Boxes that are attached to the front or rear end plates. To accommodate various length pigtail assemblies, a stainless steel spacer plate, maximum 0.950 inches thick, may be installed between the lock box and the stainless steel housing. The pigtail assembly maintains the radioactive source in a central location within the DU shield, which provides maximum shielding to the public. Maintaining the location of the radioactive source is an important safety requirement since significant displacement of the source from the stored position would elevate the surface and 1-meter dose rates.

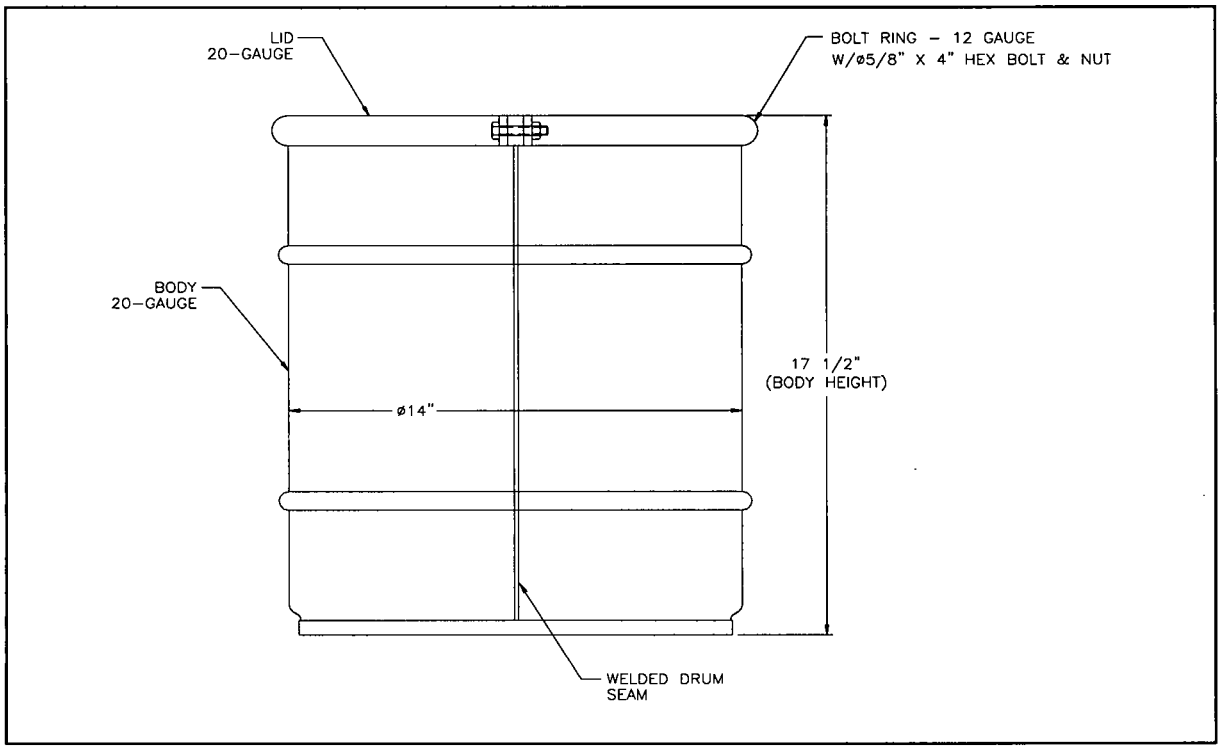

Figure 2-1 - OP-100 Packaging

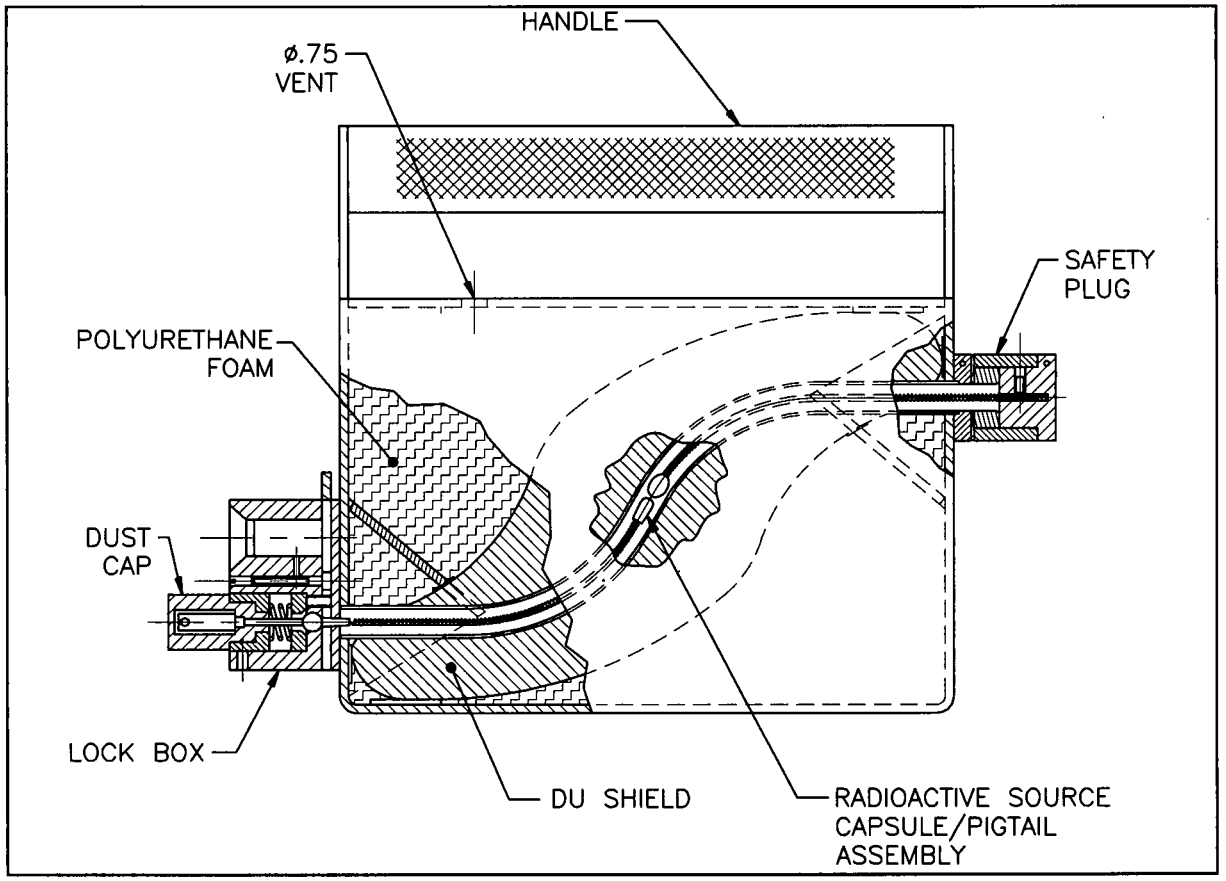

Figure 2-2 - Sectional View of the IR-100 Exposure Device

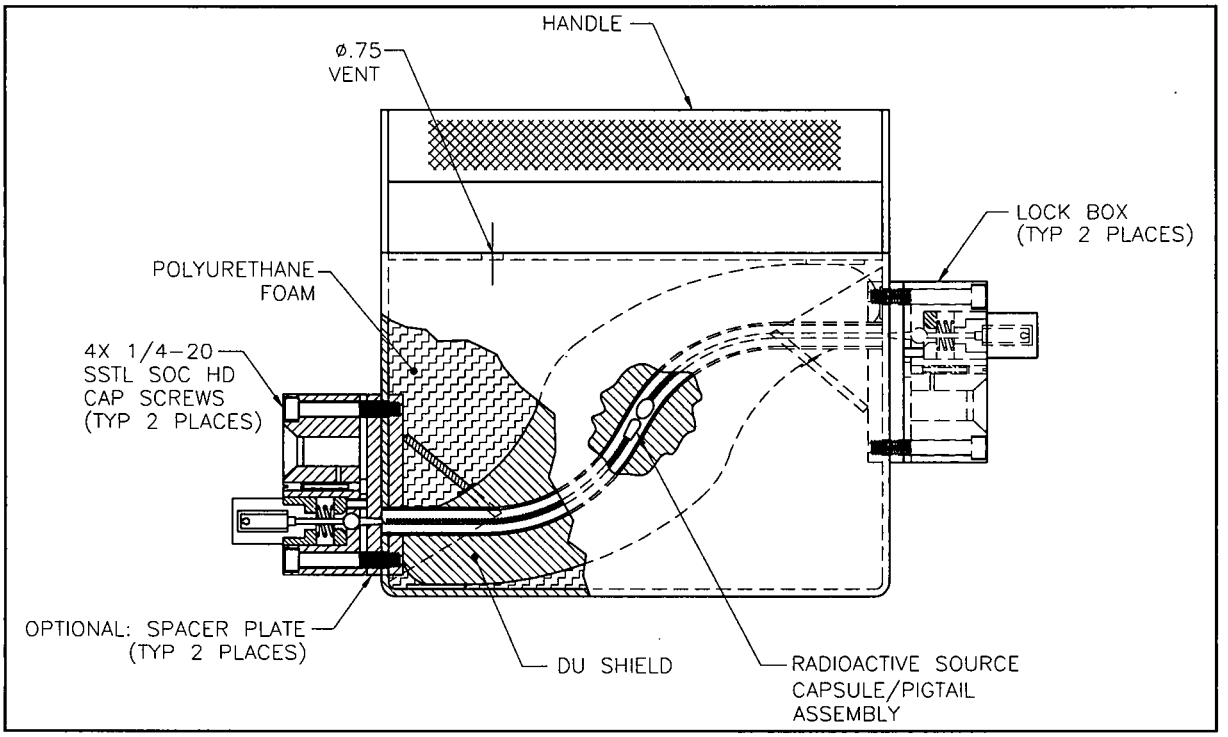

Figure 2-3 - Sectional View of the IR-50 Source Changer

2.1.2 Design Criteria

2.1.2.1 Basic Design Criteria

The OP-100 package is primarily demonstrated to satisfy the requirements of 10 CFR 71 via full-scale tests.

2.1.2.2 Miscellaneous Structural Failure Modes

2.1.2.2.1 Brittle Fracture

The structural materials of the OP-100 packaging include carbon steel sheet, stainless steel and DU. Although carbon steel can be subject to brittle fracture, the thin, 12-gauge carbon steel material used in the construction of the drum is not susceptible to brittle fracture since the thickness is below 0.625 inches per NUREG/CR-1815[4]. The other materials are 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 package 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.

[4] NUREG/CR-1815, *Recommendations for Protecting Against Failure by Brittle Fracture in Ferritic Steel Shipping Containers Up to Four Inches Thick.*

The DU shield material, which is enclosed by the stainless steel housing of the IR-100 or IR-50 devices, has been drop and puncture tested at temperatures less than –20 °F (-49 °F to -23 °F). As documented in Section 2.7.1, the OP-100 package satisfactorily 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 package, the brittle fracture of the DU shield component is not of concern.

2.1.2.2.2 Fatigue

Because the payloads of OP-100 package are an essentially a rigid body, no structural failures of the confinement boundary due to fatigue will occur.

2.1.2.2.3 Buckling

The OP-100 package, with either the IR-100 or IR-50 devices, 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 tests of the OP-100 and IR-100 packages.

2.1.3 Weights and Center of Gravity

The maximum gross weight of the OP-100 package is 77 pounds. The center of gravity is approximately at the geometric center of the 10-gallon drum.

2.2 Materials

2.2.1 Material Properties and Specifications

Since the evaluation of the OP-100 package is via test, it is not necessary to specify the material properties for evaluation by analysis.

2.2.2 Chemical and Galvanic Reactions

The carbon steel drum communicates only with the plywood dunnage within the drum. 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 carbon steel of the OP-100 package, or the austenitic stainless steel and depleted uranium (DU) comprising the structural materials of the IR-100 or IR-50 payloads. As discussed in Section 2.1.1, *Discussion*, the interior polyurethane foam in both the IR-100 and IR-50 devices 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 10-gallon steel drum for the OP-100 package is fabricated and certified to comply with DOT/UN Standard No. 1A2/X150/S (steel drum w/ removable head, satisfies Packaging Groups I, II, & III Tests, intended for solids [Specific Gravity = 1.5] or inner packagings). The IR-100 and IR-50 devices are fabricated utilizing conventional metal forming and joining techniques. Materials for these devices 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[5].

2.3.2 Examination

The primary safety function of the IR-100 and IR-50 devices 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 or IR-50 device. 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 OP-100 package is 14 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 OP-100 package.

2.4.2 Tamper Indicating Device

A tamper indicating seal (wire/lead security seal) is attached to the 5/8 × 4 inch bolt on the drum closure ring, which provide visual evidence that the closure was not tampered. Thus, the requirements of 10 CFR §71.43(b) are satisfied.

2.4.3 Positive Closure

The OP-100 package cannot be opened inadvertently. Positive closure of the OP-100 package is provided by the drum closure ring that is secured with a 5/8-inch × 4 inch hex bolt. In addition, the Lock Box assembly secures the source pigtail assembly in its proper shielded position in the IR-100 or IR-50 devices. 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.

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[5] 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.

2.4.4 Valves

Because the OP-100 package 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. Two 1/4-inch diameter vent holes, located approximately 180° apart, are drilled into the side wall of the drum to preclude pressure buildup within the drum cavity. 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 OP-100 package design satisfies the requirements of 10 CFR §71.71. Thus, the requirements of 10 CFR §71.43(f) are satisfied.

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 OP-100 package.

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 OP-100 package.

2.5 Lifting and Tie-down Devices for All Packages

2.5.1 Lifting Devices

The OP-100 package does not incorporate any lifting device in its design. The steel drum is manually lifted without any special devices and/or tools. Therefore, the requirements of 10 CFR §71.45(a) are not applicable to the OP-100 package.

2.5.2 Tie-Down Devices

The OP-100 package design has no tie-down devices. Therefore, the requirements of 10 CFR §71.45(b) are not applicable.

2.6 Normal Conditions of Transport

2.6.1 Heat

The IR-100 and IR-50 devices were 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 of the OP-100 package in an ambient environment of 100 °F and full insolation is 137 °F.

2.6.2 Cold

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

2.6.3 Reduced External Pressure

The OP-100 package 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 OP-100 package 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 OP-100 package are such that the water spray test identified in 10 CFR §71.71(c)(6) will have a negligible effect on the package. The two vent holes are covered by adhesive tape during transport to preclude the intrusion of water into the drum cavity.

2.6.7 Free Drop

Since the gross weight of the OP-100 packaging 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 bottom drop was performed on an OP-100 packaging 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 OP-100 packaging to protect the IR-100 or IR-50 devices and maintain their 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 exterior materials of construction do not include wood or fiberboard, as delineated in 10 CFR §71.71(c)(8).

