71-9290

Safety Analysis Report for F430/GC-40 Transport Package

IN/TR 1608 F430 (2c)

Non-Proprietary Information

MDS Nordion
Science Advancing Health

MDS Nordion Package Engineering

IN/TR 1608 F430 (2c)

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NOTE: The portion of this text affected by changes is indicated by a vertical line in the margin.

CHAPTER 1 - GENERAL INFORMATION

This chapter of the MDS Nordion F-430 Transport Package Safety Analysis Report (SAR) presents a general introduction to and description of the MDS Nordion F-430 transport package. Figures 1.1 through 1.4 show main dimensions and materials of this package.

1.1 INTRODUCTION

The MDS Nordion F-430 transport package has been developed as a safe means of transporting MDS Nordion's Gammacell-40 (GC-40) irradiator containing cesium-137 sealed sources in Special Form.

The F-430 provides impact and thermal protection for the radioactive contents. Containment is provided by the sealed source and shielding by the GC-40 irradiator body.

Each F-430 packaging is assigned a unique serial number. Therefore a typical model/serial number on the identification plate is "F-430-xx" meaning F-430 is the model and xx is the numeric serial number of the packaging.

This safety analysis report demonstrates that the F-430 meets the requirements of 10CFR Part 71, Packaging and Transport of Radioactive Material, and the requirements for type B(U)-96 packages as defined in IAEA TS-R-1, Regulations for the Safe Transport of Radioactive Material.

1.2 PACKAGE DESCRIPTION

1.2.1 Packaging

The F-430 is a stainless steel drum 1.27m (50") outside diameter, 1.27m (50") tall placed on a removable mild steel skid 1.27 x 1.27 x 0.20m (50" x 50" x 8"). It has a cylindrical cavity 0.914m (36") diameter, 0.895m (35.25") tall. The main [redacted].

The weights of the different F-430/GC40 configurations discussed in this analysis are summarized in Table 1.1 below. The maximum design weight of the F-430/GC40 is 3175 kg (7000 lb.). The maximum payload (for example GC40 head and inner frame) is 1820 kg (4000 lb.).

Table 1.1: Summary of F-430/GC40 Weights

Component	Nominal Weight, Lower Head Configuration	Nominal Weight, Upper Head Configuration	Test Specimen Weight
GC40 Head	1241 kg (2735 lb.)	1157 kg (2550 lb.)	1740 kg (3835 lb.)
Inner Brace	209 kg (460 lb.)	170 kg (375 lb.)	209 kg (460 lb.)
F430 Overpack	1198 kg (2640 lb.)	1198 kg (2640 lb.)	1209 kg (2665 lb.)
Tie Down Collar	154 kg (340 lb.)	154 kg (340 lb.)	N/A
Total	**2802 kg (6175 lb.)**	**2679 kg (5905 lb.)**	**3158 kg (6960 lb.)**

[redacted]

[redacted]

[redacted]

For overhead lifting the F-430 overpack is equipped with four hoist rings on the top surface. Each hoist ring alone is rated for 32kN (7000lb) with a breaking strength of 156kN (35000lb), and the overpack can be lifted by any single hoist ring. For tie-down, at the time of shipping, the F-430 is fitted with a tie-down collar.

The F-430 package provides its contents with impact and thermal protection. Containment is provided by Special Form sealed source and shielding by the GC-40 irradiator (lower or upper head). The GC-40 consists of a lead-shielded cask, and a source drawer, which houses one Cesium-137 sealed source (maximum activity 2kCi).

A detailed, step-by-step procedure for preparation for shipment is included in Chapter 7. In addition the GC-40 loading and unloading procedures are also included in Chapter 7.

The F-430 package is identified with appropriate identification plates and labelling affixed on the fireshield.

The engineering information drawings of the F-430 transport package are provided in Appendix 1.3.2.

1.2.2 Operational Features

[redacted]

The outside surface of the package is smooth and can be easily decontaminated.

[redacted]

1.2.3 Contents of Packaging

The primary purpose of the F-430 overpack is to transport MDS Nordion's GC-40 irradiator (upper or lower heads). GC-40 is a [redacted].

The radioactive source is Cesium-137 in the form of cesium chloride compressed powder pellets. This source is contained inside stainless steel capsules (C-440, C-161 Type 8, see Appendix 4.5.1). Maximum activity is 2000 Ci per source, which generates about 10W of decay heat. The sealed sources are double walled stainless steel of a cylindrical shape 40mm in diameter, 43mm long (1.57" diameter, 1.70" long), and weighing approximately 235g (8.3 oz). The sealed sources meet the requirements for Special Form Radioactive Material.

It is the intent of this application to qualify other contents that will weigh up to 1820kg (4000lb) and generate a decay heat load of up to 100 W (170 Btu/h). Refer to chapter 3, appendix 3.7.1, finite element analysis for increased decay heat load inside F-430 overpack.

The radiation levels external to the package do not exceed 200 mrem/h at the surface of the package and the Transport Index ≤ 10.

1.3 APPENDICES

For the <u>List of References</u> see Appendix 2.10.1 in Chapter 2.

This section contains the following appendices.

Appendix 1.3.1	Specification sheet for the F-430/GC-40 package.
Appendix 1.3.2	[redacted]
Appendix 1.3.3	USNRC Device Registration for Gammacell 40

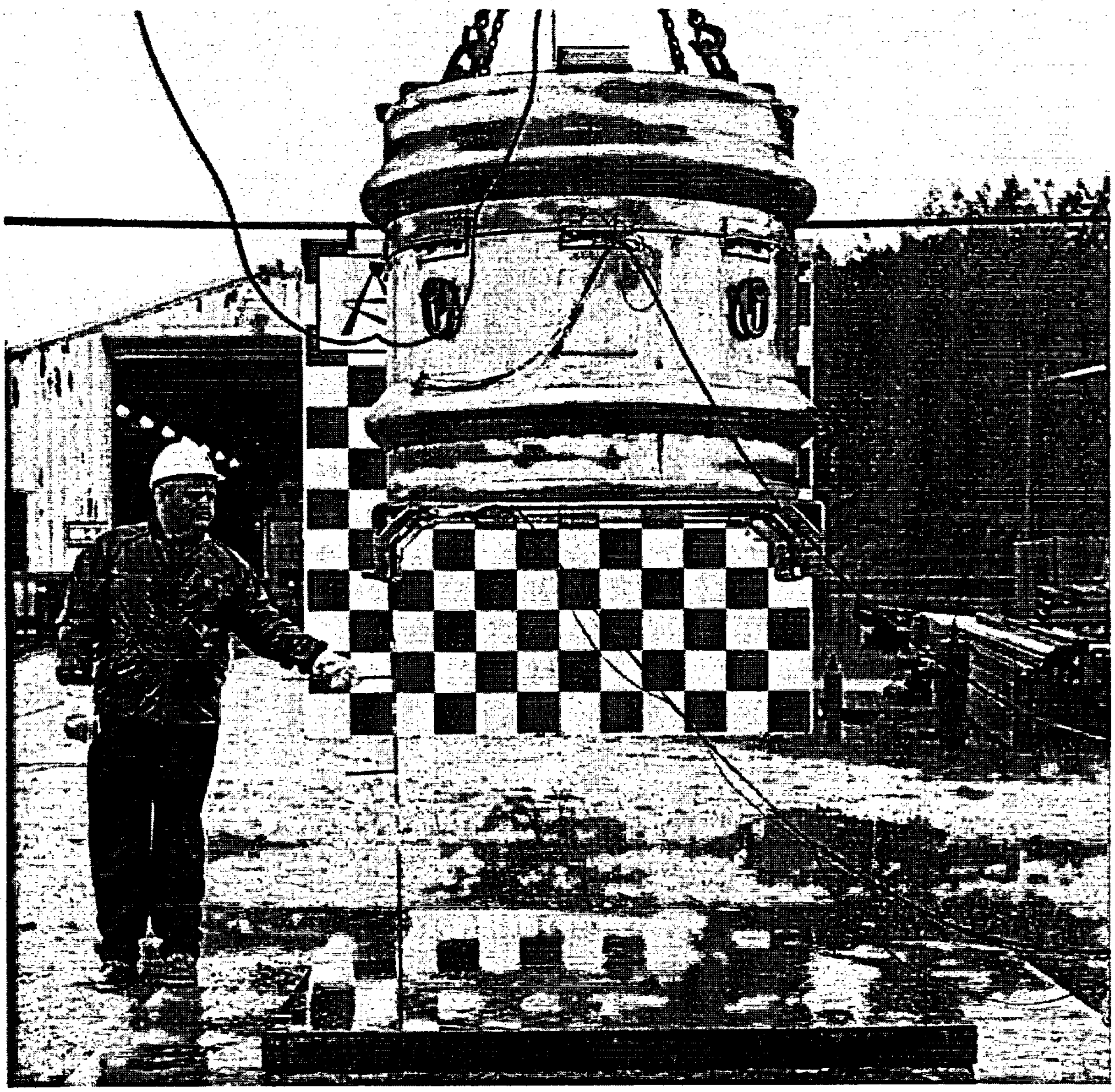

Figure 1.1: F-430 Overpack prior to 1.2m normal drop test (Photo 9910-23698-2)

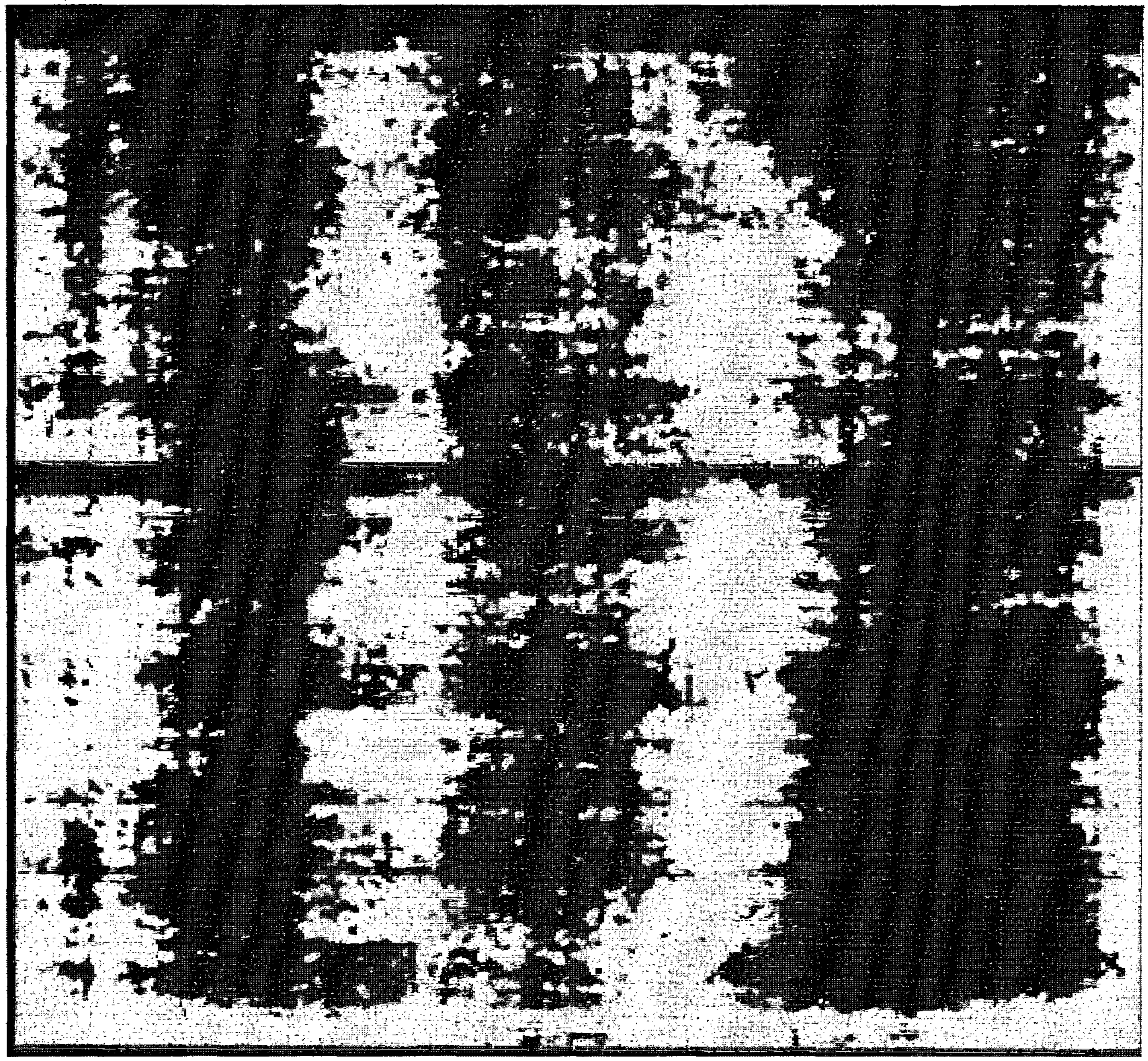

Figure 1.2: [redacted]

