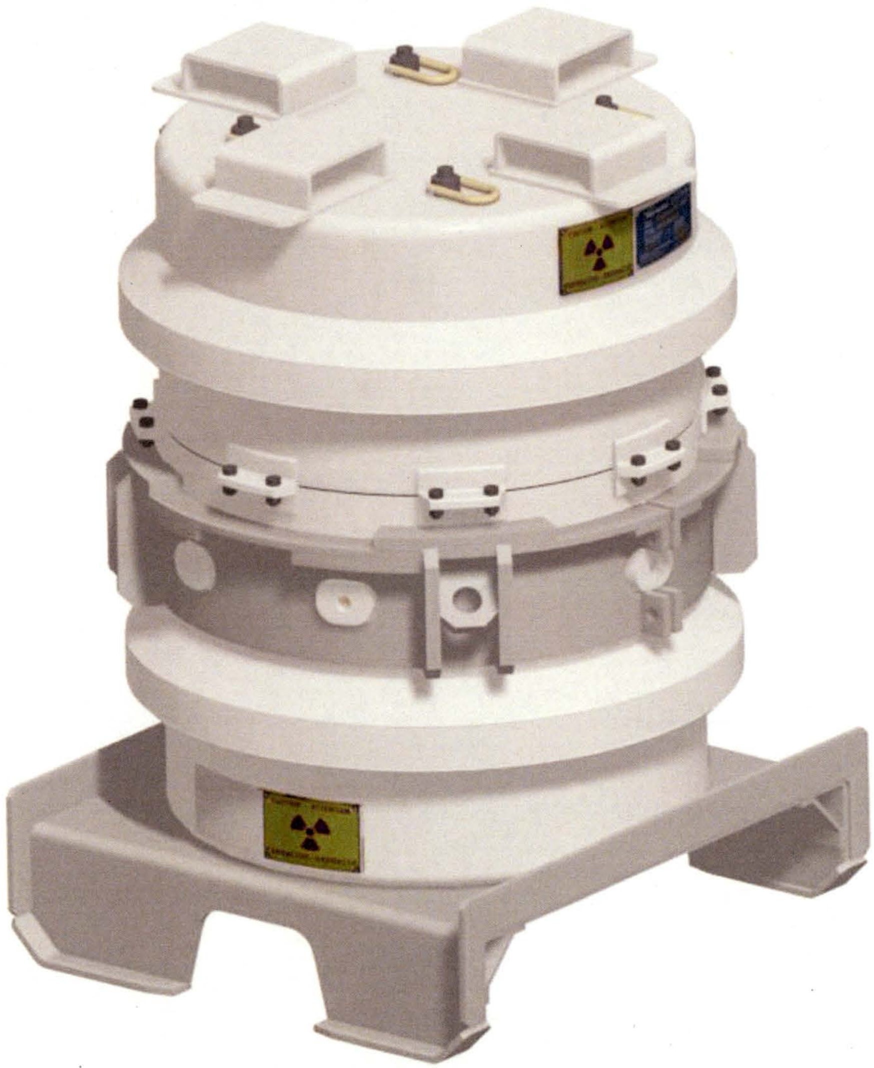
F-431 Transport Package
Safety Analysis Report



IN/TR 1913 F-431 (D)

Non-proprietary Information

Best® Theratronics

F-431 Transport Package Safety Analysis Report

Signatures

Prepared by: [redacted] Date: July 19, 19

Reviewed by: Date: July 19/2019

Approved by: Date: July 22, 2019

Document History

Date	Version	Comments	Prepared by	Reviewed by	Approved by
Apr. 2003	1	DCN: A1297-D-20A	[redacted]		
Sept. 2003	1a	DCN: A1297-D-32A Revised Chap's 1 & 2, Append's 1.3.2 & 2.10.2			
Apr. 2004	2	DCN: A1297-D-45A			
May 2019	C	DC31445			
July 2019	D	DC31451			

TABLE OF CONTENTS

APPENDIX 9.3.1: USNRC Quality Assurance Program Approval for Radioactive Material Packages, Approval No. 0943 124

CHAPTER 1 – GENERAL INFORMATION

This chapter of the Best Theratronics F-431 Transport Package Safety Analysis Report (SAR) presents a general introduction to and description of the Best Theratronics F-431 transport package. Figures 1.1a, 1.1b, and 1.2 show the main dimensions and materials of this package.

1.1 INTRODUCTION

The Best Theratronics F-431 transport package has been developed as a safe means of transporting Best Theratronics' Gammacell-1000 and Gammacell-3000 (GC1000 and GC3000) irradiators containing cesium-137 sealed sources.

Each F-431 packaging has a payload of only one GC1000 or GC3000. The F-431 provides impact and thermal protection for the radioactive contents. Containment is provided by the sealed source and shielding by the GC1000 or GC3000 irradiator shield.

Each F-431 packaging is assigned a unique serial number. Therefore a typical model/serial number on the identification plate is "F-431 Serial number XX" meaning F-431 is the model and XX is the numeric serial number of the packaging. The GC1000 or GC3000 head inside the F-431 will have a different serial number from the F-431.

This safety analysis report demonstrates that the F-431 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-431 is a stainless steel cylinder 1,067 mm (42 in.) in outside diameter, 1,283 mm (50.5 in.) tall and placed on a removable mild steel skid 1,118 mm x 1,003 mm x 203 mm (44 in. x 39.5 in. x 8 in.). It has a cylindrical cavity 559 mm (22 in.) in diameter by 813 mm (32 in.) tall. The empty overpack weighs 1,050 kg (2,300 lb.) including the skid. The maximum weight of its contents is 1,225 kg (2,700 lb.). [redacted]

[redacted]

Other features related to the thermal protection are vent holes that relieve pressure that develops between walls during an accidental fire. These vent holes are plugged with plastic pipe plugs that are designed to melt in the fire. Four vents are located in the main cover (inside the lifting pockets), and four on the main body. The inner cover has four vent holes and [redacted] a 19 mm (3/4 in.) hole located at the bottom of the stainless steel shell that [redacted] (see Figure 1.2).

[redacted]

For overhead lifting the F-431 overpack is equipped with four hoist rings on the top surface. For tie-down, the F-431 is fitted with a collar. The tie-down collar clamps around the mid-section of the F-431 and has four lugs to which the tie-downs are fastened.

The F-431 package provides its contents with impact and thermal protection. Containment is provided by sealed sources and shielding by the GC1000 or GC3000 irradiator.

The gammacell irradiator is held in position inside the F-431 cavity with shipping braces. A different brace design is used for each gammacell model, and the braces are typically made from wood. To facilitate air transport, the shipping braces may incorporate steel plates in order to reduce the Transport Index. Regardless of the gammacell model and the design of the shipping braces, the maximum weight of the F-431 payload (i.e. gammacell and its shipping braces) shall not exceed 1,225 kg (2,700 lb.).

The features of the GC1000 and GC3000 are summarized in Table 1.1. The GC1000 and GC3000 consist of a lead-shielding cask, and a source cavity, which houses up to eight Cesium-137 sealed sources inside a source holder. The source holder is a stainless steel assembly and sometimes includes additional tungsten or other shielding metals. It serves as a cradle for the sources, and also provides shielding for the sealed sources. The maximum total activity of Cs-137 is 113 TBq (3,050 Ci).

The procedure for preparing the F-431 for shipment is described in Chapter 7.

The F-431 package is identified with appropriate identification plates and labelling affixed on the fireshield.

The engineering information drawings of the F-431 transport package are provided in Appendix 1.3.2.

Table 1.1: Features of the GC1000 and GC3000

Gammacell Model	Rated Capacity	Nominal Diameter	Nominal Height	Nominal Pb Thickness	Steel Shell Thickness	Approximate Weight
GC1000	113 TBq (3,050 Ci)	457 mm (18 in.)	610 mm (24 in.)	150 mm (6 in.)	9.5 mm (0.375 in.)	1,054 kg (2,324 lb.)
GC3000	113 TBq (3,050 Ci)	457 mm (18 in.)	610 mm (24 in.)	110 mm (4.35 in.)	9.5 mm (0.375 in.)	1,091 kg (2,404 lb.)

1.2.2 Operational Features

[redacted] The shape of the package prevents the collection and retention of water. The outside surface of the package is smooth and can be easily decontaminated.

[redacted] The GC1000 or GC3000 head is braced inside the cavity (see Figure 1.2). In order to facilitate tie-down for shipment, a tie-down collar is added at the time of shipment. There are no other special operational features, and no other features are added at the time of transport.

1.2.3 Contents of Packaging

The primary purpose of the F-431 overpack is to transport the GC1000 and GC3000 irradiators. These are blood irradiators with lead shielding encased in a steel shell. The radioactive sources are Cesium-137 in the form of cesium chloride compressed powder pellets. The radioactive material is contained inside stainless steel capsules. These are described in Chapter 4. The maximum activity inside the package is 113 TBq (3,050 Ci), which generates about 15W of decay heat. The sealed sources are double walled stainless steel with a cylindrical shape.

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

1.3 APPENDICES

This section contains the following appendices.

Appendix 1.3.1: Specification Sheet for the F-431/GC000 Package

Appendix 1.3.2: F-431 Engineering Information Drawing

[redacted]

Figure 1.1a: [redacted]

[redacted]

Figure 1.1b: [redacted]

[redacted]

Figure 1.2: [redacted]

APPENDIX 1.3.1:
Specification Sheet for the F-431/GC000 Package

IN/SS 1915 F431 (C)

[redacted]

APPENDIX 1.3.2:
F-431 Engineering Information Drawing

F643101-001 (K)

[redacted]

[redacted]

CHAPTER 2 – STRUCTURAL EVALUATION

This chapter presents structural evaluation demonstrating that the Best Theratronics F-431 package design meets all applicable structural criteria. The F-431 package is evaluated and shown to provide adequate impact protection for the payload. Normal and hypothetical accident condition evaluations are performed in accordance with regulatory requirements. The evaluations of the F-431 are based on tests that were performed on the Best Theratronics F-430 transport package. The test data for the F-430 is presented in Appendices 2.10.3a and 2.10.3b.

2.1 STRUCTURAL DESIGN

2.1.1 Description

The F-431 has been designed to transport Best Theratronics' Gammacell 1000 and Gammacell 3000 (GC1000 and GC3000). The principal structural components of the F-431 package are illustrated in Figures 1.1a, 1.1b, and 1.2 (Chapter 1). The F-431 container [redacted]

The F-431 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-431 packaging.

Shielding is provided mainly by the GC1000 or GC3000 shielding head, and containment is provided by the sealed source inside the shielding head.

The **impact shield** has a [redacted]

[redacted] There are two bumpers on the circumference to protect the segmented flange used to attach the F-431 cover.

For tie-down, a collar is fitted around the F-431. The tie-down collar incorporates four lugs to which the tie-down chains are fastened.

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-431 container provides space for the gammacell head. Up to eight sealed sources are loaded into the GC1000 or GC3000 head. The outer assembly of the sealed source is made from stainless steel type 316L and is defined as the CONTAINMENT.

The **removable skid** is formed from mild steel plate (ASTM A-36) and is designed to facilitate handling and stacking of the F-431 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 sealed sources.

2.1.2.1.1 Containment Structures

For Normal Conditions of Transport (NCOT), the assessment criteria used ensures that the stresses in general do not exceed the lesser of 2/3 of yield stress or 1/3 ultimate tensile strength.

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 use the static models and values of static yield strength of the materials to represent dynamically loaded components. These results are conservative since the dynamic strength of a material is typically greater than the static strength [5].

2.1.2.1.2 Non-Containment Structures

For **Normal Conditions of Transport (NCOT)**, the assessment criteria used ensure that the stresses in general do not exceed the lesser of 2/3 of yield stress or 1/3 ultimate tensile strength at the temperature. For lifting and handling loads, the maximum allowable stresses are one third of the material yield strength.

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, the stresses are shown to be less than the static ultimate strength of the material at the temperature.

The F-431 overpack and the internal fixing brace are permitted to exceed yield stress for accident conditions. The acceptance criterion for all impact related loads within the container is that the steel envelope surrounding the lead shielding (the GC1000 or GC3000 irradiator) does not breach in normal and accident conditions

Structural analyses use the static models and values of static yield strength of the materials to represent dynamically loaded components. The results are conservative as the dynamic strength of a material is typically greater than the static strength [5].

2.1.2.2 Miscellaneous Structural Failure Modes

2.1.2.2.1 Brittle Fracture

The Cs-137 source capsules, and [redacted] exhibit ductile-to-brittle transition in the temperature range of interest.

2.1.2.2.2 Fatigue

[redacted]

Fatigue concerns associated with normal vibrations over the road are addressed in section 2.6.4.

2.2 WEIGHTS AND CENTERS OF GRAVITY

The total design weight of the Best Theratronics F-431 package, including a payload of 1,225 kg (2,700 lb.), is 2,270 kg (5,000 lb.). The package is nearly symmetrical, therefore, the center of gravity (cog.) is very near the geometric center of the container. The center of gravity (cog.) of the F-431 package is 570 mm (22.4 in.) from the top of the removable (shipping) skid, or 800 mm (31.4 in.) from the ground.

2.3 MECHANICAL PROPERTIES OF MATERIALS

The Best Theratronics F-431 package is fabricated primarily [redacted] The general arrangement drawings presented in Figure 1.3 and Appendix 1.3.2 define the specific material used for each item of the Best Theratronics F-431 package. Table 2.1 presents the mechanical properties of the materials used in the F-431.

Table 2.1: Mechanical Properties of Materials Used in the F-431						
Item	Materials	Min. UTS		Min. YS		Reference
		(MPa)*	(ksi)*	(MPa)*	(ksi)*	
1	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]

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

The only other material used in the package is [redacted] this material is not considered in this analysis.

[redacted]

[redacted]

Figure 2.1: [redacted]

2.4 GENERAL STANDARDS FOR ALL PACKAGES

This section demonstrates that the F-431 transport container complies with the general standards for all packaging.

a) Minimum Package Size

The height and diameter of the F-431 are 129 cm (50.7 in.) and 107 cm (42 in.) respectively without the shipping skid. Both these dimensions are greater than the minimum required dimension of 10 cm (4 in.).

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 (see 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-431 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 Surfaces of the Package

In Appendix 3.7.1, it is demonstrated that the temperature of the accessible surface of the package, with the package in still air at 38°C (100°F) and in the shade, is 39°C. This 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-431 package to allow for continuous venting during transport.

2.4.1 Chemical and Galvanic Reactions

[redacted]

2.4.2 Positive Closure

Closure 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 procedure for preparing the F-431 for shipment is discussed in Chapter 7.

2.4.3 Lifting Devices

The F-431 package can be lifted using four hoist rings on its top surface. Each hoist ring can swivel and turn to take a load of 3,200 kg (7,000 lb.) in any direction (see appendix 2.10.6).

The F-431 can also be lifted using fork lift pockets attached to the top of the package. A lifting analysis is included in Appendix 2.10.7.

2.4.4 Tie-down Devices

The F-431 is fitted with a tie-down collar that fits around the F-431 and rests on four bosses that protrude from the outside surface of the package.

The stress analysis of the tie-down arrangement is presented in Appendix 2.10.2. Under a tie-down load due to 10 g, 5 g, 2 g acting concurrently on the F-431 package, the calculated stresses in the package do not exceed yield stress.

2.4.5 Maximum Normal Operating Pressure

Under the accident conditions of transport (ACOT) the maximum pressure inside the sealed sources would be 106 kPa. Since the temperatures and pressures will be lower under normal conditions of transport, the maximum normal operating pressure inside the sealed source will be less than 106 kPa. This is significantly lower than the 700 kPa permitted by the regulations [3].

2.4.6 Assessment of the Tie-down Collar Bolted Connection

Stresses in the bolts that fasten together the two halves of the tie-down collar were considered as to tension, shear and bending. Analysis is included in Appendix 2.10.8.

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,

- there is no loss or dispersal of any radioactive material,
- there is no significant increase in external radiation levels,
- there is no substantial reduction in the effectiveness of the packaging, and
- there is 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 1 Rem per hour (10 mSv/h) at 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 provided by the sealed sources.

2.5.1 Load Resistance

In this section, it will be shown that the F-431 package can support a distributed load equal to the greater of five times its weight or 13 kPa times the vertical projected area of the package.

The outside diameter of the F-431, including the bumpers, is 1,065 mm (41.94 in.). Therefore the projected area of the package is 0.89 m^2 (1,380 $in.^2$). This area times a pressure of 13 kPa yields a force of 11.6 kN (2,600 lb.). Since this is significantly less than five times the weight of the package (111 kN or 25,000 lb.), the latter force will be used in the analysis below.

The smallest area for normal stresses is the outer shell.
$A = \pi Dt = 3.14 * 36.7 * 0.105 = 12.1\ in.^2\ (7{,}800\ mm^2)$

Normal stresses produced by the load of 5 times 5,000 lb. are $\sigma = 25{,}000/12.1 = 2{,}066$ psi (14.2 MPa)

[redacted]

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

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

The load on one lifting pocket is one quarter of the total stacking load, or 25,000/4 = 6,250 lb.

Shear stress in the fillet welds then is $\tau = 6250/3.02 = 2069$ psi (14.3 MPa)

Bending stresses are:
$\sigma = 6LFy/[bh^2] = 6 * 5 * 6{,}250 / [4 * 0.707 \times 0.19 \times 5.62^2] = 11{,}048$ psi (76 MPa)

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

$\sigma_n = 1/2\ [\sigma + \sqrt{(\sigma^2 + 4\tau^2)}]$
$\sigma_n = 1/2\ [11{,}048 + \sqrt{(11{,}048^2 + 4*2{,}069^2)}] = 11{,}423$ psi (79 MPa)
$\sigma_s = 1/2\sqrt{(\sigma^2 + 4\tau^2)}]$
$\sigma_s = 1/2\sqrt{(1{,}148^2 + 4*2{,}069^2)}] = 5{,}899$ psi (41 MPa)

[redacted]

Therefore it is safe to stack 25,000 lb. (11,340 kg) on top of the F-431 container.

2.5.2 External Pressure

The outer assembly of the cesium-137 sealed sources is the containment system for the F-431 package. It will be shown that the capsules are capable of withstanding pressures far in excess of 170 kPa (25 psi) as specified in this section.

Chapter 4 provides a description of the sealed sources. The following analysis bounds the maximum tube and end cap stresses for a 25 psig external pressure.

Two (2) regions shall be analyzed. They are:

- The cylindrical tube with the minimum wall thickness. The worst case is the C-378 sources (0.025 in. wall thickness and 0.63 in. outside diameter) (see table 4.1).
- The end cap. The worst case is the C-378 sources (0.63 in. diameter with minimum thickness of 0.025 in.) (see table 4.1).

2.5.2.1 Stress in Cylindrical Tube

The maximum hoop stress due to external pressure p is given by:

$\sigma_2 = pd/2t$

Where

p = external pressure = 25 psig
d = mean diameter = 0.63 - 0.025 = 0.605 in.
t = wall thickness of tube at the end cap region = 0.020 in.(min.)
σ_2 = 25 x 0.605/(2 x 0.020)
= 378 psi

2.5.2.2 Stress in the End Cap

The maximum bending stress due to internal pressure p is given by [11]:

$\sigma_b = k\, pr^2/t^2$

Where

p = external pressure = 25 psig
r = radius of end cap = 0.63/2 = 0.315 in.
t = thickness of the end cap = 0.025 in. (min.)
k = 0.75 [11], based on the plate edge fixation.
σ_b = $0.75 \times 25 \times 0.315^2/0.025^2$
= 2,977 psi

Note that this analysis is conservative because the radius of the end cap was assumed to be the same as that of the source. In reality the radius of the end cap is smaller.

2.5.2.3 Factor of Safety and Margin of Safety

For SS316L, the minimum tensile strength is 25,000 psi.
Factor of Safety (FS)

FS = Allowable stress/Applied stress
= Yield Stress of ss316/ stress in end cap
= 25,000 psi/2,977 psi
= 8.4

Margin of Safety, MS

MS = FS – 1 = 8.4 – 1 = 7.4

In summary, due to external pressure of 25 psig in the sealed sources,
the maximum hoop stress in any of the sealed source tubes = 378 psi
the maximum bending stress in any of the sealed source end caps = 2,977 psi.

Based on a yield stress of 25,000 psi for SS316L, the sealed sources have a Factor of Safety of 8.4 and a Margin of Safety of 7.4.

Therefore the containment, (i.e. the outer assembly of the C-1000, C-1001, C-3000, C-3001, C-378, ISO-10000 and RAMCO-50 sealed sources) will maintain its structural integrity.

2.6 NORMAL CONDITIONS OF TRANSPORT

The following sections demonstrate that the F-431 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 the shielding,
- there will be no changes affecting the ability of the package to withstand the hypothetical accident conditions of transport, and
- 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-431 Package is reported in Chapter 3, Section 3.4.

2.6.1.1 Summary of Pressures and Temperatures

For 3,050 Ci of Cs-137 in sealed sources inside the cavity of the F-431, the maximum steady state source temperature was determined to be less than 326°C under the Normal Conditions of Transport (see chapter 3, section 3.5.3).

In chapter 3, section 3.5.6, it is demonstrated that the sealed source can withstand the pressure resulting from a temperature rise to 326°C. Therefore, the sealed source can withstand the maximum internal temperature resulting from the Normal Conditions of Transport.

2.6.1.2 Differential Thermal Expansion

The F-431 and its payload will be unaffected by the thermal gradients predicted for the Normal Conditions of Transport. Temperatures are relatively low and do not impose significant stresses.

2.6.1.3 Thermally Induced Stress

In chapter 3, section 3.5.6, it is demonstrated that the maximum temperature in the sealed sources is 326°C due to ACOT. The resultant pressure inside the sources is 106 kPa (15 psi). Since the temperatures and pressures under Accident Conditions of Transport (ACOT) are higher than under Normal Conditions of Transport (NCOT), the maximum stress in the capsules will be less than 106 kPa (15 psi) under NCOT.

In section 2.6.3 below, this pressure will be considered in conjunction with a decrease in ambient pressure. The resulting capsule stresses will be analyzed.

2.6.2 Cold

A steady-state ambient temperature of -40°F (-40°C) 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 2.1.2.2 of this chapter.

Because of the low internal heat generation (15 Watts) and the high thermal conductivity of the lead, stainless steel and carbon steel, the primary materials used in the construction of the gammacell, no steep thermal gradients exist in the gammacell to cause thermal stresses. Similarly, because of the low heat and the large size of the F-431, the thermal gradients across the F-431 are very small and do not result in appreciable stresses.

2.6.3 Pressure

The containment for the package is provided by the sealed sources. As discussed in section 2.5.2, these sources are capable of withstanding an external pressure of 25 psia.

The internal pressure in the sealed sources must also be considered. The worst case would occur when the sealed sources are at their maximum normal operating temperature, and the F-431 experiences a dramatic drop in atmospheric pressure. Paragraph 619 of IAEA TS-R-1 [3] requires that packages transported by air have a containment system capable of withstanding a reduction in ambient temperature to 5 kPa. The following discussion considers thermally induced stresses in the sealed sources in combination with a drop in ambient pressure.

In Chapter 3, section 3.5.6, it is demonstrated that the maximum temperature in the sealed sources is 326°C due to ACOT. The resultant pressure differential is 106 kPa. Assuming a drop in ambient pressure of 100 kPa, the total effective pressure inside the sealed sources is 206 kPa. However, in section 2.5.2 it was shown that the sealed sources are capable of withstanding an external pressure of 170 kPa (25 psi) with a factor of safety of 8.4. In other words, the sources can withstand an external pressure of 1,428 kPa. Due to symmetry, the sources are capable of withstanding this pressure internally. Therefore the sealed sources can withstand the internal pressure caused by thermal expansion and a drop in ambient pressure.