2.6.9 Compression

A 399-pound force, which is greater than five times the gross package weight, was applied to the OP-100 package top surface while sitting in its normal upright position for a period of 24 hours. 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 using a IR-50 device. The first two drop tests were onto the outlet end (safety plug end) and the Lock Box end. Both drops resulted in a 3/16-inch spherical dent in the impacted surface. The third drop test was onto the side of the drum body. The result of the third drop was a 3/16-inch spherical dent in the impacted surface. There was no loss in operational capability of the OP-100 package due to any of the impact events. 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 OP-100 package 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 OP-100 package. 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

The drop orientations selected for testing are intended to maximize the damage to the Model OP-100 package and cause a potential opening or separation of the drum lid from the drum body. Once the drum lid opens or separates from the drum body, the Model IR-100 Exposure Device or IR-50 Source Changer is assumed to be fully exposed (i.e., separated from the drum overpack and plywood support structure).

2.7.1.2 Test Sequence for the Selected Tests

Based on the above discussions, and to maximize the damage to the Model OP-100 package and potentially opening the drum lid or damaging the IR-100 or IR-50 device, the OP-100 package was tested for four specific, HAC 30 foot free drop conditions:

1. Bottom Drop on Drum: This orientation will result in the maximum inertia loading of the drum with the IR-50 Source Changer as the payload. The intent of this drop orientation is to develop maximum g forces in the packaging to attempt to separate the Source Changer from the drum/plywood support structure. The bottom drop orientation was also selected for the normal condition drop since this orientation is the most probable to occur in actual use in the field.

2. Side Drop on Drum Closure Ring Bolt (0° Circumferential Orientation): This orientation targets the 5/8-inch diameter drum closure ring bolt that secures the steel closure ring and the drum longitudinal weld seam. The closure ring in turn secures the steel lid to the drum body. Failure of the closure ring bolt could result in a failure of the closure ring and hence, allow the steel drum lid to open or separate from the drum body. Failure of the drum weld seam could also fully expose the payload device. This orientation furthers targets the lock box of either the IR-100 Exposure Device or the IR-50 Source Changer.
3. Side Drop on Opposite Side of Drum Closure Ring Bolt (180° Circumferential Orientation): This orientation targets the Safety Plug of the IR-100 Exposure Device due to its minimal distance between the drum side wall and the plug. Failure of the Safety Plug could potentially result in movement of the DU shield assembly and/or cause a radiation streaming problem which would exceed the maximum allowable dose rate permitted by 10 CFR 71.
4. CG Over Drum Closure Ring Bolt: This orientation again targets the 5/8-inch diameter drum closure bolt, but results in maximum deformation of the closure bolt/ring assembly. Should this deformation be sufficiently severe, the steel closure ring potentially may be dislodged and/or broken and allow the steel drum lid to separate from the drum body. This orientation will be applied only to the IR-50 Source Changer.

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 OP-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 OP-100 packaging 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 OP-100 package to maintain the shielding integrity of the IR-100 or IR-50 devices. Significant results of the free drop testing are as follows:

- No failure of the drum closure lid/closure ring bolt occurred which would have permitted the potential separation of the payload from the protective overpack.
- 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 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.

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/ft^3 (1,000 kg/m^3), and radioactive contents greater than 1,000 A_2, not as special form. The payload of the OP-100 package is special form. Therefore, the dynamic crush test of 10 CFR §71.73(c)(2) is not applicable to the OP-100 package.

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 OP-100 package to adequately withstand this specified drop condition is demonstrated via testing of four, full-scale, OP-100 test packages.

2.7.3.1 Technical Basis for the Puncture Drop Tests

The drop orientations selected for puncture testing are intended to maximize the damage to the Model OP-100 package and cause a potential opening or separation of the drum lid from the drum body. Once the drum lid opens or separates from the drum body, the Model IR-100 Exposure Device or IR-50 Source Changer is assumed to be fully exposed (i.e., separated from the drum overpack and plywood support structure).

For the above reasons, testing included orientations that affect the closure ring (which secures the drum lid), the Lock Box (which secures the special form source), and 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 three 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

Separate orientations were identified for the OP-100 package with the IR-100 Exposure Device and the IR-50 Source Changer for the puncture bar tests. For the OP-100 package with the Model IR-100 Exposure Device, the two orientations selected are:

1. Side Drop on Drum at 0° Circumferential Orientation: This side orientation compounds the damage sustained by the 30-foot free drop and continues to attack the welded lock box of the IR-100 Exposure Device.
2. Side Drop on Drum at 180° Circumferential Orientation: This side orientation compounds the damage sustained by the 30-foot free drop and continues to attack the Shield Plug of the IR-100 Exposure Device.

For the OP-100 package with the IR-50 Source Changer, the two orientations selected are:

1. Side Drop on Drum at 180° Circumferential Orientation: This side orientation compounds the damage sustained by the 30-foot free drop and continues to attack the bolted lock box of the IR-50 Source Changer.
2. CG Over Drum Closure Ring Bolt: This orientation compounds the damage sustained by the 30-foot free drop and continues to attack the 5/8-inch diameter drum closure bolt of the OP-100 package with the IR-50 Source Changer. Should this deformation be sufficiently severe, the steel closure ring potentially may be dislodged and/or broken and allow the steel drum lid to separate from the drum body.

Based on the above general discussions, the CTUs were specifically tested for four 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 OP-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 OP-100 packaging 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 OP-100 package to maintain the shielding integrity of the IR-100 or IR-50 devices. Significant results of the puncture drop testing are as follows:

- No failure of the drum closure lid/closure ring bolt occurred which would have permitted the potential separation of the payload from the protective overpack.
- 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.

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

Test No.	Test Description (Certification Test Unit No.)	Temperature (as measured)	Test Unit Angular Orientation		Remarks
			Axial (0° = vertical)	Circumferential (0° = closure bolt)	
1	4 foot bottom drop w/ IR-50 (CTU-1)	93 - 97 °F	0°	NA	NCT impact on most probable orientation in field to cause damage.
2	30 foot bottom drop w/ IR-50 (CTU-1)	93 - 106 °F	0°	NA	HAC impact on region to cause maximum inertia loading.
3	30 foot side drop on drum closure ring bolt, weld seam w/ IR-100 (CTU-2)	-22/-32 °F (interior) 73 – 110+ °F (surface)	90°	0°	HAC impact producing maximum load on closure bolt/drum seam.
4	30 foot side drop on side opposite drum closure ring bolt w/ IR-100 (CTU-3)	-22/-32 °F (interior) 73 – 110+ °F (surface)	90°	180°	HAC impact to attack the Safety Plug opposite the Lock Box.
5	30 foot side drop on drum closure ring bolt w/ IR-50 (CTU-1)	99 - 125 °F	90°	0°	HAC impact producing maximum load on closure bolt/drum seam.
6	30 foot, CG over drum closure ring bolt w/ IR-50 (CTU-4)	107 - 118 °F	131°	0°	HAC impact to cause maximum deformation of drum closure ring.
7	Puncture drop on drum side w/ IR-100 (CTU-2)	-24/-25 °F (interior) 72 – 88 °F (surface)	90°	0°	Puncture in area expected to increase damage of drum/IR-100 resulting from free drop.
8	Puncture drop on drum side w/ IR-100 (CTU-3)	-23/-25 °F (interior) 74 – 91 °F (surface)	90°	180°	Puncture in area expected to increase damage of drum/IR-100 resulting from free drop.
9	Puncture drop on drum side w/ IR-50 (CTU-1)	105 - 115 °F	90°	180°	Puncture in area expected to increase damage of drum/IR-50 resulting from free drop.
10	Puncture drop, CG over drum closure ring bolt w/ IR-50 (CTU-4)	103 - 110 °F	131°	0°	Puncture in area expected to increase damage of drum/IR-50 resulting from free drop.
11	Thermal Test (CTU-3)	Ave. 1,553 °F	0°	NA	Thermal testing of most damaged CTU.

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 OP-100 packaging 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., plywood, 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 package was orientated such that the through-wall piercing in the carbon steel drum shell and the gap in the closure lid would result in the possible formation of a chimney. Thus, complete combustion of the interior plywood, and possibly the foam and the DU material, would result.

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 OP-100 packaging 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 OP-100 packaging to maintain the shielding integrity of the IR-100 or IR-50 devices, 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 OP-100 package does not carry fissile material, and therefore, this section does not apply.

2.7.6 Immersion – All Packages

The OP-100 package 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 OP-100 package 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 OP-100 package 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 OP-100 packaging 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 OP-100 package.

2.9 Accident Conditions for Fissile Material Packages for Air Transport

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

2.10 Special Form Certification

The contents of the OP-100 package 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 and Se-75 capsule 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.

2.11 Fuel Rods

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

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[6]. The Certification Tests are fully documented in the certification test report[7].

2.12.1.1 Introduction

The OP-100 packaging, 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 OP-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 OP-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 the shielding integrity of the IR-100 or IR-50 devices.

Significant results of the free drop tests are as follows:

- No failure of the drum closure lid/closure ring bolt occurred which would have permitted the potential separation of the payload from the protective overpack.
- 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 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.

Significant results of the puncture drop testing are as follows:

- No failure of the drum closure lid/closure ring bolt occurred which would have permitted the potential separation of the payload from the protective overpack.
- 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 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.

Significant results of the thermal testing are as follows:

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[6] Title 10, Code of Federal Regulations, Part 71 (10 CFR 71) *Packaging and Transportation of Radioactive Material*, 1-1-14 Edition.

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

- 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 and steel drum.
- The plywood support structure was completely consumed in the test without any effect on the payload.
- 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 lbs_m, which is more than 125 times the mass of the OP-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 thick 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 OP-100 package 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 OP-100 package consists of a 10-gallon steel drum which houses a plywood support structure and either a Model IR-100 Exposure Device or a Model IR-50 Source Changer. The drum is certified to comply with DOT/UN Standard No. 1A2/X150/S (steel drum w/ removable head, satisfies Packaging Groups I, II, & III Tests, intended for solids [Specific Gravity = 1.5] or inner packagings). The plywood support structure centrally locates the Model IR-100 or the Model IR-50 within the steel drum overpack. The steel drum lid is secured by a 12-gauge, ASTM A366 carbon steel closure ring which is secured with a 5/8-inch diameter × 4 inch long carbon steel hex bolt. Although the bolt threads into the closure ring lug, a hex nut is added for additional security. The drum lid and body are fabricated using 20-gauge, ASTM A366 carbon steel. The maximum gross weight of the OP-100 package is 77 pounds.

The IR-100 Exposure Device 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.

Prior to free drop, puncture, and thermal testing, two OP-100/IR-100 CTUs and two OP-100/IR-50 CTUs were loaded with a dummy source capsule assembly to simulate the Ir-192 special form capsule. The actual weight was 71 pounds for the OP-100/IR-100 CTUs. The OP-100/IR-50 CTUs weighed 74 pounds (CTU-1) and 73 pounds (CTU-4). Aside from the dummy source capsule assembly, the CTUs were identical to the OP-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 or IR-50 devices 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/IR-50 devices are 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 OP-100 packaging 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 attempt to separate the IR-100 or IR-50 device from the drum and cause damage to the Lock Box or cause significant movement of the special form source within the DU shield. 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 OP-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

Certification testing the OP-100 package was performed at temperatures below -20 °F and as high as 125 °F. The results of the OP-100 package testing demonstrated that extreme temperatures had no effect on the shielding integrity of the IR-100 or IR-50 devices. 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 OP-100 package 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 OP-100 package and potentially opening the drum lid or damaging the IR-100 or IR-50 device, four orientations have been selected for the free drop testing:

1. Bottom Drop on Drum: This orientation will result in the maximum inertia loading of the drum with the IR-50 Source Changer as the payload. The intent of this drop orientation is to develop maximum g forces in the packaging to attempt to separate the Source Changer from the drum/plywood support structure. The bottom drop orientation was also selected for the normal condition drop since this orientation is the most probable to occur in actual use in the field.
2. Side Drop on Drum Closure Ring Bolt (0° Circumferential Orientation): This orientation targets the 5/8-inch diameter drum closure ring bolt that secures the steel closure ring and the drum longitudinal weld seam. The closure ring in turn secures the steel lid to the drum body. Failure of the closure ring bolt could result in a failure of the closure ring and hence, allow the steel drum lid to open or separate from the drum body. Failure of the drum weld seam could also fully expose the payload device. This orientation furthers targets the lock box of either the IR-100 Exposure Device or the IR-50 Source Changer.
3. Side Drop on Opposite Side of Drum Closure Ring Bolt (180° Circumferential Orientation): This orientation targets the Safety Plug of the IR-100 Exposure Device due to its minimal distance between the drum side wall and the plug. Failure of the Safety Plug could potentially result in movement of the DU shield assembly and/or cause a radiation streaming problem which would exceed the maximum allowable dose rate permitted by 10 CFR 71.
4. CG Over Drum Closure Ring Bolt: This orientation again targets the 5/8-inch diameter drum closure bolt, but results in maximum deformation of the closure bolt/ring assembly. Should this deformation be sufficiently severe, the steel closure ring potentially may be dislodged and/or broken and allow the steel drum lid to separate from the drum body. This orientation will be applied only to the IR-50 Source Changer.

Separate orientations were identified for the OP-100 package with the IR-100 Exposure Device and the IR-50 Source Changer for the puncture bar tests. For the OP-100 package with the Model IR-100 Exposure Device, the two orientations selected are:

1. Side Drop on Drum at 0° Circumferential Orientation: This side orientation compounds the damage sustained by the 30-foot free drop and continues to attack the welded lock box of the IR-100 Exposure Device. Should this result in a failure of the lock box or significant relative deformation between the lock box and the DU shield assembly, then the radiation dose rate might exceed the maximum allowable dose rate 1,000 mrem/hr at 1-meter permitted by 10 CFR 71.
2. Side Drop on Drum at 180° Circumferential Orientation: This side orientation compounds the damage sustained by the 30-foot free drop and continues to attack the Shield Plug of the IR-100 Exposure Device. Should this result in a failure of the Safety Plug or significant relative deformation between the Safety Plug and the DU shield assembly, then the radiation dose rate might exceed the maximum allowable dose rate 1,000 mrem/hr at 1-meter permitted by 10 CFR 71.

For the OP-100 package with the IR-50 Source Changer, the two orientations selected are:

1. Side Drop on Drum at 180° Circumferential Orientation: This side orientation compounds the damage sustained by the 30-foot free drop and continues to attack the bolted lock box of the IR-50 Source Changer. Should this result in a failure of the lock box or significant relative deformation between the lock box and the DU shield assembly, then the radiation dose rate might exceed the maximum allowable dose rate of 1,000 mrem/hr at 1-meter permitted by 10 CFR 71.
2. CG Over Drum Closure Ring Bolt: This orientation compounds the damage sustained by the 30-foot free drop and continues to attack the 5/8-inch diameter drum closure bolt of the OP-100 package with the IR-50 Source Changer. Should this deformation be sufficiently severe, the steel closure ring potentially may be dislodged and/or broken and allow the steel drum lid to separate from the drum body.