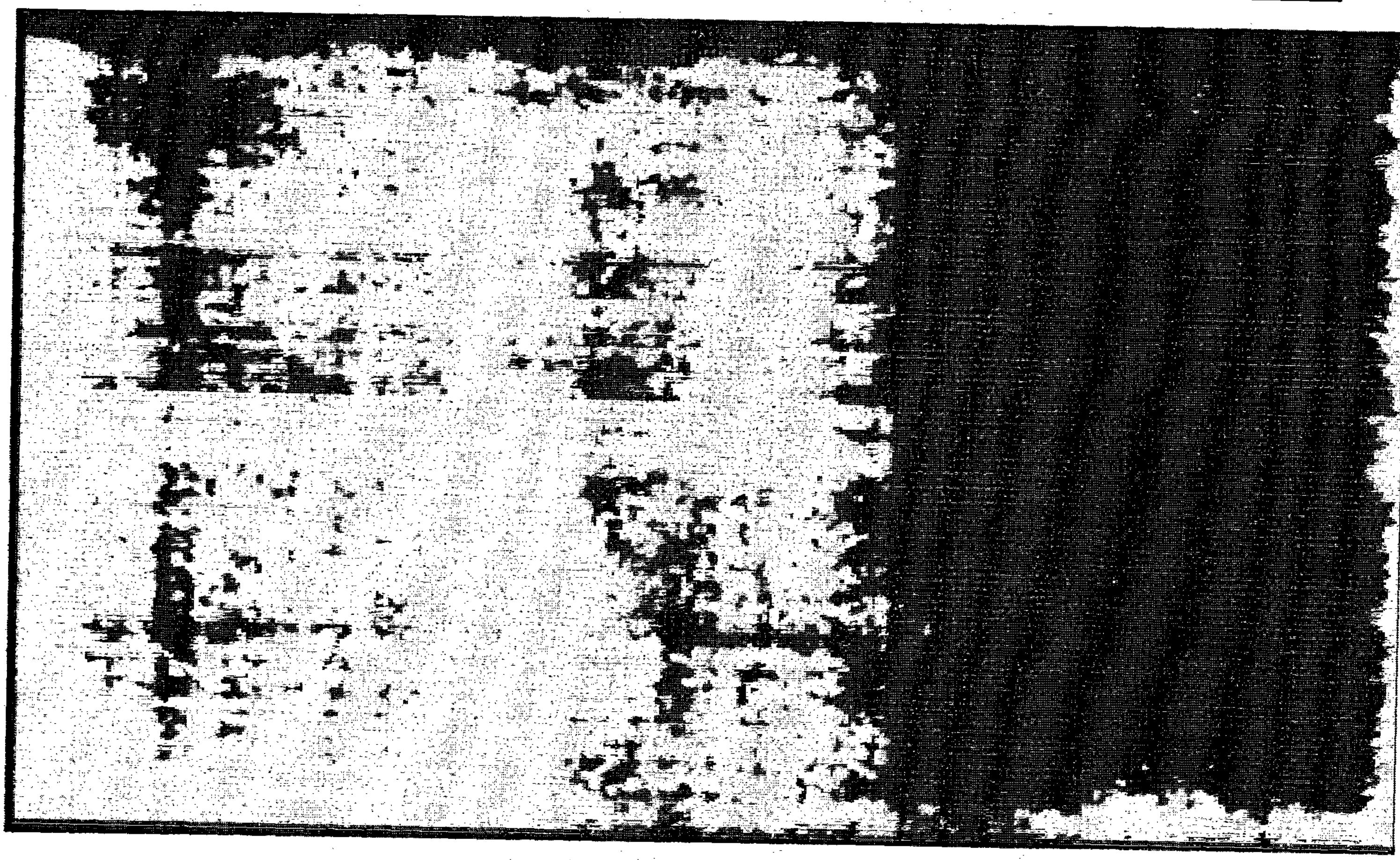

Figure 1.3: [redacted]

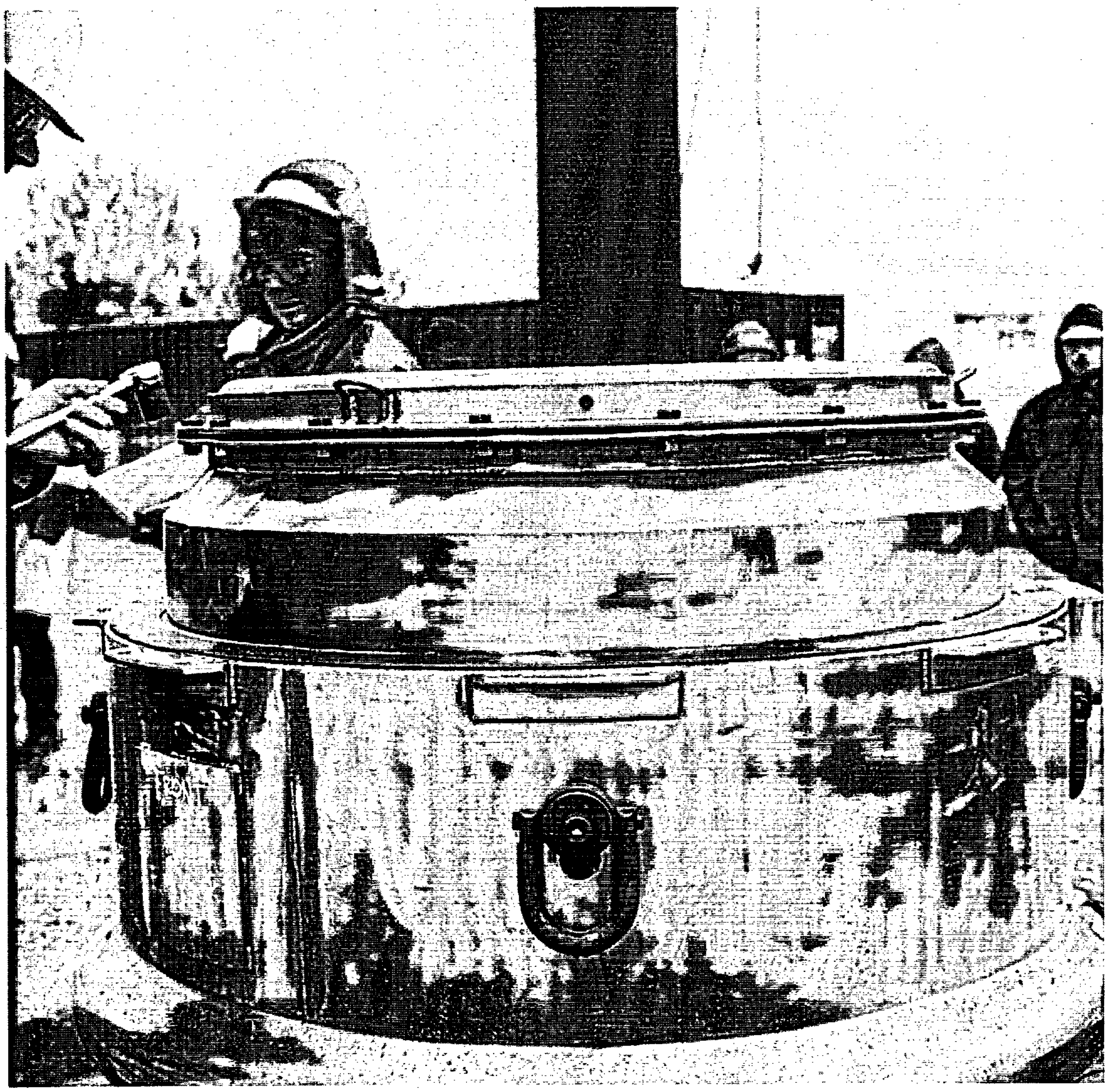

Figure 1.4: F-430, Main Cover Removed

APPENDIX 1.3.2: [redacted]

CHAPTER 2 – STRUCTURAL EVALUATION

This chapter presents structural evaluation demonstrating that the MDS Nordion F-430 package design meets all applicable structural criteria. The energy absorbing crush shield, the container and the fire shield are evaluated and shown to provide adequate protection for the payload. Normal and hypothetical accident condition evaluations are performed in accordance with regulatory requirements. Experimental verification and evaluation are of the following two forms:

- Drop test data using a full-scale F-430 overpack.
- Steady state, non-destructive tests using full-scale F-430 overpack.

The test data are presented in the Appendices.

2.1 STRUCTURAL DESIGN

2.1.1 DESCRIPTION

The principal structural members and components of the F-430 package are illustrated in Figures 1.2 & 1.3 (Chapter 1). The F-430 container consists of [redacted].

The F-430 packaging consists of three basic components. They are:

1. **Impact shield,** [redacted]
2. **Fire shield,** [redacted].
3. **Removable skid,** which facilitates the handling of the F-430 packaging.

These features do not provide containment.

The impact shield [redacted].

[redacted]

For tie-down, a tie-down collar is fitted around the F-430 at the time of shipment.

For overhead lifting, there are four hoist rings located on the top of the container, and four forklift pockets.

[redacted]

The cavity of the F-430 container provides space for the GC-40 upper or lower head. A sealed source is loaded into the GC-40 head. The outer assembly of the C-440 sealed source is made from stainless steel type 316L, and it is defined as the CONTAINMENT. All sealed sources for the GC-40 meet the requirements for Special Form Radioactive Material (see Appendix 4.5.1).

The removable skid is formed from a mild steel plate (ASTM A-36) and it is designed to facilitate handling and stacking of F-430 container.

2.1.2 DESIGN CRITERIA

2.1.2.1 Basic Design Criteria

This section describes the design criteria used to assess the package performance. The load combinations and factors used in the assessment of the package design are as specified in the applicable sections of the regulations.

Primary containment is provided by the special form sealed source.

2.1.2.1.1 Containment Structures

For Normal Conditions of Transport (NCOT), [redacted].

For Hypothetical Accident Conditions of Transport (HACOT), the failure of any component is not permitted to affect the ability of the package to meet the requirements of the regulations. The failure of any component that would potentially affect the ability of the package to meet these requirements is analyzed and in general the stresses are shown to be less than the static ultimate strength of the material.

Structural analyses [redacted]

2.1.2.1.2 Non-Containment Structures

For Normal Conditions of Transport (NCOT), the [redacted].

For Hypothetical Accident Conditions of Transport (HACOT), the failure of any component is not permitted to affect the ability of the package to meet the requirements of the regulations. The failure of any component, which could potentially affect the ability of the package to meet these requirements, is analyzed and, in general, [redacted].

[redacted]

[redacted]

2.1.2.2 Miscellaneous Structural Failure Modes

2.1.2.2.1 Brittle Fracture

The Cs-137 source capsules, [redacted], are fabricated of type 304L or 304 austenitic stainless steel. Since austenitic stainless steel does not exhibit ductile-to-brittle transition in the temperature range of interest (down to –40°C), it is safe from brittle fracture.

The closure bolts [redacted].

[redacted]

2.1.2.2.2 Fatigue

Normal operating [redacted].

[redacted]

2.1.2.2.3 Buckling

[redacted]

2.2 WEIGHTS AND CENTERS OF GRAVITY

The total design weight of the MDS Nordion F-430 package, including a payload of 18kN (4000lb), is 31kN (7000lb). The container is nearly symmetrical, therefore, the center of gravity (cog.) is very near the geometric center of the container. The center of gravity (cog.) of F-430 package is 58cm (23") from top of the removable (shipping) skid, or 80cm (31.5") from the ground.

2.3 MECHANICAL PROPERTIES OF MATERIALS

The MDS Nordion F-430 package is [redacted] polyurethane foam.

Table 2.1: Mechanical Properties of Materials

Item	Materials	Min. UTS (Mpa)*	Min. YS (Mpa)*	Reference
1	[redacted]	[redacted]	[redacted]	[redacted]
2	[redacted]	[redacted]	[redacted]	[redacted]
3	[redacted]	[redacted]	[redacted]	[redacted]
4	[redacted]	[redacted]	[redacted]	[redacted]
5	[redacted]	[redacted]	[redacted]	[redacted]
6	[redacted]	[redacted]	[redacted]	[redacted]
7	[redacted]	[redacted]	[redacted]	[redacted]

* Properties at 23°C
**Compressive stress at 50% strain

The carbon steel material is ASTM A-36; this is not an ASME material, however it is acceptable for use as it is used for the removable shipping skid. Other material used in the package is neoprene used as a gasket for both covers. The purpose [redacted]

[redacted]

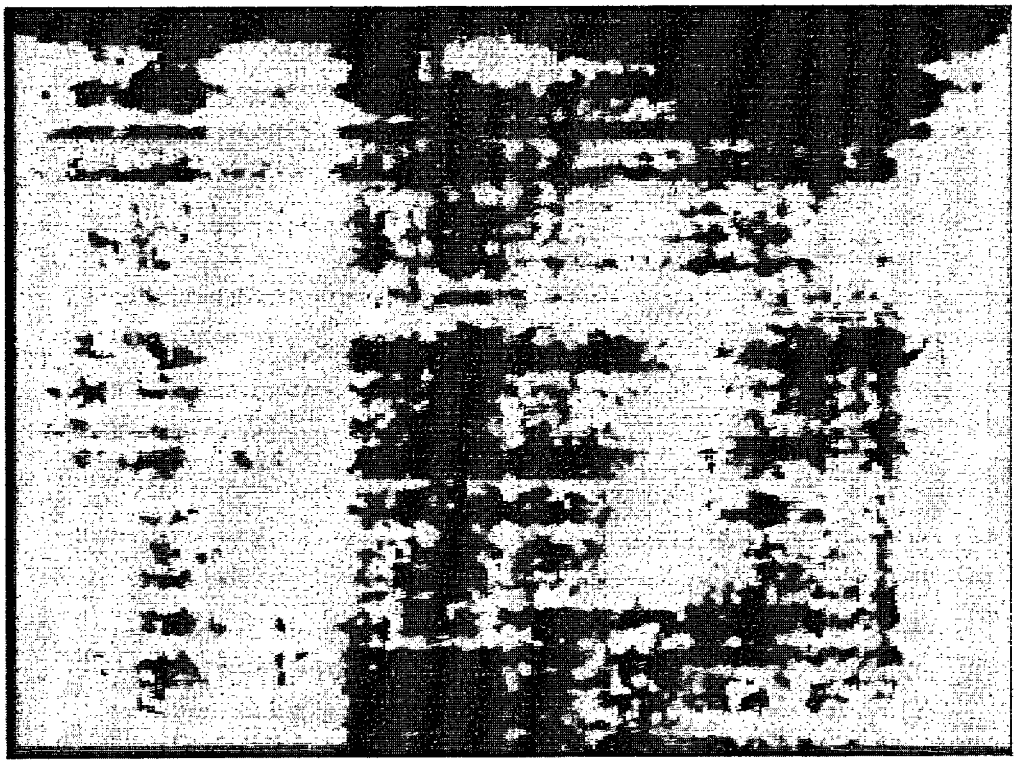

Figure 2.1: [redacted]

2.4 GENERAL STANDARDS FOR ALL PACKAGES

This section demonstrates that the F-430 transport container complies with the general standards for all packaging..

a) **Minimum Package Size**

The minimum transverse dimension of the package (without the removable shipping skid) is 135cm (53.3") and the minimum longitudinal dimension (without the removable shipping skid) is 141cm (55.5"). Both these dimensions are greater than the minimum required dimension of 10cm (4 ").

b) **Tamper-Indicating Feature**

A "lock wire" or equivalent will be used between the main cover and the body of the package during a loaded shipment as illustrated in the Engineering Information Drawings (Appendix 1.3.2). Damage to this device provides evidence of tampering.

c) **Positive Closure**

See section 2.4.2 for discussion of the positive fastening devices for the containment system.

d) **Chemical and Galvanic Reactions**

See section 2.4.1 for discussion on chemical and galvanic reactions.

e) Valves

There are no valves or pressure relief devices on the F-430 package.

f) **Package Performance under Normal Conditions of Transport**

See section 2.6 for demonstration of the package performance under normal conditions of transport it is demonstrated that:

- There would be no loss or dispersal of radioactive contents.
- There would be no significant increase in external radiation levels.
- There would be no substantial reduction in the effectiveness of the packaging.
- There would be no increase in external radiation levels in excess of 20%.

g) **Temperature of Accessible Surface of the Package**

In Appendix 3.7.1 it is demonstrated that the temperature of the accessible surface of the package, with the package loaded with 2000 Ci of Cs-137, and in still air at 38°C (100°F) and in the shade, is less than the 50°C (122°F) limit, for non-exclusive use shipment, and for shipment by air.

h) **Features for Continuous Venting during Transport**

There are no features on the F-430 package to allow for continuous venting during transport.