2.6.4 Vibration

2.6.4.1 Sealed Sources

The C-1000, C-1001, C-3000, C-3001 and C-378 sealed sources have been tested to a minimum of Class 3 vibration test requirements of ANSI N542 [4] or ISO 2919 [12]. 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. This test is significantly more severe than any vibration that the sources will encounter during normal transport [8]. Due to the similarity in design and weight, the C-1001, C-3001, ISO-1000 and RAMCO-50 sealed sources are also capable of withstanding any vibration encountered during normal transport.

2.6.4.2 Packaging

[redacted] Similarly, the lead inside the gammacell irradiator dampens vibration [7]. Therefore the vibration normally incident to transport will have no effect on the F-431 packaging. This is further supported by Best Theratronics' operational experience with shipments of packages of comparable size and mass.

2.6.4.3 Fasteners

[redacted] The variation on the nominal torque is ±10%.

Fasteners for the inner and outer cover and on the tie-down collar may be susceptible to the effects of vibration. 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 3 mm (1/8 in.) thick between the main cover and body of the package. Polyurethane foam vent holes are plugged with plastic pipe plugs, ¾ in. NPT. Therefore, the F-431 can withstand the water spray test during normal transport without any loss of integrity.

2.6.6 Free Drop

10 CFR 71.51 [1] and IAEA TS-R-1 §646 [3] require that the package be designed such that if it were subjected to the Free Drop Test, that it would prevent loss or dispersal of the radioactive contents and a significant loss of shielding integrity. Since the F-431 has a mass less than 5,000 kg, the required height for the Free Drop test is 1.2 m (4 ft.).

In section 2.7 below, it is demonstrated that the F-431 is capable of withstanding 9 m Free Drop tests and Puncture tests without significant damage to the sealed sources or the shielding. Specifically, it is shown that:

1. The sealed sources are undamaged and are still contained inside the gammacell irradiator.
2. There is no measurable increase (less than 20%) in the surface radiation on the F-431 transport package.

Therefore, the F-431 could also survive the less severe 1.2 m drop test and meet the regulatory requirements.

2.6.7 Corner Drop

10 CFR 71.71 (c) (8) [1] and IAEA TS-R-1 §722 [3] require that this test only be performed on fiberboard, wood, or fissile material rectangular packages not exceeding 50 kg (110 lb.) and fiberboard, wood or fissile material cylindrical packages not exceeding 100 kg (220 lb.). Since the F-431exceeds 100 kg in weight, this test is not required by the regulations.

2.6.8 Penetration

The F-430 test specimen was tested by dropping 6 kg steel round bar (3.2 cm in diameter with hemispherical end) from 1.7 m onto the container. Two drops were performed in two different locations (top and side). Only small dents were observed. Refer to the Test Report provided in Appendix 2.10.3a and/or 2.10.3b. Since the F-431 is constructed with the same materials, it would experience the same results.

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-431 Transport Package, meets all regulatory requirements when subjected to the hypothetical accident conditions of transport.

2.7.1 Free Drop

In this section, the performance of the F-431 will be evaluated by comparison with other packages that were subjected to the Free Drop Tests. The F-431 will be compared to the F-430, on which the F-431 design is based, and to the GC3000 irradiator, which was subjected to a free drop without any impact protection.

2.7.1.1 Comparison of the F-430 and F-431

The F-430 Package was designed and manufactured by Best Theratronics. A full scale prototype was manufactured and subjected to the regulatory tests, including the free drop test.

The F-431 design is based on that of the F-430. The F-431 is smaller, and is intended to transport smaller and lighter payloads. The two packages are shown in Figure 2.2 and their features are summarized in Table 2.2. Other than the differences in dimensions, the F-430 and F-431 are constructed identically.

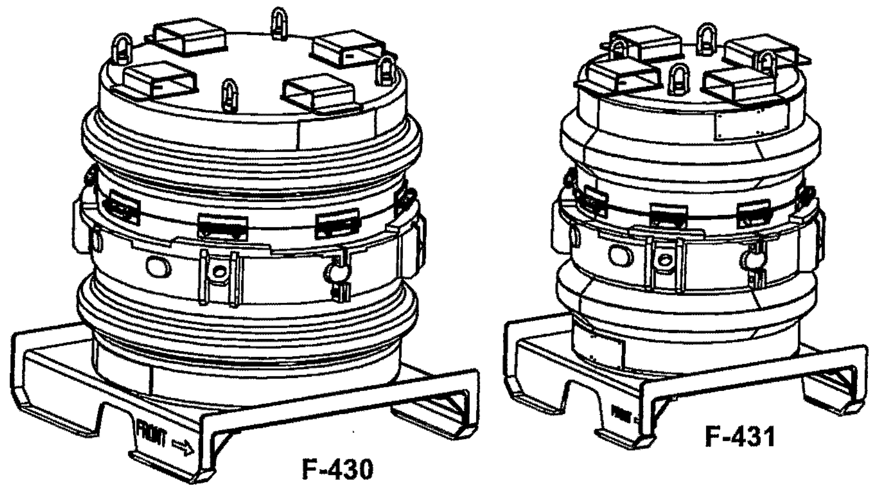


Figure 2.2: F-430 and F-431 Transport Packages

Table 2.3: Comparison of F-431 and F-430 Transport Packages			
Feature	F-430	F-431	Scale Ratio (F431/F430)
Package height	1,250 mm (49.25 in.)	1,205 mm (47.5 in.)	H_{431}/H_{430} = 0.96
Package diameter	1,410 mm (55.44 in.)	1,065 mm (41.94 in.)	D_{431}/D_{430} = 0.76
Package weight	3,175 kg (7,000 lb.)	2,270 kg (5,000 lb.)	W_{431}/W_{430} = 0.71
Cavity height	820 mm (32.25 in.)	815 mm (32.0 in.)	h_{431}/h_{430} = 0.99
Cavity diameter	915 mm (36.0 in.)	560 mm (22.0 in.)	d_{431}/d_{430} = 0.61
Max payload weight	1,820 kg (4000 lb.)	1,225 kg (2,700 lb.)	w_{431}/w_{430} = 0.70
Inner cover fasteners	[redacted]	[redacted]	$Fastener_{431}/Fastener_{430}$ = 1.0
Outer cover fasteners	[redacted]	[redacted]	$Fastener_{431}/Fastener_{430}$ = 1.0

2.7.1.2 Prototype Testing

The analysis of the Free Drop test will refer to testing done with the F-430 and the GC3000. The F430 test specimen was subjected to three free drop tests from 9 m and four puncture tests. The results of these tests are presented in Appendix 2.10.3a and/or 2.10.3b. The GC3000 was subjected to one 9 m test without a protective overpack. The results of this test are presented in Appendix 2.10.4.

2.7.1.3 End Drop

The F-430 was dropped inverted from 9 m onto its end. After the test, there was no compromise in the integrity of the package. The results are presented in Appendix 2.10.3a and/or 2.10.3b. The F-431 is expected to perform equally well as a result of a 9 m Free Drop test onto its top or bottom. This is further supported by the testing performed on a GC3000 with no protective overpack. The GC3000 was dropped from 9 m onto an unyielding surface (refer to Appendix 2.10.4). After the drop test, the GC3000 was subjected to a radiation survey, and no increase in the radiation levels was measured. Also, there was no visible damage to the simulated sealed sources.

2.7.1.4 Side Drop

The F-430 test specimen containing a Gammacell 40 (GC40) was dropped from 9 m onto its side. The impact caused the skid to break free of the package, the bumpers to collapse locally and the foam to crush 2 in. deep on the side of the package. [redacted] on the exterior of the package (i.e. between the F-430 and the target), [redacted] on the interior of the package (i.e. between the payload and the F-430). This is because the contact area between the F-430 and the drop target is much less than the contact area between the payload and the F-430, as illustrated in Figure 2.3.

The peak decelerations measured on the F-430 payload (i.e. GC40) [redacted] (refer to Appendix 2.10.3 a and/or 2.10.3b) The average deceleration was approximately [redacted] As a result of the drop, four bolts were broken on the main cover. However, the cover remained securely attached and there was no breach in the stainless steel skin. Inspection of the GC40 after the drop tests were completed and showed that there was no significant damage to the GC40 (shielding) nor the simulated sealed source (containment).

To determine the effect of a side drop on the F-431, the geometries of the F-430 and F-431 will be compared. A 9 m side drop would cause the bumper and [redacted] The depth of crush in the F-431 is a function of the dimensions and weight of the package. Specifically, the crush depth, δ, is proportional to the weight of the package, inversely proportional to the length, and approximately inversely proportional to the cube root of the diameter.

$$\delta \propto W,$$

$$\delta \propto 1/\mathrm{H},$$

$$\delta \propto 1/D^{1/3}$$

where
δ = crush depth
W = weight of the package
H = height of the package
D = diameter of the package

In equation form,

$$\delta_{F431} = \delta_{F430} * \left(\frac{W_{F431}}{W_{F430}}\right) * \left(\frac{H_{F430}}{H_{F431}}\right) * \left(\frac{D_{F430}}{D_{F431}}\right)^{1/3}$$

Substituting the package's scale ratios from Table 2.2, we find that

$$\delta_{F431} = \delta_{F430} * 0.81$$

Thus we expect that the amount of deformation for the F-431 would be almost the same as that of the F-430. Similarly, the acceleration experienced by the payload would be essentially the same.

Therefore, the F-431 would survive the 9 m Free Drop test with no significant damage. Specifically, the package's ability to provide shielding, containment and protection against fire would not be compromised.

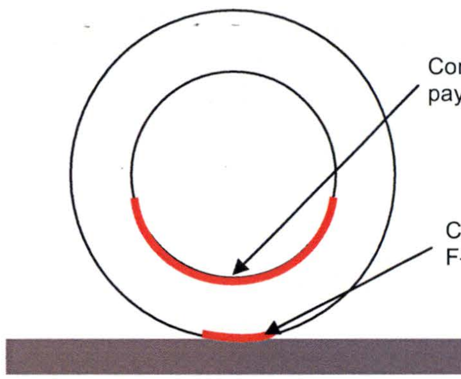


Figure 2.3: Contact Areas for 9 m Side Drop

2.7.1.5 Corner Drop

In this orientation, contact area of the package with the target is minimized, and therefore the amount of deformation is maximized and the deceleration is minimized. This was confirmed with the testing on the F-430, where peak accelerations were measured in the range [redacted] (refer to Appendix 2.10.3a and/or 2.10.3b). The F-431 has almost identical geometry in this orientation, and so the deformation of the container on impact would be similar. Since the F-430 sustained only moderate damage from this test, and since this orientation is the least damaging for the payload, the F-431 would also fare well during this test.

2.7.1.6 Conclusions

The different orientations for the 9 m Free Drop Test have been analyzed by comparison with the tests performed on the F-430 package and the GC3000. It was demonstrated that the tests would not result in significant damage to the F-431. Specifically, the F-431 would continue to provide radiation shielding, containment, and protection from an accidental fire.

2.7.2 Puncture

The full-scale F-430 test specimen was subjected to four 1 m puncture tests in a variety of different orientations (refer to Appendix 2.10.3a and/or 2.10.3b). The damage caused to the test specimen was minor when compared to the results of the Free Drop Test. Specifically, no additional bolts were broken and the lid remained attached securely to the package. The outer skin of the package [redacted]

The F-431 is similar to the F-430 in that the stainless steel outer skin is the same thickness and [redacted] Since the F-431 is a lighter package, the damage from the Puncture Test will be less. Therefore, the performance requirements for the puncture test under the hypothetical accident conditions of transport are satisfied.

2.7.3 Thermal

The thermal protection area of the F-431 package is 4.9 m^2 (53 $ft.^2$) on the outside and 1.9 m^2 (21 $ft.^2$) on the inside (cavity surface). [redacted] Prior to the hypothetical fire test, all the thermal protection is retained around the package. Assuming that the same amount of foam is damaged as with the F-430 (a conservative assumption, since the F-430 weighs 40% more than the F-431), [redacted] would be compressed during the puncture test [redacted]

[redacted]

The temperature increases within the F-431 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

There is no increase in pressure inside the F-431 cavities due to the hypothetical accident conditions of transport thermal test, as discussed in Section 3.5.4. The maximum temperature inside the Gammacell is 151°C. The maximum temperature and pressure inside the sealed source are 326°C and 106 kPa, respectively.

2.7.3.2 Differential Thermal Expansion

The maximum differential thermal expansion occurs during the fire test 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 [redacted] the material will flow in areas of high thermal stresses.

2.7.3.3 Stress Calculations

The stresses caused as a result of the hypothetical accident conditions of transport thermal test are discussed in Section 3.5.5. Since the thermal gradients are low in the containment system and in the Shielding Head, the thermal stresses in these key components are negligible. The pressure inside the sealed source is calculated in Section 3.5.6. It is concluded that the sources can easily withstand this pressure.

2.7.4 Water Immersion

The water immersion test, with an external gauge pressure of water of 21 psi (145 kPa), will not have a significant effect on the performance of this package. This is justified as follows:

1. [redacted]
2. The gammacells consist of steel encased lead and will not be significantly affected by water.
3. The stainless steel Cs-137 source capsules were shown in section 2.5.2 to be capable of withstanding a pressure in excess of 170 kPa (25 psi).

2.7.5 Summary of Damage

Nine drop tests were performed on a full-scale F-430. Since the F-431 is a smaller and lighter package, many of the F-430 test results are applicable to the F-431. The F-431 was also assessed by comparison with the GC3000, which was subjected to a 9 m drop without protective packaging.

By comparison, it was demonstrated that the damage to the F-431 packaging would be as follows:

1. There would be no cracks in the body of the payload irradiator. The source capsules would suffer no visible damage. The lead housing would have only minor dents and scratches.
2. The payload would not pierce the F-431 cavity. The inner lid would not lose any bolts and would keep the contents shielded from fire.
3. The main cover would stay in place.
4. Radiation levels following the drop testing would not increase measurably.

2.8 SPECIAL FORM

The sealed sources that are transported within the F-431 are discussed in Chapter 4. The applicable Special Form Certificates are included in the appendices to Chapter 4.

All source models, with the exception of the RAMCO-50 source, have been certified to meet the requirements of Special Form Radioactive Material. In this section, the RAMCO-50 source will be compared to the other source models in the F-431, and it will be shown that the RAMCO-50 source satisfies the requirements for Special Form.

The C-378, C-3001, and C-3100 source capsules were tested and shown to meet the Special Form requirements of the IAEA Safety Series TS-R-1 [3]. The Special Form Certificates CDN/0017/S-96, GB/373/S-96, and CDN/0035/S-96 are included in Appendices 4.4.1, 4.4.5 and 4.4.13. The C-1000, C-1001, C-3000 and ISO-1000 source capsules were tested and shown to meet the Special Form requirements of earlier versions of the Regulations for the Safe Transport of Radioactive Material. The Special Form Certificates CDN/0011/S, GB/372/S-85, CDN/0012/S-85 and USA/0192/S are included in Appendices 4.4.2, 4.4.3, 4.4.4 and 4.4.6. The requirements for the qualification of Special Form radioactive material as specified in 10 CFR 71 Section 71.75 are identical to those specified in the IAEA Regulations [1, 3, 14, 15].

The C-3100 Source testing was done in accordance with International Standard ISO 2919:2012 (E) Edition [13].

The RAMCO-50 sealed source has not been certified to meet the requirements for Special Form Radioactive Material. However, in the following paragraphs, it is shown to meet the requirement for Special Form Radioactive Material by comparison with the C-378, C-1000, C-1001, C-3000, C-3001 and ISO-1000 sealed sources. Furthermore, the Sealed Source Registration for the RAMCO-50 Source, NR-0880-S-804-S, states that these sources would be expected to maintain their containment integrity for normal conditions of use and the accidental conditions which might occur. The registration certificate is included in Appendix 4.4.12

2.8.1 Description

The C-378, C-1000, C-1001, C-3000, C-3001, C-3100, ISO-1000 and RAMCO-50 Sealed Sources are depicted in Chapter 4, Figures 4.2 through 4.9.

The C-378, C-1000, C-1001, C-3000, C-3001, C-3100, and RAMCO-50 models are made with type 316L stainless steel. The ISO-1000 model is made with type 304L stainless steel. All models have the following features

1. an outer stainless steel capsule with fusion welded end cap
2. an inner stainless steel capsule with fusion welded end cap
3. Cesium-137 radioactive material in the form of Cesium Chloride.

The dimensions of the seven source models are summarized in Table 2-4.

Table 2-4: Summary of C-378, C-1000, C-1001, C-3000, C-3001, C-3100, ISO-1000 and RAMCO-50 Sealed Source Dimensions								
Dimension	C-378 (in.)	C-1000 (in.)	C-1001 (in.)	C-3000 (in.)	C-3001 (in.)	C-3100 (in.)	ISO-1000 (in.)	RAMCO-50 (in.)
Outer Tube O.D.	0.620	0.500	0.500	0.687	0.687	0.692	0.497	0.500
Tube Wall Thickness	0.025	0.035	0.039	0.035	0.039	0.039	0.035	0.020
Capsule Length	10.99	10.69	10.69	10.69	10.69	10.69	10.68	4.500 to 5.375
End Cap Diameter	0.577	0.444	0.427	0.631	0.614	0.616	0.431	0.460
End Cap Thickness	0.025	0.315	0.039	0.315	0.039	0.30	0.315	0.100

2.8.2 Free Drop

The requirements for the Free Drop Test as specified in 10 CFR Part 71 Section 71.75(b)(1) are identical to those of the IAEA Regulations to which the C-378, C-1000, C-1001, C-3000, C-3001 and ISO-1000 capsules were tested and certified. See the Special Form Radioactive Material Certificates in the appendices to Chapter 4.

Since the RAMCO-50 source is very similar to the other source designs and shapes and has a length and weight of approximately one half of the other models, it would suffer less damage and therefore pass the Free Drop Test.

2.8.3 Percussion Test

The requirements for the Percussion Test as specified in 10 CFR Part 71 Section 71.75(d)(1) are identical to those of the IAEA Regulations to which the C-378, C-1000, C-1001, C-3000, C-3001 and ISO-1000 capsules were tested and certified. See the Special Form Radioactive Material Certificates in the appendices to Chapter 4.

Since the RAMCO-50 source is very similar to the other source designs, shapes and weights, it would also pass the Percussion Test.

2.8.4 Bending

The requirements for the Bending Test as specified in 10 CFR Part 71 Section 71.75(b)(3) are identical to those of the IAEA Regulations to which the C-378, C-1000, C-1001, C-3000, C-3001 and ISO-1000 capsules were tested and certified. See the Special Form Radioactive Material Certificates in the appendices to Chapter 4.

Since the RAMCO-50 source is very similar to the other source designs and shapes and has a length of approximately one half of the other models, it would suffer less damage and therefore pass the Bending Test.

2.8.5 Heat Test

The requirements for the Heat Test as specified in 10 CFR Part 71 Section 71.75(b)(4) are identical to those of the IAEA Regulations to which the C-378, C-1000, C-1001, C-3000, C-3001 and ISO-1000 capsules were tested and certified. See the Special Form Radioactive Material Certificates in the appendices to Chapter 4.

Since the RAMCO-50 source is very similar to the other source designs, shapes and weights, it would also pass the Heat Test.

2.8.6 Leaching Assessment

The C-378, C-1000, C-1001, C-3000, C-3001 and ISO-1000 Sealed Sources have been shown to be leaktight (see the Special Form Radioactive Material Certificates in the appendices to Chapter 4). By definition, since the sources are leaktight, there will be no release of radioactive material. Therefore the sources meet the leaching assessment criteria.

Since the RAMCO-50 source is very similar to the other source designs, shapes and weights, it also satisfies the leaching assessment criteria.

2.8.7 Summary

The C-378, C-1000, C-1001, C-3000, C-3001, C-3100 and ISO-1000 Sealed Sources have been certified to meet the requirements for Special Form Radioactive Material.

The RAMCO-50 source has been demonstrated by comparison also to satisfy the requirements for Special Form.

2.9 FUEL RODS

This requirement is not applicable since the F-431 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 Chapter 2. For convenience, it is divided into subsections, which are referenced in the body of this chapter or submission.

Appendix 2.10.1: List of References for Chapter 2

Appendix 2.10.2: Tie-down Analysis of the F-431 Package

Appendix 2.10.3a: F-430 Test Report, IN/TR 1604 F430

Appendix 2.10.3b: Supplementary Safety Analysis Report for the F-430 Transport Package, IN/TR 6088 F-430

Appendix 2.10.4: Test Report for GC3000 Removable Plug, IN/TR 1691 GC3000

Appendix 2.10.5: [redacted]

Appendix 2.10.6: Hoist Rings

Appendix 2.10.7: Lifting Analysis for the F-431 Overpack

Appendix 2.10.8: Assessment of the F-430 Tie-down Collar Bolted Connection

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] IAEA Safety Standard Series No. TS-R-1, *Regulations for the Safe Transport of Radioactive Material*. 1996 Edition (Revised). Vienna, 2000.

[4] US Department of Commerce/National Bureau of Standards. NBS Handbook 126, American National Standard N542; Sealed Radioactive Sources, Classification, 1977.

[5] J. H. Evans, ORNL. Proceedings of the 4th International Symposium on Packaging and Transportation of Radioactive Materials, Miami Beach, Florida, September 22-27, 1974. "Experimental Studies of the Strain-Strain Properties of Cask Materials under Specified Impact Conditions", pp. 232-243.

[6] ASME BPV Code, Section III.

[7] [redacted]

[8] RDT Standard No. F-8-11T, Fuel Shipping Container Tie-down for Truck Transport, Division of Reactor Research and Development, US, ERDA. January 1975.

[9] W. R. Holman & R. T. Longland. NUREG/CR-1815; UCRL-53013, "Recommendations for Protecting Against Failure by Brittle Fracture in Ferritic Steel Shipping Packages up to Four Inches Thick".

[10] American Society for Metals. Metals Handbook, Volume I, Tenth Edition. Ohio, Materials Park, 1990.

[11] McGraw-Hill Book Company. Mark's Standard Handbook for Mechanical Engineers, Eighth Edition.

[12] ISO 2919, Radiological Protection – Sealed Radioactive Sources – General Requirements and Classification. 1999.

[13] ISO 2919:2012 (E) Radiological Protection – Sealed Radioactive Sources – General Requirements and Certification.

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

[15] IAEA Safety Standard No. 6, Regulations for the Safe Transport of Radioactive Material. 1973 Edition. Vienna. 1973.

APPENDIX 2.10.2: Tie-down Analysis of the F-431 Transport Package

1. INTRODUCTION

In this appendix, the F-431 package tie-down arrangement is analysed 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 A2.10.2-1. The tie-down arrangement is illustrated in Figure A2.10.2-1.

The F-431 is used in conjunction with a tie-down collar that girdles the F-431 at mid-height. The tie-down collar incorporates four lugs to which the tie-down chains are attached. It rests on four oblong bosses, welded to the circumference of the F-431.

Table A2.10.2-1: 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-431 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.