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 were 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

A OP-100 packaging will be subjected to a 30-minute, 1,475 °F thermal test in accordance with 10 CFR §71.73(c)(4). Because CTU-3 experienced the most damage 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 OP-100 CTU was oriented such that the through-wall piercing in the carbon steel drum shell and the gap in the closure lid would result in the possible formation of a chimney. Thus, complete combustion of the interior plywood, and possibly the foam and the DU material, would result.

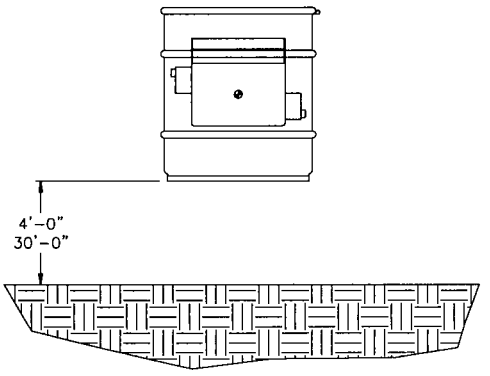
2.12.1.6 Test Sequence for Selected Free Drop, Puncture Drop and Thermal Tests

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

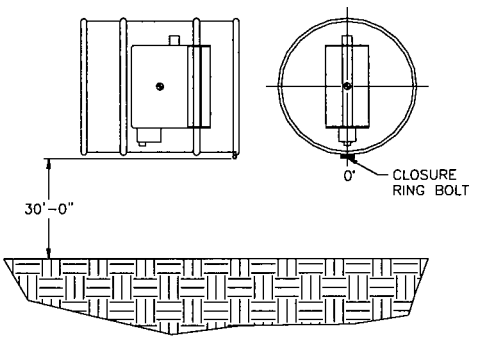
2.12.1.6.1 Certification Test Unit No. 1 (CTU-1)

Free Drop No. 1 is a NCT free drop from a height of four feet, impacting the bottom of the drum. 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.

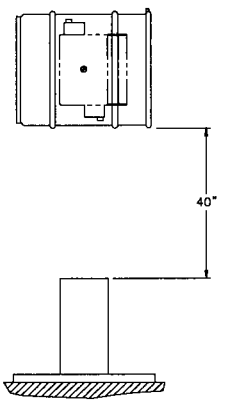
Free Drop No. 2 is a HAC free drop from a height of 30 feet, impacting the bottom of the drum, which is the same impact pint as the NCT Free Drop No. 1. In this way, NCT and HAC free drop damage is cumulative. The 30 foot drop height is based on the requirements of 10 CFR §71.73(c)(1). The purpose of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



Free Drop No. 5 is a HAC free drop from a height of 30 feet, impacting the side of the drum on the drum closure ring bolt. 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 load on the closure bolt/drum seam in an attempt to separate the IR-50 device from the drum.

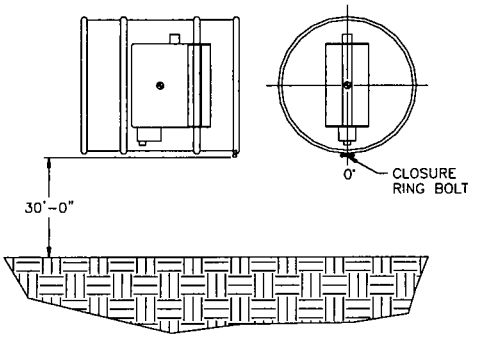


Puncture Drop No. 9 impacts directly onto the damage created by Free Drop Test No. 5, directly on the Lock Box. The puncture drop height is based on the requirements of 10 CFR §71.73(c)(3). The purpose of Puncture Drop No. 9 is to attempt to increase the damage due to Free Drop No. 5, and potential damage the Lock Box and displace the source capsule.

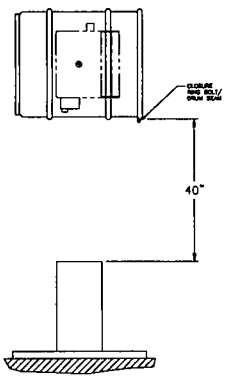


2.12.1.6.2 Certification Test Unit No. 2 (CTU-2)

Free Drop No. 3 is a HAC free drop from a height of 30 feet, impacting the drum side on the closure ring bolt and weld seam. The test is performed with the CTU between -20 °F and 0 °F. 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 inertia loading of the closure ring bolt.

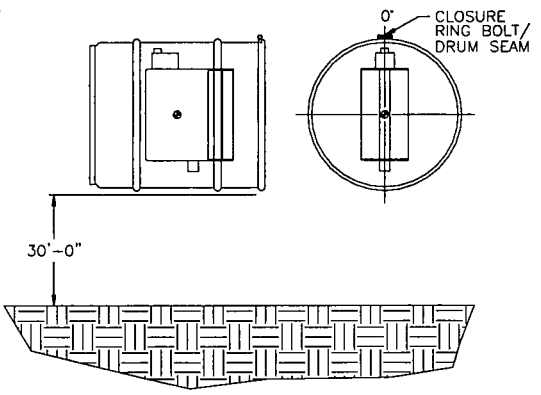


Puncture Drop No. 7 impacts directly onto the damage created by Free Drop Test No. 3, directly on the Lock Box. The puncture drop height is based on the requirements of 10 CFR §71.73(c)(3). The purpose of Puncture Drop No. 7 is to attempt to increase the damage due to Free Drop No. 3, and potential damage the Lock Box and displace the source capsule.

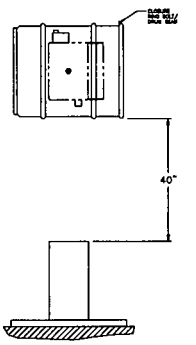


2.12.1.6.3 Certification Test Unit No. 3 (CTU-3)

Free Drop No. 4 is a HAC free drop from a height of 30 feet, impacting the drum side opposite the closure ring bolt and weld seam with the IR-100. The test is performed with the CTU between -20 °F and 0 °F. 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 to the Safety Plug.

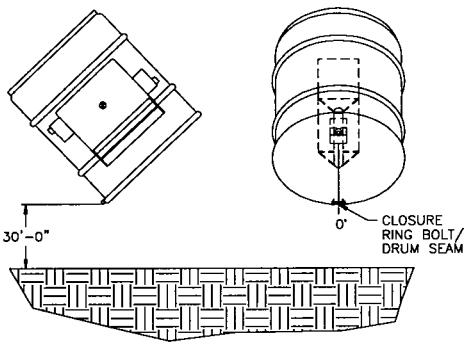


Puncture Drop No. 8 impacts directly onto the damage created by Free Drop Test No. 4, directly on the Lock Box. The puncture drop height is based on the requirements of 10 CFR §71.73(c)(3). The purpose of Puncture Drop No. 7 is to attempt to increase the damage due to Free Drop No. 3, and potential damage the Lock Box and displace the source capsule.

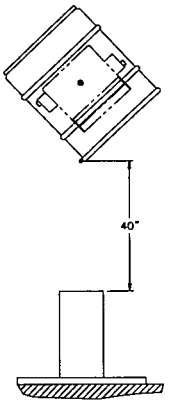


2.12.1.6.4 Certification Test Unit No. 4 (CTU-4)

Free Drop No. 6 is a HAC free drop from a height of 30 feet, impacting the closure ring bolt. The test is performed with the CTU at ambient temperature. 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 deformation to the closure ring/closure bolt.



Puncture Drop No. 8 impacts directly onto the damage created by Free Drop Test No. 6, directly on the closure ring bolt. The puncture drop height is based on the requirements of 10 CFR §71.73(c)(3). The purpose of Puncture Drop No. 8 is to attempt to increase the damage due to Free Drop No. 6, and potential damage the closure ring/closure ring bolt, and separate the drum lid from the drum body.



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 2.12.1-38 sequentially photo-document the certification testing process for the OP-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 bottom of the OP-100 package. The following list summarizes the test parameters:

- verified longitudinal angle as 0° ±1°
- verified drop height as 4 feet, +3/-0 inches (actual drop height 4 feet)
- measured ambient and package temperatures as 79 °F and 93 - 97 °F respectively
- conducted test at 10:20 a.m. on Tuesday, 7/28/98

The packaging rebounded upon impact. There was no visible damage other than oil canning of the drum bottom by the internal plywood support structure. The impact damage is shown in Figure 2.12.1-3.

2.12.1.7.1.2 CTU-1 Free Drop Test No. 2

Free Drop No. 2 is a HAC free drop from a height of 30 feet, impacting the bottom of the OP-100 package. The following list summarizes the test parameters:

- verified longitudinal angle as 0° ±1°
- verified drop height as 30 feet, +3/-0 inches (actual drop height 30 feet)
- measured ambient and package temperatures as 83 °F and 93 - 106 °F respectively
- conducted test at 10:33 a.m. on Tuesday, 7/28/98

The packaging rebounded upon impact. There was no visible damage other than the continued oil canning of the drum bottom by the internal plywood support structure (deformation measured at approximately 1/2-inch. The impact damage is shown in Figure 2.12.1-4.

2.12.1.7.1.3 CTU-1 Free Drop Test No. 5

Free Drop No. 5 impacted directly onto the closure ring bolt/drum seam. As shown in Figure 2.12.1-5, the CTU was oriented 90° with respect to the horizontal impact surface (longitudinal angle 90°, circumferential angle 0°). The following list summarizes the test parameters:

- verified longitudinal angle as 90° ±1°
- verified circumferential angle as 0° ±1°
- verified drop height as 30 feet, +3/-0 inches (actual drop height 30 feet)
- measured ambient and package temperatures as 89 °F and 99 - 125 °F respectively
- conducted test at 11:35 a.m. on Tuesday, 7/28/98

The packaging rebounded upon impact. A 6-inch wide × 1/2-inch deep flat developed over the full length of the drum. No other damage was visible. The impact damage is shown in figure 2.12.1-6.

2.12.1.7.1.4 CTU-1 Puncture Drop Test No. 9

Puncture Drop No. 7 impacted directly onto the damage created by Free Drop Test 5, directly on the Lock Box of the IR-100. As shown in Figure 2.12.1-7, the CTU was oriented 90° with respect to the horizontal impact surface (longitudinal angle 90°, circumferential angle 0°). The following list summarizes the test parameters:

- verified longitudinal angle as 90° ±1°
- verified circumferential angle as 0° ±1°
- verified drop height as 40 inches, +1/-0 inches (actual drop height 40 inches)
- measured ambient and package temperatures as 93 °F and 105 - 115 °F respectively
- conducted test at 2:20 p.m. on Tuesday, 7/28/98

The packaging rebounded upon impact. The Lock Box pierced through the outer steel shell of the drum. The impact damage is shown in Figure 2.12.1-8.

2.12.1.7.1.5 CTU-1 Post-Test Radiation Survey

Post-test radiation survey of the OP-100 CTU-2 (IR-50 device) was performed on Tuesday, 8/19/98. The post-test radiation survey was performed using an Ir-192 special form source. Prior to removing the dummy pigtail source assembly, the position of the dummy source was measured relative to the portal outlet end. With this known position, the dummy source pigtail assembly was removed and the active radioactive source was re-installed. The strength of the source on the day of the survey was 83 Ci. To account for the maximum allowable payload of 120 Ci of Ir-192, the measured values were adjusted upward by the ratio of 120/83 or 1.4458. 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			
6-3/4 (6-7/8)**	71	72	146	51	0.4	0.6	0.7	0.4	0.1	0.1	0.3	0.3

* Measured from the source portal exit end

** Position of dummy source could not be duplicated with an active source due to the dummy pigtail/ball being jammed into the trap of the lock from the drop impact.

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.

2.12.1.7.1.6 CTU-1 Post-Test Disassembly

Post-test disassembly of CTU-1 was conducted on performed on Tuesday, 8/19/98. The plywood support structure and the lower Lock Box were damaged. No other damage was visible. The post-test disassembly is shown in Figure 2.12.1-9 and 2.12.1-10.

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 closure ring bolt. As shown in Figure 2.12.1-11 the CTU was oriented 90° with respect to the horizontal impact surface (longitudinal angle 90°, circumferential angle 0°). The following list summarizes the test parameters:

- verified longitudinal angle as 0° ±1°
- verified circumferential angle as 0° ±1°
- verified drop height as 30 feet, +3/-0 inches (actual drop height 30 feet, 1 inch)
- measured ambient and package temperatures as 88 °F and –30/-39 °F (interior), 73 – 110 °F (surface) respectively
- conducted test at 11:45 a.m. on Tuesday, 7/28/98

The packaging rebounded upon impact. The brass dust cover on the Lock Box pierced through the steel wall of the drum. The closure ring bolt/ring deformed approximately 1 inch. The impact damage is shown in Figure 2.12.1-12.

2.12.1.7.2.2 CTU-2 Puncture Drop Test No. 7

Puncture Drop No. 7 was intended to impact directly onto the damage created by Free Drop Test 3, directly impacting the Lock Box. As shown in Figure 2.12.1-13, the CTU was oriented 90° with respect to the horizontal impact surface (longitudinal angle 90°, circumferential angle 0°). The following list summarizes the test parameters:

- verified longitudinal angle as 90° ±1°
- verified circumferential angle as 0° ±1°
- verified drop height as 40 inches, +1/-0 inches (actual drop height 40 inches)
- measured ambient and package temperatures as 96 °F and –27 °F (interior), 72 – 88 °F (surface) respectively
- conducted test at 3:08 p.m. on Tuesday, 7/28/98

The packaging rebounded upon impact. The brass dust cover on the Lock Box pierced through the steel wall of the drum. The impact damage is shown in Figure 2.12.1-14 and Figure 2.12.1-15.

2.12.1.7.2.3 CTU-2 Post-Test Radiation Survey

Due to the severe damage to the Lock Box, a radioactive special form capsule assembly could not be installed into CTU-2 and perform a post-test radiation survey (refer to Figure 2.12.1-16).

2.12.1.7.2.4 CTU-2 Post-Test Disassembly

Post-test disassembly of IR-100 CTU-2 was performed on Tuesday, 8/19/98. The plywood support structure and the brass dust cap on the Lock Box were damaged. The damage is shown in Figure 2.12.1-17 and Figure 2.12.1-18.