2.4.1 CHEMICAL AND GALVANIC REACTIONS

The [redacted]

[redacted]

2.4.2 POSITIVE CLOSURE

Closure of the components of the package is maintained using threaded fasteners at the following locations:

- Main cover is fixed to the main body [redacted].
- Inner cover is fixed to the main body [redacted].

A wire seal is incorporated into the cocoon closure to ensure that it cannot be inadvertently opened. The Preparation for Shipment Procedure is found in Chapter 7.

2.4.3 LIFTING DEVICES

The F-430 package can be lifted using four hoist rings on its top surface. Each hoist ring can swivel and turn to take a load of 31kN (7000 lb) in any direction. (See appendix 2.10.2 and 2.10.7).

2.4.4 TIE-DOWN DEVICES

For tie-down, the F-430 is fitted with a tie-down collar at the time of shipment. The tie-down collar girdles the mid-section of the F-430 and includes four tie-down lugs.

Stress Analysis of the tie-down arrangement is presented in Appendix 2.10.3. Under a tie-down load due to 10g, 5g, 2g acting concurrently on the F-430 package, the calculated stresses in the F-430 package do not exceed yield stress.

The package is typically secured to the transporting vehicle using good transport practice of blocking, bracing and chaining to the package. The blocking and bracing shall be such that the package cannot change position during conditions normally incident to transportation.

2.5 ADDITIONAL REQUIREMENTS FOR TYPE B PACKAGES

This section describes how the standards for type B packages are satisfied.

1) When subjected to the tests for Normal Conditions of Transport section 2.6 of this analysis shows,
   - the loss or dispersal of any radioactive material is less than $A_2 \times 10^{-6}$ per hour,
   - there is no significant increase in external radiation levels and
   - there is no substantial reduction in the effectiveness of the packaging.
   - there would be no increase in external radiation levels in excess of 20%.
2) When subjected to the tests for Hypothetical Accident Conditions of Transport section 2.7 of this analysis shows,
   - the loss or dispersal of any radioactive material is less than A_2 per week and
   - the external radiation dose rate is less than one rem per hour at one (1) meter from the external surface of the package.
3) The containment of the radioactive material after the tests for the Normal and Hypothetical Accident Conditions of Transport is demonstrated by the Special Form status of the sealed source.

2.5.1 LOAD RESISTANCE

The removable skid of the F-430 package will support a uniformly distributed load equal to five times the weight of the package. (See Appendix 2.10.4). In addition, the F-430 container in vertical position will support a distributed load equal to five times the weight of the package.

The smallest area for normal stresses is the outer shell.

$A = \pi Dt = 3.14 * 50 * 0.105 = 16.5 in^2 (10645 mm^2)$

Normal stresses produced by the load of 5 times 7000lb are $\sigma = 35000/16.5 = 2121$psi (14.6MPa)

The normal yield stress of 304L stainless steel is 33000psi (228MPa), which gives the factor of safety of 15.5.

The smallest area for shear stresses fillet weld on the ribs that attach lifting pockets to the lifting brace band.

$A_S = 4L(0.707t) = 4 * 5.62 * 0.707 * 0.19 = 3.02in^2$ ($1948mm^2$)

Load on one lifting pocket is one quarter of the total stacking load, or 35000 / 4 = 8750lb. (39kN).

Shear stress in the fillet welds is then $\tau = 8750 / 3.02 = 2897$psi (20MPa)

Bending stresses are

$\sigma = 6LFy/[bh^2] = 6 * 5 * 8750 / [4 * 0.707 \times 0.19 \times 5.62^2] = 15467$psi (107MPa)

For combined tension and shear, the maximum normal and shear stresses are:

$$\sigma_n = 1/2\,[\sigma + \sqrt{(\sigma^2 + 4\tau^2)}]$$

$$\sigma_n = 1/2\,[15467 + \sqrt{(15467^2 + 4*2897^2)}] = 15992\text{psi (110MPa)}$$

$$\sigma_s = 1/2\sqrt{(\sigma^2 + 4\tau^2)}]$$

$$\sigma_s = 1/2\sqrt{(15467^2 + 4*2897^2)}] = 8258\text{psi (57MPa)}$$

The safety factor for normal stress is 33000/15992 = 2.06 (neglecting the presence of crush foam whose compressive strength is 250psi or 1.7MPa), and for shear stresses SF = 0.57*33000/8258 = 2.28.

Therefore it is safe to stack 35000lb (156kN) on top of the F-430 container.

2.5.2 EXTERNAL PRESSURE

The outer assembly of the cesium-137 Special Form sealed sources is the containment system for the F-430 package and it exceeds the requirements for performance under an external pressure of 140kPa (20psi) as specified in this section. The source capsules (C-440 and C-161 Type 8) have been tested and certified to meet the requirements of ANSI Standard N542 for sealed radioactive sources to an external pressure of 70MPa (10150psia). See Chapter 4, Appendix 4.5.1 for the ANSI certificate of sealed source classification designation and performance.

Safety Factor = Tested pressure/required pressure

= ANSI N542, Class 5 level, External Pressure/25psi
= 10150/25 = 406.

2.6 NORMAL CONDITIONS OF TRANSPORT

The following sections demonstrate that the F-430 transport package meets the regulatory requirements for the normal conditions of transport. In particular, it is shown that:

- there will be no loss or dispersal of contents
- there will be no structural changes reducing the effectiveness of components required for shielding
- there will be no changes affecting the ability of the package to withstand the hypothetical accident conditions of transport
- there will be no increase in external radiation levels in excess of 20%.

2.6.1 HEAT

A detailed thermal evaluation of the normal conditions of transport as they apply to the F-430 Package is reported in Chapter 3, Section 3.4. For 2kCi of Cs-137 in GC-40 inside the cavity of F-430 overpack, the maximum steady state temperature within the cavity will not exceed 142°C (287°F). Refer to Thermal Analysis, Appendix 3.7.2.

Due to the very low temperature increase inside the overpack cavity the pressure build-up inside the cavity of the F-430 is negligible.

The sealed sources used in the package meet the requirements for Special Form Radioactive Material. They have been shown to remain leak tight following temperature tests at 800° C, which is well in excess of the temperatures expected during transport, and certainly less than the 55°C limit for air transport.

2.6.2 COLD

A steady-state ambient temperature of -40°C (-40°F) would not adversely affect the ability of the package to contain its radioactive contents or shield the environment. There are no liquids present within the package to freeze under these conditions nor are the materials used in the construction of the package subject to brittle fracture as discussed in section 2.1.2 of this report.

Because of the high thermal conductivity of the lead, stainless steel and carbon steel, the primary materials used in the construction of the container of this package, no steep thermal gradients exist in the container to cause significant thermal stresses.

Tests on prototype sealed sources demonstrate that containment is maintained at -40°C. (See Chapter 4, Appendix 4.5.1).

2.6.3 PRESSURE

An external pressure equal to 25kPa (3.5psi) absolute would have no effect on the package. [redacted].

Prototype sealed sources have been tested to 2068kPa (300psi) and have been found to remain leak tight. (See Appendix 2.10.5). This also demonstrates that they will not leak as a result of the 95kPa drop in pressure associated with air transport.

2.6.4 VIBRATION

2.6.4.1 Special Form Sealed Sources

The C-440 and C161 Type 8 sealed source are designed, tested and certified to meet the Class 3 vibration test requirements of ANSI N542 [10]. This test requires the capsules to be subjected to vibrations ranging from 25 to 500 Hz at 5G peak amplitude and 90 to 500 Hz at 10G peak amplitude. According to RDT Standard No. F-8-9T (Ref. [38]), the highest frequency of vibration encountered during normal transport by road is 500 Hz. Hence this test, along with operational experience, provides assurance that the Cs-137 sealed source is unaffected by the vibrations due to normal conditions of transport.

2.6.4.2 Fasteners

[redacted]

Fasteners for inner and outer cover are considered susceptible to the effects of the vibrations. Therefore, these assemblies utilize standard spring lock washers, which prevent the bolts from loosening.

2.6.5 WATER SPRAY

Water leakage is prevented by a neoprene gasket 3mm (1/8") thick between the main cover and body of the package. Polyurethane foam vent holes are plugged with plastic pipe plugs, 3/4" NPT. Therefore, the F-430 can withstand the water spray test during normal transport without any loss of integrity.

2.6.6 FREE DROP

2.6.6.1 Demonstration of Compliance

A full scale F-430 test packaging has been used to demonstrate compliance with the Normal conditions of transport tests. The test was managed by the test plan document (Ref. [48]) and the Quality plan document (Ref. [49]). Tests where completed at Chalk River Laboratory (CRL) of Atomic Energy of Canada Limited (AECL), Chalk River, Ontario, Canada, on October 13, 1999. Tests were witnessed by the Canadian Nuclear Safety Commission and the United States Nuclear Regulatory Commission staff.

The tested F-430 contained a GC-40 irradiator (lower head) with 4.9kN (1100lb) extra weight. The extra weight consisted of lead poured inside the cavities of the GC-40 irradiator. The additional weight provides a measure of conservatism to the results, and is representative of other configurations that may be shipped within the F-430.

The GC-40 lower head was chosen as it is the heaviest and most irregular component that may be shipped in the F-430. The base plate of the GC-40 lower head has sharp corners that could pierce through the overpack walls. In contrast, the upper head is lighter and more regular. The GC-40 is also the irradiator that will be shipped most often in the F-430.

The results of these tests are directly applicable to the lighter upper head and similar irradiators with regular features and similar weights.

The prototype (total weight of 3160kg or 6970lb) was subjected to a drop test program consisting of nine drop tests. The drop tests included the tests for normal and accident conditions of transport tests, and were carried out on a single full-scale F-430/GC-40 prototype. The tests were completed in the following sequence:

Test #1:	Normal 1.2m Free Drop Test: Upright orientation.
Test #2:	Normal 1.2m Free Drop Test: Top edge orientation
Test #3:	9m Free Drop Test: Upside down orientation
Test #4:	9m Free Drop Test: Top edge orientation
Test #5:	1m Pin Drop Test: Impact top center of container
Test #6:	1m Pin Drop Test: Impact side center of container
Test #7:	9m Free Drop Test: Horizontal (side) orientation
Test #8:	1m Oblique Pin Drop Test: Impact side center of container
Test #9:	1m Pin Drop Test: Impact segmented flange (horizontal orientation)

The F-430 was opened only after the first drop test and condition of the contents was visually checked. At the conclusion of each test, the test packaging fasteners were not replaced. The cask was left untouched throughout the program, with the exception of accelerometer instrumentation. Damage was cumulative giving the results an added degree of conservatism.

2.6.6.2 Test Objectives

The purpose of the tests, in addition to conditioning the package for the Hypothetical Accident conditions tests, was to generate the maximum load on the key structural components and the design features. These are:

1. Retention of main cover.
2. Retention of inner cover.
3. No structural damage to the GC-40 lead housing
4. No damage to the source capsule.

In summary, the results of the drop tests were satisfactory. Both outer and inner cover remained in place, thermal protection was not significantly damaged, and neither was the containment or shielding of the radioactive source.

2.6.6.3 Test Temperature

All free drop testing, performed on October 13 and 14, 1999 at Chalk River, Ontario, Canada, was conducted at ambient temperature between 2°C and 8°C (35 to 46°F).

2.6.6.4 Target

The drop test facility is located at AECL-Research Co., Chalk River, Ontario, Canada. It consists of an impact pad and a drop tower with hoisting and release mechanisms. The base pad is fabricated from reinforced concrete (of size approximately 3m x 3m x. 3m) resting on a solid bedrock. The upper surface of the pad is covered with a 2.4m x 1.8m x 10cm thick alloy steel plate (Specification ASTM A-203 Grade E: YS = 390MPa). The top steel plate has a provision for mounting a target pin for puncture tests.

2.6.6.5 Extrapolation to other Package Contents

F-430 container was primarily designed for the transportation of GC-40 irradiator. Tests were completed using the GC-40 lower head (1240kg) with an additional 500kg of payload (2735lb and 1100lb respectively). This additional weight was in form of lead cast inside the GC-40 irradiator. (See Appendix 2.10.5) Internal bracing required to keep the GC-40 in place during transport weighed 208kg (460lb). Therefore the total payload weighed 1948kg. The radioactive contents were simulated using an inactive C-440 source capsule.

It is the intent of this application to demonstrate that other contents that weigh up to 1820kg (4000lb, including necessary internal bracing), fit the cylindrical cavity (91cm or 36" diameter, 89cm or 35.25" tall), and generate up to 100 W of heat can also be transported. It is submitted that the test results are directly applicable to other contents provided that the internal bracing used to shore the contents inside the cavity have similar features to the tested configuration.

As mentioned in Chapter 1, F-430 overpack provides its contents with crush protection and fire protection. A single prototype package was successfully drop tested multiple times in varying orientations with contents weighing 1950kg (4300lb). Any other contents weighing up to the tested capacity will be protected against impact in a similar manner. Internal bracing should resemble the one used for the GC-40 lower head (plywood base, and stainless steel frame that distributes load equally into the cavity wall and lid).

Thermal analysis of F-430 / GC-40 was completed using a conservative decay heat load of 100W to prove that the thermal protection provided by F-430 overpack is adequate for higher internal heating than the one generated by 2kCi of Cesium-137 (which corresponds to about 10W). Therefore, any contents that generates up to 100W of heat will be protected against the regulatory accidental fire.

When radioactive contents are to be shipped inside the F-430 overpack, MDS Nordion shall supply the regulatory bodies with all the documentation required that describes the alternative radioactive contents, the method of bracing inside the transport cavity, and thermal analysis for that contents inside the F-430 overpack.

2.6.6.6 Internal Heating

The assessment of the performance of F-430 under Normal and Hypothetical Accident condition tests is based on the response on a full-scale model. In service F-430 will operate at a range of temperatures imposed by the radioactive contents and the ambient conditions. Steady state temperature tests of the F-430, before and after the drop test program, have been conducted (see Appendix 2.10.5 for details).

The irradiator body surface temperature has been taken as the critical temperature of the F-430 container since the mild steel housing contains lead shielding of the source. For the normal conditions test, the temperature of the test packaging was 22°C without the solar heat load. With 38°C ambient temperature and the solar heat load (800W on flat surfaces, 400W on curved surfaces) the temperatures rose to maximum of 126°C (top surface of container) and 138°C on the surface of the irradiator body. (Refer to Chapter 3, Appendix 3.7.2)

2.6.6.7 Pressure Buildup

The two covers on the F-430 (main and inner cover) are not watertight. The mating surfaces between cover and main body are not machined hence not exactly flat. Air can escape or enter the transport cavity even with all closure bolts tight and neoprene gasket in place. Therefore, pressure build-up inside the cavity of the F-430 is negligible.