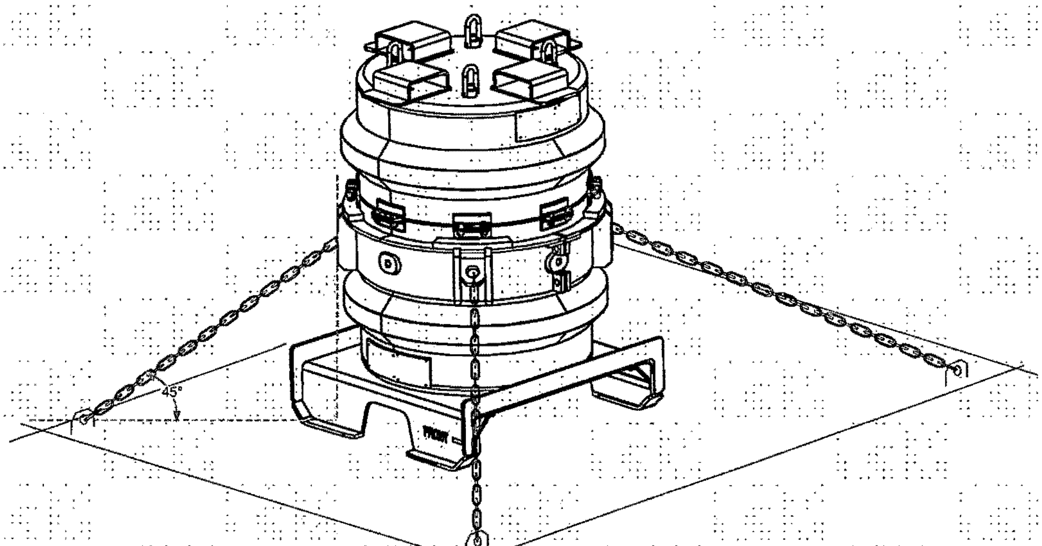


Figure A2.10.2-1: F-431 Tie-Down Arrangement

3. STRESS ANALYSIS OF THE F-431 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-431 was modeled as a right cylinder, made up of layers [redacted] The features of the model and their properties are listed in Table A2.10.2-2. The payload (e.g. GC1000 or GC3000) was simulated by a hollow cylinder made of lead. The lead thickness was selected in order to produce a total mass of 5,000 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 A2.10.2-1 were applied to the model.

The model statistics are listed in Table A2.10.2-3. The stress results are shown in Figure A2.10.2-2.

Table A2.10.2-2: Finite Element Model Features and Properties

Feature	Material	Young's Modulus	Poisson's Ratio
Layer 1 (outer most)	[redacted]	[redacted]	[redacted]
Layer 2	[redacted]	[redacted]	[redacted]
Layer 3	[redacted]	[redacted]	[redacted]
Layer 4	Lead	2.42 X 10^6 psi	0.44
[redacted]	[redacted]	[redacted]	[redacted]

Table A2.10.2-3: Finite Element Model Statistics

Model Entities	Points: 6253, Edges: 32463, Faces: 47772
Finite Elements	Type: P-element, Beams: 3, Shells: 1995, Solids: 21566
Total Elements	23564
Contact Regions	8
Convergence Method	Multi Pass Adaptive

3.2 Tie-Down Collar Stresses

The stresses in the tie-down collar are shown in figure A2.10.2-3.

The highest stresses in the model occur in one of the tie-down collar lugs. Figures A2.10.2-4 and A2.10.2-5 show the stresses in the lug that is loaded with the tie-down chain with the highest load. In Figures A2.10.2-4 and A2.10.2-5, the maximum stress is [redacted]. This is safely below the yield strength of [redacted]

Away from the tie-down lug, the maximum stress occurs in the top stiffener, adjacent to the lug discussed above (refer to Figure A2.10.2-3). This stress is [redacted] This is safely below the yield strength of [redacted] Figure A2.10.2-6 shows the stress distribution through the tie-down collar at this location.

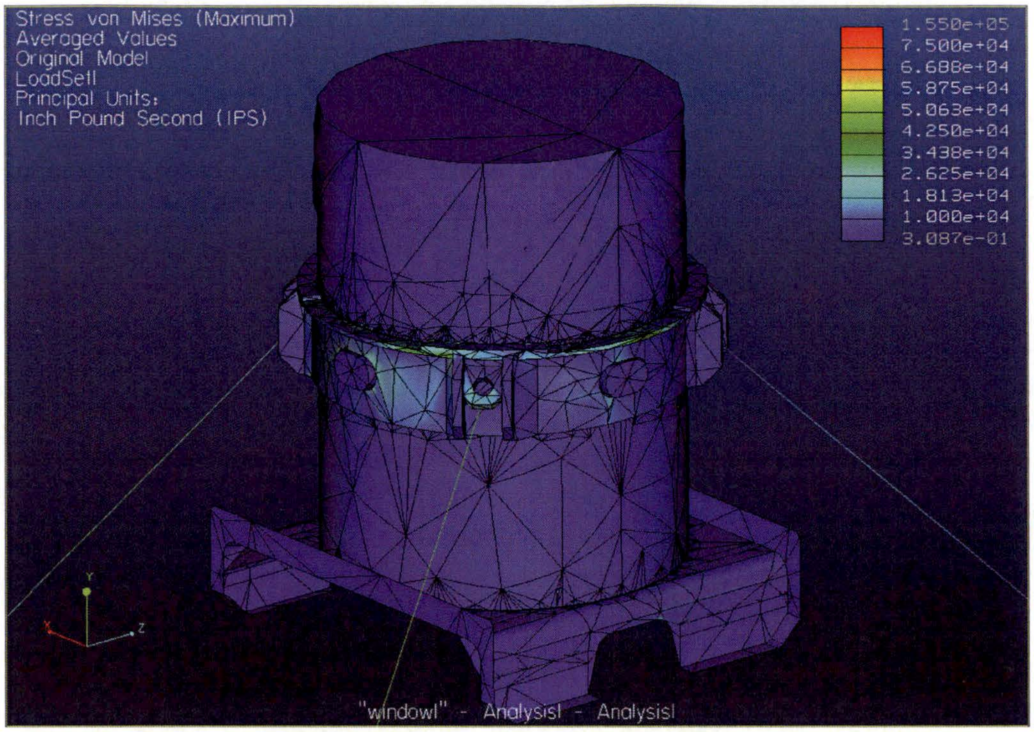


Figure A2.10.2-2: Tie-Down Stresses in the F-431

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-431 skin will be neglected.

The maximum load in the tie-down chains is 20,000 lb. The horizontal and vertical components of this force are 14,140 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 = 14,140 lb.
A = stress area of the bolt, based on the root dia. = 0.431 in.^{2} (root dia. = 0.741 in.)

Therefore σ = 32,790 psi

The bolts [redacted]

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

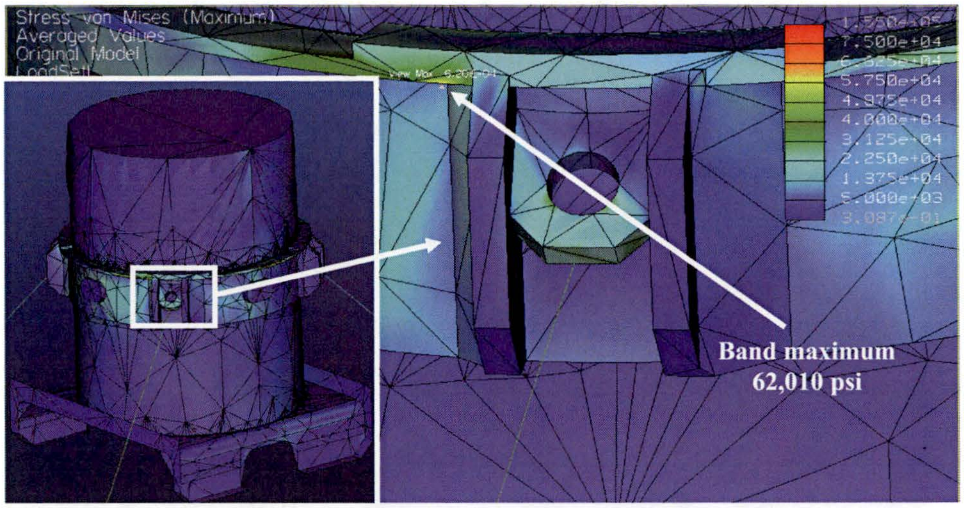


Figure A2.10.2-3: Stresses in the F-431 Tie-Down Collar

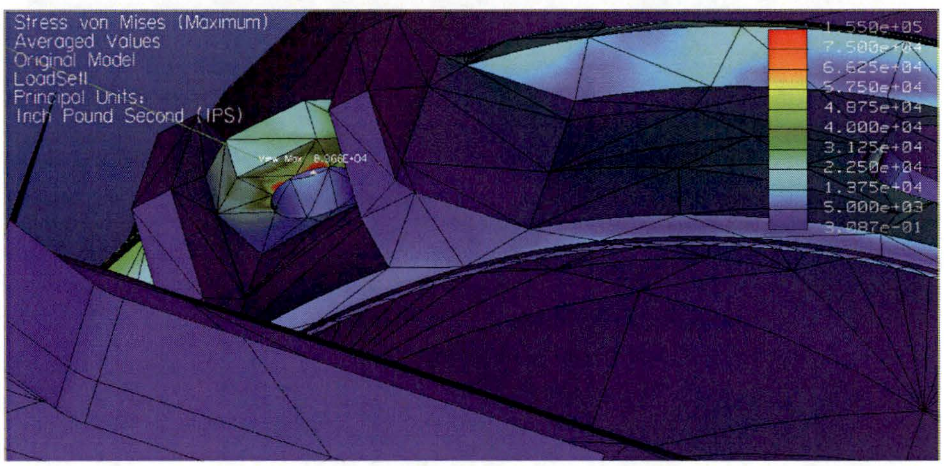


Figure A2.10.2-4: Stresses in the Tie-Down Lug

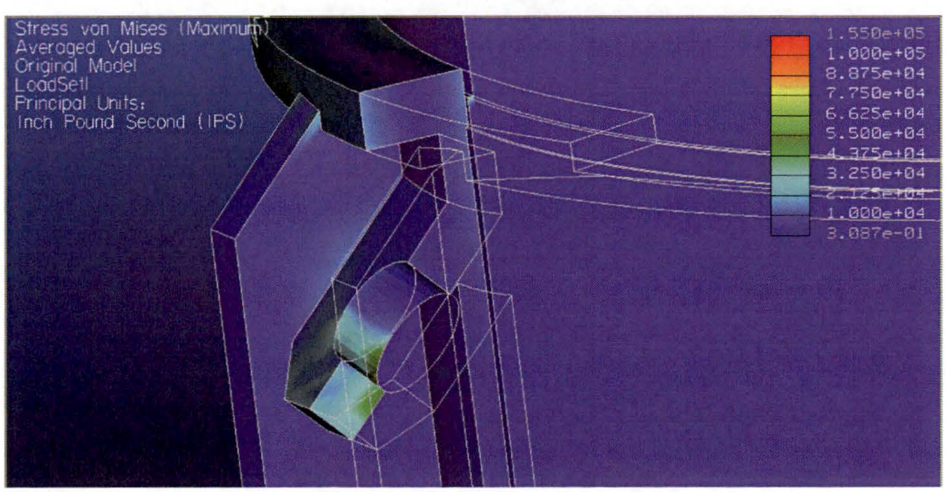


Figure A2.10.2-5: Stress Distribution in the Tie-Down Lug

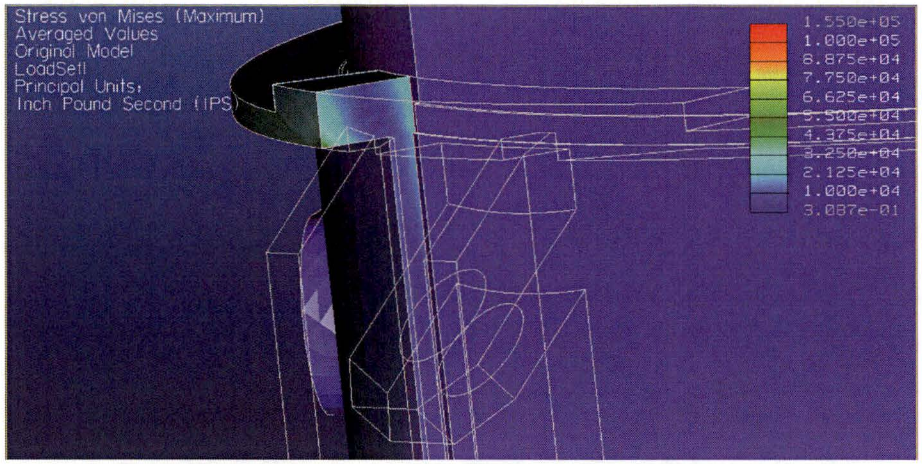


Figure A2.10.2-6: Stress Distribution in the Tie-Down Band

3.3 Stresses in the F-431 Main Body

The stresses in the bosses and the boss ring are shown in Figures A.2.10.3-7 and A.2.10.3-8.

The results show that the stresses in the F-431 are highest in the skin, just above the internal band. The maximum stress is 20,610 psi. This is safely below the minimum yield strength of [redacted].

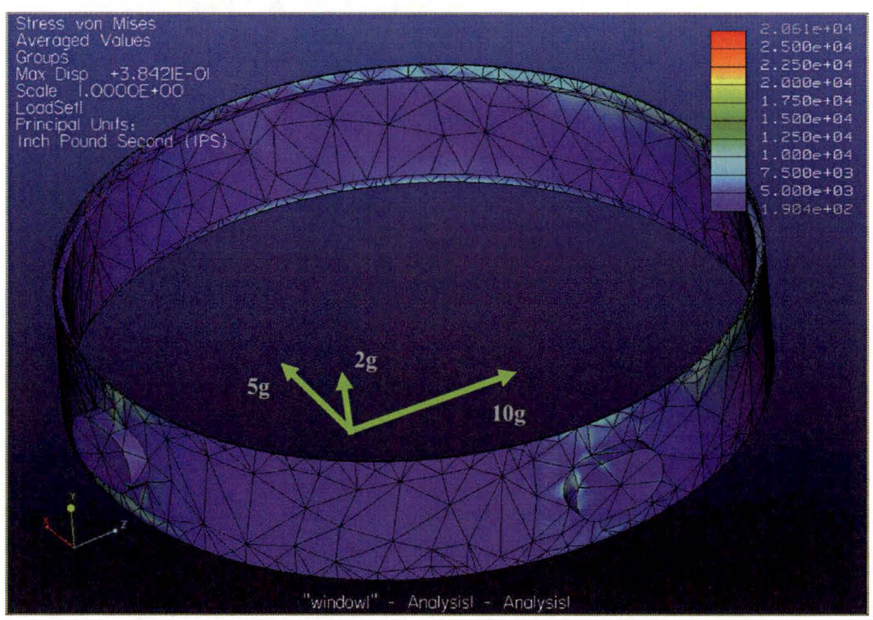


Figure A2.10.2-7: Stresses in the F-431 Skin and Inner Ring

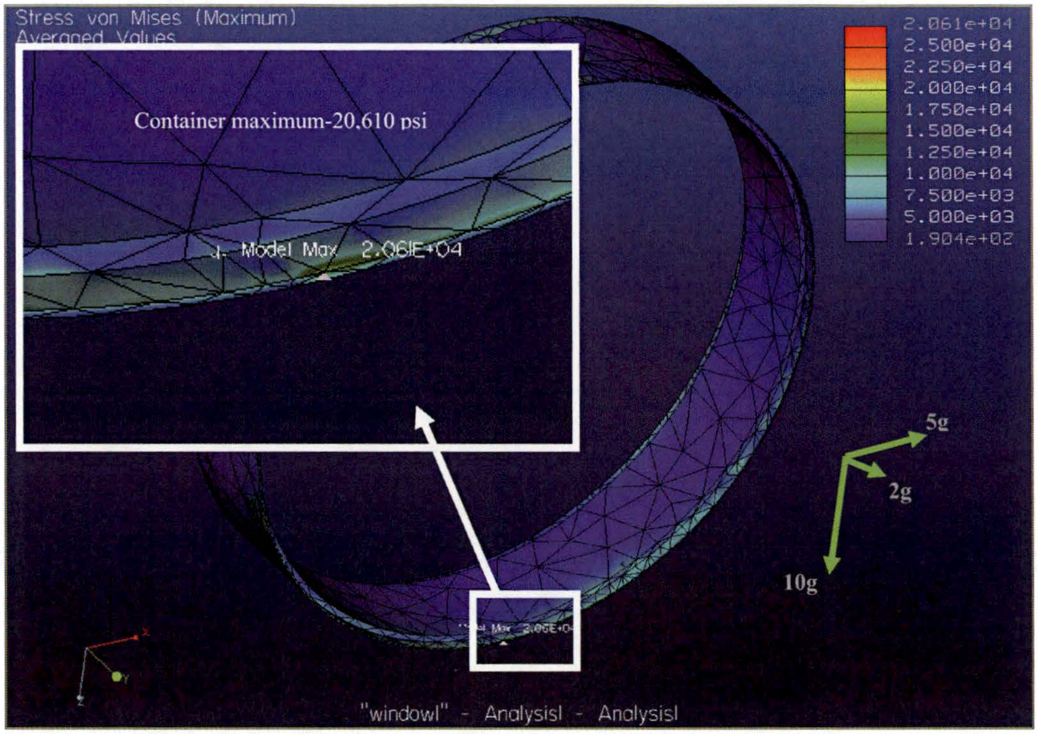


Figure A2.10.2-8: Stresses in the F-431 Skin and Inner Ring

5. CONCLUSIONS

The maximum stress in the body of the F-431 package is 20,610 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 [redacted] 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 [redacted] 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.

6. REFERENCES FOR APPENDIX 2.10.2

[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.

APPENDIX 2.10.3a:
F-430 Test Report

IN/TR 1604 F430 (1b)

F-430 Test Report

Signatures

Prepared by: [redacted] Date: 02/08/28

Reviewed by: Date: 2-8-28

Approved by: Date: 02 Sept 24

Document History

Date	Version	Comments	Prepared by	Reviewed by	Approved by
June 2000	1	CCF A1297-C-00A	J. Krupka	J. Smith	M. Krzaniak
Oct 2000	1a	A1297-D-07A Revised Pages: 15,25,29,31,41,48,50	J. Krupka	J. Smith	M. Krzaniak
July 2002	1b	A1297-D-12A Revised TOC, Pages 6, 29, 48, 50, add title page for Append 1, remove Append 2 (photos)			

[redacted]

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

TABLE OF CONTENTS

List of Appendices

List of Figures

1. INTRODUCTION

The F-430 transport package has been designed to ship GC-40 (Upper and Lower Heads separately), and other units that will fit the transport cavity and do not exceed the container payload capacity of 4300 lb (1950kg). Because of its irregular shape and larger mass the GC-40 Lower Head was tested inside the new overpack rather than the Upper Head.

This test report provides the results of regulatory tests on the full scale F-430 test specimen to meet IAEA Safety Series No. 6, Regulations for the Safe Transport of Radioactive Materials, 1985 edition (as amended 1990) [1] and 10 CFR Part 71 [2] requirements. Where applicable, a description of tests and detailed test procedures are included.

Tests were conducted according to IN/TP 1493 F430 (2) test plan in Fall of 1999.

2. PRE-DROP TESTS

2.1 Inspect F-430 Test Specimen for Fit

Report Type	Date of Test	
Pre-Drop	July 20, 1999	
Test Name/Description	**Test Number**	**Test Plan**
Inspect F-430 Test Specimen for Fit	5.1.1	IN/TP 1493 F430 (2)

Test Details

1. Fitting of main cover was checked.
2. Fitting of internal brace on both GC-40 lower head specimens (drop test specimen **A**, non-drop test specimen **B**) was checked.
3. Fitting of internal brace with GC-40 lower head (both specimens A and B) inside transport cavity was checked.

Observations

1. The main cover fit on the main body of the container without interference when aligned in one position. This position was marked on the mating flanges with a groove (instead of a guide pin). If main cover was turned to align with a different flange on the main body, interference of main cover with the body was observed.
2. Internal fixing brace fitted both GC-40 lower head specimens outside the container. The brace rested on the top face (cone flange) of the irradiator, and had 1/16" to ¼" clearance with the irradiator side to side and front to back.
3. Drop test specimen A with the fixing brace was installed inside the transport cavity during manufacturing. Since the radial clearance between the fixing brace and the cavity was small and non-uniform, GC-40 had to be rotated by about 35° away from the front-to-back centerline (Figure 1).
4. Non-drop test specimen B fitted inside the cavity with the inner brace without rotation. That is, the irradiator cylinder axis was aligned with the container front-to-back axis.

Results

1. When properly aligned, main cover fit on the body of the container without interference, as required. All bolt holes were aligned to accommodate sixteen 5/8" bolts.
2. Outside of the container the internal fixing brace fitted properly on both GC-40 irradiators.
3. Inside the F-430 container both specimens A and B fitted with the fixing brace on, but had to be rotated as required to fit.

Conclusions

1. Main cover fitted on the container body. Larger radial clearance and locating pin are recommended for future containers.
2. Internal fixing brace fitted over both specimens A and B of GC-40.
3. Internal fixing brace with either specimen of GC-40 fitted inside the transport cavity with difficulties, and larger cavity diameter is required on future containers.
4. Internal components of GC-40 (source drawer and dummy source) fit properly.
5. One of the purposes of drop test #4 was to check if the sharp corner of GC-40 base plate could pierce through the cavity wall. Turning GC-40 by 35° meant that this possible piercing would better be tested in drop test #7.

Personnel	Name	Title	Signature / Date
Test Conducted by:	Jiri Krupka	Package Engineer	J. Krupka 00/06/19
Reviewed by:	Benjamin Prieur	QC Technician	B Prieur 2000/06/15
Approved by:	Dave Whitby	Senior QC Technician	D Whitby 00-06-15

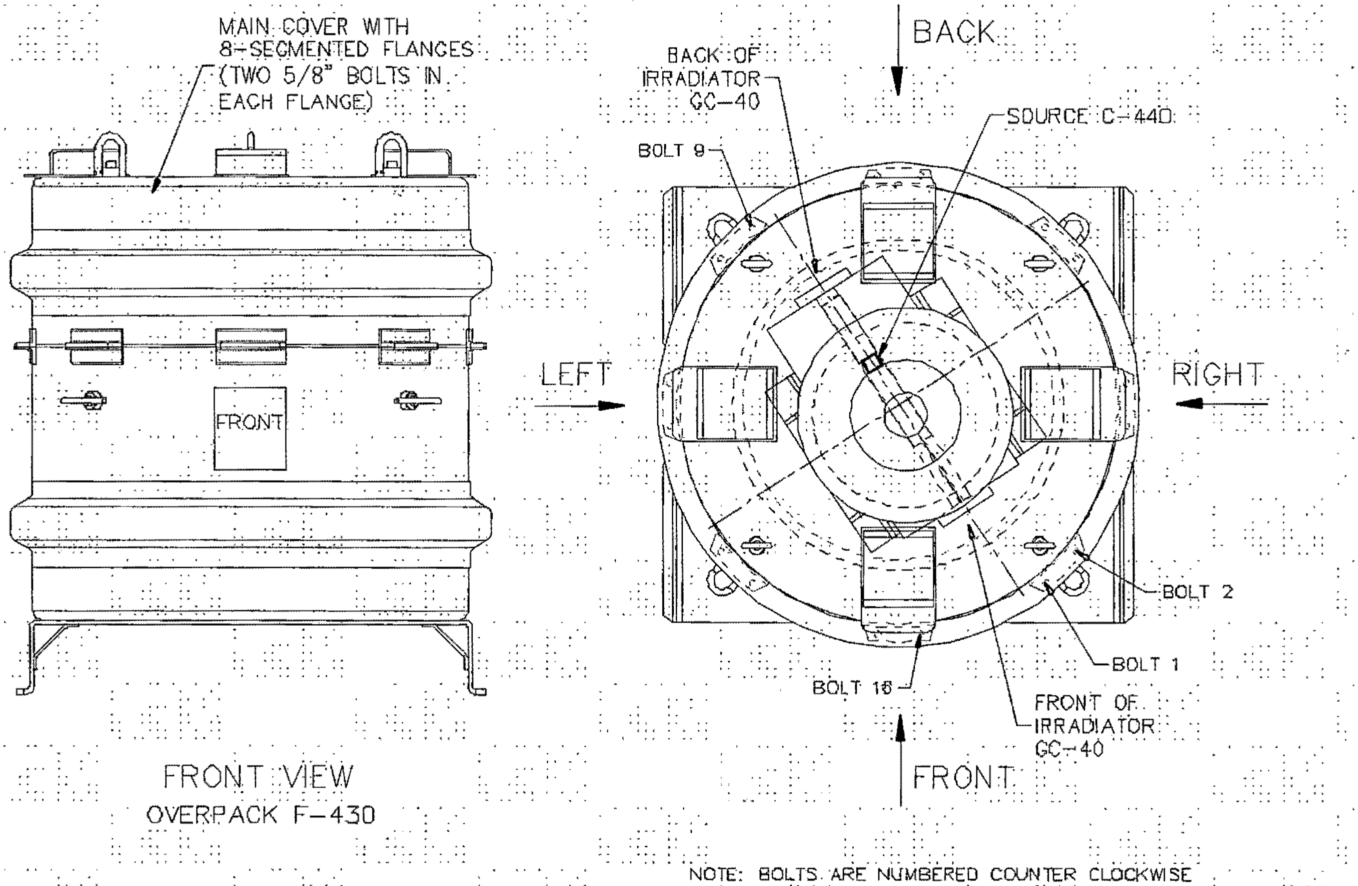


Figure 1, Orientation of GC-40 and Bolt Numbering

2.2 Weigh F-430 Test Specimen

Report Type	**Date of Test**	
Pre-Drop	August 9, 1999	
Test Name/Description	**Test Number**	**Test Plan**
Weigh F-430 Test Specimen	5.1.2	IN/TP 1493 F430 (2)

Test Details

The F-430 components were weighed in Industrial Operations of MDS Nordion

Equipment

1. Measurement System International digital scale (overhead load cell)
Model: Portaweigh Model 4300, Serial No: 40524/67782, MDSN Inventory No: 13531
Calibrated: 03/07/1997 (recalibrated in April 2000 without correction)
Capacity: 20,000lb, Accuracy: +/- 5lb.