2.12.1.7.3 Certification Test Unit No. 3 (CTU-3)

2.12.1.7.3.1 CTU-3 Free Drop Test No. 4

Free Drop No. 4 is a HAC free drop from a height of 30 feet, impacting the side of the drum opposite the closure ring bolt/weld seam. The CTU was tested at a temperature between -20 °F and 0 °F. As shown in Figure 2.12.1-19, the CTU was oriented 25° with respect to the horizontal impact surface (longitudinal angle 90°, circumferential angle 180°). The following list summarizes the test parameters:

- verified longitudinal angle as 90° ±1°
- verified circumferential angle as 180° ±1°
- verified drop height as 30 feet, +3/-0 inches (actual drop height 30 feet)

- measured ambient and package temperatures as 95 °F and –45/-49 °F (interior), 30 °F (surface) respectively
- conducted test at 1:35 a.m. on Tuesday, 7/28/98

The packaging rebounded upon impact. The lid separated from the drum body approximately 100 degrees around the circumference (radial distance approximately 15 inches). The impact produced a flat approximately 1 inch deep × 8 inches wide. The Safety Plug was loose, with a crack observed in the knurled section. The impact damage is shown in Figure 2.12.1-20 and Figure 2.12.1-21.

2.12.1.7.3.2 CTU-3 Puncture Drop Test No. 8

Puncture Drop No. 8 was intended to impact directly onto the damage created by Free Drop Test 4, directly impacting side of the drum opposite the closure ring bolt/weld seam. The CTU was tested at a temperature between -20 °F and 0 °F. As shown in Figure 2.12.1-22, the CTU was oriented 68° with respect to the horizontal impact surface (longitudinal angle 90°, circumferential angle 180°). The following list summarizes the test parameters:

- verified longitudinal angle as 90° ±1°
- verified circumferential angle as 180° ±1°
- verified drop height as 40 inches, +1/-0 inches (actual drop height 40 inches)
- measured ambient and package temperatures as 95 °F and –23/-25 °F (interior), 74 - 91 °F (surface) respectively
- conducted test at 3:40 p.m. on Tuesday, 7/28/98

The packaging rebounded upon impact. The impact resulted in a slight increase of the opening in the drum lid at approximately 90° from impact point. The Safety Plug produced a through-wall puncture of approximately 1½ inches in diameter. The impact also further compressed the drum shell/closure ring. The impact damage is shown in Figure 2.12.1-23.

2.12.1.7.3.3 CTU-3 Thermal Test

Since CTU-3 was the most damaged test unit, it was selected for the thermal test. The following list summarizes the test parameters:

- The OP-100 CTU-3 was orientated in the upright position, with the closure lid facing downward (longitudinal angle 180°, circumferential angle NA). The CTU was placed on fire bricks to provide as much surface area as possible for heat transfer during the test (refer to Figure 2.12.1-24).
- 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 10:36 a.m. on Tuesday, 8/11/98.

- Completion of thermal test at 11:06 a.m. on Tuesday, 8/11/98 (refer to Figure 2.12.1-25).

2.12.1.7.3.4 CTU-3 Post-Test Radiation Survey

Post-test radiation survey of the OP-100 CTU-3 was performed on Tuesday, 8/19/98. The post-test radiation survey was performed using an Ir-192 special form source. Prior to removing the dummy pigtail source assembly, the position of the dummy source was measured relative to the portal outlet end. With this known position, the dummy source pigtail assembly was removed and the active radioactive source was re-installed. The strength of the source on the day of the survey was 83 Ci. To account for the maximum allowable payload of 120 Ci of Ir-192, the measured values were adjusted upward by the ratio of 120/83 or 1.4458. 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			
6-9/16	101	77	127	61	0.6	0.6	0.7	0.9	0.1	0.1	0.1	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.

2.12.1.7.3.5 CTU-3 Post-Test Disassembly

Post-test disassembly of OP-100 CTU-3 was performed on Tuesday, 8/19/98. Upon removal of the drum lid, the plywood support structure was found to be totally consumed by the test. Both the Lock Box dust cap and the Safety Plug were found to be damaged due to the free drop tests. No other damage of the IR-100 device was visible (refer to Figures 2.12.1-26 and 2.12.1-27.

An abrasive cutting wheel was utilized to cut and remove one side of the stainless steel housing sheet of the IR-100 device. Upon removal of the stainless steel sheet, the presence of foam char demonstrated the intumescent behavior of the polyurethane foam, as shown in Figure 2.12.1-28. Following removal of the foam char, visual examination of the DU shield and the DU shield support brackets was performed. As shown in Figures 2.12.1-29, 2.12.1-30, and 2.12.1-31, there was no indication of any weld/structural failure or deterioration of the DU shield material or the DU support brackets.

2.12.1.7.4 Certification Test Unit No. 4 (CTU-4)

2.12.1.7.4.1 CTU-4 Free Drop Test No. 6

Free Drop No. 6 is a HAC free drop from a height of 30 feet, impacting the closure ring bolt. As shown in Figure 2.12.1-32, the CTU was oriented 140° with respect to the horizontal impact surface (longitudinal angle 140°, circumferential angle 0°). The following list summarizes the test parameters:

- verified longitudinal angle as 140° ±1°
- verified circumferential angle as 0° ±1°
- verified drop height as 30 feet, +3/-0 inches (actual drop height 30 feet)

- measured ambient and package temperatures as 96 °F and 107 - 118 °F respectively
- conducted test at 12:03 p.m. on Tuesday, 7/28/98

The packaging rebounded upon impact. The closure ring deformed inward, with both the handle edge and the Lock Box piercing the shell of the drum. In addition, the pigtail plug end and lock were damaged. The impact damage is shown in Figure 2.12.1-33.

2.12.1.7.4.2 CTU-4 Puncture Drop Test No. 10

Puncture Drop No. 10 was intended to impact directly onto the damage created by Free Drop Test 6, directly impacting the closure ring bolt. As shown in Figure 2.12.1-34, the CTU was oriented 140° with respect to the horizontal impact surface (longitudinal angle 140°, circumferential angle 0°). The following list summarizes the test parameters:

- verified longitudinal angle as 140° ±1°
- verified circumferential angle as 0° ±1°
- verified drop height as 40 inches, +1/-0 inches (actual drop height 40 inches)
- measured ambient and package temperatures as 98 °F and 103 - 110 °F respectively
- conducted test at 1:02 p.m. on Tuesday, 7/28/98

The packaging rebounded upon impact. The impact continued driving the closure ring bolt/closure ring inward, resulting in further tearing of the outer steel shell. The impact event and damage are shown in Figure 2.12.1-35 and Figure 2.12.1-36 respectively.

2.12.1.7.4.3 CTU-4 Post-Test Radiation Survey

Post-test radiation survey of the OP-100 CTU-4 was performed on Tuesday, 8/19/98. The post-test radiation survey was performed using an Ir-192 special form source. 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 radioactive source was re-installed. The strength of the source on the day of the survey was 83 Ci. To account for the maximum allowable payload of 120 Ci of Ir-192, the measured values were adjusted upward by the ratio of 120/83 or 1.4458. 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			
6-15/16	90	51	127	61	0.6	0.7	0.9	1.9	0.1	0.1	0.1	0.3

* 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.

2.12.1.7.4.4 CTU-4 Post-Test Disassembly

Post-test disassembly of OP-100 CTU-4 was performed on Tuesday, 8/19/98. The plywood support structure and the handle were damaged. The damage is shown in Figure 2.12.1-37 and Figure 2.12.1-38.

In conclusion, the OP-100 packaging design has been demonstrated to satisfy the requirements of Subpart F, 10 CFR 71 for the transportation of special form radioactive material.

Table 2.12.1-1 - Summary of OP-100 Certification Tests in Sequential Order[1]

Test No.	Test Description (Certification Test Unit No.)	Temperature (as measured)	Test Unit Angular Orientation		Remarks
			θ[2]	ϕ[3]	
1	4 foot bottom drop w/ IR-50 (CTU-1)	93 - 97 °F	0°	NA	NCT impact on most probable orientation in field to cause damage.
2	30 foot bottom drop w/ IR-50 (CTU-1)	93 - 106 °F	0°	NA	HAC impact on region to cause maximum inertia loading.
3	30 foot side drop on drum closure ring bolt, weld seam w/ IR-100 (CTU-2)	-22/-32 °F (interior) 73 – 110+ °F (surface)	90°	0°	HAC impact producing maximum load on closure bolt/drum seam.
4	30 foot side drop on side opposite drum closure ring bolt w/ IR-100 (CTU-3)	-22/-32 °F (interior) 73 – 110+ °F (surface)	90°	180°	HAC impact to attack the Safety Plug opposite the Lock Box.
5	30 foot side drop on drum closure ring bolt w/ IR-50 (CTU-1)	99 - 125 °F	90°	0°	HAC impact producing maximum load on closure bolt/drum seam.
6	30 foot, CG over drum closure ring bolt w/ IR-50 (CTU-4)	107 - 118 °F	131°	0°	HAC impact to cause maximum deformation of drum closure ring.
7	Puncture drop on drum side w/ IR-100 (CTU-2)	-24/-25 °F (interior) 72 – 88 °F (surface)	90°	0°	Puncture in area expected to increase damage of drum/IR-100 resulting from free drop.
8	Puncture drop on drum side w/ IR-100 (CTU-3)	-23/-25 °F (interior) 74 – 91 °F (surface)	90°	180°	Puncture in area expected to increase damage of drum/IR-100 resulting from free drop.
9	Puncture drop on drum side w/ IR-50 (CTU-1)	105 - 115 °F	90°	180°	Puncture in area expected to increase damage of drum/IR-50 resulting from free drop.
10	Puncture drop, CG over drum closure ring bolt w/ IR-50 (CTU-4)	103 - 110 °F	131°	0°	Puncture in area expected to increase damage of drum/IR-50 resulting from free drop.
11	Thermal Test (CTU-3)	Ave. 1,553 °F	0°	NA	Thermal testing of most damaged CTU.

Notes:

1. Tested 7/28/98 and 8/11/98.
2. Longitudinal angle, θ, is relative to long axis of packaging (i.e., 0° is vertical).
3. Circumferential angle, ϕ, is relative to rotation of package around longitudinal axis (i.e., 0° is closure bolt).