2.6.6.8 Normal Free Drop Test Orientations and Justification

2.6.6.8.1 Drop test height

Since the F-430 package weight was less than 5000kg (11,000lb) the free drop test distance was 1.2m (4 ft).

2.6.6.8.2 Upright and top edge orientation

The upright orientation is the normal lifting position, and the concern was that all fasteners (two covers and the removable skid) remain in place, and the contents does not suffer visible damage.

The top edge orientation causes a maximum deformation and exposes all bolted connections to shear forces.

2.6.6.9 Pass/fail Criteria and Justification

1) Both main and internal covers attached.

   Justification: F-430 must not lose the ability to withstand accident condition tests.

2) Package surface dose rates increase by no more than 20%.

   Justification: regulatory requirement.

2.6.6.10 Test Results

In this section the key test results are taken from Appendix 2.10.5.

1) Test #1: Upright orientation. Both covers and the removable skid remained securely attached. The principal damage was to the skid, and to the body of the container near the feet of the skid (see Figure 2.2). The GC-40 irradiator was placed on four layers of 19mm (3/4") plywood. After this first drop test the two covers were removed, [redacted]. No visible damage to the GC-40 was noted and the inside of the F-430 was not significantly damaged.

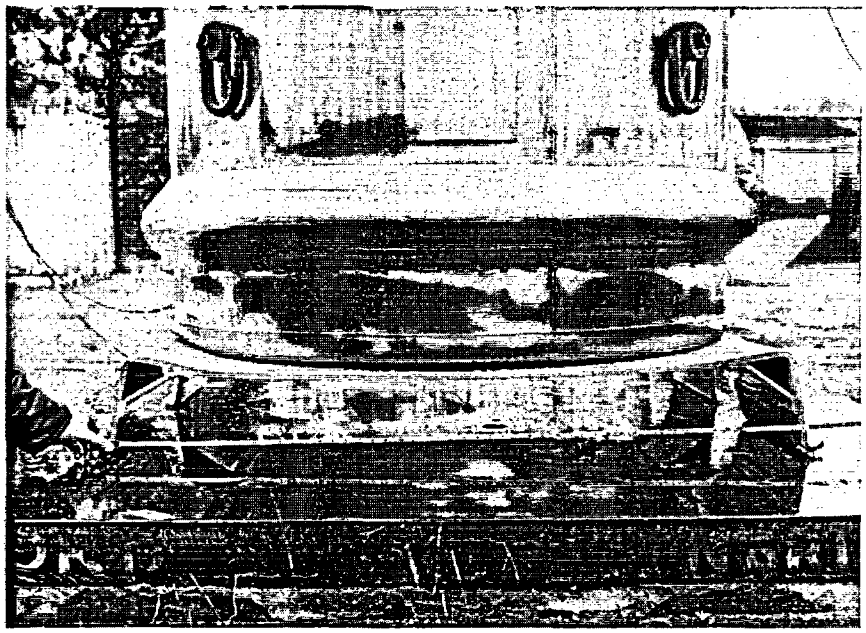

Figure 2.2: Test # 1, F-430 After 1.2m Upright Drop

2) Test #2: Top corner drop. Both covers and the removable skid remained securely attached. The principal damage was to the body of the container, locally around the impact area. [redacted]

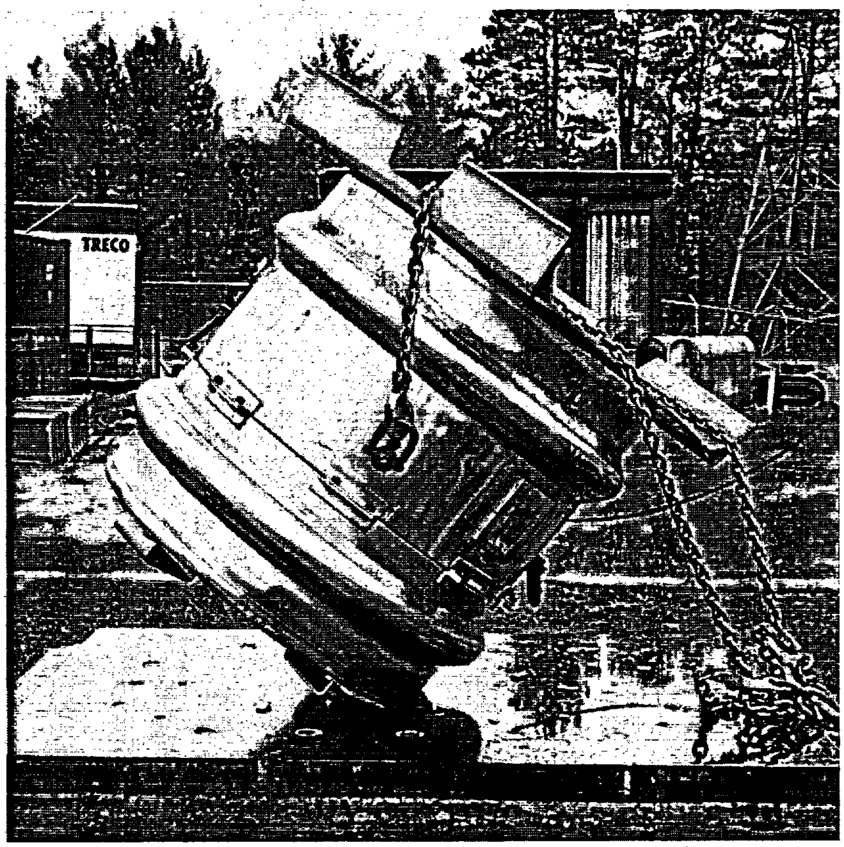

Figure 2.3: Test #2, F-430 After 1.2m Top Edge Drop

2.6.6.11 Shielding

There was no shielding test (radiation survey) conducted right after the free drop test on the test packaging as this would have interrupted the balance of the accident drop testing program.

Radiation surveys were done before and after the complete drop test program. Readings before and after the regulatory drop testing were the same (0.05mR/h) on contact with the bottom exterior surface (the skid). (Refer to appendix 2.10.5.)

2.6.6.12 Conclusions

Full-scale testing has demonstrated the ability of the F-430 transport package to maintain its structural integrity and shielding effectiveness under the regulatory Normal Conditions of Transport.

2.6.7 CORNER DROP

Refer to Section 2.6.6.10 and Appendix 2.10.5.

2.6.8 PENETRATION

Prior to the regulatory drop testing a penetration test was performed by dropping 6kg steel round bar (3.2cm in diameter with hemispherical end) from 1.7m onto the container so as to damage the containment system. Two drops were done in two different locations (flat top and round side, without additional steel backing).

In either case the outer stainless steel shell did not break. Only small dents were observed. Refer to Test Report (Appendix 2.10.5)

2.6.9 COMPRESSION

The effect of package compression are discussed in section 2.5.1

2.7 HYPOTHETICAL ACCIDENT CONDITIONS

This section demonstrates that the performance of the F-430 Transport Package, meets all regulatory requirements when subjected to the hypothetical accident conditions of transport.

2.7.1 FREE DROP

There are several drop orientations of the F-430 to be considered in determining the one most likely to result in the greatest cumulative damage when the package is subjected to the subsequent Puncture, Thermal and Water Immersion tests.

[redacted]

2.7.1.1 Worst Drop Orientation

The most damaging 9m drop test orientation for the F-430 transport package with GC-40 lower head irradiator has been looked at from two points of view.

a) What orientation that will cause the worst damage to the GC-40 irradiator (shielding and containment).

b) What orientation that will cause the worst damage to the F-430 container (crush and fire protection).

A) The GC-40 irradiator is retained inside the container cylindrical cavity with a rigid steel brace that provides the irradiator with radial and axial support Axial support downward is the square base of the irradiator. See Figure 2.4.

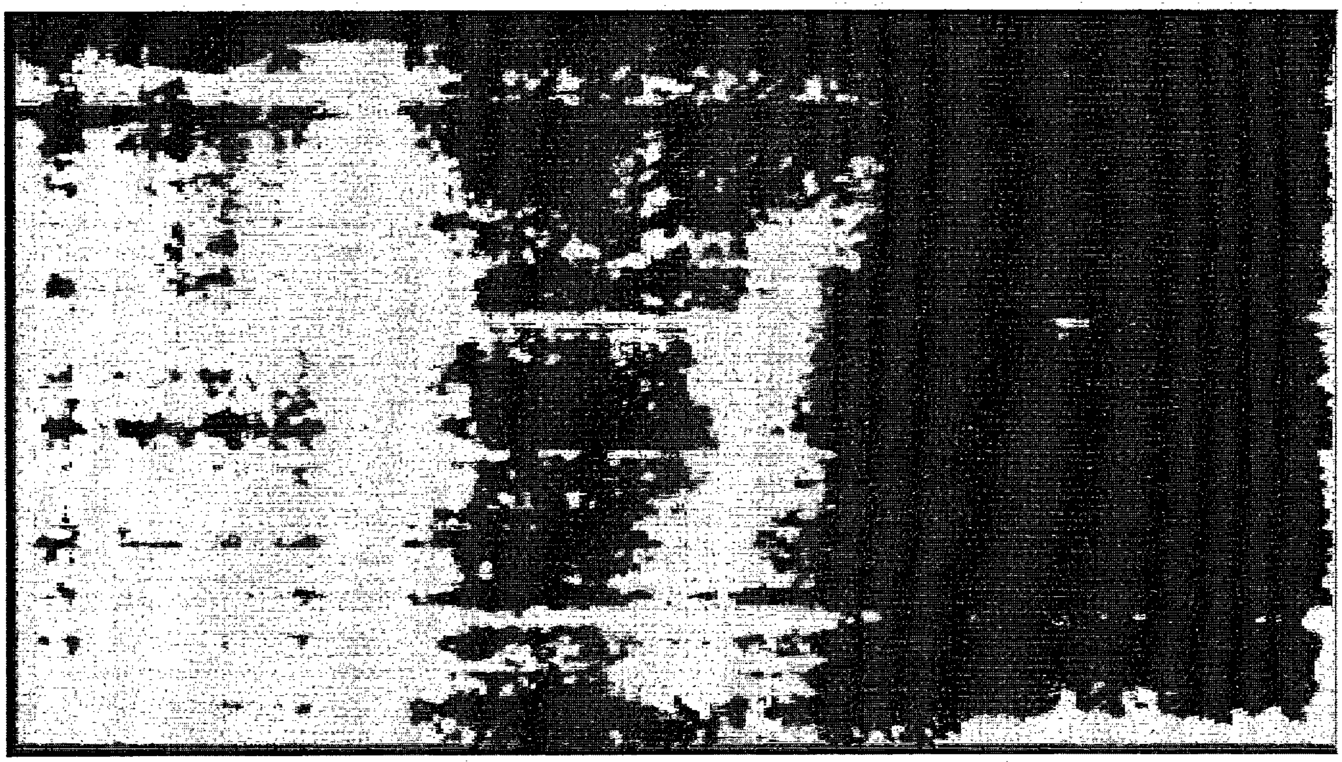

Figure 2.4: F-430 with GC-40 Irradiator (lower head)

[redacted]

To cause the maximum damage to the irradiator during impact, the irradiator must undergo maximum possible deceleration. The container's position for maximum deceleration is upside down. This is justified as follows:

Deceleration magnitude G can be theoretically approximated as

$$G = H / h$$

Where H = drop height (in)

h = deformation distance (in)

G = multiple of gravitational acceleration (no units)

To reach high G with H fixed at 9m, one needs deformation distance h. The larger the area impacting the target, the less deformation distance h. This notion eliminates corner (edge) drops and side drops, leaving upright or upside down orientations.

Finite element analysis of the removable shipping skid (Appendix 2.10.4) shows the way the skid will deform. This was also confirmed during drop test #1. The deformation for this right side up orientation after a 9m drop would be at least 0.15m. Most of this deformation would be to the skid and the edges of the container body near the skid feet. Very little deformation would be inside the container, since the square base of the GC-40 has a [redacted].

In the upside down orientation the distance before reaching a very large impact area [redacted].

Therefore, the largest deceleration is expected [redacted]

In this position the GC-40 irradiator is expected to undergo the worst dynamic loading during accidental 9m drop.

B) Significant damage to the crush protection resulting from the first 9m accidental drop could cause shielding or containment failure on the subsequent accidental 1m pin drop. However, the preservation of the thermal protection is more of a concern.

   Therefore, maximum damage results from orientations that may cause the overpack [redacted] to open or may otherwise expose the irradiator to the hottest temperatures possible in the following accidental fire.

2.7.1.2 Prototype Testing

Full-scale 9m drop tests were completed on the same prototype that had been tested for the normal conditions of transport. One bolt on the main cover was removed to simulate damage resulting from a 1m pin drop. The following series of accidental drop tests was.

Test #3:	9m Free Drop Test: Upside down orientation
Test #4:	9m Free Drop Test: Top edge orientation
Test #5:	1m Pin Drop Test: Impact top center of container
Test #6:	1m Pin Drop Test: Impact side center of container
Test #7:	9m Free Drop Test: Horizontal (side) orientation
Test #8:	1m Oblique Pin Drop Test: Impact side center of container
Test #9:	1m Pin Drop Test: Impact segmented flange (horizontal orientation)

Each of these drops included the supplemental 500kg (1100lb) weight. The package hoist rings were removed for safety.

The GC-40 and the sealed source were not examined until all tests had been completed.

Test methods, procedures, and the targets are described in section 2.6.6.1 and 2.6.6.4.

In test #3 (for maximum deceleration) [redacted] (Figure 2.5.). This gives an indication of internal deformation and a spring back action of the contents. [redacted]. Due to rain and wet surface of the container, the accelerometer connections loosened and the signal was lost, hence no deceleration values were recorded for this drop test. [redacted]. Bolts were checked by hand, and confirmed as finger tight. There were no penetrations into the stainless steel shell and the two halves of the overpack remained securely attached.