2. Mettler Balance
Type P3, Serial No: 230493, MDSN Inventory No: 6-745-006
Calibrated: 13. May, 1999
Capacity: 3000g +/- 1g

3. Toledo Scale
Model 2184, Serial No: 585 5524-5TL, MDSN Inventory No: 6-745-85
Calibrated: 1. October, 1999
Capacity: 400lb +/- 0.1lb

Results

Main Body (including skid and plywood inserts) = 1760 lb
Main Cover = 745lb
Inner Cover = 160 lb
Internal Brace = 460 lb
GC-40 drop test specimen A (including source drawer and dummy source) = 3835 lb
GC-40 non-drop test specimen B (SN 004-1, including drawer and source) = 2735 lb
Source Drawer = 28.8 lb
Dummy Source C-440 = 234 g

Conclusions

The total weight of the F-430/GC-40 test specimen was 6960 lb.

Personnel	**Name**	**Title**	**Signature / Date**
Test Conducted by:	Jiri Krupka	Package Engineer	
Reviewed by:	Benjamin Prieur	QC Technician	
Approved by:	Dave Whitby	Senior QC Technician	

2.3 Dimensional Measurement of F-430 Test Specimen

Report Type	**Date of Test**	
Pre-Drop	August 9, 1999	
Test Name/Description	**Test Number**	**Test Plan**
Dimensional Measurement of F-430 Test Specimen	5.1.3	IN/TP 1493 F430 (2)

Test Details
The F-430 pertinent dimensions were recorded. Refer to Figure 2.

Results/Observations

Dimension	Nominal Value [in]	Measured Value [in]	Comments
A	61.88	61.75, 61.50	
B	50.22	50.20, 50.30	Note 1
C	50.00	50.00, 49.90	
D	50.00	49.75, 50.00	
E	31.00	31.15, 31.12	
F	18.75	18.75, 18.56	
G	44.50	44.50, 44.80	
H	8.00	8.00	
I	2.61	2.75	
J	7.00	7.25	
K	7.00	7.20	
L	44.00	43.93, 44.00	Note 1
M	13.00	13.20, 12.90	
N	9.50	9.50, 9.40	
O	1.50	1.50	
P	2.88	2.60, 2.80	
Q	33.75	33.75	
R	35.50	35.50	Note 1

Note 1:
All diameters were slightly out of round, but within acceptable limits (max 3/8").

Conclusions

No deviation listed above affect the form, fit of function of the F-430/GC-40, and had no significant effect on container's performance and evaluation.

Personnel	**Name**	**Title**	**Signature / Date**
Test Conducted by:	Jiri Krupka	Package Engineer	
Reviewed by:	Benjamin Prieur	QC Technician	
Approved by:	Dave Whitby	Senior QC Technician	

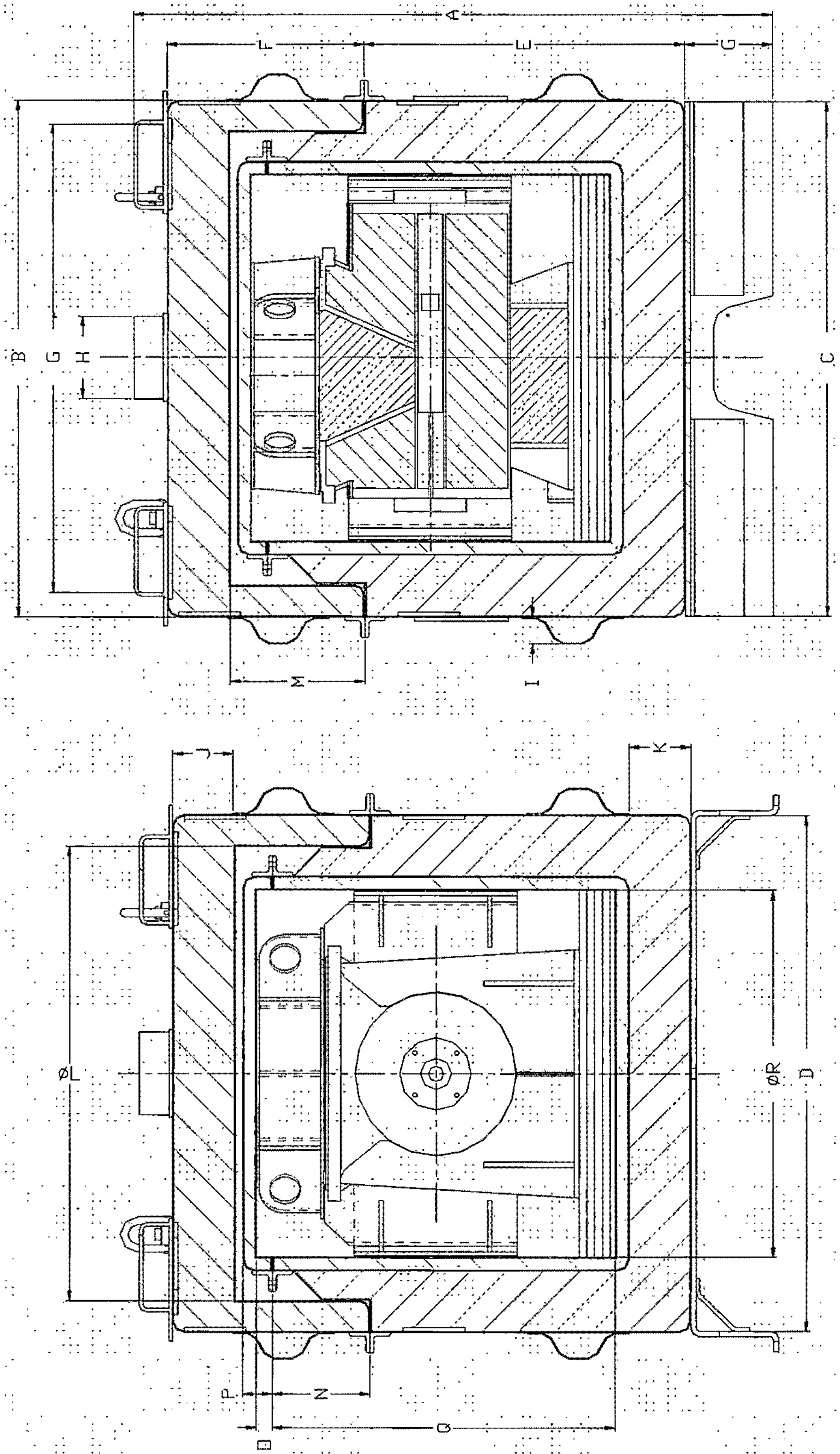


Figure 2, F-430 Container, Pre-Drop Dimensions

2.4 Dimensional Measurement of GC-40 Drop Test Specimen

Report Type	**Date of Test**	
Pre-Drop	August 9, 1999	
Test Name/Description	**Test Number**	**Test Plan**
Dimensional Measurement of GC-40 Drop Test Specimen	5.1.4	IN/TP 1493 F430 (2)

Test Details

The GC-40 pertinent dimensions were recorded. Refer to Figure 3.

The following dimensions were chosen as reference for before and after drop comparison. The nominal values are omitted as the measured values are relevant to the evaluation of the performance of the GC-40.

Results/Observations

Dimension	Nominal Value [in]	Measured Value [in]	Comments
A		24.8, 24.9	
B		13.75, 13.81	
C		10.50	
D		6.88	
G		4.31	
H		4.31	
I		0.63	
J		1.43	
K		4.59	
L		1.38	
M		5.62	
N		5.87	
O		5.56	
P		0.87	

Conclusions

The above data are intended for comparison of before and after drop testing. See section 5.3.3

Personnel	**Name**	**Title**	**Signature / Date**
Test Conducted by:	Jiri Krupka	Package Engineer	
Reviewed by:	Benjamin Prieur	QC Technician	
Approved by:	Dave Whitby	Senior QC Technician	

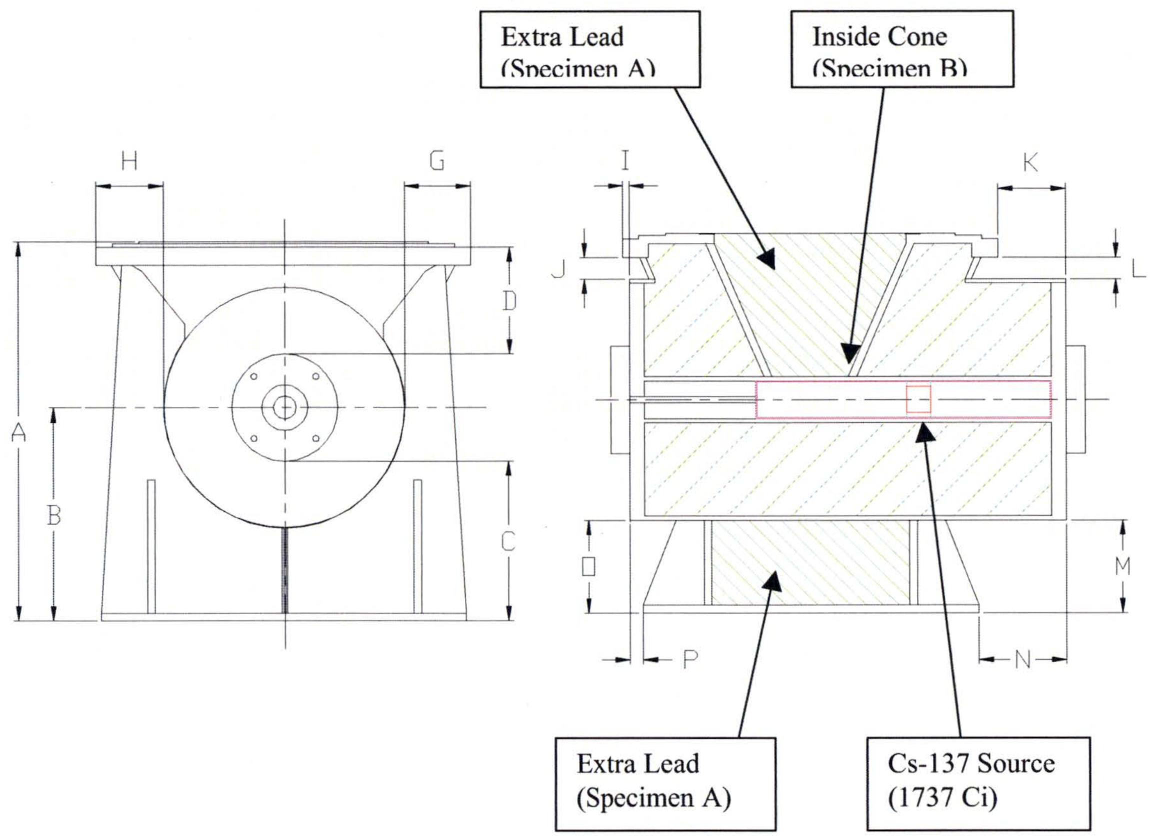


Figure 3, GC-40 Lower Head, Pre-Drop Dimensions

2.5 Dimensional Measurement of C-440 Dummy Source

Report Type	**Date of Test**	
Pre-Drop	August 9, 1999	
Test Name/Description	**Test Number**	**Test Plan**
Dimensional Measurement of C-440 Dummy Source	5.1.5	IN/TP 1493 F430 (2)

Test Details

Dummy source was visually inspected and outside dimensions were recorded.

Results/Observations

Visual inspection: Clean, smooth dent-free surface.

Diameter: 1.568"
Length: 1.696"

Dummy source slides freely into the source cavity inside the source drawer. Internal retaining ring that keeps source in place was installed and provides a slight axial movement of source inside the cavity (approximately 0.020")

Conclusions

The above data are intended for comparison of before and after drop testing. See section 5.3.4.

Personnel	Name	Title	Signature / Date
Test Conducted by:	Jiri Krupka	Package Engineer	
Reviewed by:	Benjamin Prieur	QC Technician	
Approved by:	Dave Whitby	Senior QC Technician	

2.6 Helium Leak Test of C-440 Dummy Source

Report Type	**Date of Test**	
Pre-Drop	August 14, 1999	
Test Name/Description	**Test Number**	**Test Plan**
Helium Leak Test of C-440 Dummy Source	5.1.6	IN/TP 1493 F430 (2)

Test Details

Calibrated helium leak tester: Model: Varian Auto-test 947
Serial number: DJAE 2001

Results/Observations

Helium Leak testing was performed on C440 capsule #1271 prior to drop testing within overpack F-430 /GC-40 prototype.

The capsule was Helium pressurized (bombed) for 2 hours at 300 psi.

Immediately following pressurization, the source capsule was helium leak tested and no leaks were detected to 1 X 10^{-9} Std cc/sec.

Conclusions

Dummy source passed helium leak testing.

Personnel	**Name**	**Title**	**Signature / Date**
Test Conducted by:	John Culbertson	Met. Laboratory	
Reviewed by:	Jiri Krupka	Package Engineer	
Approved by:	John Smith	Quality Assurance	

2.7 Inspection of Source Drawer

Report Type	Date of Test	
Pre-Drop	August 9, 1999	
Test Name/Description	**Test Number**	**Test Plan**
Inspection of Source Drawer	5.1.7	IN/TP 1493 F430 (2)

Test Details
Dummy source was visually inspected and outside dimensions were recorded.

Results/Observations

Visual inspection: Clean, smooth dent-free surface.

Diameter: 2.476"

Length: 28.63"

Source drawer slides freely into the cavity inside the GC-40 lower head. It is held axially with bronze nuts (one on each end). These nuts were finger tight before and after drop testing and provided zero axial clearance for the source drawer.

Conclusions

The above data are intended for comparison of before and after drop testing. See section 5.3.6.

Personnel	Name	Title	Signature / Date
Test Conducted by:	Jiri Krupka	Package Engineer	
Reviewed by:	Benjamin Prieur	QC Technician	
Approved by:	Dave Whitby	Senior QC Technician	

2.8 Radiation Survey

Report Type	Date of Test	
Pre-Drop	August 7, 1999, F-430/GC-40 Specimen A August 9, 1999, F-430/GC-40 Specimen B	
Test Name/Description	**Test Number**	**Test Plan**
Radiation Survey	5.1.8	IN/TP 1493 F430 (2)

Description

This report details the radiation survey results of the F-430 overpack prototype as outlined in the F-430 Test Plan IN/TP 1493 F430 (2).

Procedure

The GC-40 lower head specimen A (with lead dummy weights) and B (without lead dummy weights), were loaded with a C-440 source by Source Production in Cell 06. The activity measurement results of the source are as follows:

Source Type	Serial Number	Activity Content	Date of Measure	Radionuclide
C-440	A1065	1737 Ci	1998 April 21	Cs-137

Activity at the time of the survey was 1687 Ci

The loaded head was than located in an area of low radiation background levels (< 0.02 mR/h). The GC-40 head was then surveyed as per procedure CO-QC/TP-0001 (2), which meets or exceeds the technical requirements of the QC survey in procedure IN/IM 0309 GC40. The readings taken at the one meter distance from the container surface were taken using the ion chamber instrument only, so as to simulate actual shipping conditions.

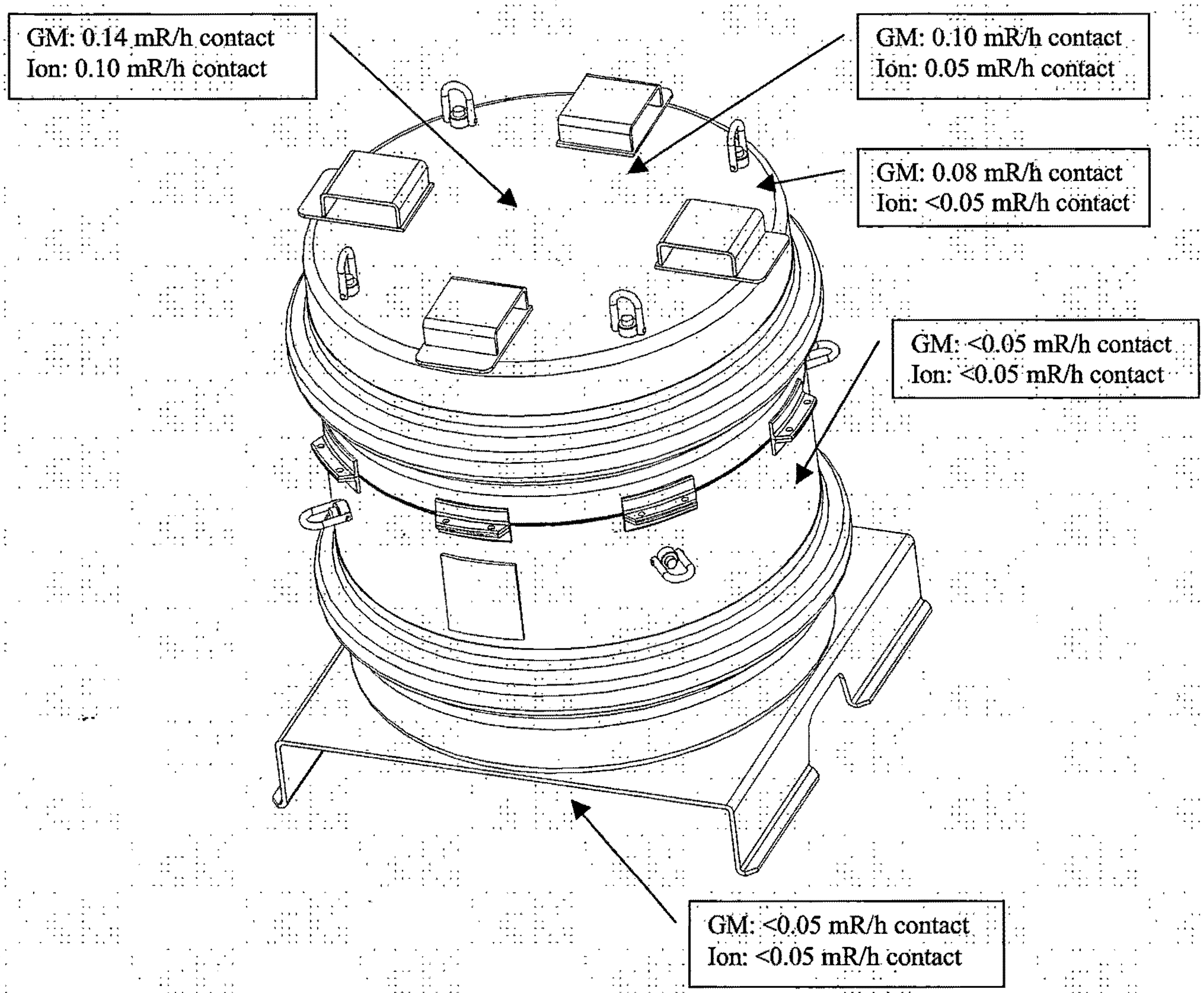
The instrumentation used for the survey is as follows:

Make	Model	Serial No.	Calibration Date	Probe Type
Victoreen	471	1432	1999 July 23	Ion Chamber
Berthold	Rato/F	2000	1999 August 07	Geiger Mueller

The head was then loaded into the F-430 overpack prototype and prepared as if for shipment. The F-430 was then surveyed as per CO-QC/IT-0001 (2). The highest readings attained for each area was recorded and detailed on the following figures. Figure 4, GC-40 (Specimen A) Inside F-430 Overpack, Pre-Drop Survey Figure 5, GC-40 (Specimen B) Inside F-430 Overpack, Pre-Drop SurveyFigure 6, GC-40 (Specimen A), Pre-Drop Survey, and Figure 7, GC-40 (Specimen B), Pre-Drop Survey.

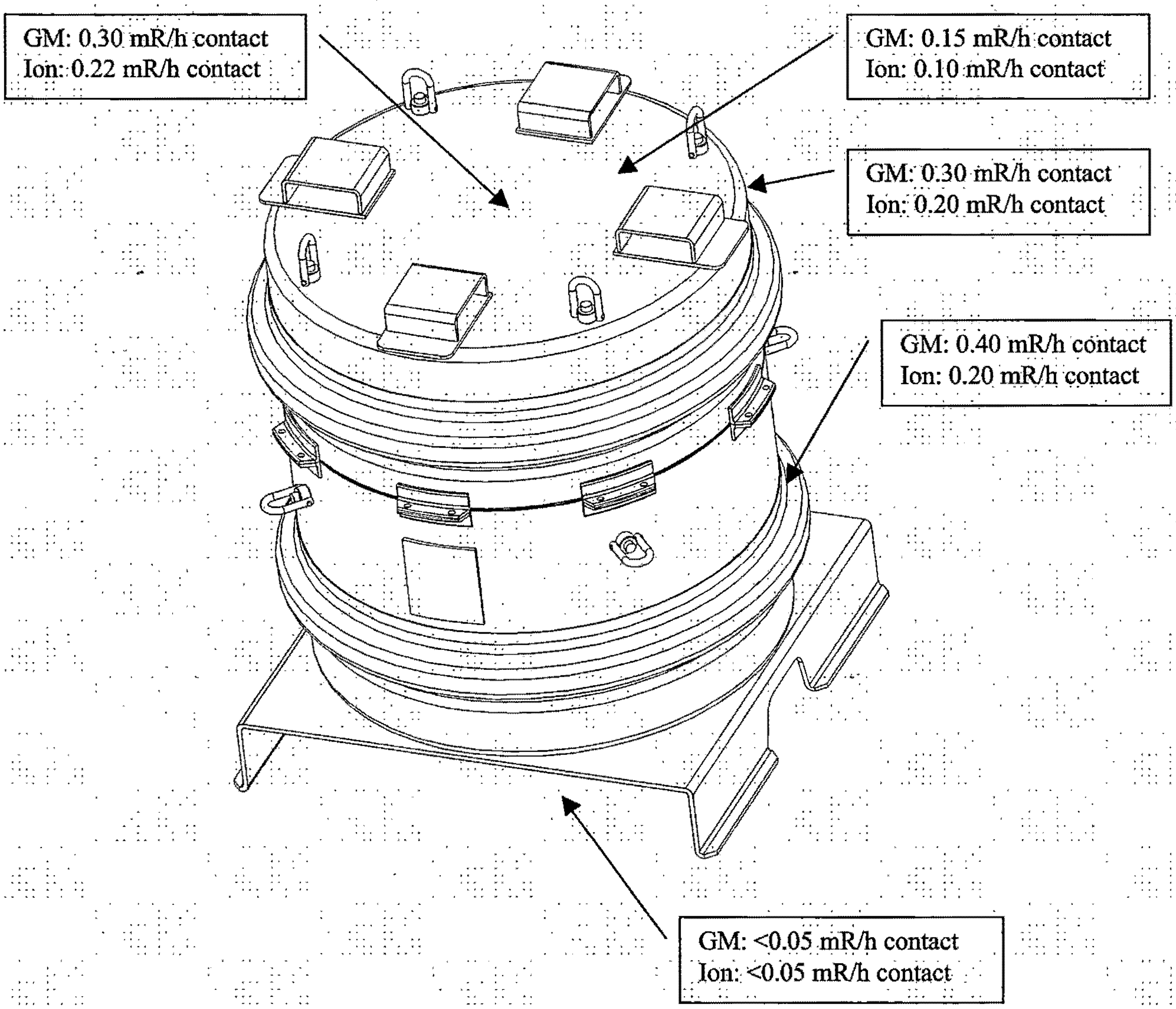
Comments

The radiation fields around the GC-40 and F-430 were typically low other than a few localized areas, most readings were barely detectable above the background levels.