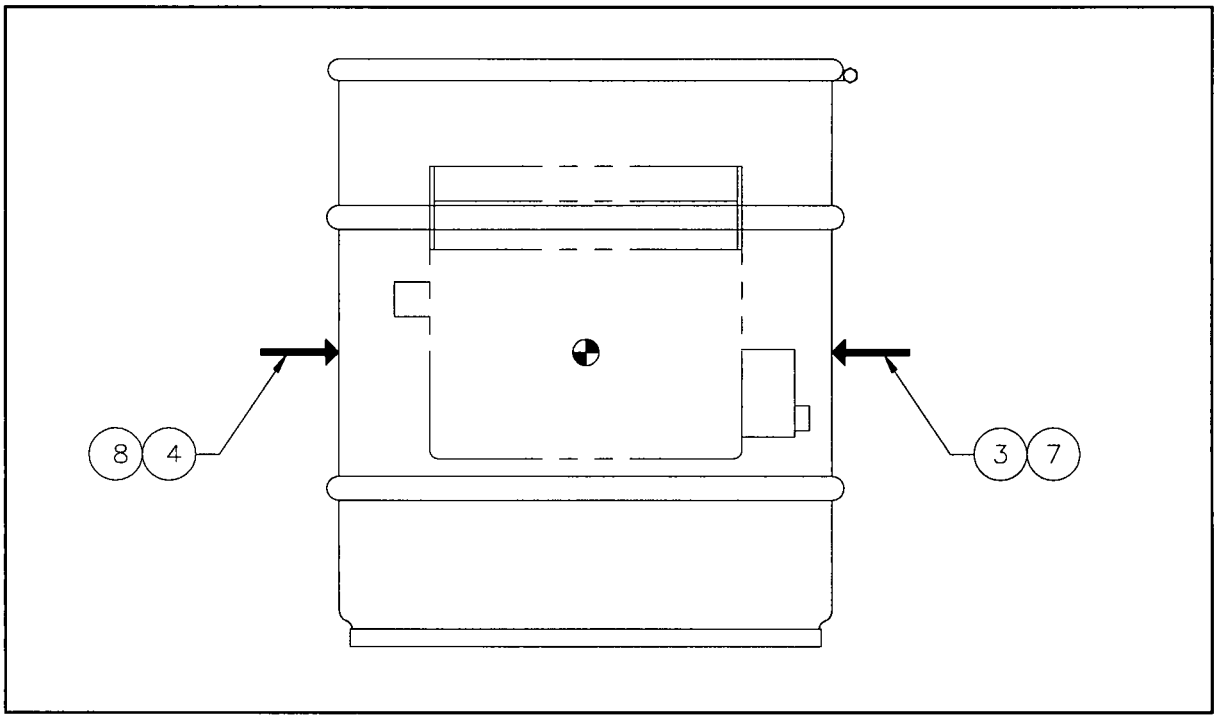


Figure 2.12.1-1 - Schematic Summary of CTU Testing with IR-100 Device

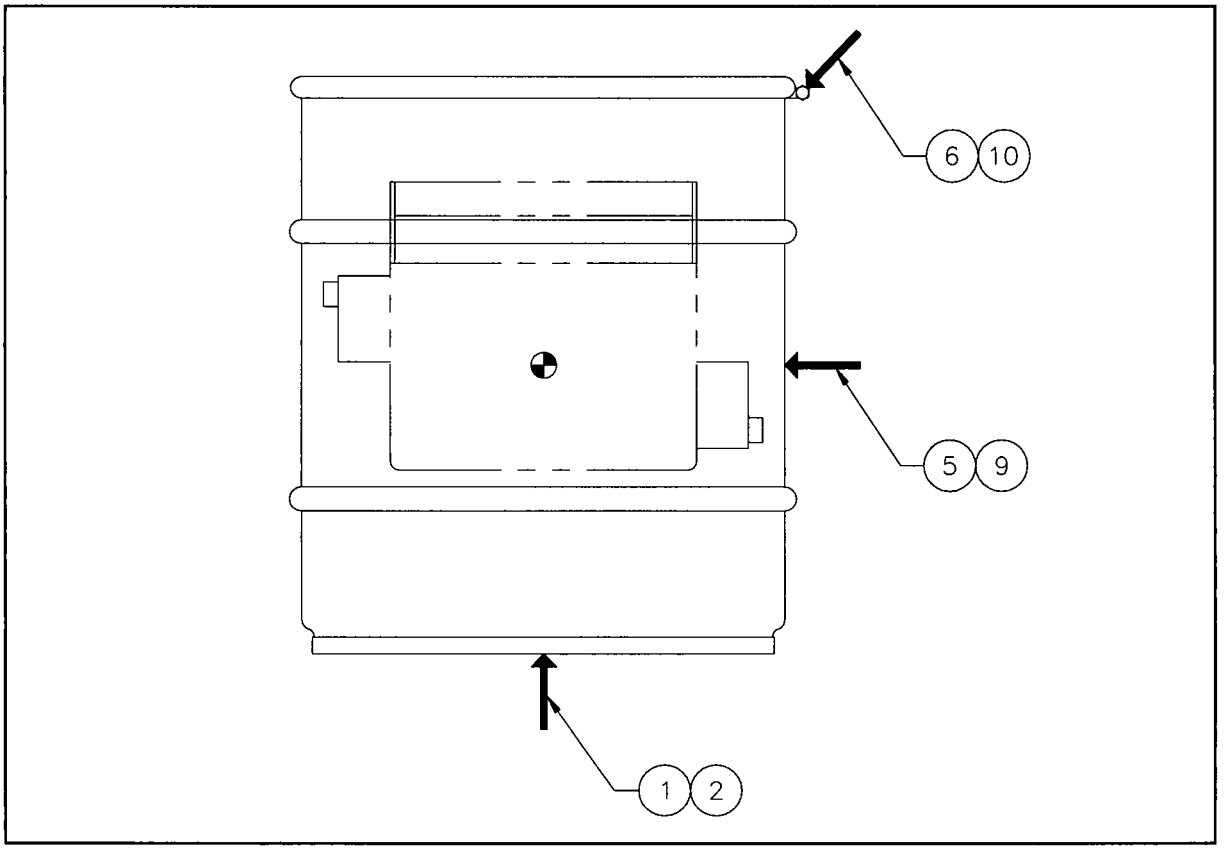


Figure 2.12.1-2 - Schematic Summary of CTU Testing with IR-50 Device

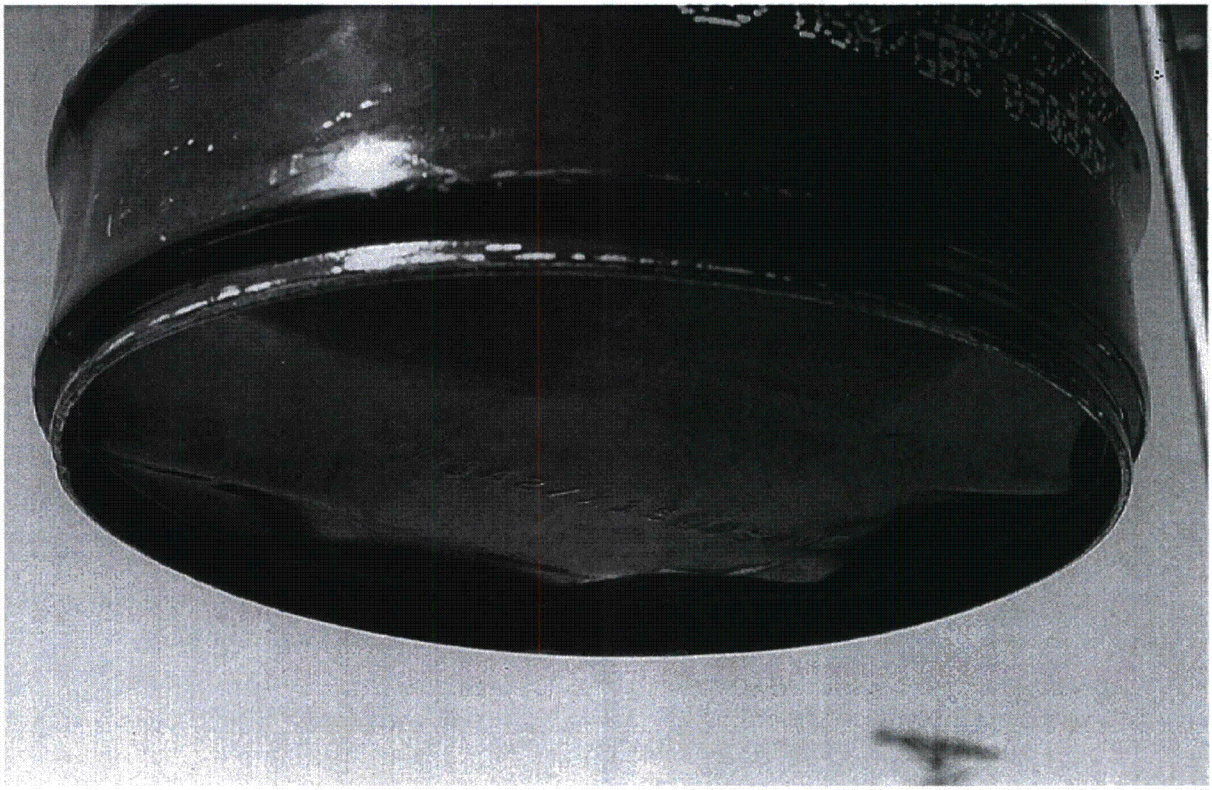


Figure 2.12.1-3 – CTU-1 Free Drop Test No. 1: View of Drum Bottom Following Impact

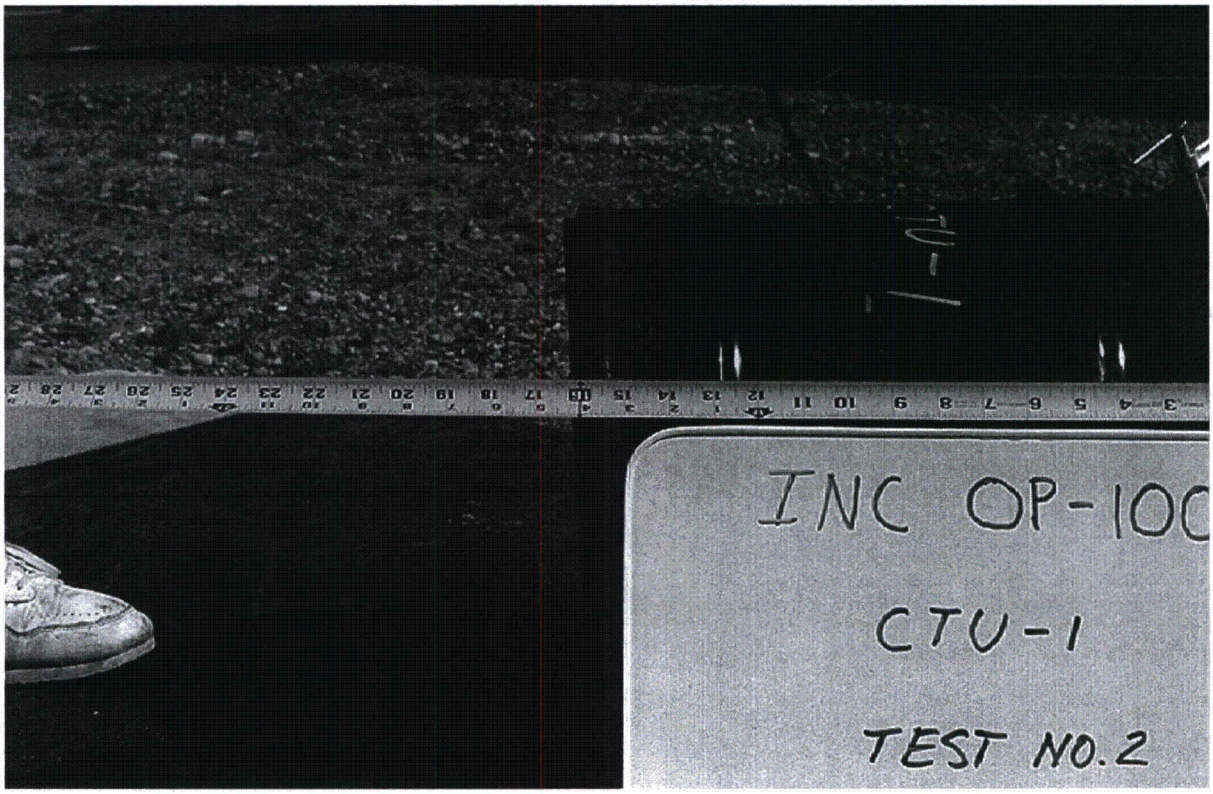


Figure 2.12.1-4 – CTU-1 Free Drop Test No. 2: Measured Bottom Deformation (~1/2 inch)

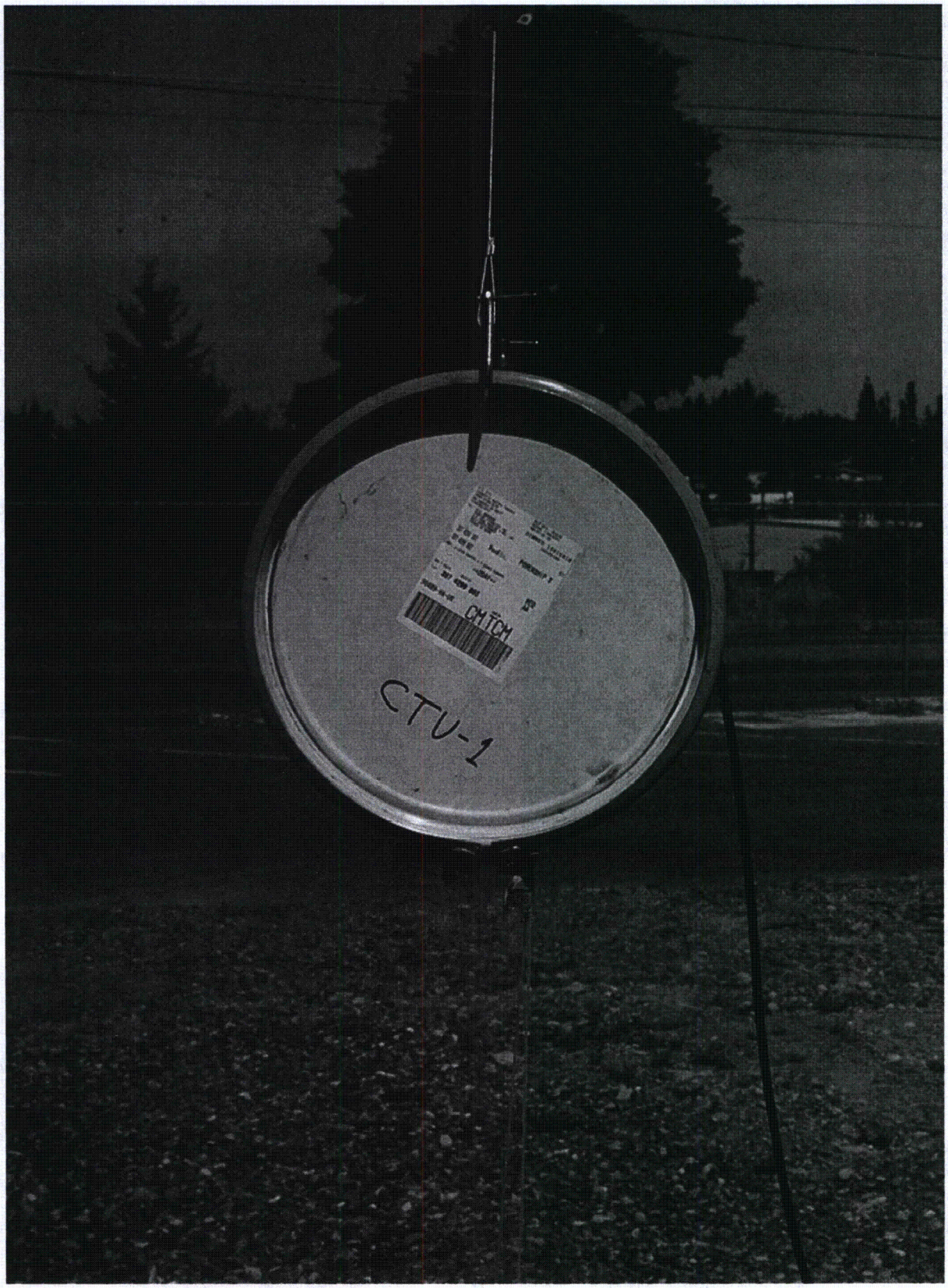


Figure 2.12.1-5 - CTU-1 Free Drop Test No. 5: Side Drop on Closure Bolt

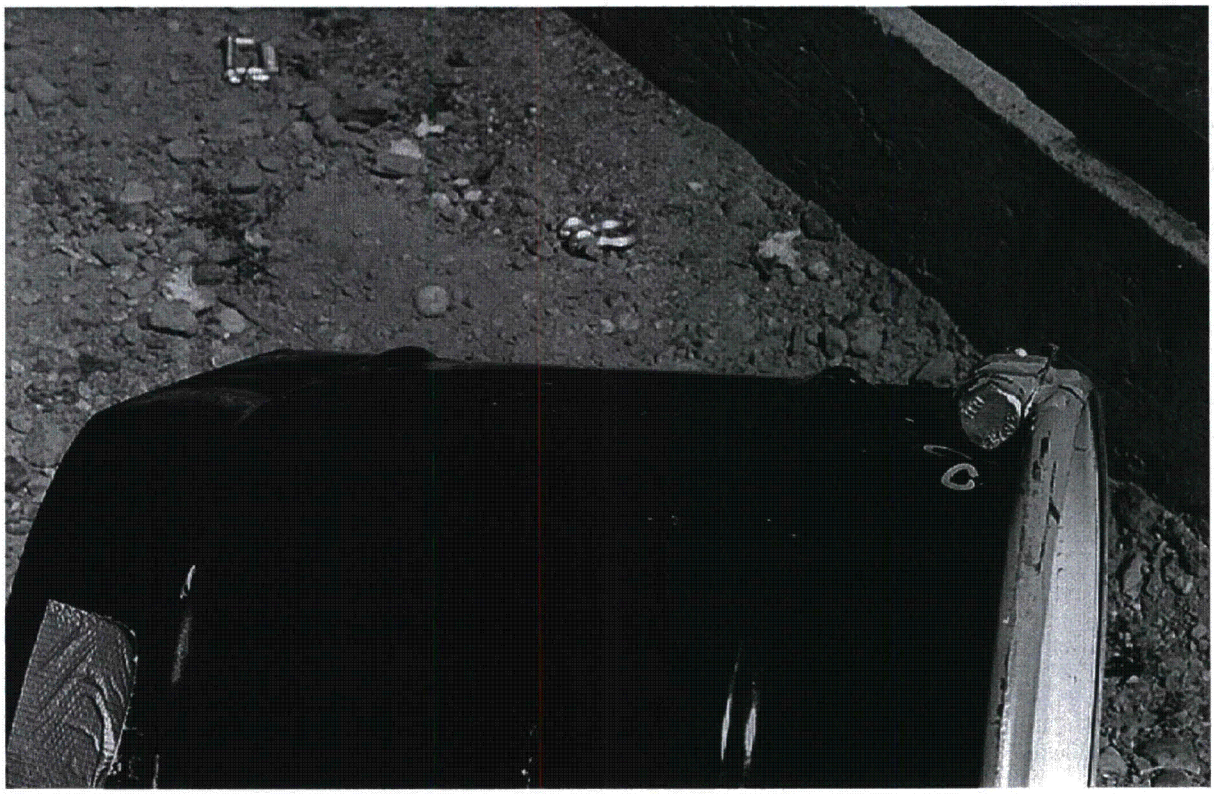


Figure 2.12.1-6 - CTU-1 Free Drop Test No.5: Flattening of Drum Side Following Impact