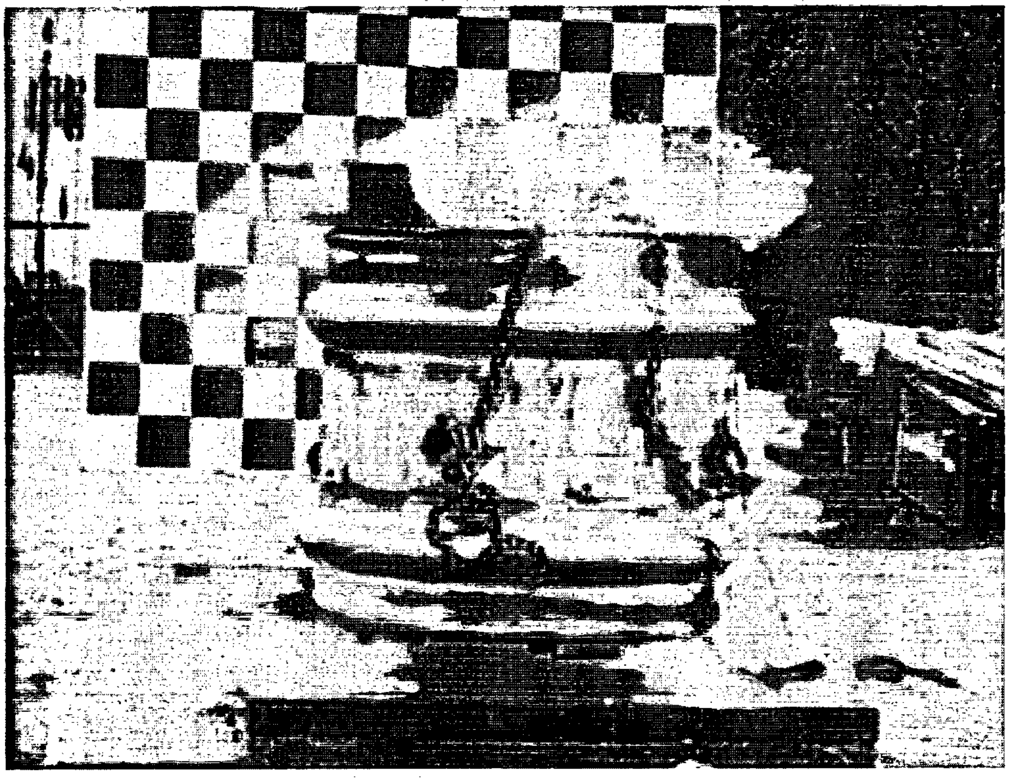

Figure 2.5: Test #3, 9m Drop with rebound

In test #4 (for maximum deformation) the [redacted]. The center of gravity was directly above the impact point since the package remained standing on its edge. [redacted]. However, from the accelerometer readings the [redacted]. See Figure 2.6.

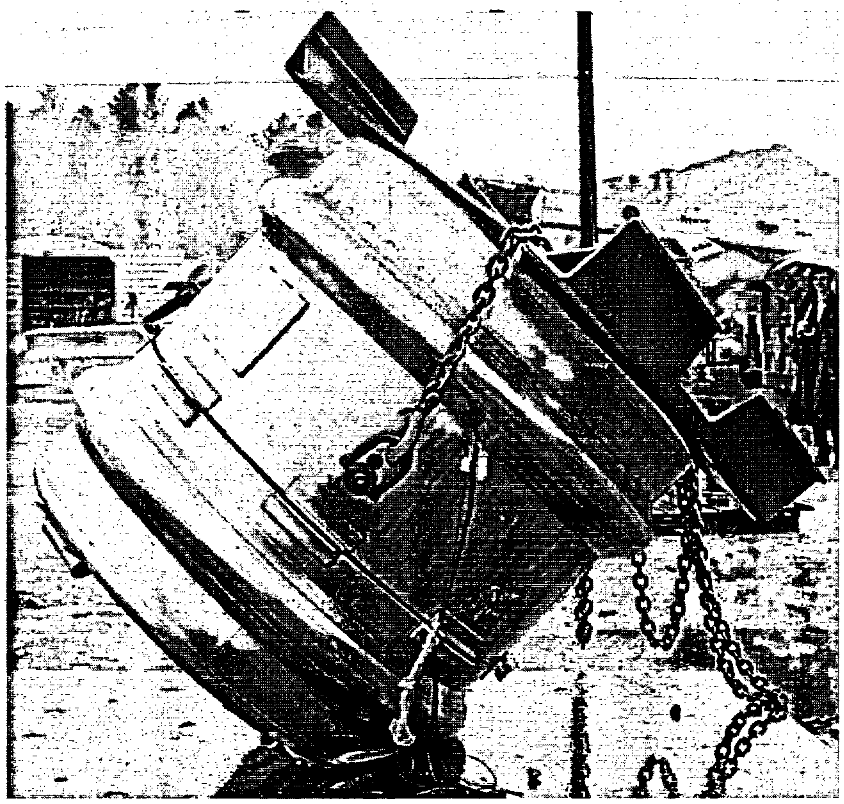

Figure 2.6: Test #4, 9m Top Edge Drop

Test #5 (to penetrate top flat surface) did not manage to break though the [redacted] likely because the [redacted]. The F-430 rolled over on its side and suffered no other major damage. The shipping skid stayed on with all bolts in.

In Test #6 (to penetrate side, curved surface) [redacted]

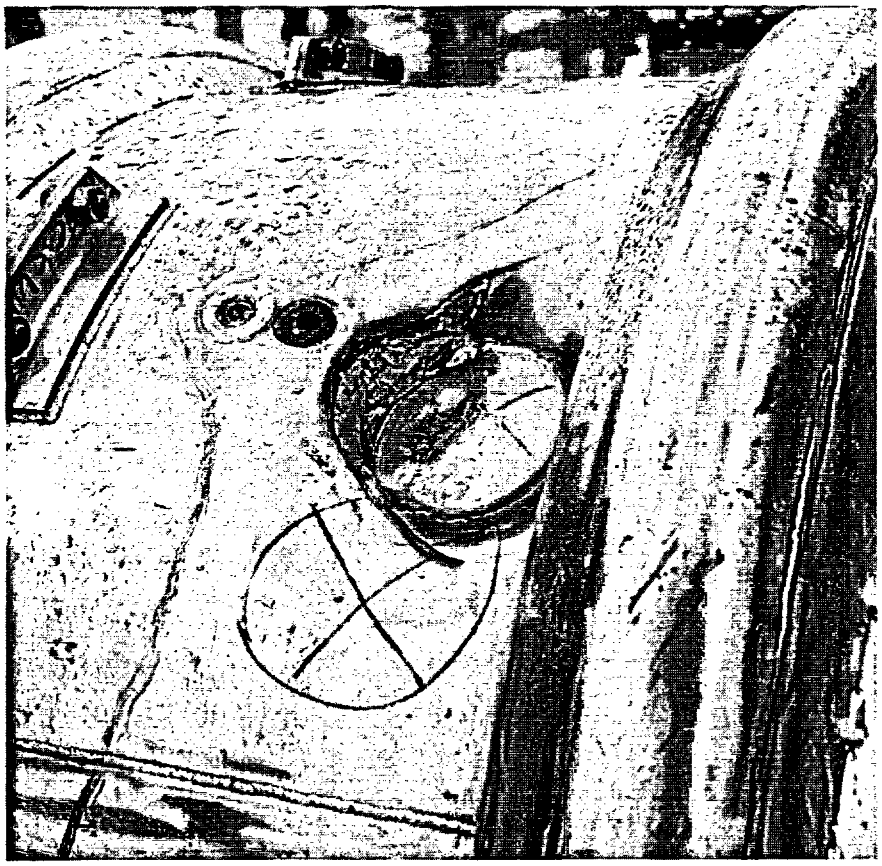

Figure 2.7: Test #6, 1m Pin Drop Test

In Test #7 (to split open the package) the highest deceleration was [redacted]. The theoretical magnitude of deceleration would than [redacted] for the bumpers is neglected and the effect of the skid is ignored.

The lowest point from which 9m height was measured was the skid's front left corner with the package in horizontal position. This resulted in additional 23cm of drop height when measured from the target surface to the bumpers (the next item to impact target after the skid). After the drop test [redacted].

[redacted]. Nevertheless, no damage was noted that could significantly affect the results of the subsequent fire test.

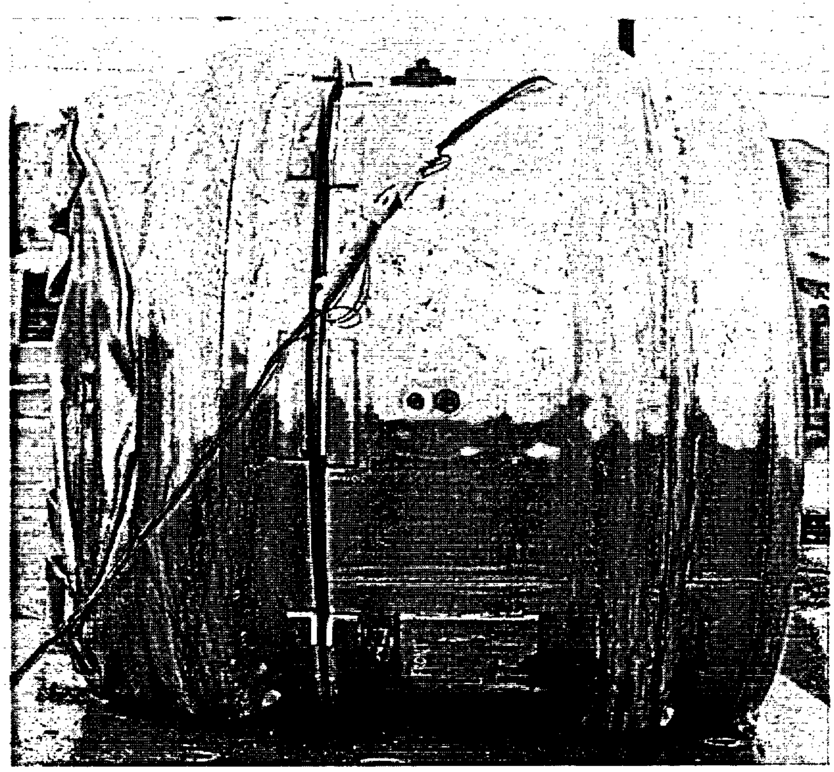

Figure 2.8: Test #7, 9m Side Drop

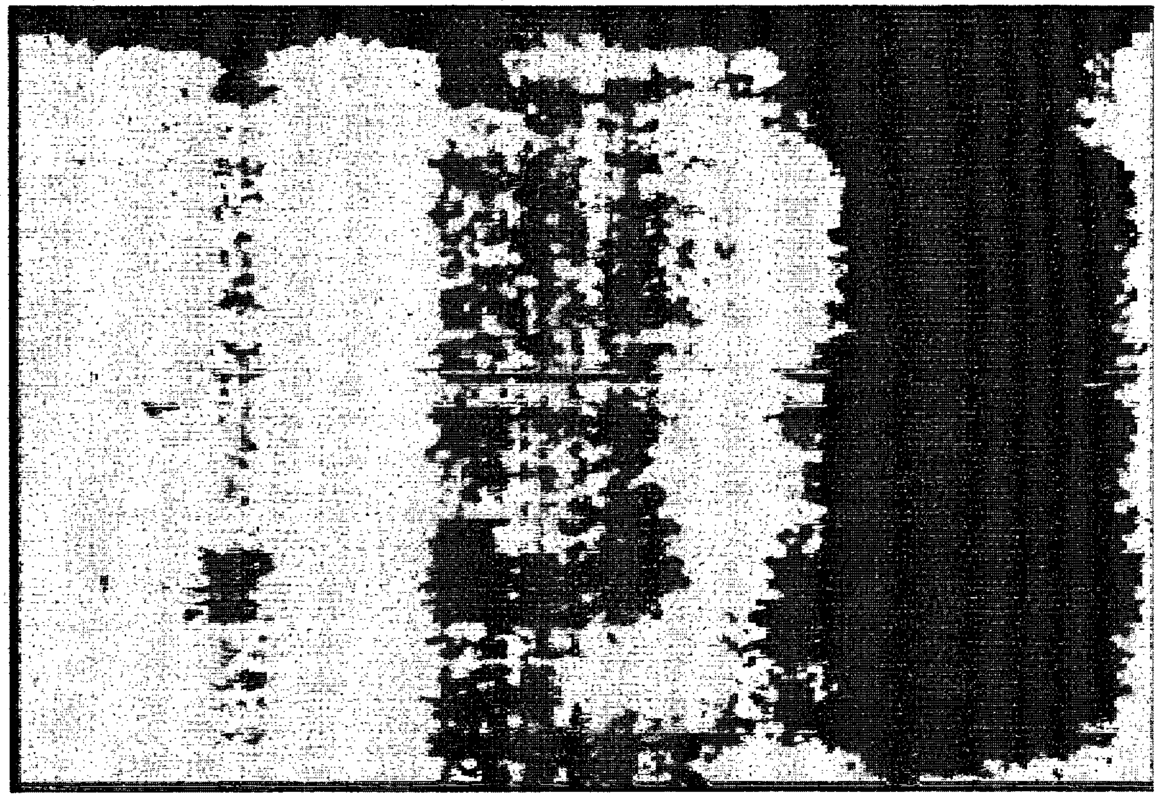

Figure 2.9: Test #7, [redacted]

During test #8 (oblique pin drop) [redacted]

[redacted]

[redacted].

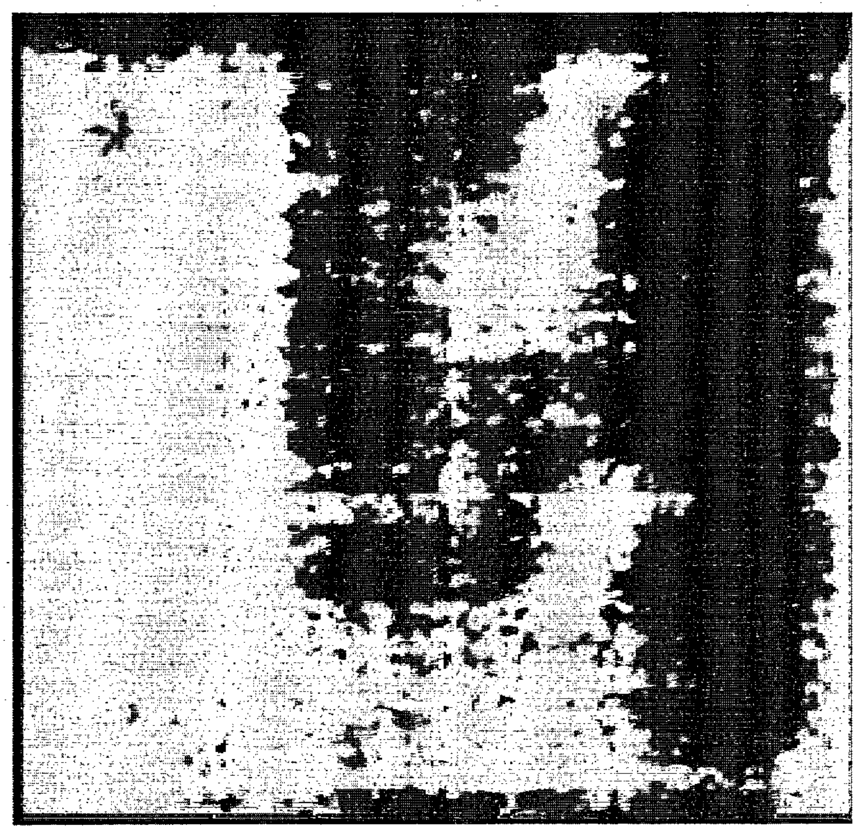

Figure 2.10: Test #8, [redacted]

Test #9 (pin side drop) attempted to remove the main cover from the container. [redacted]). After the drop test, all bolts stayed in their place and the main cover did not open.