Note: All TI measurements at 1 meter distance from the container surface were ≤ 0.05 mR/h.

Figure 4, GC-40 (Specimen A) Inside F-430 Overpack, Pre-Drop Survey



Note: All Ti measurements at 1 meter distance from the container surface were ≤ 0.20 mR/h.

Figure 5, GC-40 (Specimen B) Inside F-430 Overpack, Pre-Drop Survey

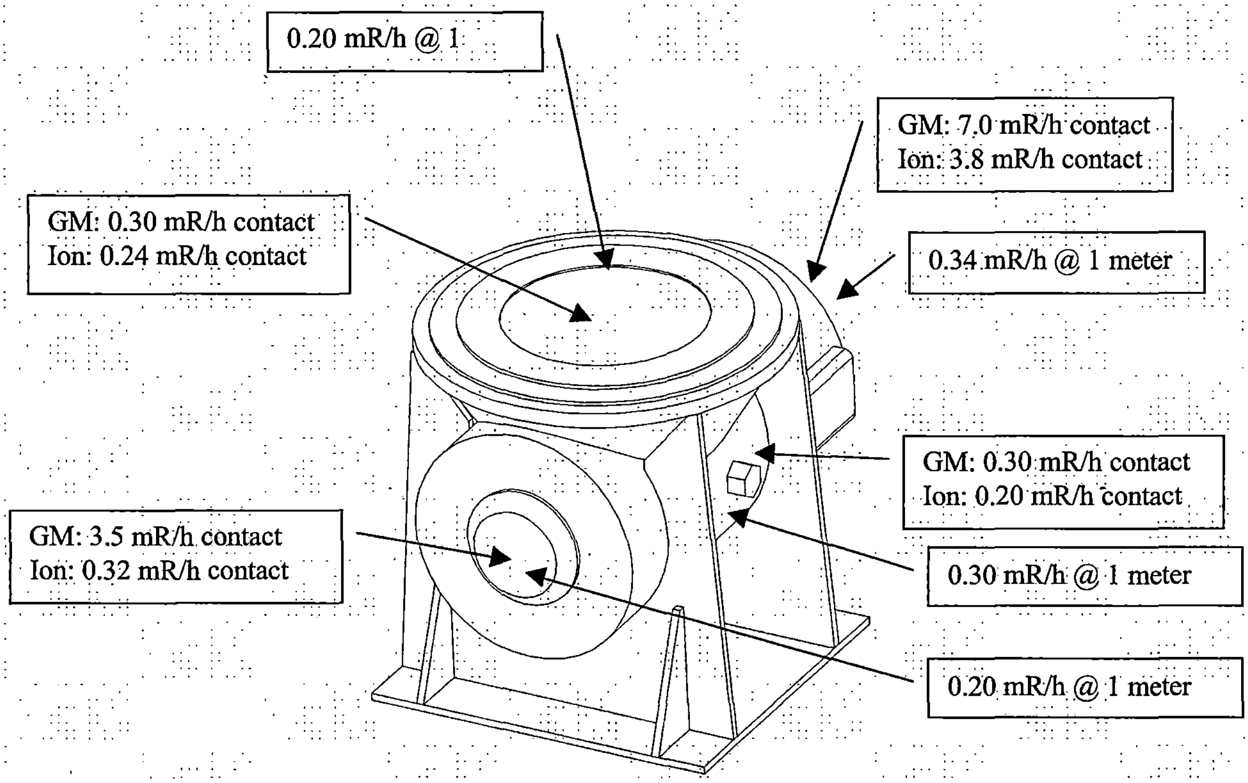


Figure 6, GC-40 (Specimen A), Pre-Drop Survey

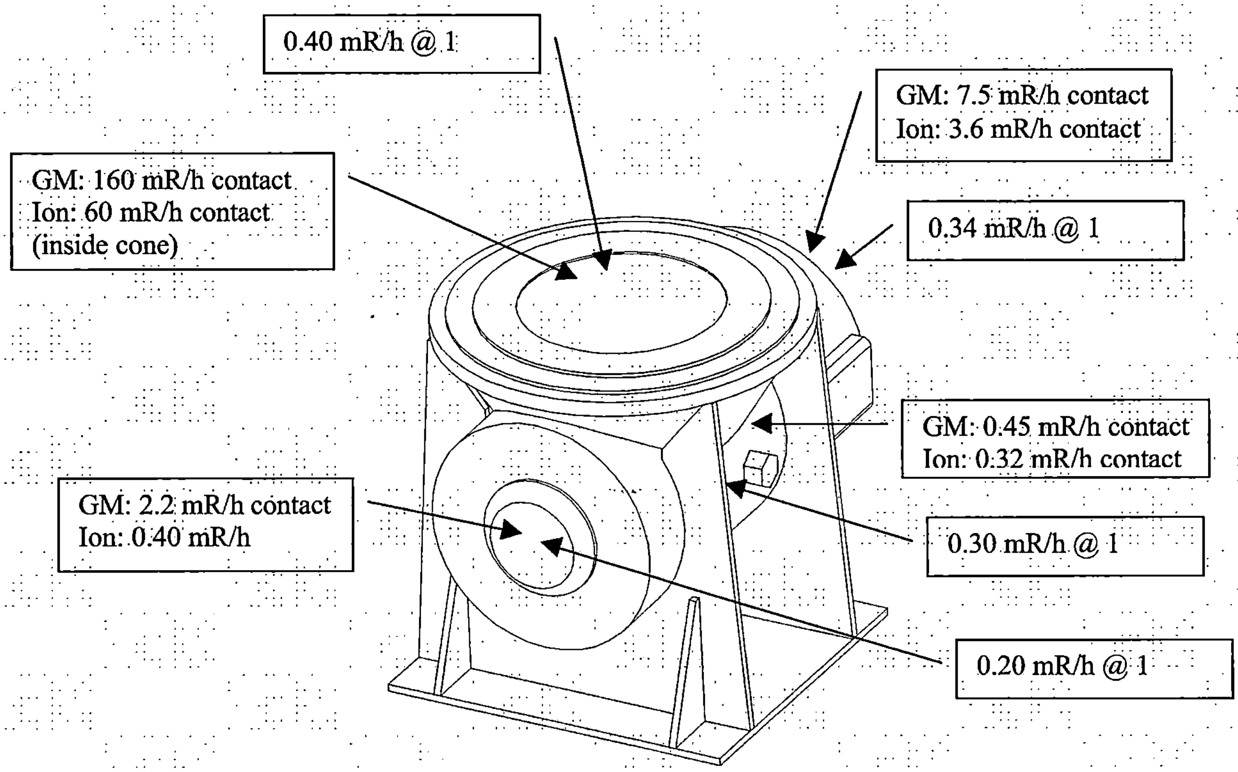


Figure 7, GC-40 (Specimen B), Pre-Drop Survey

Personnel	Name	Title	Signature / Date
Test Conducted by:	Dave Whitby	Industrial Quality Control	
Reviewed by:	Jiri Krupka	Package Engineer	
Approved by:	John Smith	Quality Assurance	

2.9 Steady State Thermal Test

Report Type	**Date of Test**	
Pre-Drop	July 26 – August 8, 1999	
Test Name/Description	**Test Number**	**Test Plan**
Steady State Thermal Test	5.1.9	IN/TP 1493 F430 (2)

EQUIPMENT:
HP Computer, MDS Nordion Inventory No. C2007
HP Monitor, MDS Nordion Inventory No. M1150
FLUKE Hydra Logger Software, Version 3.0
FLUKE Hydra Data Acquisition Unit, Model 2620, SN 5577551, Calibrated Aug. 27, 99 – See attached NDR form
Terminal Box with 20 T-type thermocouples (0.035" diameter, 20 ft long)

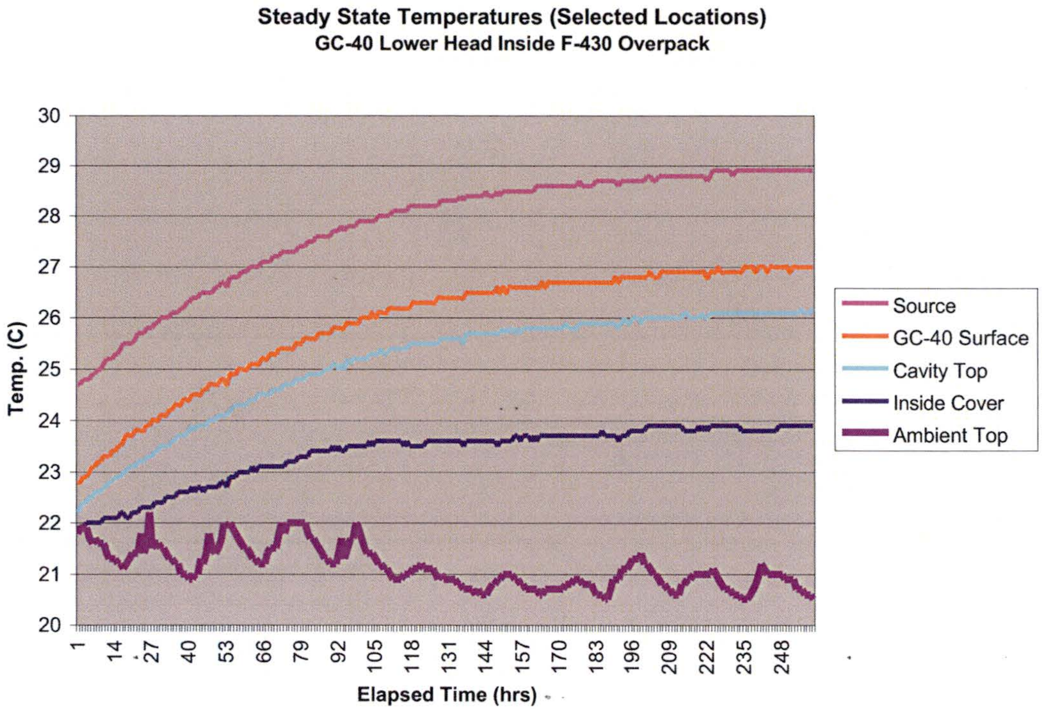
THERMOCOUPLE INSTALLATION:
Twenty thermocouples were installed at locations shown in Figure 9, and held in position with a duct tape.
A hole was drilled (0.50" diameter) through the main cover and inner cover to reach points inside the container. The hole was then sealed with a duct tape.
To measure source temperature, the source drawer had a groove machined to accommodate leads for two thermocouples (#0 and 5). A small hole was then drilled towards the center of the drawer where the tips of the two thermocouples were embedded. No glue was used since the groove and the hole provided a snug fit for the thermocouple leads.

SOURCE LOADING AND PACKAGE ASSEMBLY:
The non-drop test specimen of GC-40 lower head (SN 004-1) was loaded with C-440 live source (SN A1065, heat generated by this source was approx. 15W corresponding to 1737 Ci).
Source drawer was equipped with two thermocouples to measure source temperature.
After source was loaded in the GC-40 unit, it was instrumented with additional thermocouples, inserted in the F-430 transport cavity with the stainless steel fixing brace in place. Both covers were closed and balance of thermocouples was installed on the outside of the container.
Closure bolts were tightened but torque was not measured. Gaskets on inner and main covers were in place.

MEASUREMENTS:
Temperatures were scanned and recorded every hour until steady state conditions were reached.
Test set up was indoors in the Cobalt area of MDS Nordion, March Road, Kanata.

Results/Observations

Steady state conditions were reached in about 11 days with ambient temperatures between 21 and 22°C. Maximum temperature was the source temperature, which rose from 24.7 to 28.9°C.
See Figure 8 for detailed temperature histories.
Accuracy of results is within +/- 0.7°C as the FLUKE Data Acquisition Unit was found 0.2°C out of tolerance range (+/- 0.5°C)



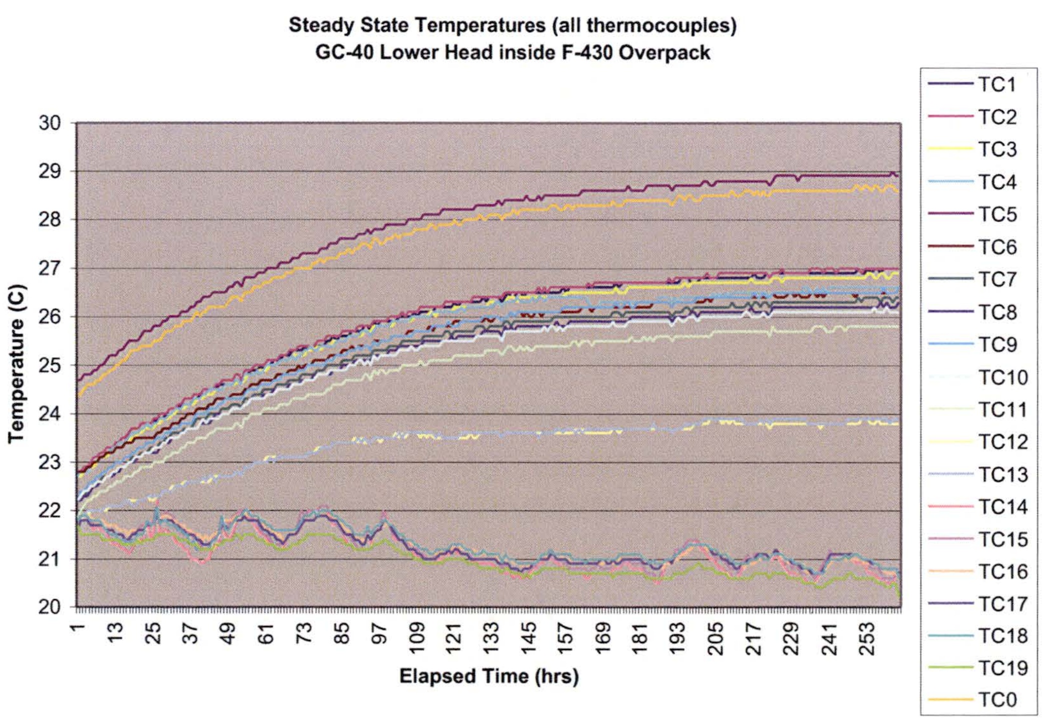


Figure 8, Steady State Temperatures, F-430/GC-40

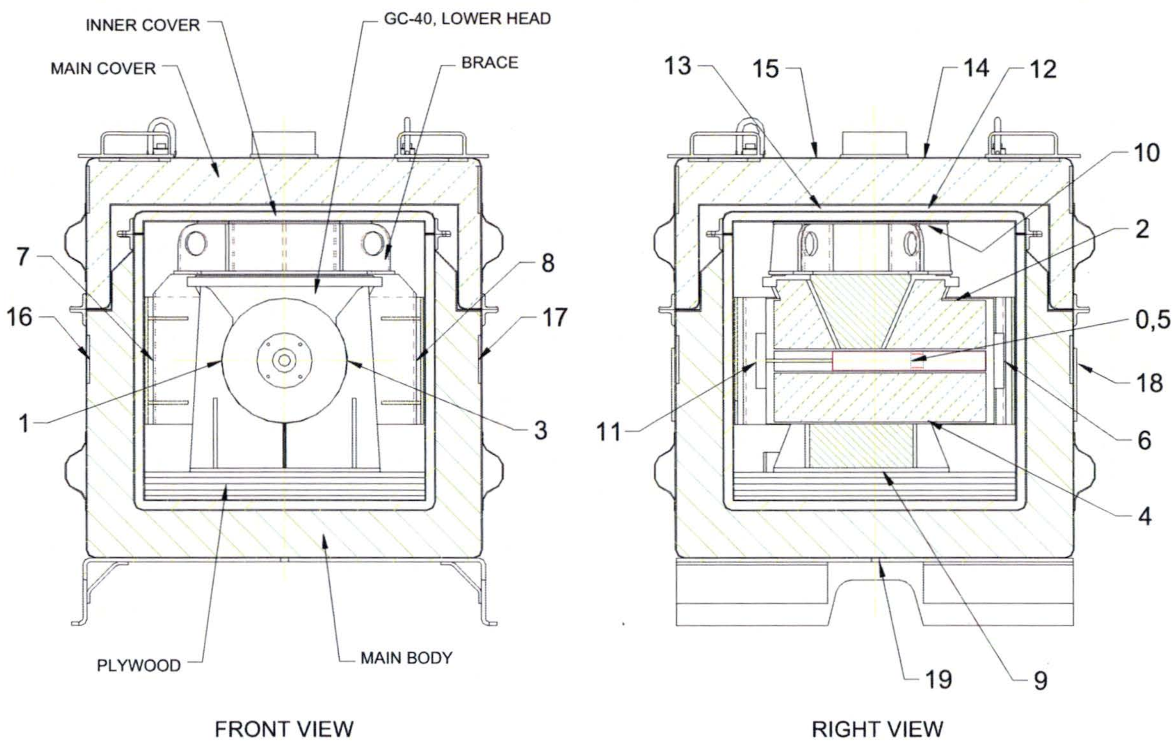


Figure 9, Thermocouple Locations

Conclusions
Temperature rise was relatively small due to small heat generated by the source.

Personnel	Name	Title	Signature / Date
Test Conducted by:	Jiri Krupka	Package Engineer	
Reviewed by:	Dave Whitby	Industrial Quality Control	
Approved by:	John Smith	Quality Assurance	

2.12 Penetration Test

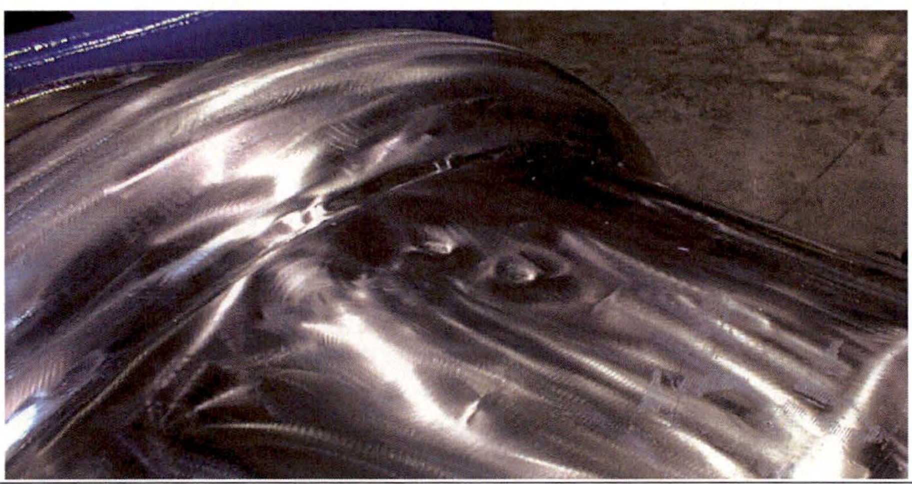
Report Type	**Date of Test**	
Pre-Drop	September 9, 1999	
Test Name/Description	**Test Number**	**Test Plan**
Penetration Test	5.1.10	IN/TP 1493 F430 (2)

Test Details

A 6 kg steel bar, 3.2 cm in diameter, 96 cm long with a spherical end was dropped from a height of 1.7m onto the surface of the container, so as to penetrate inside and damage the radioactive source.
One flat and one curved surfaces were selected in such locations, where the support was the weakest, and the distance to the source was closest.

Results/Observations

None of the 1.7m drops penetrated the surface of the container (stainless steel sheet 0.105" thick).
The largest dent depth was approximately 3mm (1/8") deep. Refer to the attached figure.



Conclusions

The container passed the penetration test as per IAEA regulations for transport packages (Type A).

Personnel	**Name**	**Title**	**Signature / Date**
Test Conducted by:	Jiri Krupka	Package Engineer	
Reviewed by:	Benjamin Prieur	QC Technician	
Approved by:	Dave Whitby	Senior QC Technician	

2.11 Modifications to GC-40 Lower Head

To demonstrate good crush properties and strength of the F-430 container, additional weight was attached to the GC-40 drop test specimen A (Figure 10). This extra weight was in form of lead poured in cavities of the body of the GC-40 unit. The total added weight was 1100 lb, which was calculated by weighing both GC-40 specimens A and B (SN 004-1).

A groove (0.230" wide, 0.150" deep) was made on the surface of the source drawer to accommodate thermocouple leads to measure source temperature during steady state.

Small tapped holes were made on the front and back faces of the GC-40 drop test unit (specimen A) for attachment of accelerometers. Refer to AECL Drop Test Report, Appendix 1.

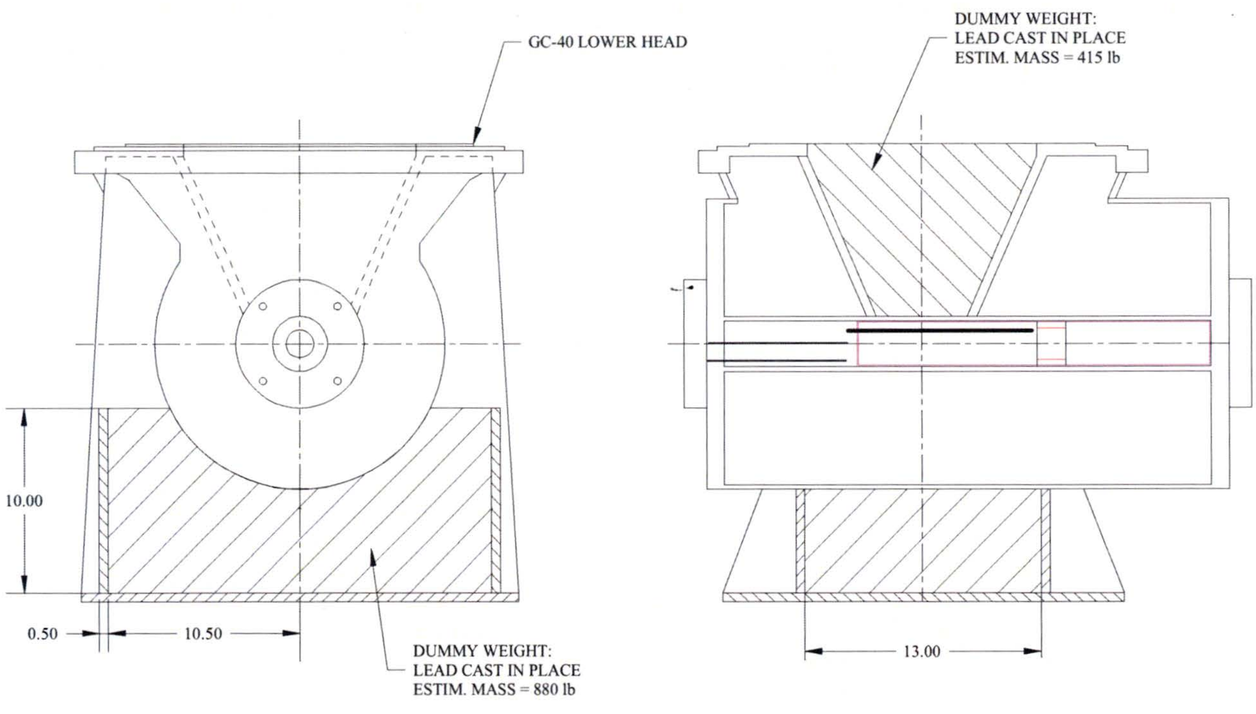


Figure 10, Dummy Weights On GC-40

2.12 Modifications to F-430 prototype

The F-430 container was built as a full-scale prototype. The only modifications made were holes for thermocouple and accelerometer wiring. These holes (1/2" diameter) had no effect on the container's performance during regulatory testing.