Figure 2.12.1-7 - CTU-1 Puncture Drop Test No. 9 Just Prior to Impact

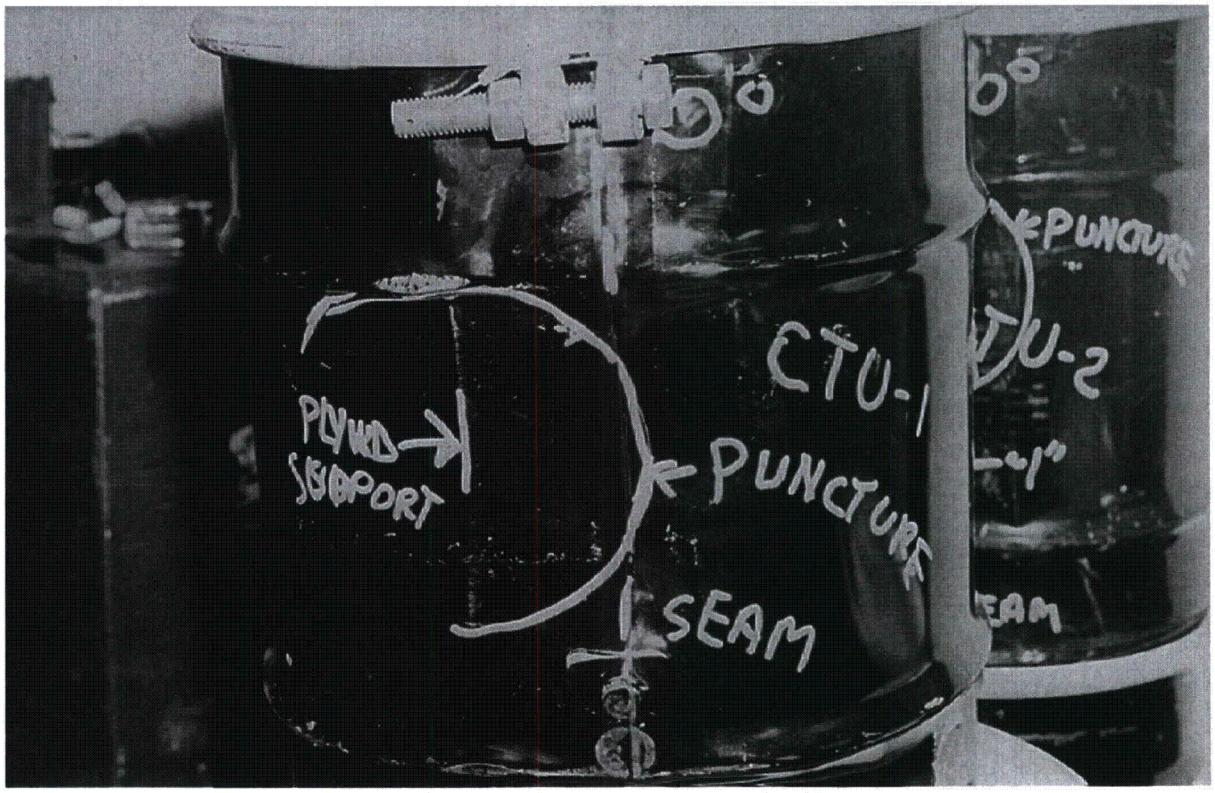


Figure 2.12.1-8 - CTU-1 Puncture Drop Test No. 9: Damage to Drum Side

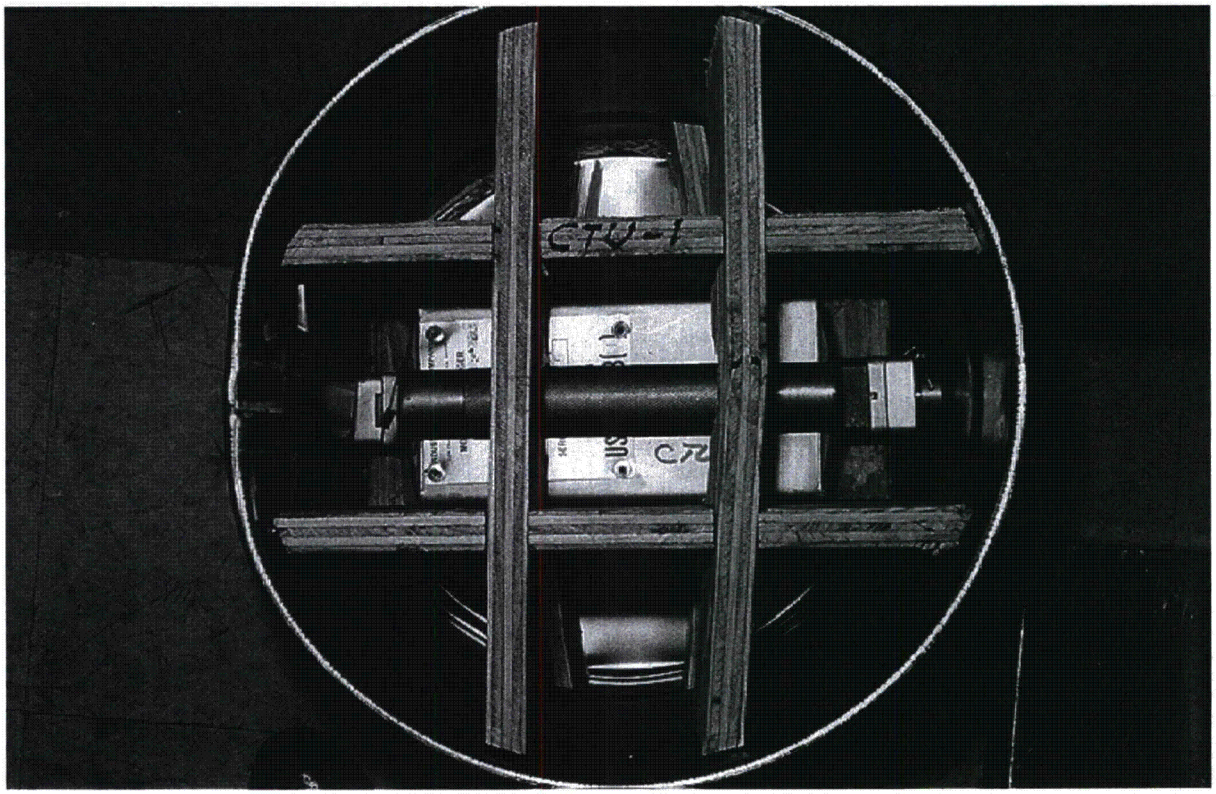


Figure 2.12.1-9 – CTU-1 Post-Test Disassembly: Condition of Plywood Support Structure