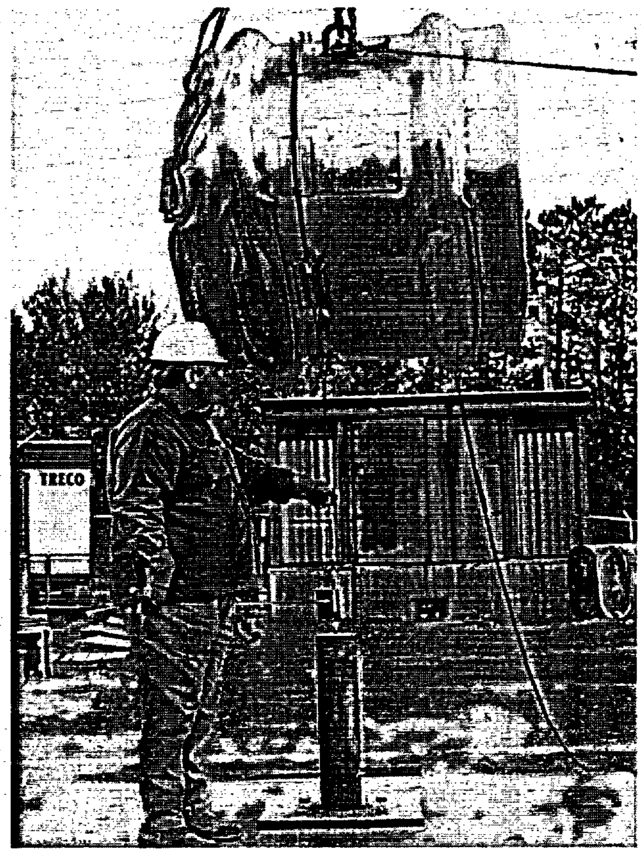

Figure 2.11: Test #9, Final Attempt To Open Main Cover (1m Pin Drop)

Following the completion of the test program the GC-40 and simulated source were removed from the overpack.

The internal damage to the container was mostly associated with the [redacted]. Helium leak testing of the simulated source showed it to be leak tight.

Radiation surveys completed following the drop test program did not show any radiation levels in excess of the regulatory requirements. The maximum radiation level was found to be 40 mR/h (see Appendix 2.10.5).

In conclusion, multiple drop tests in varying drop orientations from varying heights were completed on a single prototype F-430. No significant damage to the thermal protection was observed and the shielding and containment systems remained intact. The cumulative effect of these drops introduces a significant safety margin. This package design is in full compliance with the requirements of the regulations.

2.7.3 THERMAL

The thermal protection area of the F-430 package is 7.60m^2 (81.8ft^2) on the outside and 3.83m^2 (41.2ft^2) on the inside (cavity surface). [redacted]

[redacted].

The temperature increases within the F-430 package resulting from the hypothetical accident thermal evaluation are presented in Chapter 3, Section 3.5 and in Appendix 3.7.1. These temperature increases have minimal effects on the performance and integrity of the package. This is further discussed in Chapter 3.

2.7.3.1 Summary of Pressures and Temperatures

Since the F-430 overpack is not pressure tight (see section 2.6.6.7) and therefore pressure built up in the transport cavity cannot occur. Maximum Lead and source temperatures following the regulatory fire are the same as for the steady state conditions with solar load. They are 138°C and 142°C respectively. Refer to Appendix 3.7.1.

2.7.3.2 Differential Thermal Expansion

The maximum differential thermal expansion occurs during fire when the outside surfaces are exposed to the flame while inside the overpack temperature rises relatively slowly. However, no significant thermal stresses are expected as the package is free to expand and contract, and since the material of construction ([redacted], the material will flow in areas of high thermal stresses.

2.7.3.3 Stress Calculations

As discussed in section 2.7.3.2 stresses caused by high temperature gradients are not a threat to the overpacks thermal performance during accidental fire.

2.7.3.4 Comparison with allowable stresses

As discussed in section 2.7.3.2 stresses caused by high temperature gradients are not a threat to the overpacks thermal performance during accidental fire.

2.7.4 WATER IMMERSION

The water immersion test will not have a significant effect on the performance of this package. This is justified as follows:

[redacted]

2. Leak tightness is dependent on flatness of the gasket joints for outer and inner covers. These surfaces are not machined. They are rolled structural angles and flat plates with continuous fillet welds around the circumference. The mating surfaces may not be perfectly flat and parallel to ensure leak tightness under water.
3. The GC-40 consists of steel encased lead and will not be significantly affected by water.
4. The stainless steel Cs-137 source capsules are certified to withstand pressures up to 70MPa (10150psia) and will remain leak tight.

2.7.5 SUMMARY OF DAMAGE

Nine-drop test was carried out with a full-scale prototype as per Test Plan document (Ref. [31]) and Quality Plan documents (Ref. [32]). After the drop tests, the damage to the F-430 test packaging is as follows:

1. There were no cracks in the body of the GC-40 irradiator. The source drawer and the source capsule suffered no permanent damage. Both could be easily removed. The dimensions of the dummy C-440 did not change and the capsule passed the helium leak test. The lead housing had minor dents and scratches near the top flange of the irradiator. [redacted]
2. The F430 cavity was not pierced by the contents. The inner lid did not lose any bolts and kept the contents shielded from fire.
3. The main cover stayed in place retained [redacted].
4. Radiation levels following the drop testing did not increase by a measurable amount.

   For pictures refer to Test Report IN/TR 1604 F430 (appendix 2.10.5)

2.8 SPECIAL FORM

C-440 and C-161 Type 8 sealed sources containing cesium-137 radioactive material transported within the F-430/GC-40 package configuration, have been certified as Special Form radioactive material (Certificate No. GB/366/S-85 and CDN/0011/S respectively). (See Appendix 4.5.1.)

2.8.1 DESCRIPTION

The radioactive source capsules C-440 and C-161 transported within the F-430 package are designated as special form sealed source and are shown in Chapter 4. They consist of

1. an outer stainless steel capsule weldment
2. an inner stainless steel capsule weldment
3. Cesium-137 radioactive material encapsulated within the inner assembly.

2.9 FUEL RODS

This requirement is not applicable since the F-430 does not transport fuel rods.

2.10 APPENDICES

This section contains information in support of the analysis, assumptions and discussions presented in the various sections of the Chapter 2. For convenience, it is divided into subsections, identified as Appendix 2.10.1, Appendix 2.10.2 etc., which are stand-alone appendices and specifically referenced in the body of this chapter or submission.

Appendix 2.10.1	List of References for Chapter 2
Appendix 2.10.2	Lifting Analysis of the F-430 Package
Appendix 2.10.3	Tie-down Analysis of the F-430 Package
Appendix 2.10.4	Stresses in Removable Skid
Appendix 2.10.5	F-430 Test Report, IN/TR 1604 F430
Appendix 2.10.6	[redacted].
Appendix 2.10.7	Hoist Rings

APPENDIX 2.10.1: List of References for Chapter 2

[1] 10 CFR (Code of Federal Regulations), Chapter 1, Part 71 - Packaging and Transportation of Radioactive Material, 1-1-97 Edition.

[2] U.S. Nuclear Regulatory Commission, Regulatory guide 7.9, Standard Format and content of Part 71 applications for approval of Packaging of Type B, Large Quantity, and Fissile Radioactive material, Revision 1, January 1980.

[3] *Mark's Standard Handbook for Mechanical Engineers*, Eighth Edition.

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[6] *Machinery's Handbook*, 23th Edition.

[7] V. M. Faires, *Design of Machine Elements*, 4th Edition, Macmillan Inc.

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[9] IAEA Safety Standard, Safety Series No. 6, *Regulations for the Safe Transport of Radioactive Material*, 1985 Edition (As Amended 1990).

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[13] A. E. Spaller, "Structural Analysis of Shipping Casks, Resistance to Puncture", Vol. 2, ORNL-TM-1312, September, 1966.

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[29] J. Counts & J. B. Payne, "Critical Review of Type B Shipping Container Impact Analyses, Los Alamos, Scientific Laboratory"; published in PATRAM # 1976, Vienna, IAEA-SR-10/41, IAEA Proceedings of a Seminar, Vienna, Aug. 1976.; pp. 389-96.

[30] R. Birchall, MDS Nordion F-430 Transport Packaging Testing, Document No. A-17048-TN-1 AECL, Chalk River, Ontario, Canada, December 1999.

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[32] IN/QA 0224 Z000: Radioactive Material Transport Package **Quality Plan.**

[33] IN/TS 1467 F430: **Technical Specification** for the F-430 Overpack.

[34] CO-QC/TP-0001: Radiation Integrity for New Transport Packages Procedure.

[35] IN/OP 0019 Z000: Radioactive Material Transport Packaging Inspection and Maintenance Procedure.

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APPENDIX 2.10.3:
Tie-down Analysis of the F-430/GC40 Package

(10 pages to follow)

TIE-DOWN ANALYSIS OF F-430/GC40 PACKAGE

1. INTRODUCTION

In this appendix, the F-430 package tie-down arrangement is analyzed with respect to the requirements of 10 CFR 71.45(b) [1]. The strength of the tie-down system is evaluated based on accelerations of the transport vehicle. The accelerations are listed in Table A2.10.3-1. The tie-down arrangement is illustrated in Figure A2.10.3-1.

The F-430 is used in conjunction with a tie-down collar that girdles the F-430 at mid-height. The tie-down collar is a band that incorporates four lugs to which the tie-down chains are attached. It rests on six oblong bosses welded to the circumference of the F-430.

Table A2.10.3-1
Deceleration Values of the Vehicle as per 10 CFR 71.45 (b)

Direction	Acceleration (g's)
Vertical	2
Horizontal, along Direction of Motion	10
Horizontal, in Transverse Direction	5

2. SHIPMENT DESCRIPTION

A standard, open top trailer is normally used for the shipment of one F-430 package. The lower end of the tie-down chains are attached to the frame of the trailer while the upper end is attached to the lugs on the tie-down collar. Chocks are used to prevent sliding of the package along the floor of the trailer.

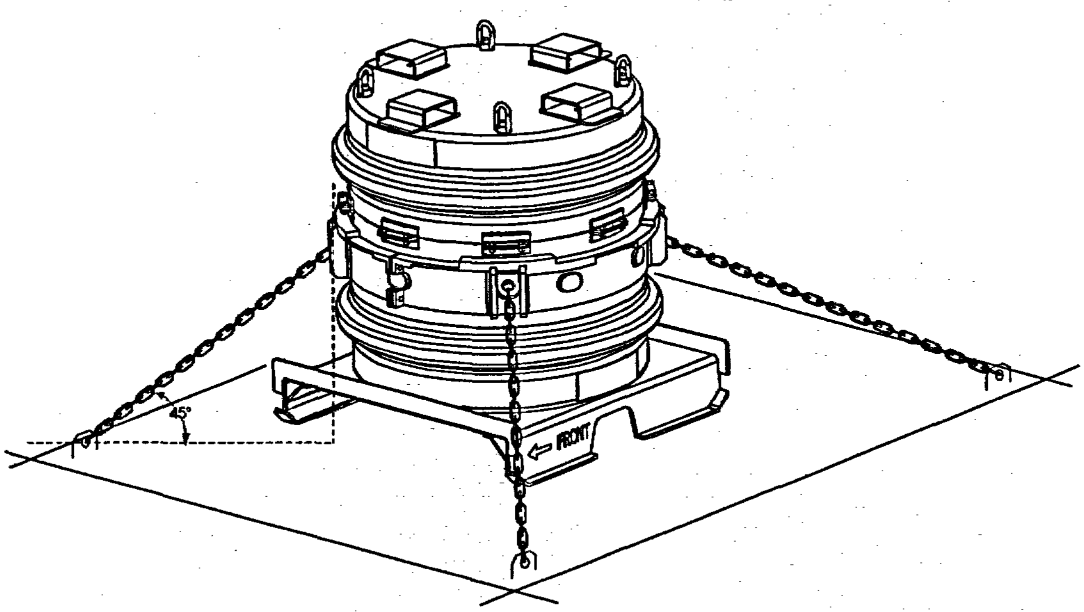


Figure A2.10.3-1
F-430 Tie-Down Arrangement

3. STRESS ANALYSIS OF THE F-430 WITH MAXIMUM TIE-DOWN FORCES

3.1 FINITE ELEMENT ANALYSIS

The tie-down system was analysed with a three dimensional model constructed using ProMechanica Structure[2]. The F-430 was modeled as a right cylinder, made up of layers [redacted]. The features of the model and their properties are listed in Table A2.10.3-2. The payload (e.g. GC40) was simulated by a hollow cylinder made of lead. The lead thickness was selected in order to produce a payload mass of 5,396 lb. The total mass of the model was 6,990 lb. The exact geometry of the tie-down collar and the shipping skid was modeled. The tie-down chains were modeled as beam elements. Only three chains were modeled, since the fourth was found to have no tensile load. The chocks were simulated by constraining the corners of the skid from translation. Similarly, the bottom of the tie-down chains were constrained from translation. The accelerations listed in Table A2.10.3-1 were applied to the model.

The model statistics are listed in Table A2.10.3-3. The Finite Element mesh is shown in Figure A2.10.3-2 and the stress results are shown in Figure A2.10.3-3.