3. DROP TESTS

The drop tests were performed at Chalk River site on October 13 and 14, 1999. Full details of the tests are included in Appendix 1, AECL Test Report, F-430 Testing.

All closure bolts and nuts were numbered to keep track of their location (Figure 1). Exterior (main cover) bolts are numbered 1 to 16, interior cover bolts are numbered 17 to 36 (clockwise when viewed from the top, starting from the front of GC-40 irradiator).
The order of drop tests deviated from the test plan in order to best demonstrate container's performance:

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)

All bolts were tightened to an 80 ft-lb torque prior to drop testing.
After test #1, the container was opened and the contents were visually inspected. GC-40 unit with its brace dropped down by about ½" (Figure 11). No damage to the GC-40 was observed. The container skid bent as shown in Figure 12
For the remaining eight drop tests bolts #7 and #23 were removed to prove redundancy in number of closure bolts. All bolts were again tightened to a 80 ft-lb torque prior to drop test #2, but were not re-torqued after. Tightening of bolts was checked by hand only ("finger tight" check).

For more damage assessment see section 4, Post Drop Tests.

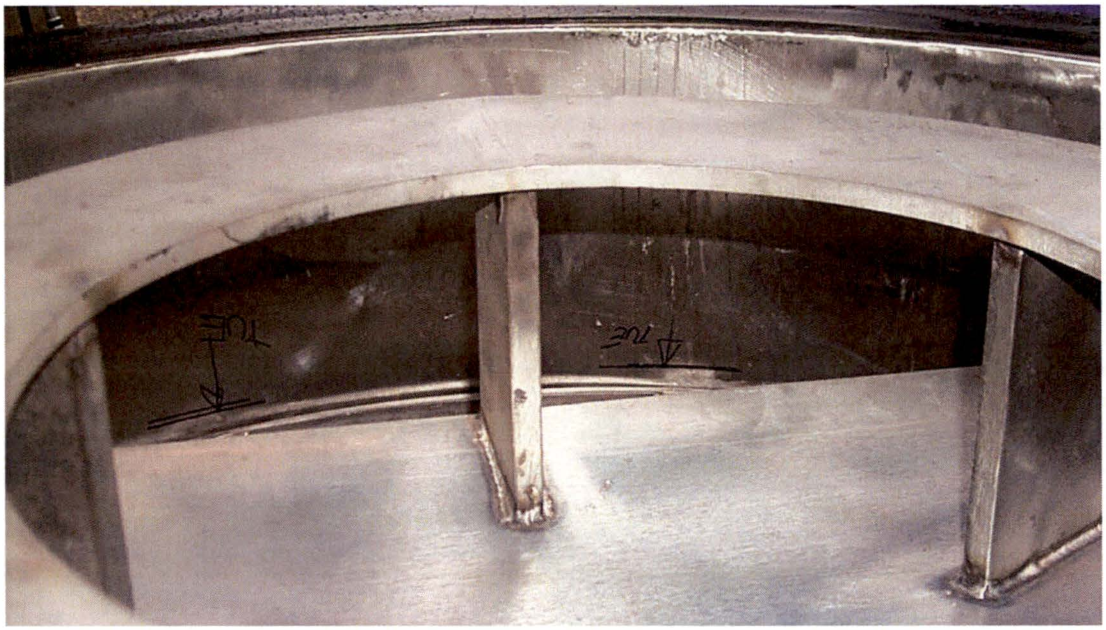


Figure 11, Brace position after drop test #1 ***(original position marked with black line)***

Full picture history of all drop test is available on a CD-ROM, or black and white prints (8" x 10"). There are 84 pictures numbered (by AECL) 9910-23698-1 through 9910-23698-84. Fast speed video during impact was also made for all drop tests (available in VHS format, MPEG digital format, and 16 mm film).

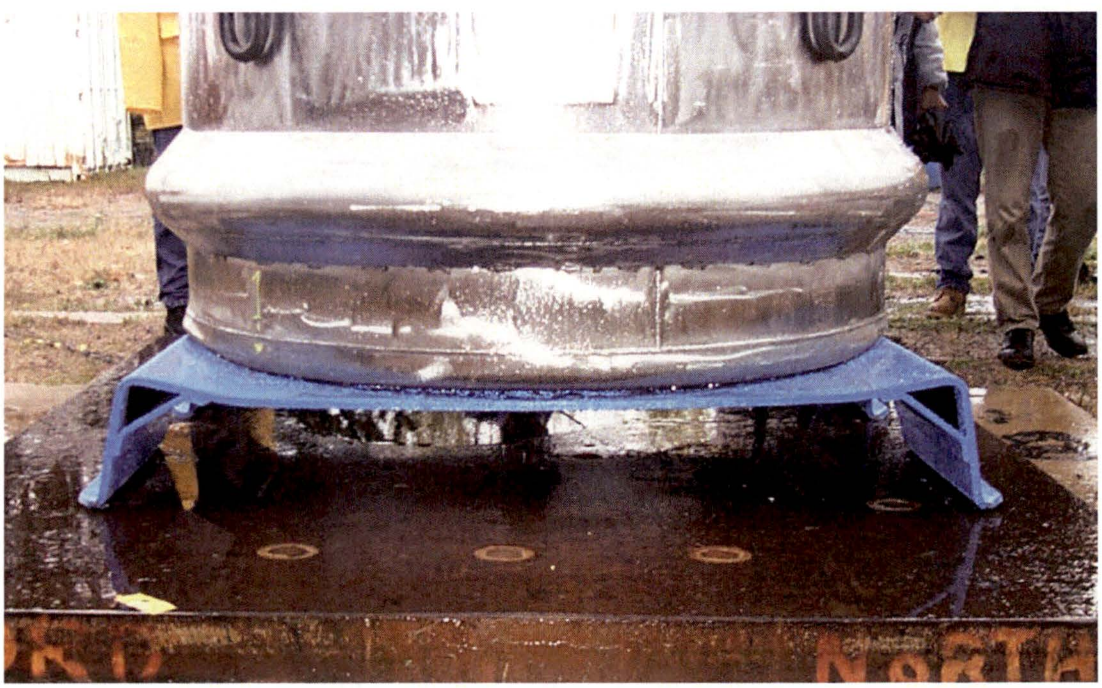


Figure 12, Damage after 1.2m normal drop.

4. POST-DROP TESTS

4.1 Damage Assessment of F-430

Report Type	Date of Test	
Post-Drop	October 22, 1999	
Test Name/Description	**Test Number**	**Test Plan**
Damage Assessment of F-430	5.3.2	IN/TP 1493 F430 (2)

Test Details

Upon receiving of the container from the drop test facilities in Chalk River (October 19, 1999), the container was brought to Nordion's Cobalt area for inspection.

Results/Observations

The Skid:
Bent during drop tests #1 and 3. It came apart from the container body during drop test #7 when the ½" bolts sheared off.

The Main Body:
Bottom edges were deformed by the skid during drop test #1 (Figure 12) and still a little more following drop test #3 under the weight of the skid and the flapping motion of the skid's feet during impact (Figure 13).
Bumper was flattened during test #7 (Figure 13), some bumper weld cracks were observed after this test (Figure 15). Outside skin was pierced during tests #6 (Figure 16) and #8 (Figure 14)
One flange segment was bent during test #9 and one segment during test #7 (Figure 13).
Internal damage was mostly in the area of the outer crush foam. Transport cavity was not pierced and no weld cracks were observed.

Inner Cover:
Inner cover with all seven bolts remained in place. The cover caved out during drop tests #3, 4, and 5, as internal brace pushed against it.

Main Cover:
After all nine drop tests the main cover stayed in place with six out of 15 bolts remaining (Figure 16). Five bolts were lost during drop test #4, and four during test #7.
Top edge was crushed in tests #2 and 4 (Figure 13). Lifting pockets were deformed during test #3 (Figure 15). One flange segment was bent during test #9, but no bolt was lost (Figure 13).

Inner Brace:
The top spacing piece (Figure 18) came apart from the band and ribs that surrounded the GC-40 unit. Impact was absorbed in the fins (six upright plates) of the top spacing piece. The band and ribs remained in place fixing the GC-40 unit in the center of the transport cavity.

Conclusions

All components performed as expected and protected the contents against impact. See section 5 for detailed discussion.

Personnel	Name	Title	Signature / Date
Test Conducted by:	Jiri Krupka	Package Engineer	
Reviewed by:	Benjamin Prieur	QC Technician	
Approved by:	Dave Whitby	Senior QC Technician	

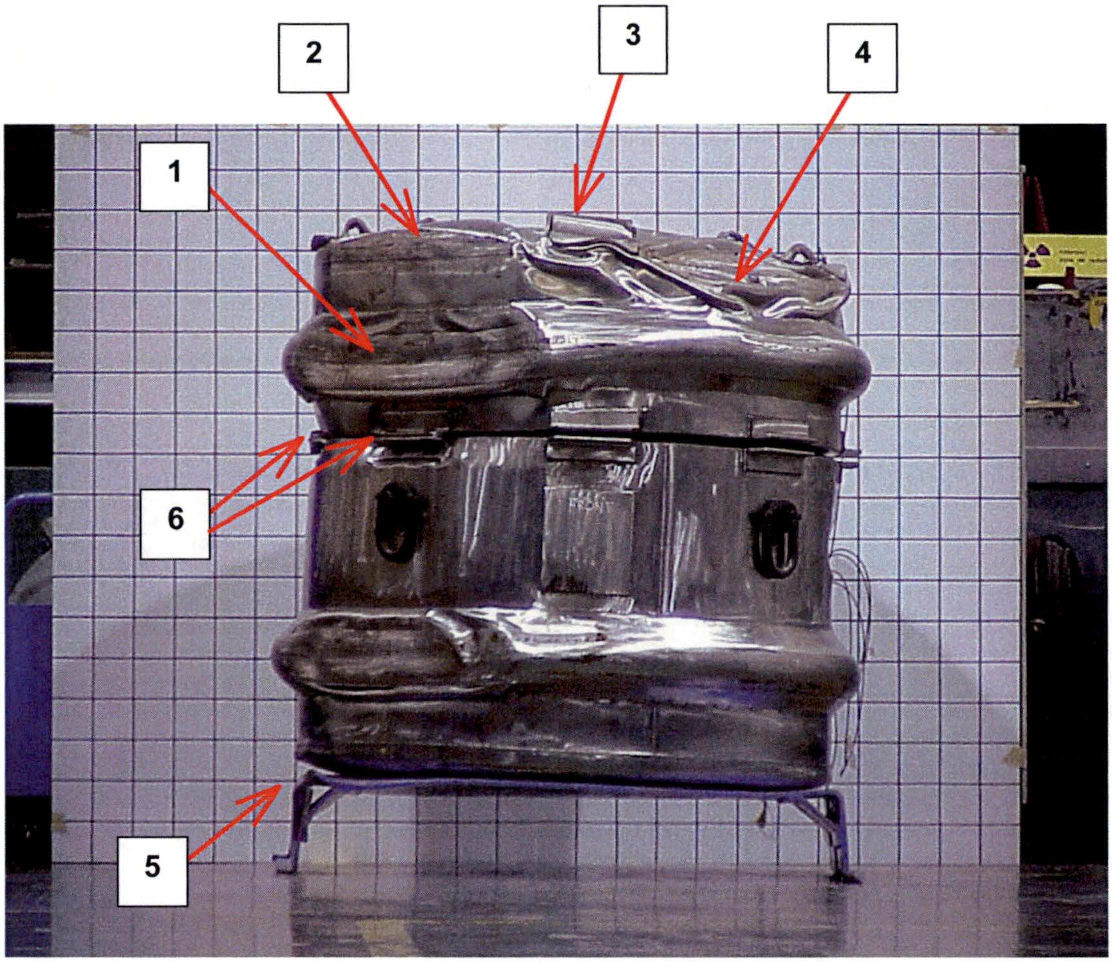


Figure 13, F-430 Post-Drop, Front View

(4" squares in background)

1. Damage after 9m side drop test #9 (tie down rings were removed prior to drop test)
2. Damage after 1.2m top edge drop
3. Damage after 9m upside down drop
4. Damage after 9m top edge drop
5. Bottom edges deformed by the skid after drop tests #1 and #3.
6. Flanges bent after tests #7 and 9.

Overpack is put on the skid without attachment (all eight ½" bolts were sheared in drop test #7. After drop testing the main cover was left with six closure bolts still in place.

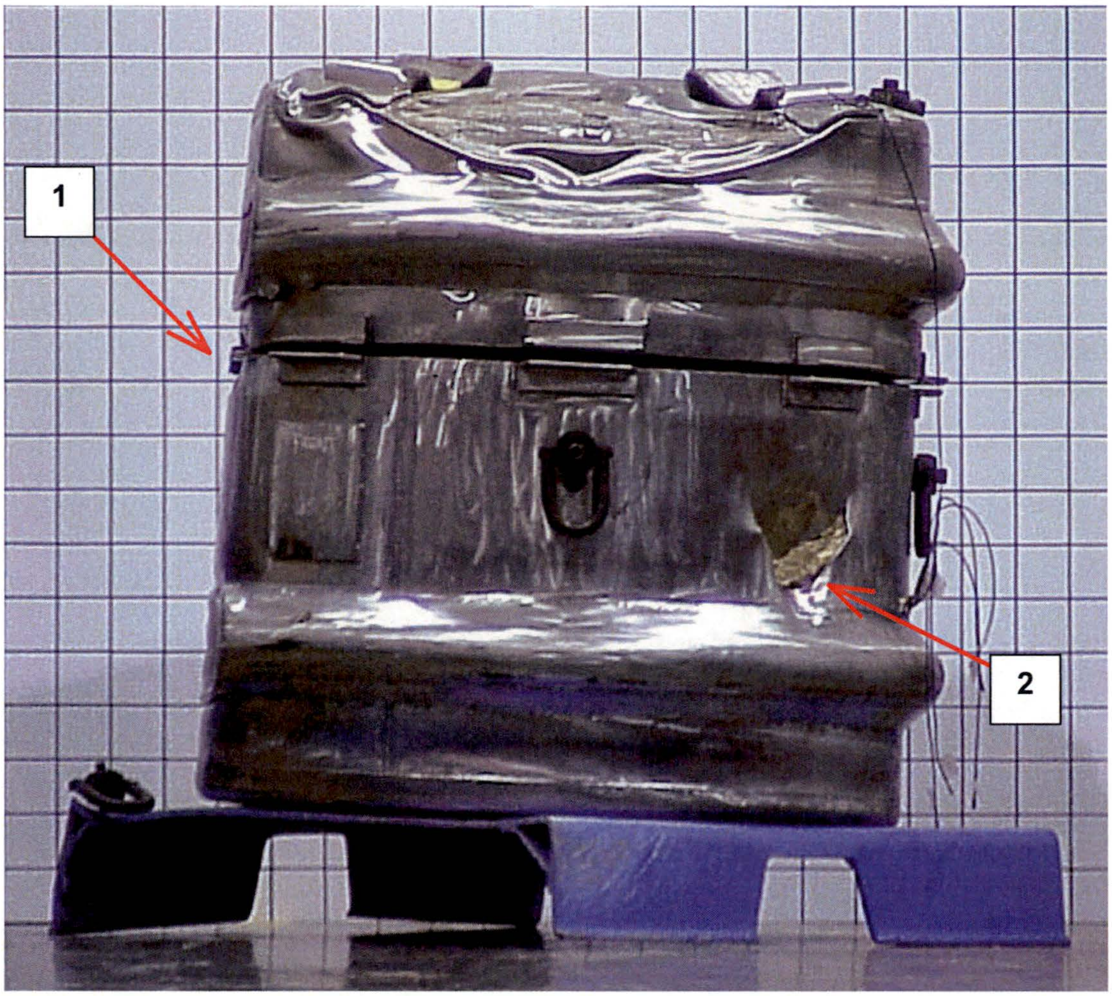


Figure 14, F-430 Post-Drop, Front-Right View
(4" squares in background)

1. Damage after 9m side drop.
2. Pierced skin after 1m oblique pin drop.

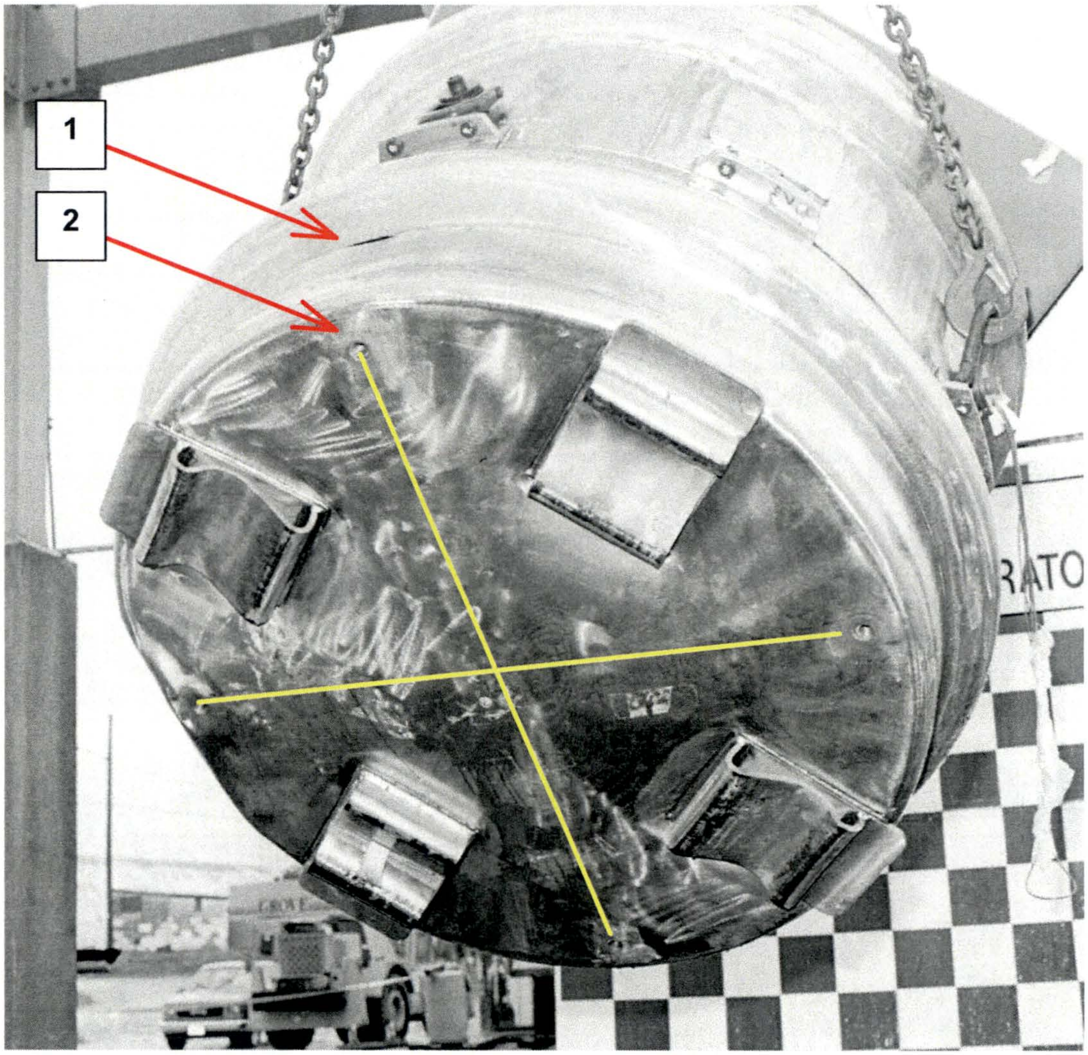


Figure 15, After 9m Inverted Drop Test (#3)

1. Bumper weld cracks occurred in the area of internal lifting brace (yellow lines) likely due to different structural stiffness. Weld cracks were observed in four locations 90° apart.
2. Prior to drop test # 3 hoist rings were removed from the top surface of the overpack for safety reasons.