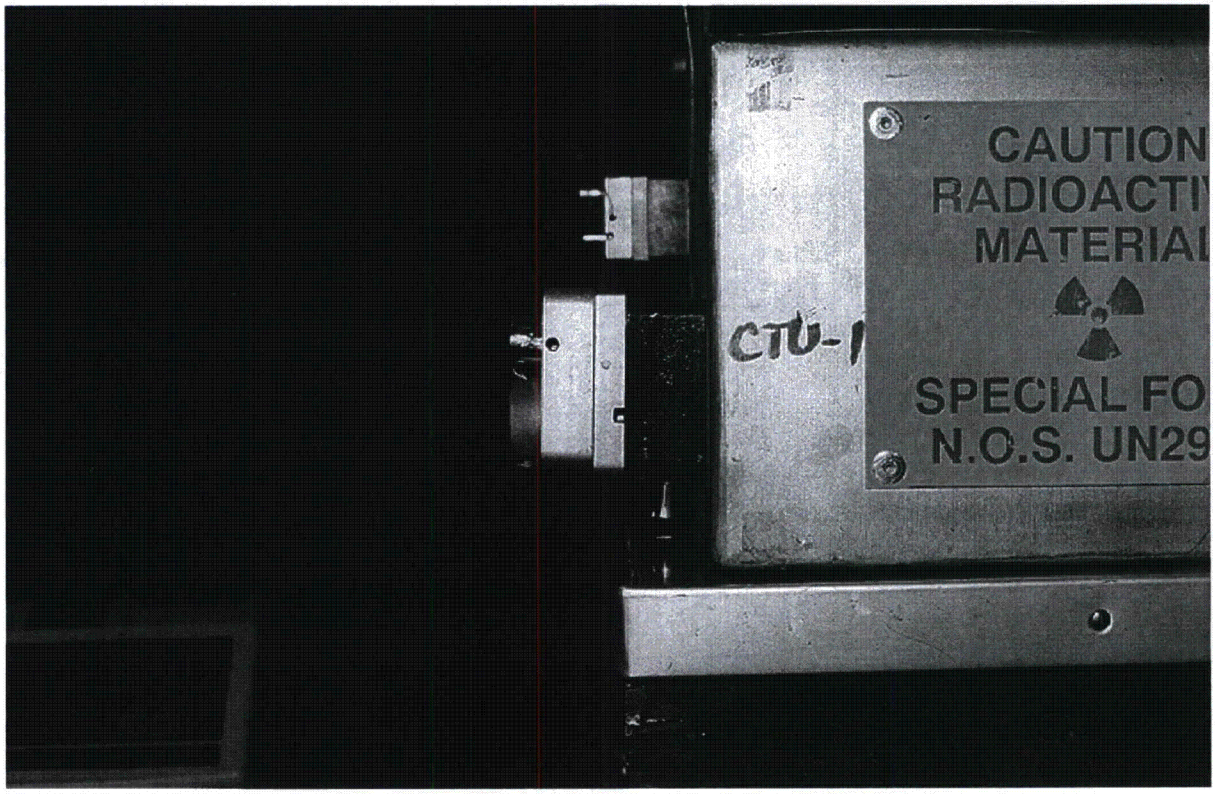


Figure 2.12.1-10 – CTU-1 Post-Test Disassembly: Condition of Lock Box/Dust Cap

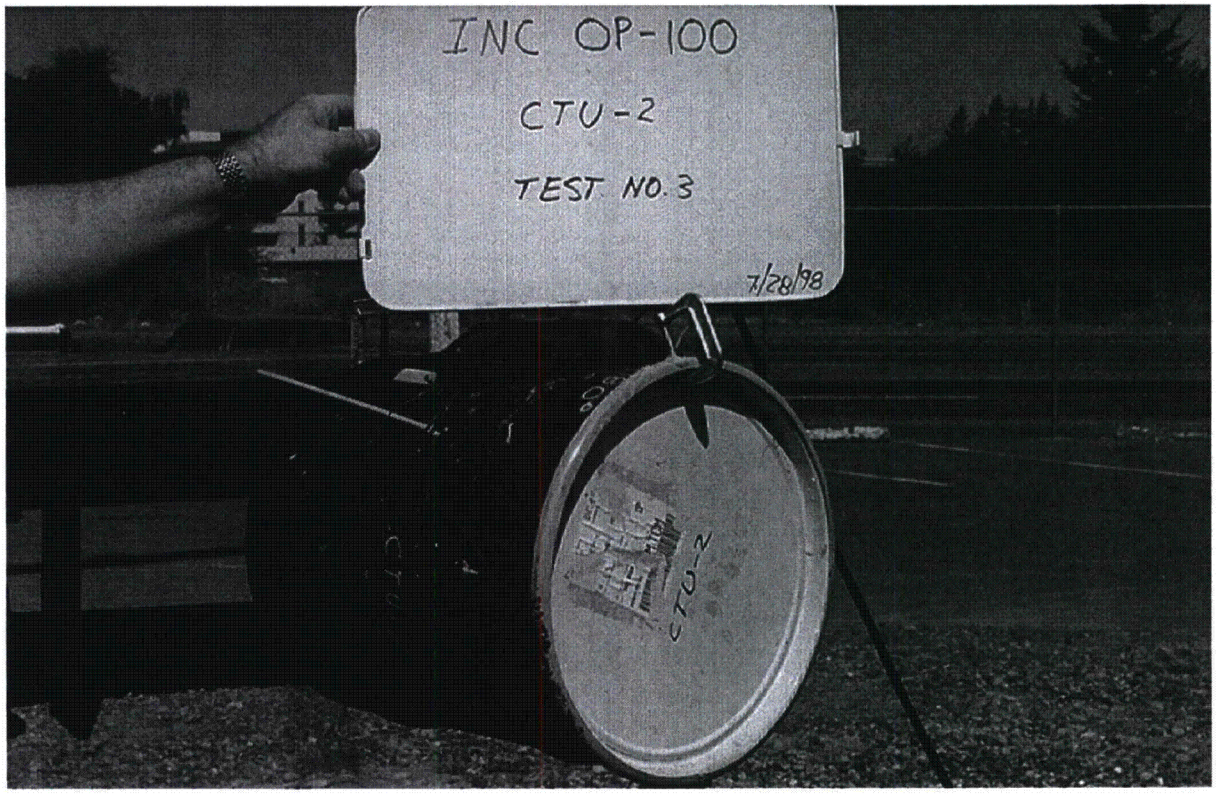


Figure 2.12.1-11 - CTU-2 Free Drop Test No. 3 Side Drop on Closure Bolt

Figure 2.12.1-12 - CTU-2 Free Drop Test No. 3: Damage to Drum Shell/Closure Bolt

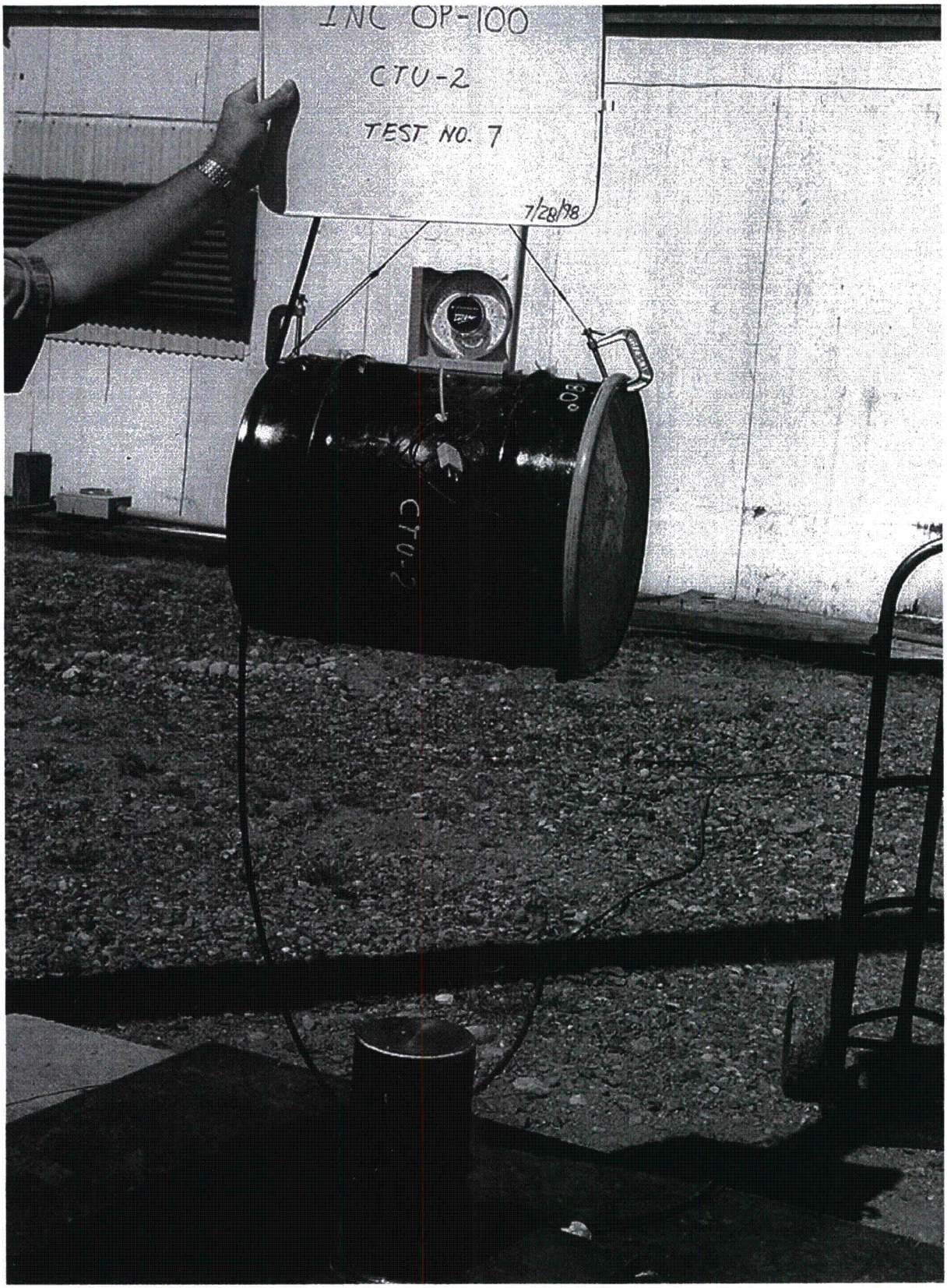


Figure 2.12.1-13 – CTU-2 Puncture Drop Test No. 7 Immediately Prior to Impact

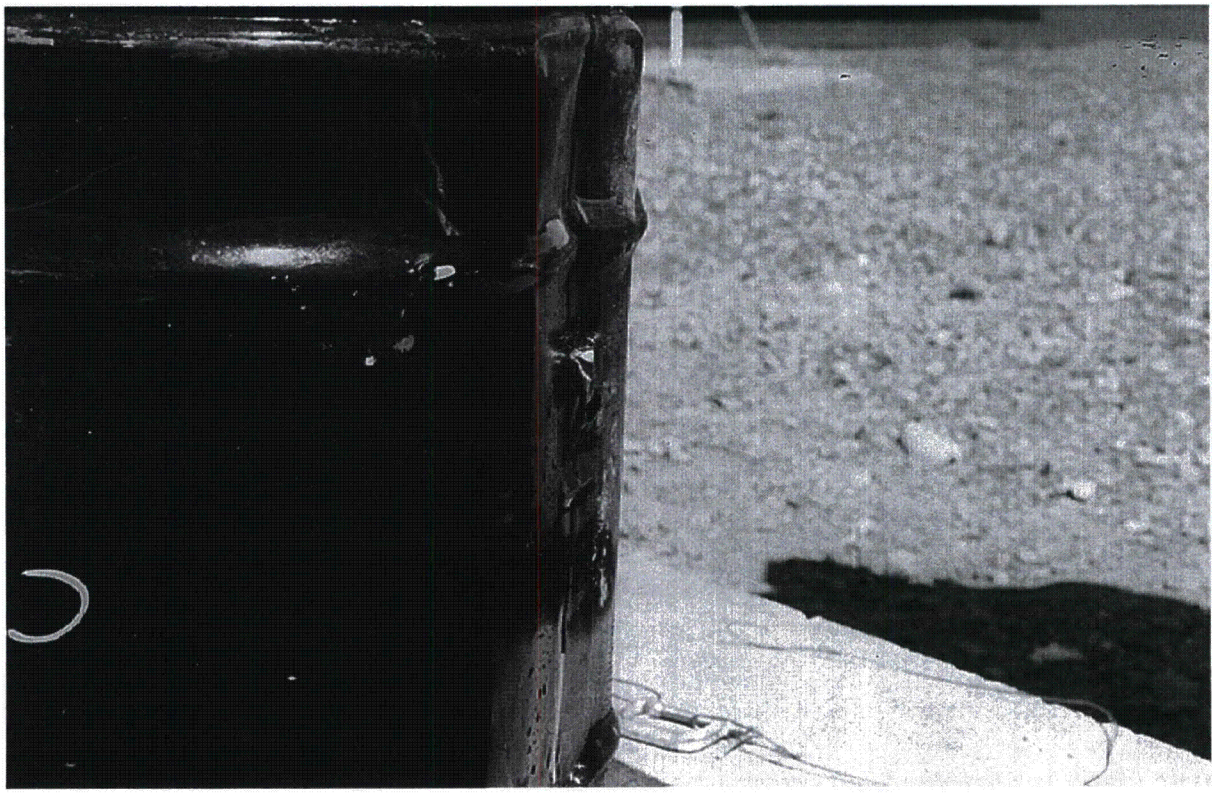


Figure 2.12.1-14 – CTU-2 Puncture Drop Test No. 7: Damage to Drum Side (Side View)

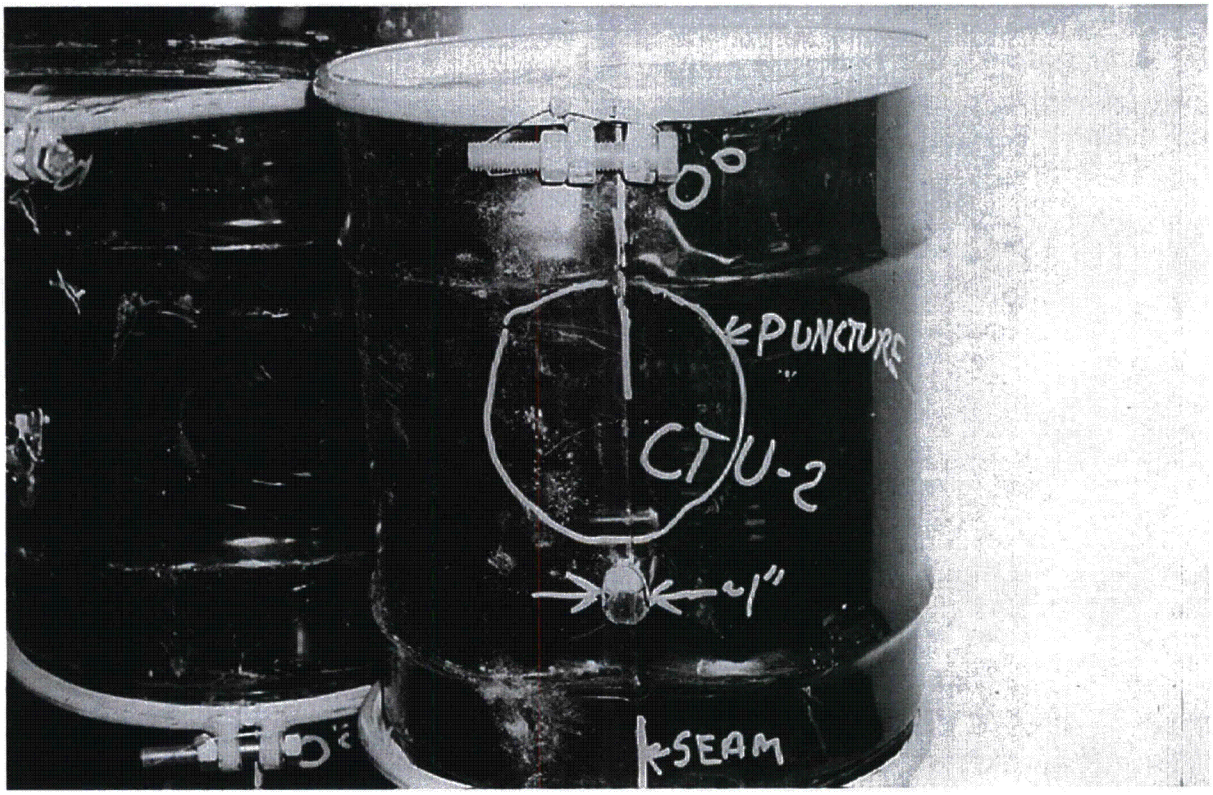


Figure 2.12.1-15 - CTU-2 Puncture Drop Test No. 7: Damage to Drum Side (Front View)

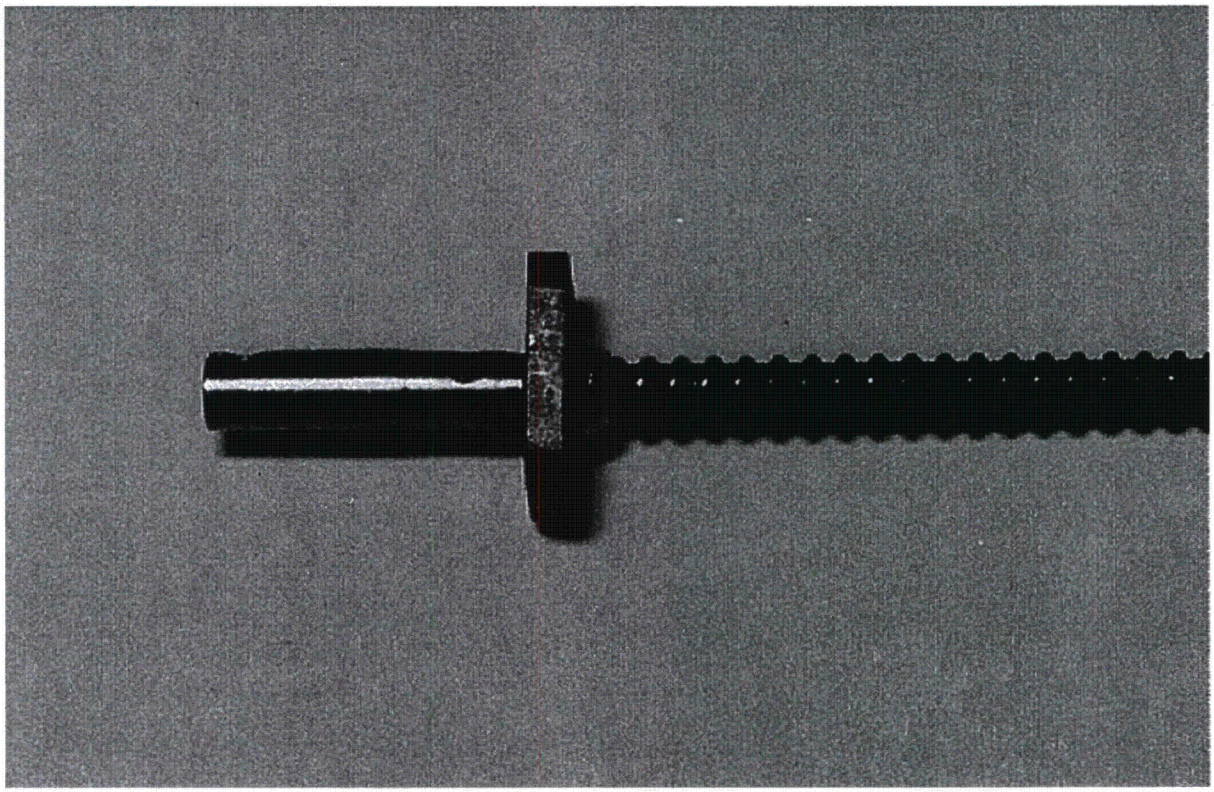


Figure 2.12.1-16 - CTU-2 Post-Test Disassembly: Jammed Ball into Trap

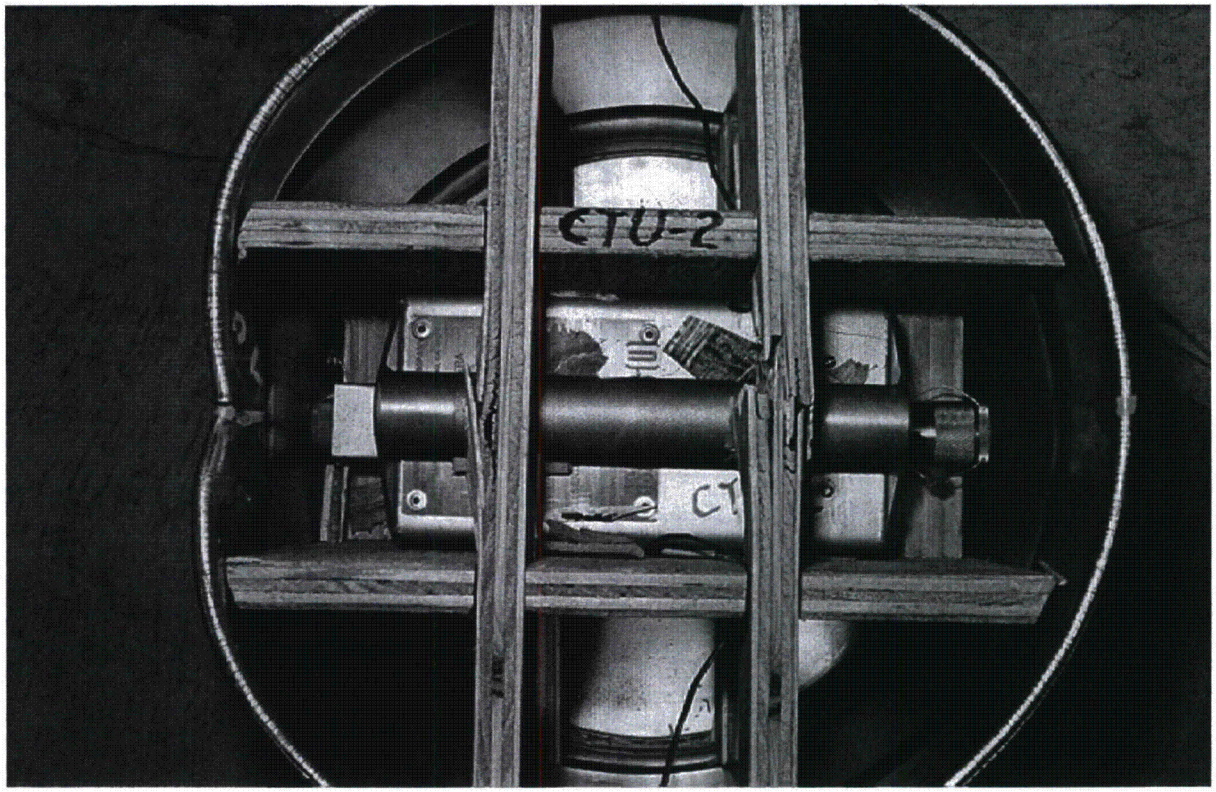


Figure 2.12.1-17 - CTU-2 Post-Test Disassembly: Condition of Plywood Support Structure