Table A2.10.3-2
Finite Element Model Features and Properties

Feature	Material	Young's Modulus	Poisson's Ratio
Layer1 (outer most)	[redacted]	[redacted]	[redacted]
Layer 2	[redacted]	[redacted]	[redacted]
Layer 3	[redacted]	[redacted]	[redacted]
Layer 4	[redacted]	[redacted]	[redacted]
Layer 5	[redacted]	[redacted]	[redacted]
Layer 6	[redacted]	[redacted]	[redacted]
Tie-Down Collar	[redacted]	[redacted]	[redacted]
Skid	[redacted]	[redacted]	[redacted]

Table A2.10.3-3
Finite Element Model Statistics

Model Entities	Points: 8763 Edges: 45564 Faces: 66761
Finite Elements	Type: P-element Beams: 3 Shells: 4280 Solids: 29969
Total Elements	34252
Contact Regions	8
Convergence Method	Multi Pass Adaptive

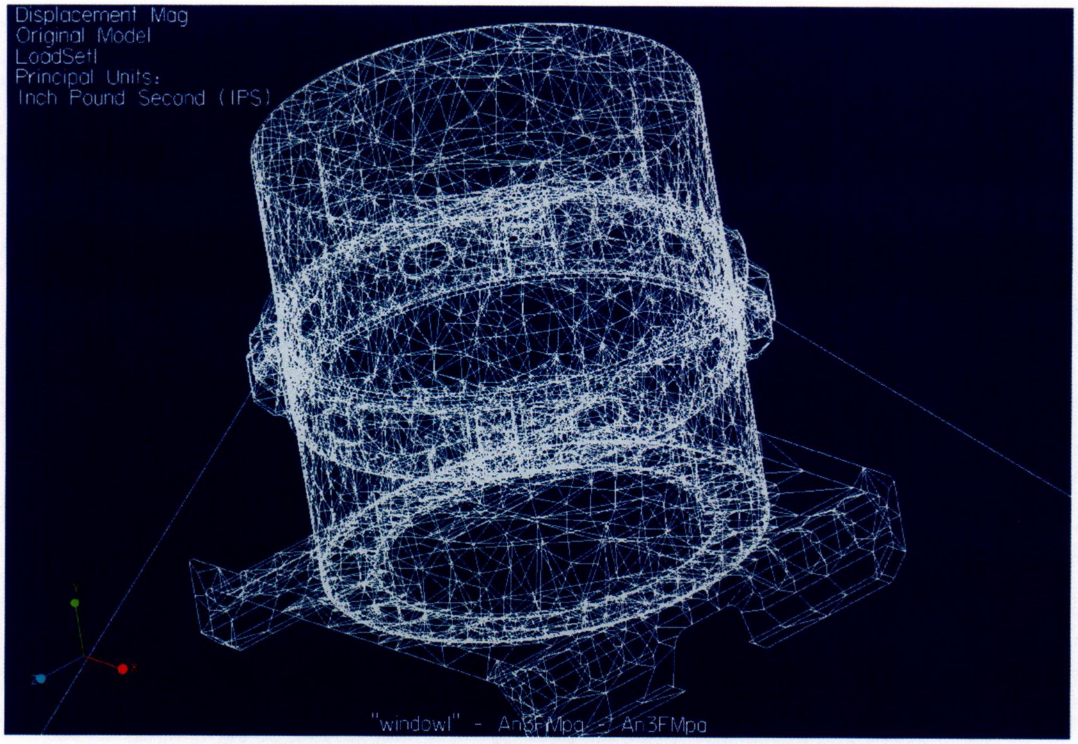


Figure A2.10.3-2
Finite Element Mesh

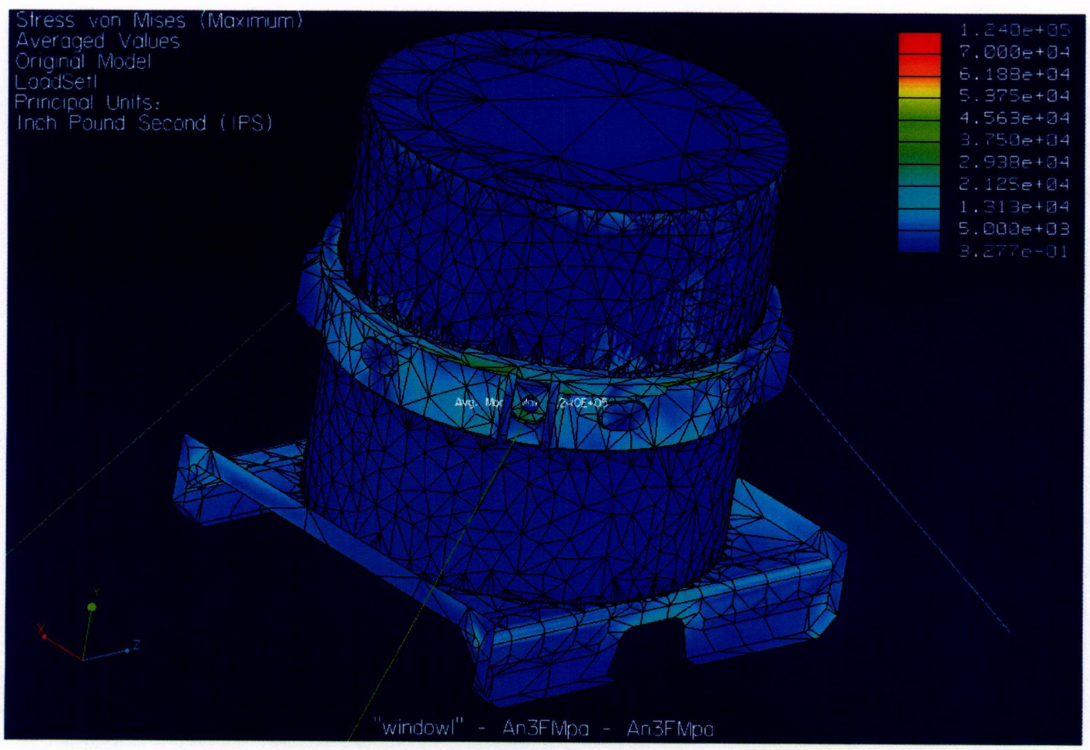


Figure A2.10.3-3
Tie-Down Stresses in the F-430

3.2 TIE-DOWN COLLAR STRESSES

The highest stresses in the model occur in one of the tie-down collar lugs. Figures A2.10.3-4 and A2.10.3-5 show the stresses in the lug that is loaded with the tie-down chain with the highest load. In Figures A2.10.3-4 and A2.10.3-5, the maximum stress shown is 124,000 psi. However this high stress is the result of a singularity caused by the chain load being applied at a single point in the model. In order to analyze more accurately the stresses in this tie-down lug, a refined and more realistic model was created. In this case the load from the tie-down chain was applied over a 30° sector in the hole through the tie-down lug, as shown in Figure A2.10.3-6. The results of this analysis are shown in Figure A2.10.3-7. The maximum stress in the tie-down lug is [redacted].

Away from the tie-down lug discussed above, the maximum stress in the tie-down collar is [redacted]. Figure A2.10.3-9 shows the stresses through the cross-section of the tie-down collar at this location.

The stress in the bolts that fasten together the two halves of the tie-down collar must also be considered. This stress will be calculated. It is assumed that only one bolt per side bears the entire load. Furthermore, the reduction in the bolt load due to the friction between the collar and the F-430 skin will be neglected.

The maximum load in the tie-down chains is 27,750 lb. The horizontal and vertical components of this force are 19,620 lb. each. Since the vertical component of the tie-down force is borne by the oblong bosses, the bolts are subjected mainly to tension.

$$\sigma = F/A$$

where

σ = stress in the bolt
F = the load in the bolt = 19,620 lb.
A = stress area of the bolt, based on the root dia. = 0.431 in.^{2} (root dia. = 0.741 in.)

Therefore,

$$\sigma = 45{,}496 \text{ psi}$$

The bolts [redacted].

Therefore, the Safety Factor for the bolts is

[redacted]

This analysis is very conservative since only one of the bolts was considered.