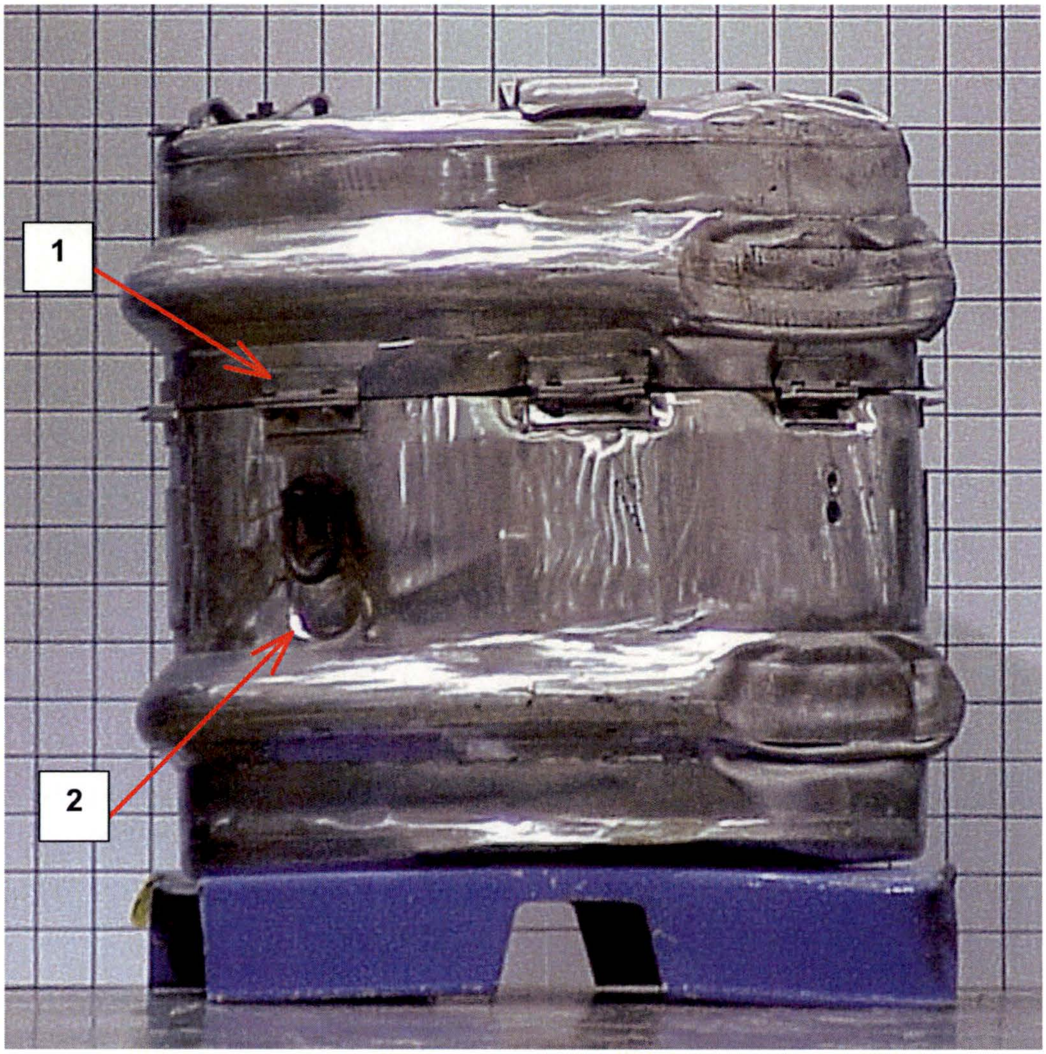


Figure 16, F-430 Post Drop, Left View

(4" squares in background)

1. Six remaining bolts that hold main cover in place.
2. Piercing of outer skin after 1m side pin drop (test #6).

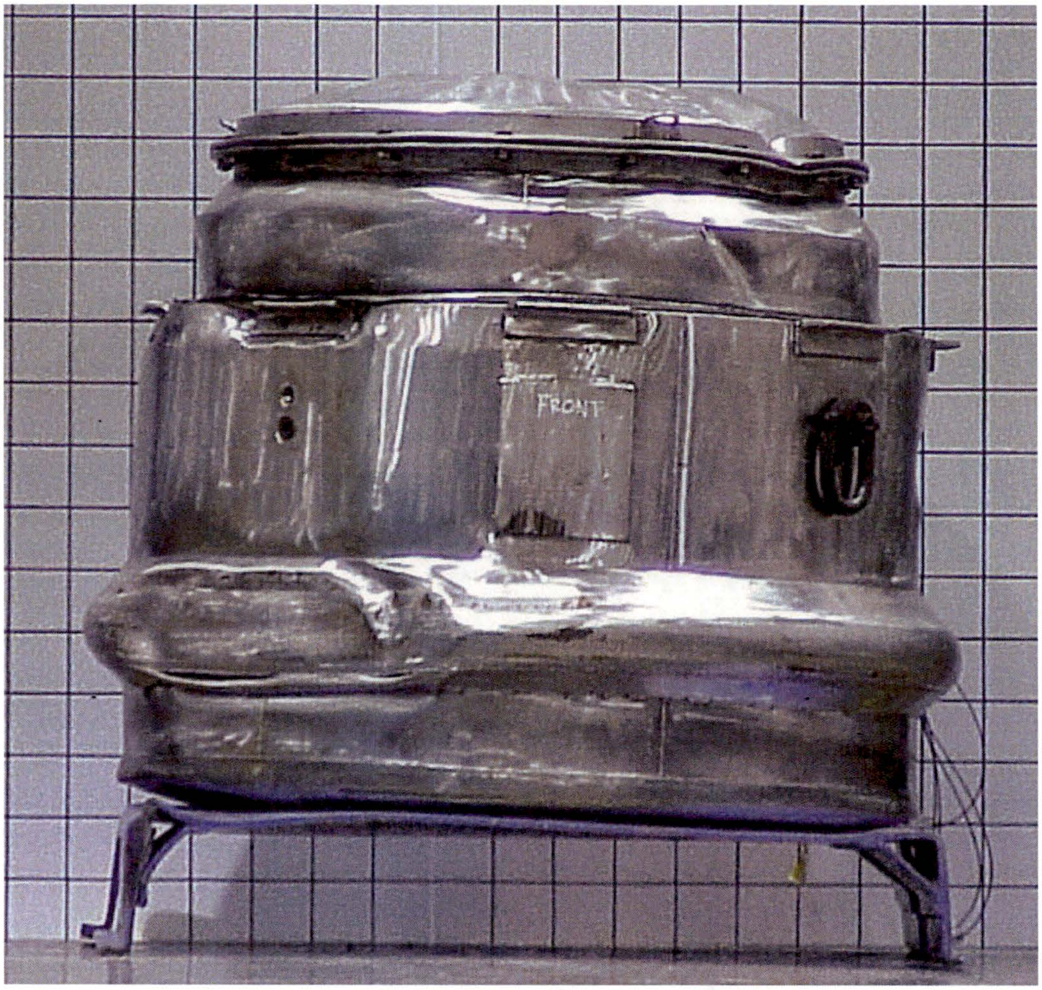


Figure 17, Front View without Main Cover

(4" squares in background)

Note: All seven bolts holding the inner cover remained in place after 9 drop tests. Internal cover deformed after inverted drop test when contents pushed on it.

Figure 18, Top Part of Inner Brace

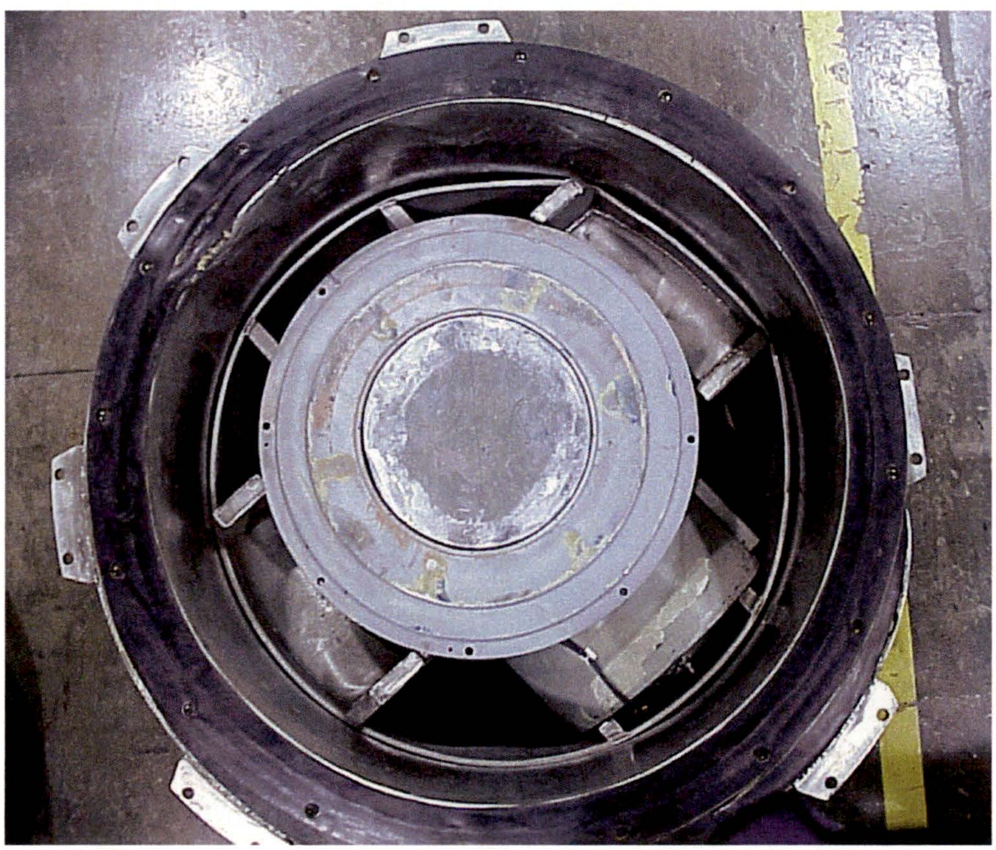


Figure 19, Lower Part of Inner Brace with GC40 Inside F-430

Figure 20, Detail of Skin Damage after Oblique Pin Drop

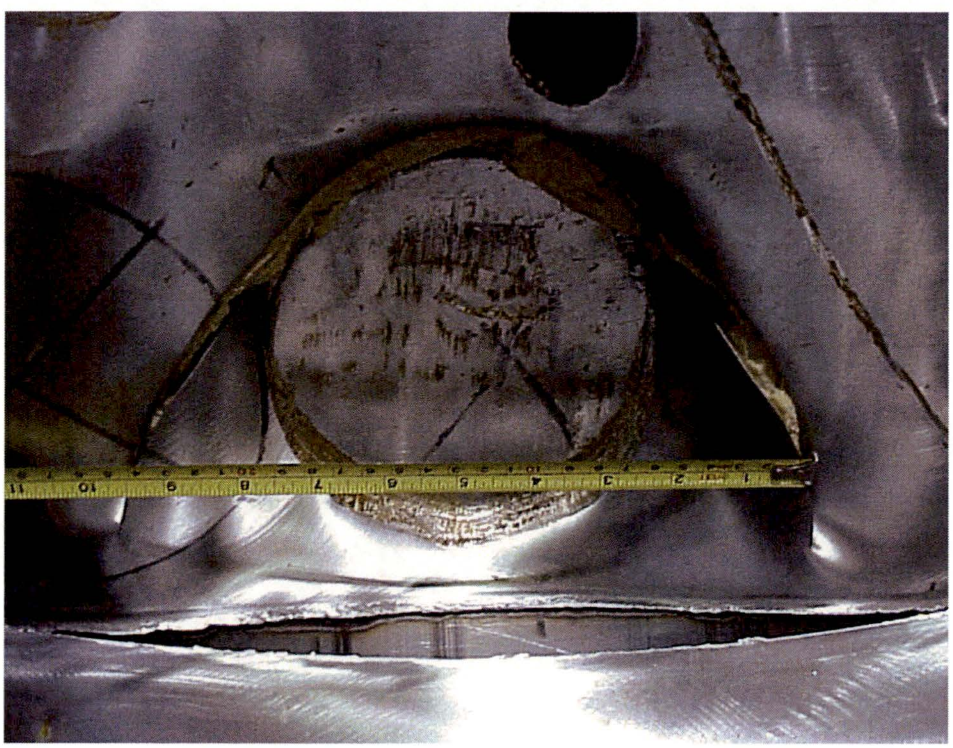


Figure 21, Detail of Skin Damage after Side Pin Drop

4.2 Damage Assessment of GC-40

Report Type	Date of Test	
Post-Drop	October 22, 1999	
Test Name/Description	**Test Number**	**Test Plan**
Damage Assessment of GC-40 Test Specimen	5.3.3	IN/TP 1493 F430 (2)

Test Details

The GC-40 pertinent dimensions were recorded. Refer to Figure 3
The following dimensions were chosen as reference for before and after drop comparison. The nominal values are omitted as the measured values are relevant to the evaluation of the performance of the GC-40.

Results/Observations

Dimension	Nominal Value [in]	Measured Value [in]	Comments
A		24.81	
B		13.81	
C		10.50	
D		6.88	
G		4.31	
H		4.31	
I		0.63	
J		1.44	
K		4.59	
L		1.38	
M		5.59	
N		5.90	
O		5.56	
P		0.78	

The only visible damage that the GC-40 suffered (with additional weight of 1100 lb) were local dents around the circumference of the cone flange (Figure 22 and Figure 23) caused during 9m inverted drops by the top ribs on the internal fixing brace (Figure 18). Source caps closure bolts remained in place (finger tight) keeping source securely in its stored position.
All components were freely disassembled and dummy C-440 source removed without any visible damage to either the source or the source drawer (Figure 24).

Conclusions

The GC-40 irradiator (lower head) with extra 1100 lb of weight survived three 30-ft, two 4-ft, and four pin drop (3-ft) tests without damage to the shielding or containment (see section 5.3.5)

Personnel	Name	Title	Signature / Date
Test Conducted by:	Jiri Krupka	Package Engineer	
Reviewed by:	Benjamin Prieur	QC Technician	
Approved by:	Dave Whitby	Senior QC Technician	

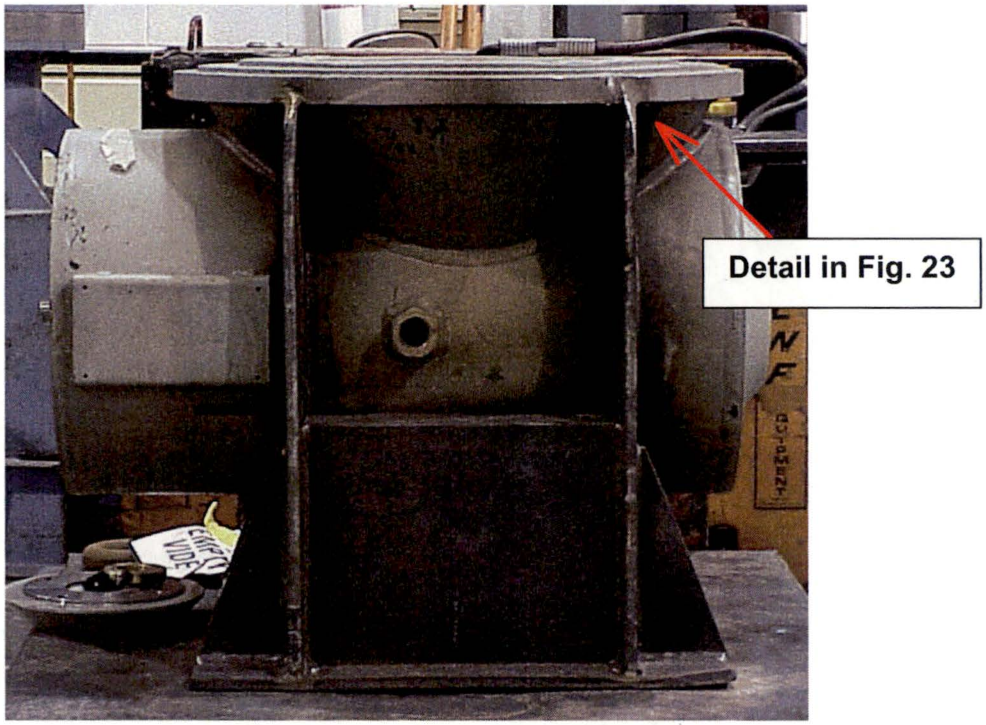


Figure 22, GC40 After Drop Testing (Left Side)

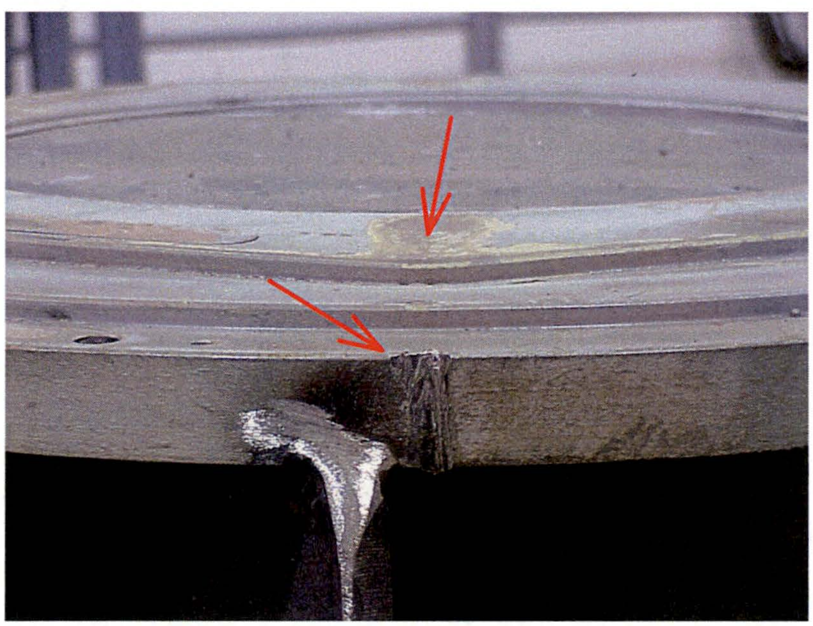


Figure 23, Detail of GC40 Flange

Arrows point to dents caused by impact against internal fixing brace.

[redacted]

Figure 24, GC40 Back View (Drawer with Dummy Source)

After drop testing source drawer and dummy source, undamaged, slide freely out of the GC40

4.3 Dimensional Measurement of C-440 Dummy Source

Report Type	Date of Test	
Post-Drop	October 22, 1999	
Test Name/Description	**Test Number**	**Test Plan**
Dimensional Measurement of C-440 Dummy Source	5.3.4	IN/TP 1493 F430 (2)
Test Details Dummy source was visually inspected and outside dimensions were recorded.		
Results/Observations		
Visual inspection: Clean, smooth dent-free surface. Diameter: 1.568" Length: 1.696" Dummy source slides freely into the source cavity inside the source drawer. Internal retaining ring that keeps source in place was installed and provides a slight axial movement of source inside the cavity (approximately 0.020")		
Conclusions		
No damage to the dummy source was detected.		

Personnel	Name	Title	Signature / Date
Test Conducted by:	Jiri Krupka	Package Engineer	
Reviewed by:	Benjamin Prieur	QC Technician	
Approved by:	Dave Whitby	Senior QC Technician	

4.4 Helium Leak Test of C-440 Dummy Source

Report Type	**Date of Test**	
Post-Drop	December 16, 1999	
Test Name/Description	**Test Number**	**Test Plan**
Helium Leak Test of C-440 Dummy Source	5.3.5	IN/TP 1493 F430 (2)

Test Details

Calibrated helium leak tester: Model: Varian Auto-test 947
Serial number: DJAE 2001

Results/Observations

Helium Leak testing was performed on C440 capsule # 1271 after drop testing within overpack F-430 / GC-40 prototype.

The capsule was Helium pressurized (bombed) for 2 hours at 300 psi.

Immediately following pressurization, the source capsule was helium leak tested and no leaks were detected to 1 X 10^{-9} Std cc/sec.

Conclusions

Dummy source passed helium leak testing after a series of 9 drop tests inside F-430/GC-40 transport container.

Personnel	**Name**	**Title**	**Signature / Date**
Test Conducted by:	John Culbertson	Met. Laboratory	
Reviewed by:	Jiri Krupka	Package Engineer	
Approved by:	John Smith	Quality Assurance	

4.5 Inspection of Source Drawer

Report Type	Date of Test	
Post-Drop	October 22, 1999	
Test Name/Description	**Test Number**	**Test Plan**
Inspection of Source Drawer	5.3.6	IN/TP 1493 F430 (2)

Test Details

Dummy source was visually inspected and outside dimensions were recorded.

Results/Observations

Visual inspection: Clean, smooth dent-free surface.

Diameter: 2.476"

Length: 28.63"

Source drawer slides freely into the cavity inside the GC-40 lower head. It is held axially with bronze nuts (one on each end). These nuts were finger tight before and after drop testing and provided zero axial clearance.

Conclusions

No damage to the dummy source was detected.

Personnel	Name	Title	Signature / Date
Test Conducted by:	Jiri Krupka	Package Engineer	
Reviewed by:	Benjamin Prieur	QC Technician	
Approved by:	Dave Whitby	Senior QC Technician	

4.6 Radiation Survey

Report Type	**Date of Test**	
Post-Drop	January 9, 2000	
Test Name/Description	**Test Number**	**Test Plan**
Radiation Survey	5.3.7	IN/TP 1493 F430 (2)

Description

This report details the radiation survey results of the F-430 overpack prototype as outlined in the F-430 Test Plan IN/TP 1493 F430 (1) after the package was drop tested at the Chalk River Nuclear Laboratory Facility.

Procedure

The drop tested GC-40, Specimen A (with lead dummy weights), and GC-40, Specimen B (without lead dummy weights) were loaded with the same C-440 source that was used in the pre-drop configuration. Source Production loaded the head in Cell 06, just as was done before the drop test. The activity measurement results of the source are as follows:

Source Type	Serial Number	Activity Content	Date of Measure	Radionuclide
C-440	A1065	1737 Ci	1998 April 21	Cs-137

Activity at the time of the survey was 1671 Ci

The loaded head was than located in an area of low radiation background levels (< 0.02 mR/h). The GC-40, Specimen A was surveyed as per procedure CO-QC/IT-0001 (2), which meets or exceeds the technical requirements of the QC survey in procedure IN/IM 0309 GC40. The readings taken at the one meter distance from the container surface were taken using the ion chamber instrument only, so as to simulate actual TI values recorded at time of shipment. The instrumentation used for the survey was as follows:

Make	Model	Serial No.	Calibration Date	Chamber Type
Victoreen	471	1432	1999 July 23	Ion Chamber
Bicron	Surveyor	B611W	1999 Nov 11	Geiger Mueller

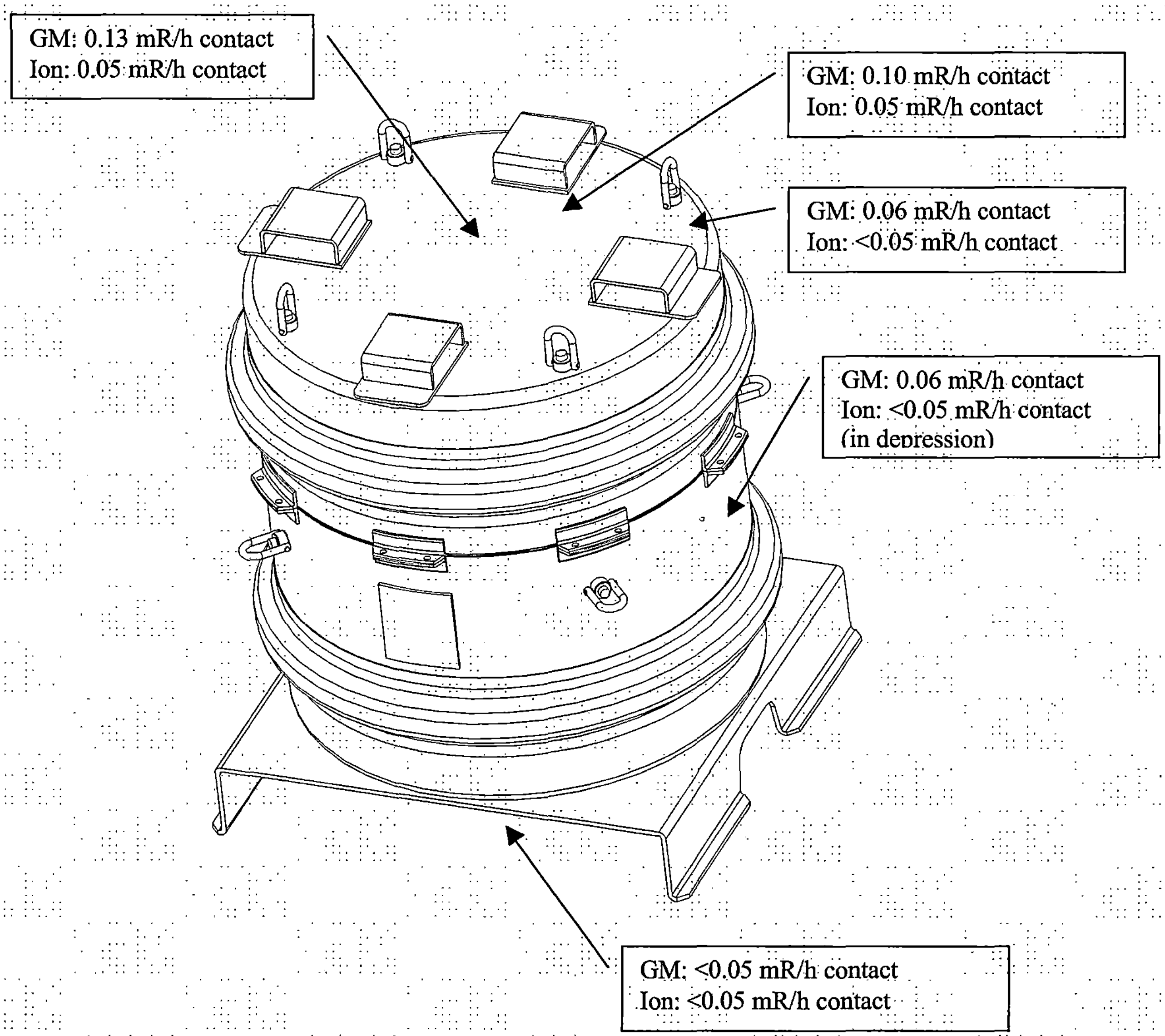
Specimens A and B were loaded into the F-430 overpack prototype and prepared as if for shipment. The F-430 was then surveyed as per CO-QC/IT-0001 (2). The highest readings attained for each area was recorded and detailed in Figure 25, Figure 26, and Figure 27.