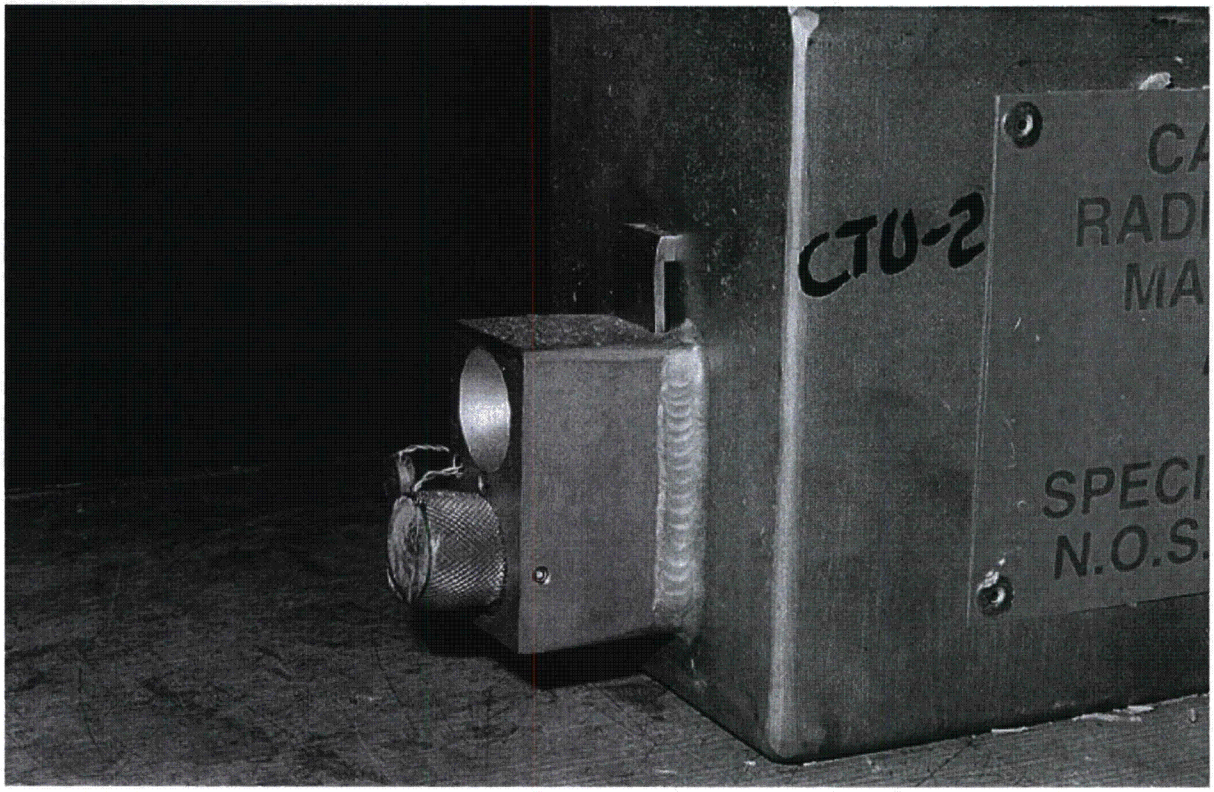


Figure 2.12.1-18 – CTU-2 Post-Test Disassembly: Jammed Lock Box Dust Cap & Indicator

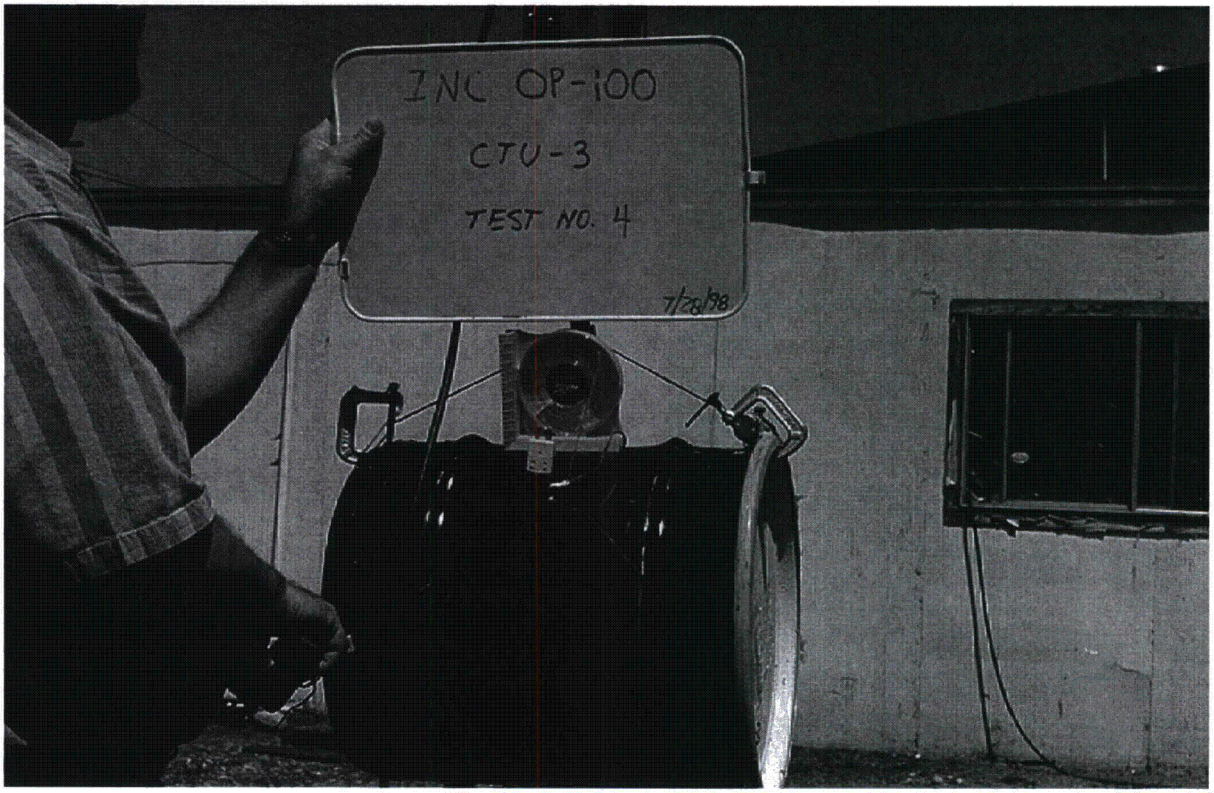


Figure 2.12.1-19 – CTU-3 Free Drop Test No. 4: Side Drop on Side Opposite Closure Bolt

Figure 2.12.1-20 – CTU-3 Free Drop Test No. 4: Damage to Closure Lid

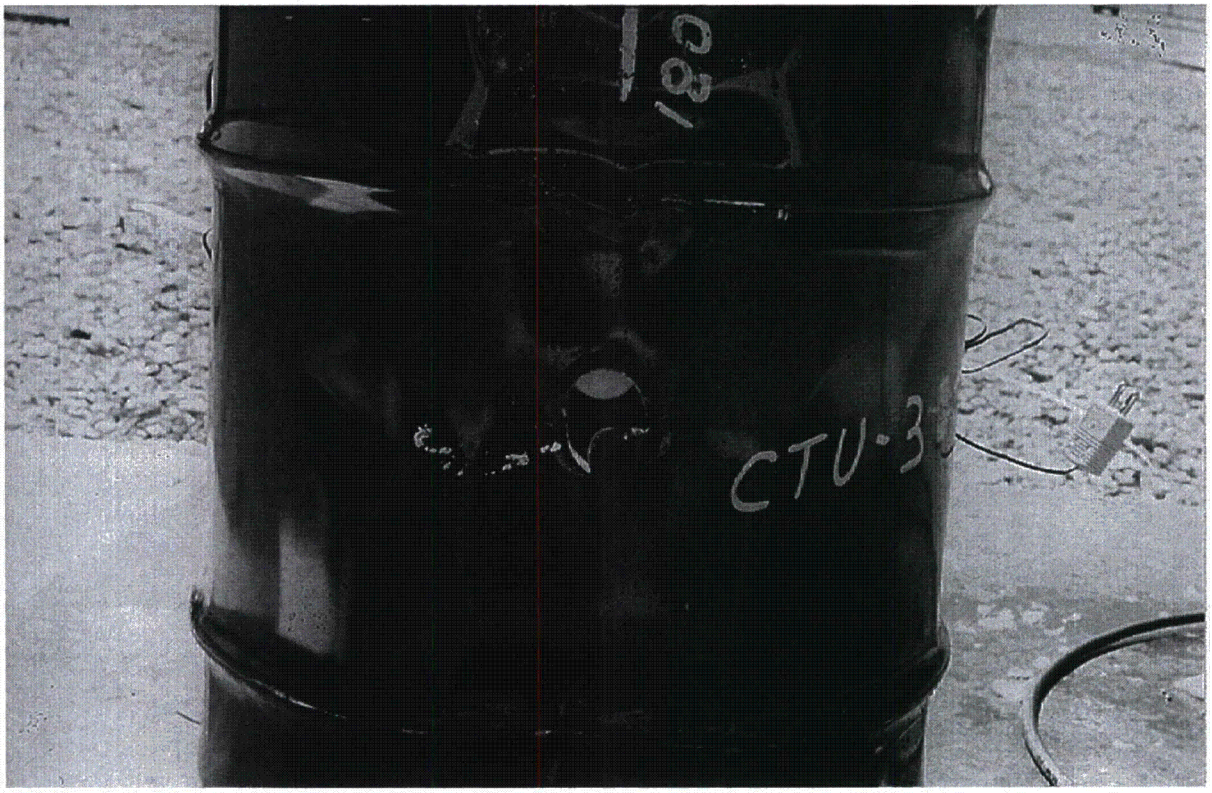


Figure 2.12.1-21 – CTU-3 Free Drop Test No. 4: Damage to Drum Shell by Safety Plug

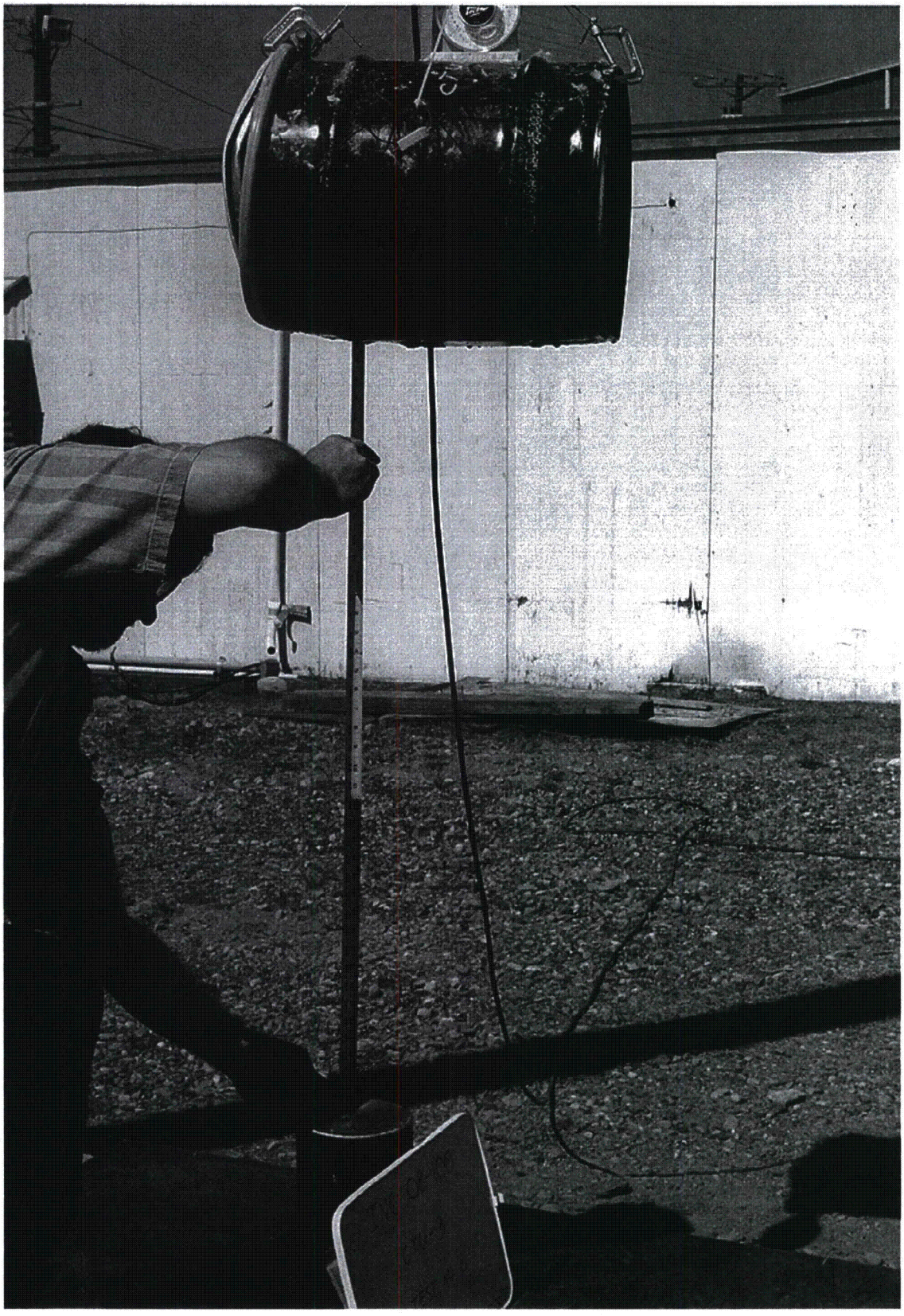


Figure 2.12.1-22 – CTU-3 Puncture Drop Test No. 8 Just Prior to Impact