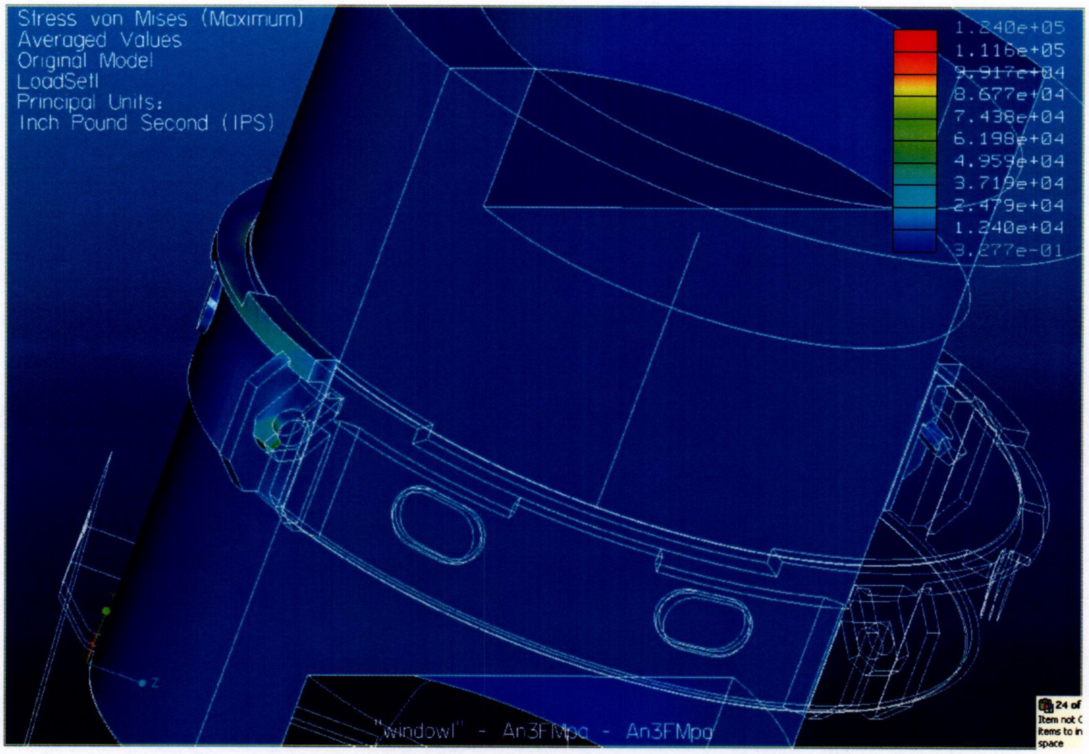


Figure A2.10.3-4
Stresses in the Tie-Down Collar

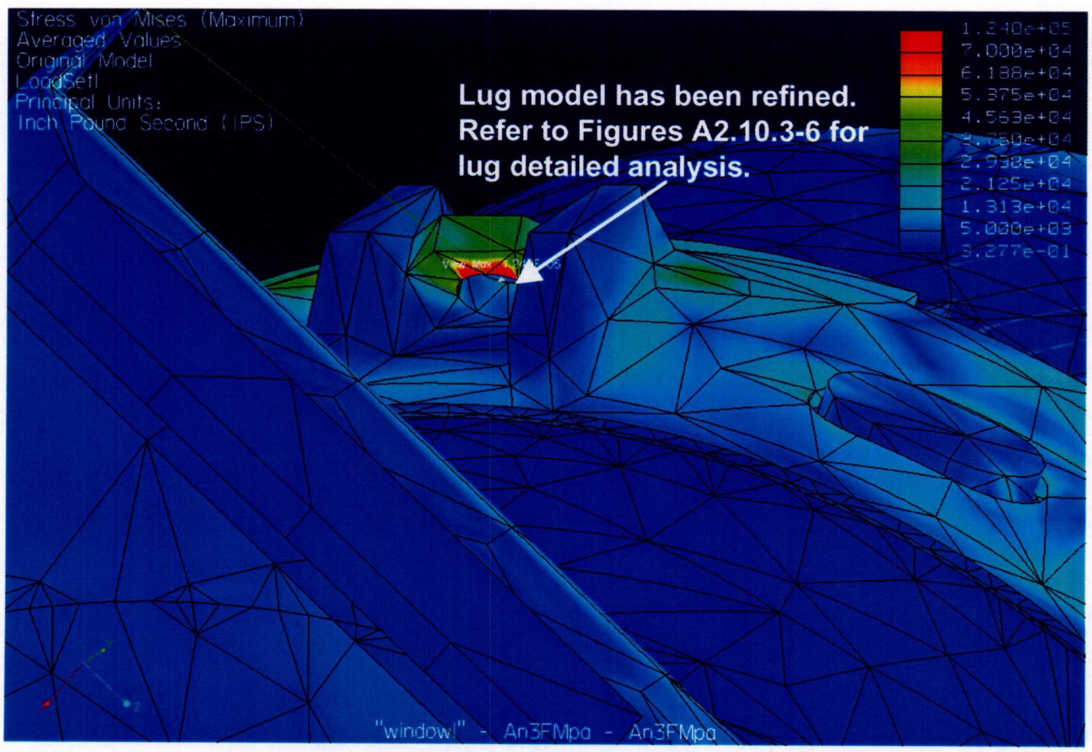


Figure A2.10.3-5
Stresses in the Tie-Down Collar

C02

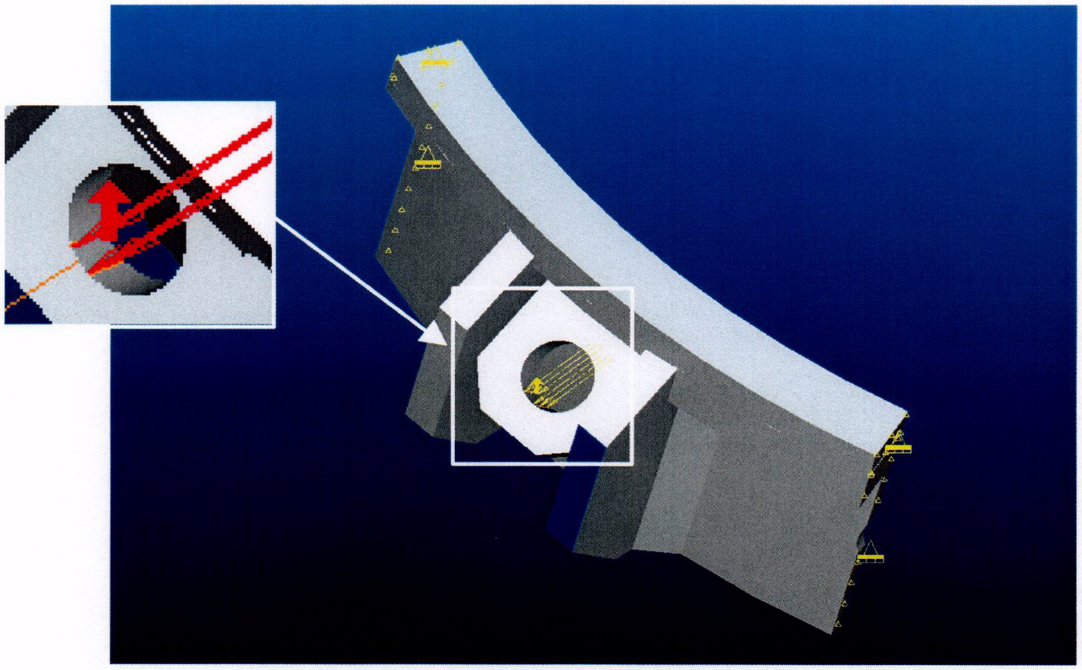


Figure A2.10.3-6
Tensile Load Applied to Tie-Down Lug

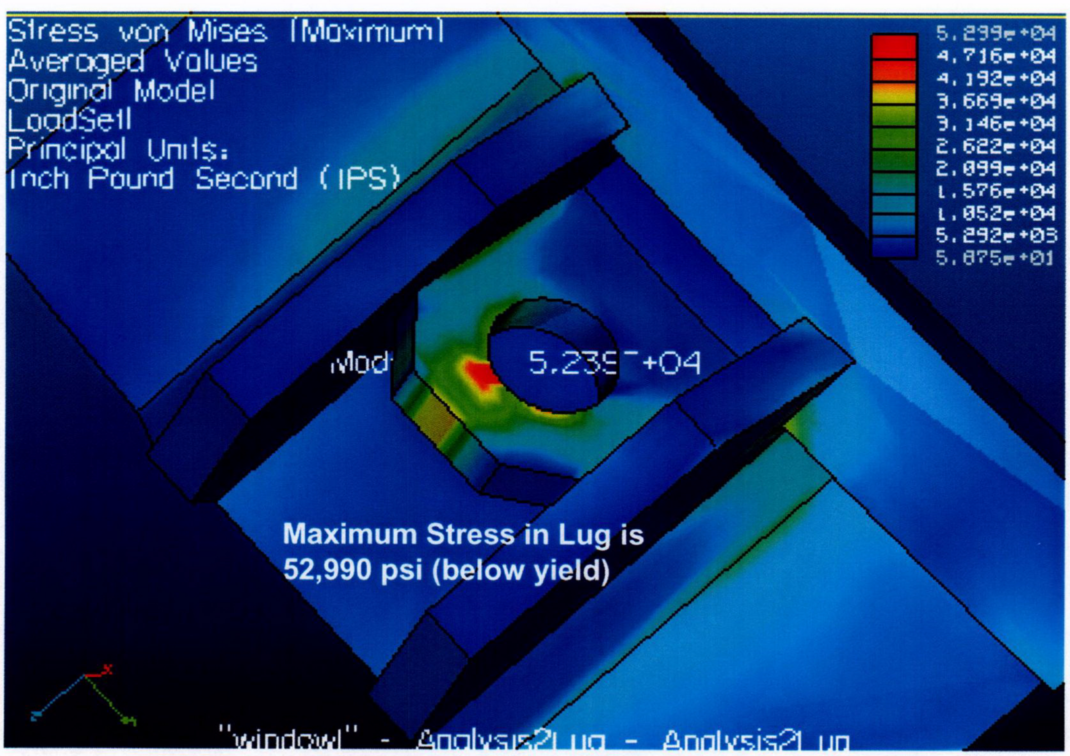


Figure A2.10.3-7
Stresses in the Tie-Down Lug

C03

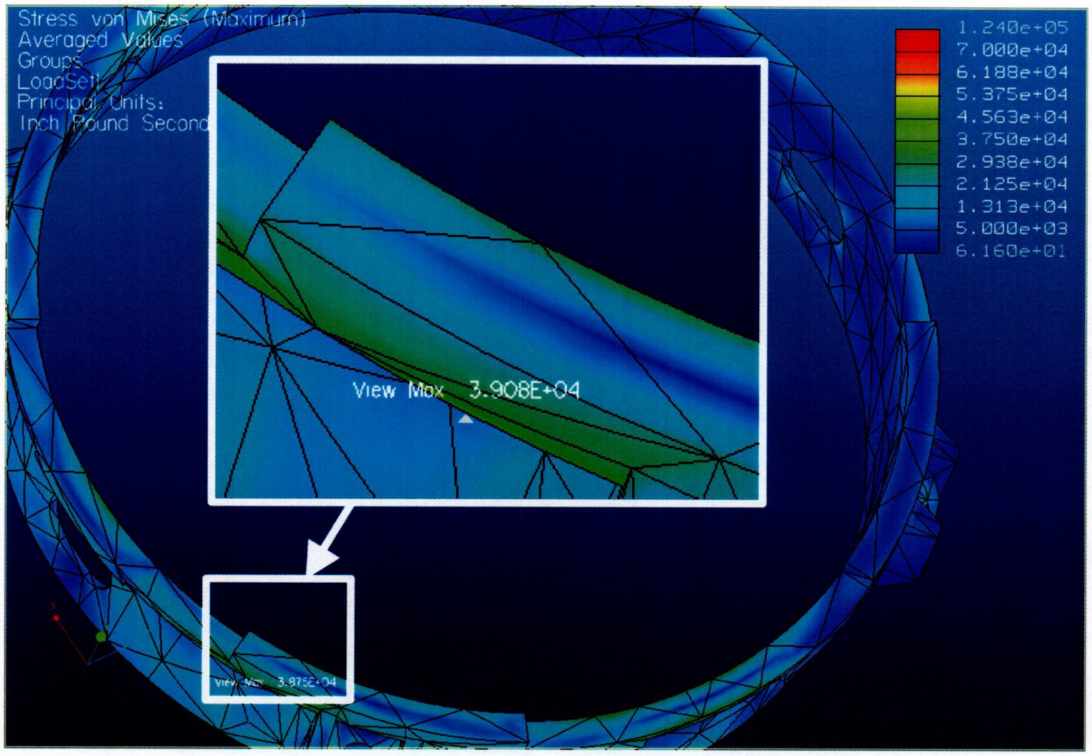
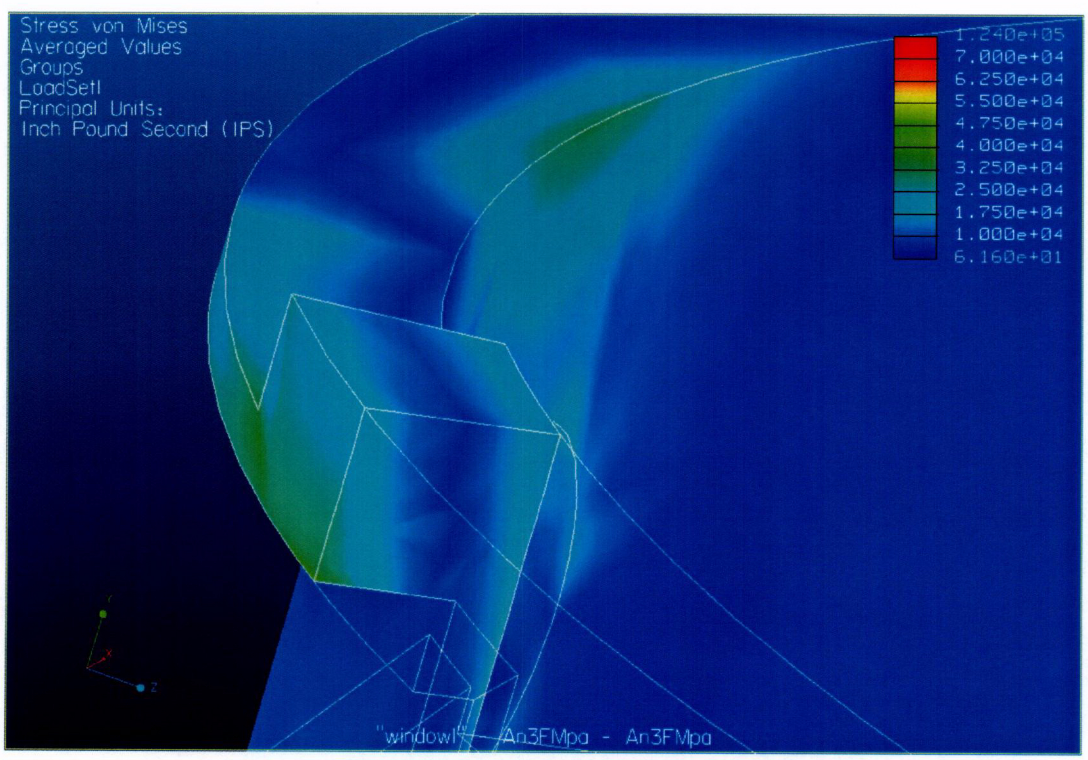


Figure A2.10.3-8
Stresses in the Tie-Down Collar



C04

Figure A2.10.3-9
Stresses in the Tie-Down Collar

3.3 STRESSES IN THE F-430 MAIN BODY

The stresses in the bosses and the boss ring are shown in Figures A.2.10.3-10 and A.2.10.3-11.

The results show that the stresses in the F-430 are highest in one of the oblong bosses. The maximum stress is 17,920 psi. Away from the boss, the highest stress in the boss ring is 16,150 psi (refer to Figure A2.10.3-11). These stresses are safely below the minimum yield strength [redacted].

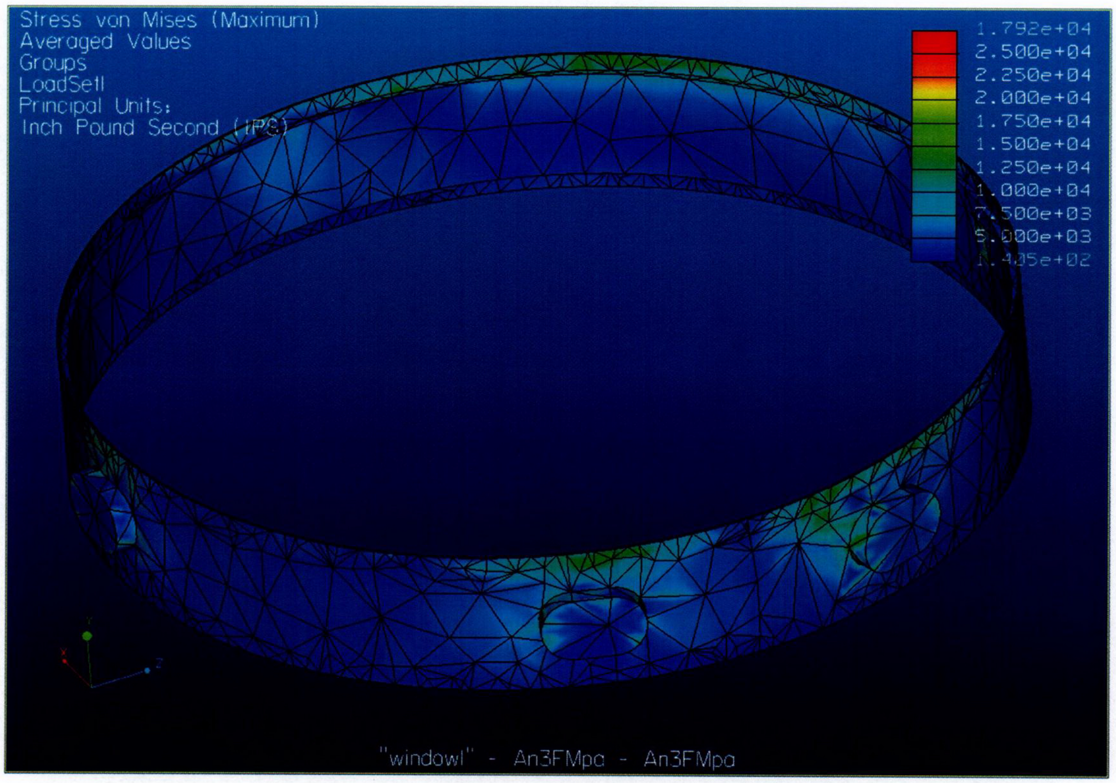


Figure A2.10.3-10
Tie-Down Stresses in the F-430 Ring and Skin

C05

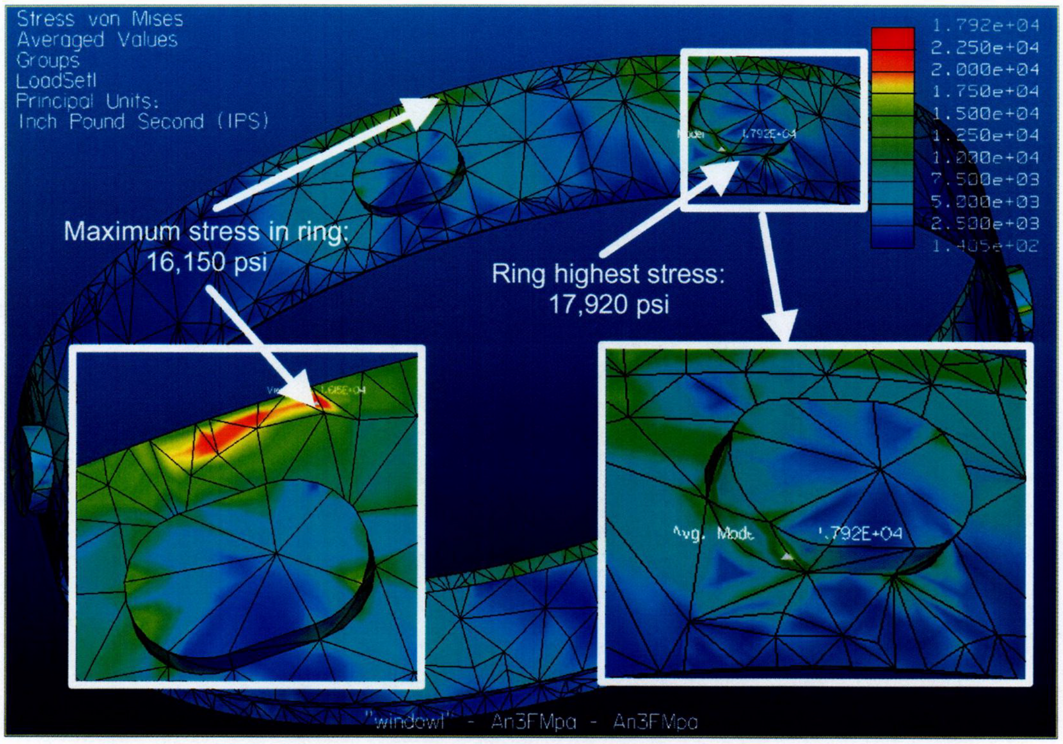


Figure A2.10.3-11
Tie-Down Stresses in the F-430 Ring and Skin

C06

5. CONCLUSIONS

The maximum stress in the body of the F-430 package is 17,920 psi when the package and its payload are subjected to the prescribed accelerations. This stress is safely below the minimum yield strength [redacted].

The maximum stress in the tie-down collar is 52,990 psi when the package and its payload are subjected to the prescribed accelerations. This is safely below the minimum yield strength of [redacted].

The maximum stress in the tie-down collar bolts is less than 45,496 psi when the package and its payload are subjected to the prescribed accelerations. This is safely below the minimum yield strength [redacted].

Therefore the tie-down system for the package satisfies the requirements of 10 CFR 71.45(b)(1).

6. REFERENCES FOR APPENDIX 2.10.3

[1] 10 CFR (Code of Federal Regulations), Chapter 1, Part 71 - Packaging and Transportation of Radioactive Material, 1-1-99 Edition.

[2] Pro/MECHANICA STRUCTURE Version 23.3(311), Parametric Technologies Corp. Waltham MA, 2001.