Comments

The radiation fields around the GC-40 and F-430 were typically low. Other than a few localized areas, most readings were barely detectable above the background levels.

There was little measurable difference in readings between the pre-drop survey and the post-drop survey. There was a small increase in readings at the damaged areas, only because the meter could be placed closer to the source position, not necessarily due to any loss of shielding.

The Design Acceptance Criteria of 80% of the regulatory limit (1000 mrem/h) was easily satisfiied when corrected to the maximum allowable activity.



Note: All Ti measurements at 1 meter distance from the container surface were ≤ 0.05 mR/h. Deformation after drop not shown

Figure 25, GC-40 (Specimen A) Inside F-430 Overpack, Post-Drop Survey

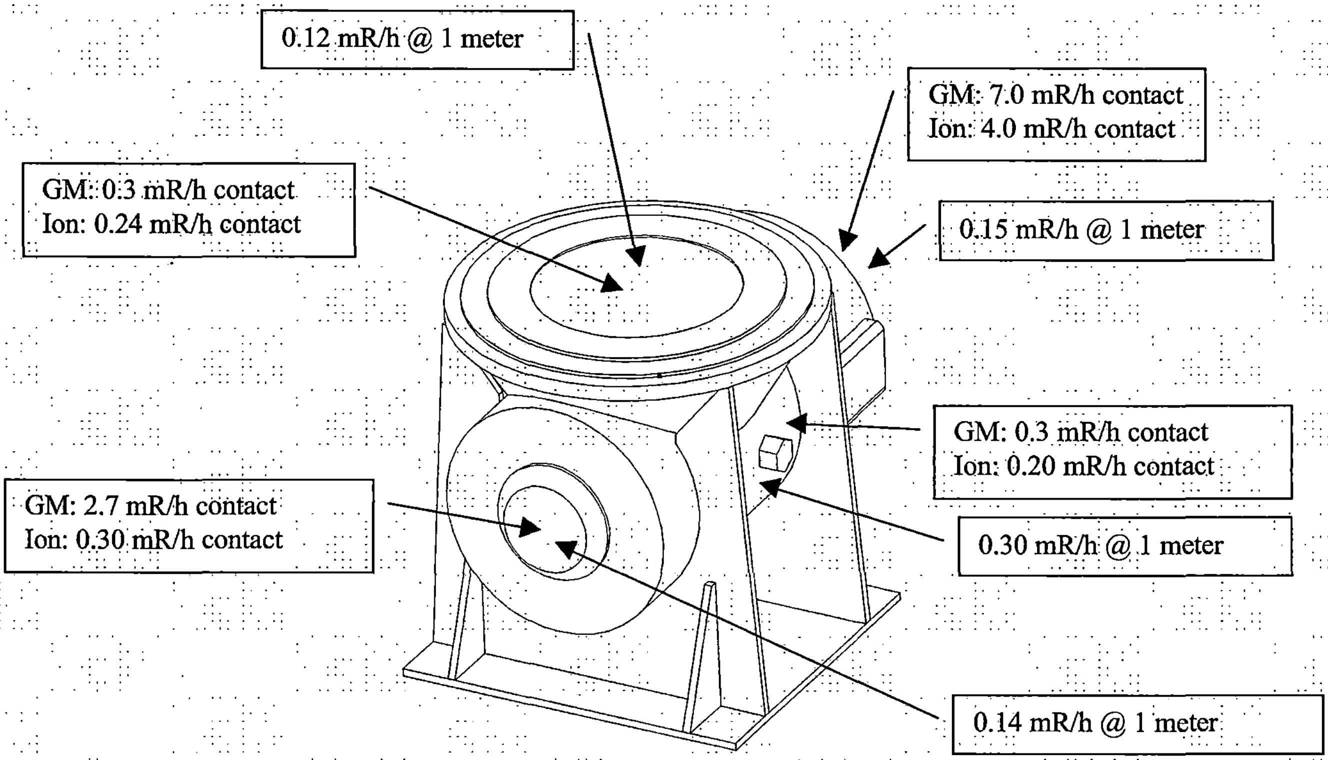
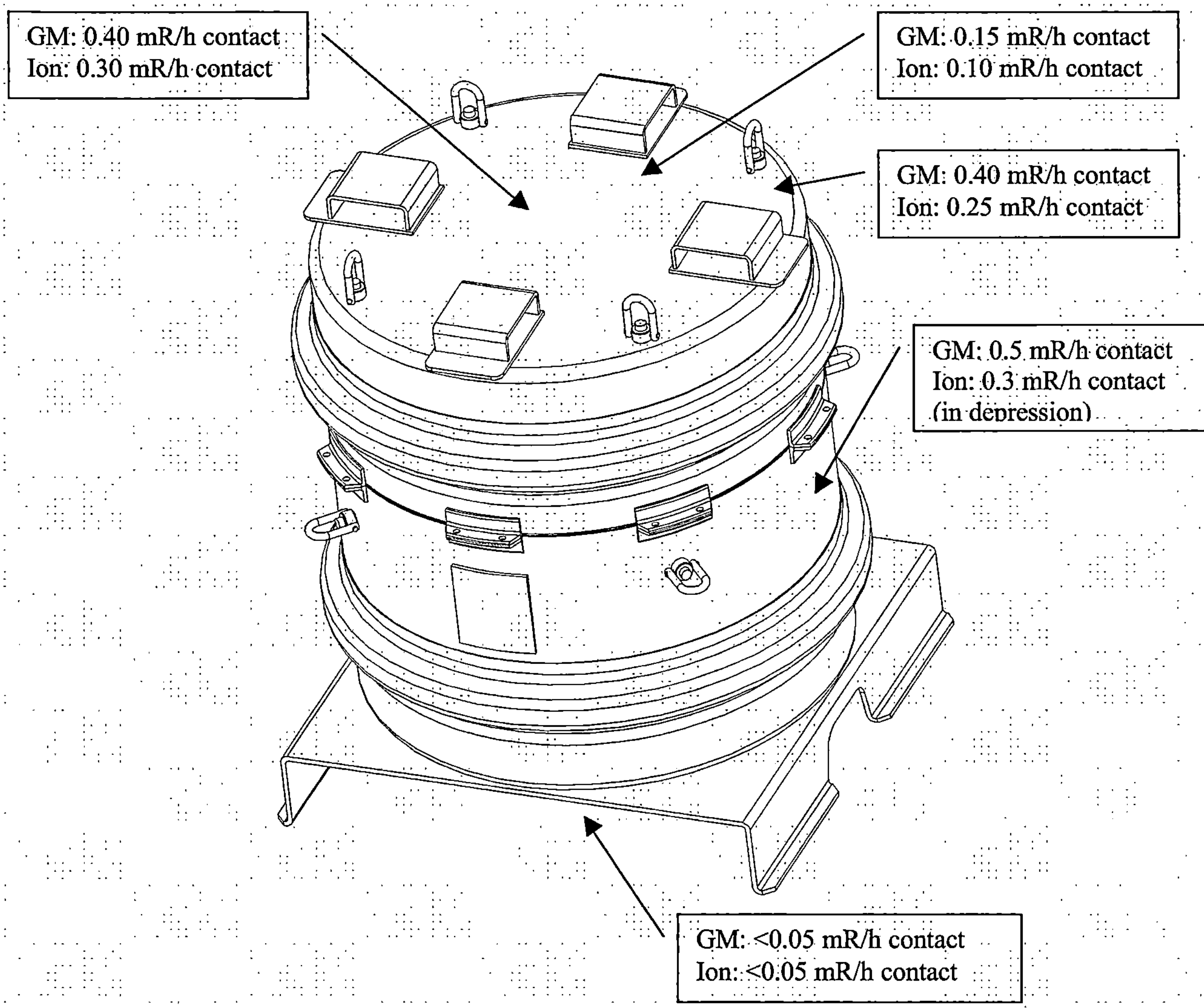


Figure 26, GC-40 (Specimen A), Post-Drop Survey



Note: All Ti measurements at 1 meter distance from the container surface were ≤ 0.20 mR/h. Deformation after drop not shown

Figure 27, GC-40 (Specimen B) Inside F-430 Overpack, Post-Drop Survey

Personnel	Name	Title	Signature / Date
Test Conducted by:	Dave Whitby	Industrial Quality Control	
Reviewed by:	Jiri Krupka	Package Engineer	
Approved by:	John Smith	Quality Assurance	

4.7 Steady State Thermal Test

Report Type	Date of Test	
Post-Drop	November 18, 1999	
Test Name/Description	**Test Number**	**Test Plan**
Steady State Thermal Test	5.3.8	IN/TP 1493 F430 (2)

Test Details

EQUIPMENT:
HP Computer, MDS Nordion Inventory No. C2007
HP Monitor, MDS Nordion Inventory No. M1150
FLUKE Hydra Logger Software, Version 3.0
FLUKE Hydra Data Acquisition Unit, Model 2620, SN 5577551, Calibrated Aug. 27, 99
Terminal Box with 20 T-type thermocouples (0.035" diameter, 20 ft long)

THERMOCOUPLE INSTALLATION:
Twenty thermocouples were installed in similar locations as shown in Fig. 5, and held in position with a duct tape.
From pre-drop results it was apparent that just a few locations needed to be measured to establish the steady state temperatures. This time the source temperature was not measured inside the source drawer. Instead, the GC-40 body top surface was monitored, along with transport cavity temperature at the top, temperature inside main cover, and ambient temperature on top of the container.

SOURCE LOADING AND PACKAGE ASSEMBLY:
The drop test specimen of GC-40 lower head was loaded with C-440 live source (SN A1065, heat generated by this source was approx. 15W corresponding to 1737 Ci).
After source was loaded in the GC-40 unit, it was instrumented with thermocouples, inserted in the F-430 transport cavity with the stainless steel fixing brace in place. Both covers were closed but with only two bolts in each cover so that covers would stay in place. (After drop testing many holes did not align on the main cover.

MEASUREMENTS:
Temperatures were scanned and recorded every hour until steady state conditions were reached.
Test set up was indoors in the Cobalt area of MDS Nordion, March Road, Kanata.

Results/Observations
Steady state conditions were reached in about 8 days with ambient temperatures around 23°C.
Maximum temperature measured was the irradiator surface temperature, which rose from 26.2 to 28.0°C.
See Figure 28 for detailed temperature histories.
Due to preserved integrity of the container after drop testing (both covers stayed in place, no direct thermal path was created) these post-drop results are virtually identical to those obtained prior to drop testing.

Conclusions
The container retained all its integrity and thermal protection after series of 9 drop tests.

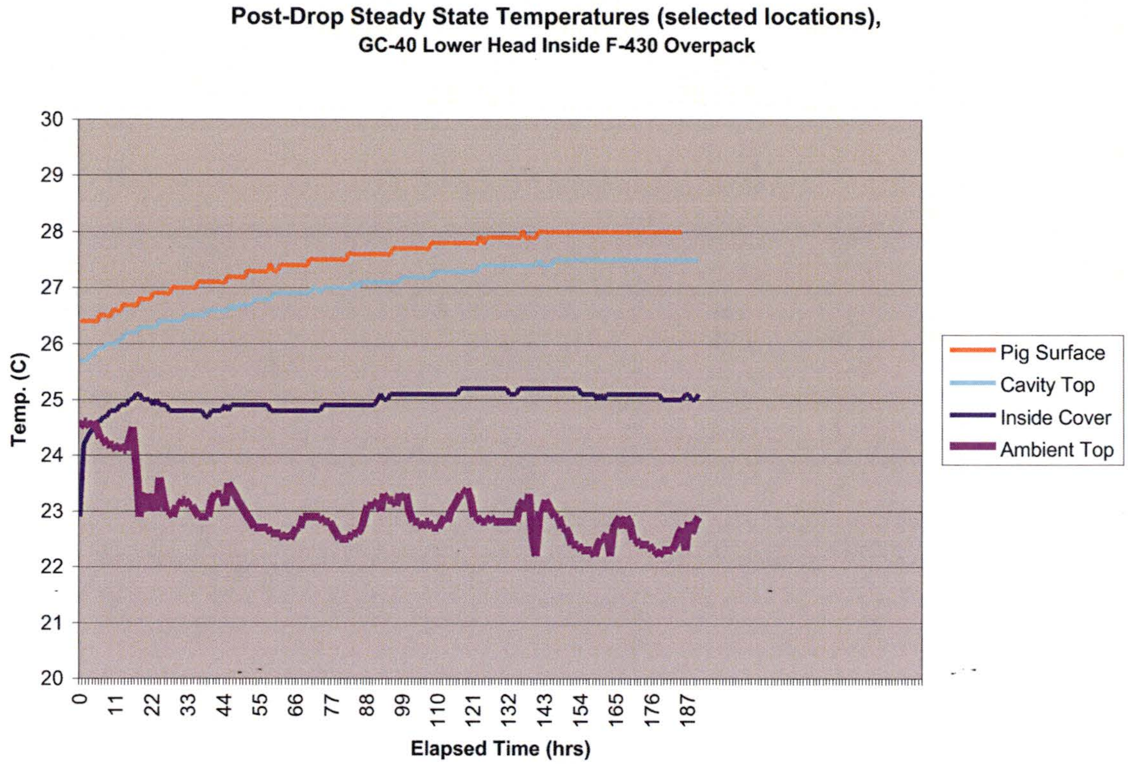


Figure 28, Post-Drop Steady State Temperatures, F-430/GC-40

Personnel	Name	Title	Signature / Date
Test Conducted by:	Jiri Krupka	Package Engineer	
Reviewed by:	Dave Whitby	Industrial Quality Control	
Approved by:	John Smith	Quality Assurance	

5.DISCUSSION OF TEST RESULTS

5.1 Inspect For Fit Test

The inner brace plays an important role during transport since its function is to keep the contents in the same position inside the cavity. It aligns the surface of the GC-40 with the surface of the cavity distributing the weight evenly on the inner walls of the container.
Since the fits of the brace inside the container were too tight, it is recommended that future containers be made 0.5" larger in diameter (from 35.5" to 36.0").
In summary, the inner brace proved itself as a suitable means to restrain the GC-40 lower head inside the transport cavity of the F-430 container.
The above conclusions also apply to the inner brace for the upper head (see Figure 29).

5.2 Dummy Weights on GC-40

1100 lb of additional lead was poured in the cavities of GC-40 lower head to prove the container crush properties and capacity.
This lead provided additional shielding to the GC-40 drop test specimen A. Therefore, standard GC-40 lower head (SN 004-1), Specimen B, was also surveyed inside the F-430 before and after drop testing using the same C-440 source to estimate the effect of drop testing on shielding integrity. See pages 15 and 41 for radiation survey results.
The extra lead inside the cone cavity does not contribute to the structural strength of the GC-40. On the contrary, it impedes the strength, making drop testing more conservative. Except for contact readings inside the cone maximum readings for both GC-40 specimens are on source drawer end plates (see Table 1). Therefore the relative comparison of radiation survey results for specimens A and B before and after drop testing gives sufficient indication of the overpacks performance and effects of drop testing on the shielding of GC-40 irradiator.

Table 1 Pre-Drop Radiation fields for GC-40 Specimens

Field Point	Specimen A (mR/h)		Specimen B (mR/h)	
	Surface	Field at 1m	Surface	Field at 1m
Front Source Drawer Cover	3.5	0.20	2.2	0.20
Rear Source Drawer Cover	7.0	0.34	7.5	0.34
Top Surface	0.30	0.20	160*	0.40
Right Side	0.30	0.30	0.45	0.30

* Inside Cone as per Figure 3. For other locations refer to Figure 6.

5.3 Drop Tests

Test #1: **1.2m 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. The GC-40 irradiator was placed on four layers of 3/4" plywood. After this first drop test the two covers were removed, and it was observed that the contents "sank" inside the cavity on average by 1/2". No visible damage was observed on the GC-40 irradiator or inside the container cavity. No damage was noted that could affect the subsequent 9m drops.

Test #2: **1.2m Top edge 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. The crush distance was approximately 2". Center of gravity was directly over the point of impact since the container remained standing on the top edge it impacted. No damage was noted that would affect the subsequent 9m drops. No damage was noted that could affect the subsequent 9m drops. No damage was noted that could affect the subsequent 9m drops.

Since the increase in radiation levels did not rise by 20% after all drop tests it is thereby implied that radiation levels did not increase by 20% after the first normal drop tests (#1 and #2).

Test #3: 9m Inverted drop (for maximum deceleration, the top four hoist rings were removed prior to this test) the high-speed video shows that the container bounced once 8-10" high after a short delay on the target surface. This gives and indication of internal deformation and a spring back action of the contents. The lifting pockets deformed in the middle, but did not flatten completely. External deformation vertical distance was less than 1/2" and internal about 3". 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. The G values are estimated at 360"/3.5" = 103g (drop test height divided by deformation distance). All fifteen exterior bolts remained in place (one bolt was removed prior to all drop tests). Bolts were checked by hand, and confirmed as finger tight. The previous two 1.2m drop tests did not significantly damage the package that would change the outcome of drop test #3.

Test #4: 9m Top edge (for maximum deformation) the container bounced once 12-14" high this time without visible delay. Center of gravity was directly above the impact point since the package remained standing on its edge. External deformation vertical distance was 4" and internal distance was likely less than 1". This would give a G value estimate below 90g (360/4). However, from the accelerometer readings the maximum accelerations were 122 g's (front of Gc40) and 139 g's (back of Gc40). Five bolts in a row were lost during the impact (3, 4, 5, 6, and 8; bolt 7 was removed prior to all drop tests) which opened up a 1/2" gap between the cover and the body in the area where the bolts were missing. The segmented flanges also shifted about 1/2" in this area. The previous drop testing of the package did not change the outcome of this drop test.

In Test #5: 1m Inverted Pin Drop (to penetrate top flat surface) there was no penetration through the stainless steel skin likely because the pin hit on the internal cross brace. The dent was only about 1/2" deep. Container rolled over on its side and suffered no other major damage. The shipping skid stayed on with all bolts in. If the pin just missed the internal cross brace the stainless steel skin surface might have ruptured, but likely not more than it did in the following pin drop test.

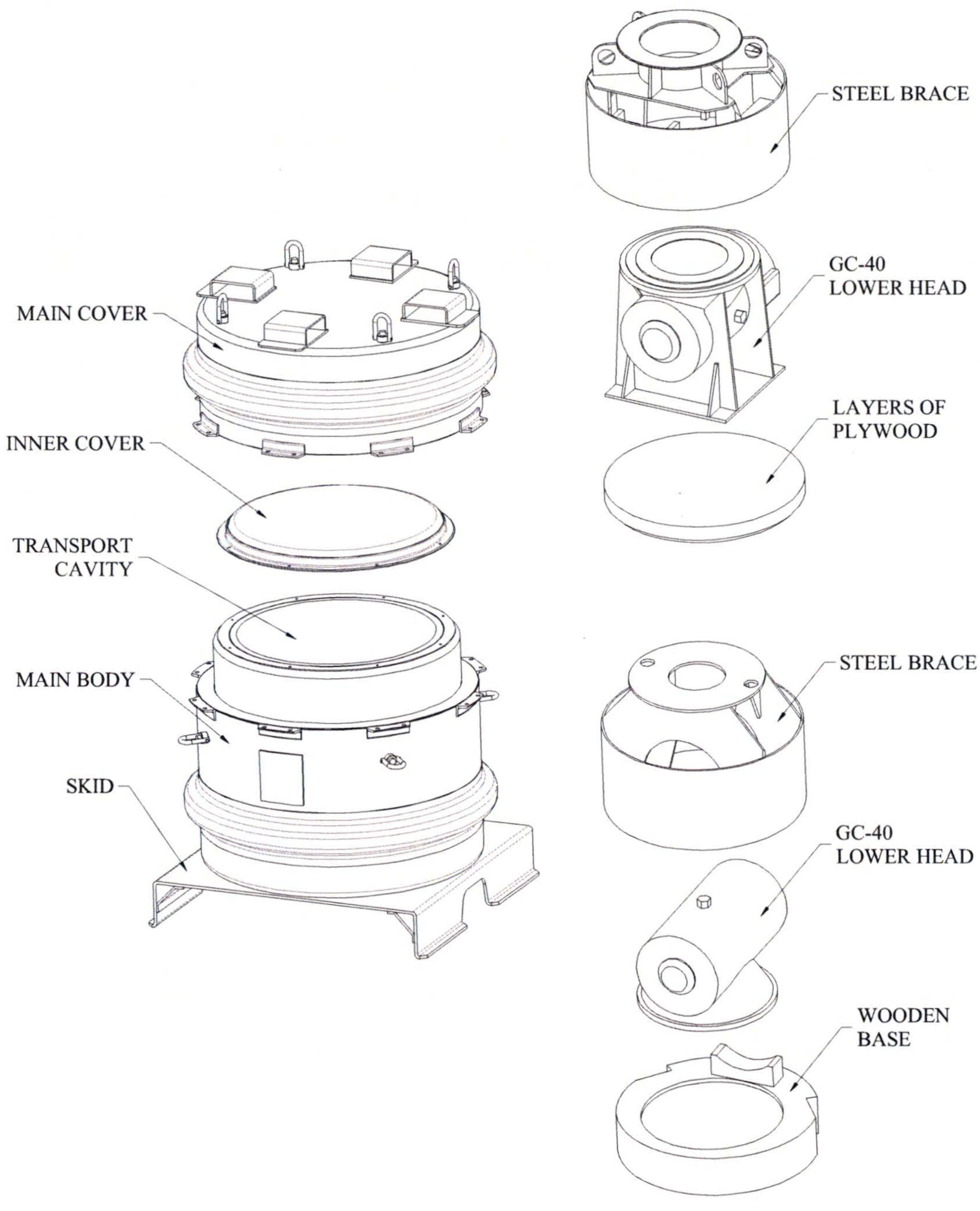


Figure 29, F-430 / GC-40 Main Components

In Test #6: 1m Side Pin Drop (to penetrate side curved surface) the regulatory pin did cut through the container's stainless steel skin exposing about 30in^2 of the FR-3708 polyurethane foam. The maximum depth of the penetration into the package was about 3". This failure was expected, and the magnitude of the foam exposure was one of the test objectives. Crush protection was not lost since there are a total of 6" of FR-3708 foam all around the package.

Test #7: 9m Side Drop (to split open the package) This orientation yielded the highest measured deceleration (157 and 164 g's). First a corner of the skid impacted which sheared the skid's eight 1/2" bolts and the skid was projected about 6 feet from the point of impact. Then the two bumpers impacted immediately followed by a vertical rebound 14" high. The deformation on the main body was only about 2". The theoretical magnitude of deceleration would than be 360"/2" = 180g, neglecting the crush distance of 2.5" for the bumpers and the shearing of the skid bolts.
The lowest point from which 30-ft height was measured was the skid's front left corner with the package in horizontal position. This resulted in additional 9" 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 4 bolts were lost on the main cover (1, 2, 15, 16), leaving six bolts (9, 10, 11, 12, 13, 14). The main cover opened up a gap of 15/16" with the main body. The performance of the package was significantly affected by the previous tests. This cumulative damage adds conservatism to the drop test results.

During test #8 (1m oblique pin drop) the package's skin was pierced exposing 35in^2 of polyurethane foam. This is considered the worst possible damage that the regulatory pin drop could cause the F-430 container. There is no other "softer" area or location on the outside of the package that could cause more damage to the thermal protection, shielding and containment.

Test #9 (1m side pin drop) was the final attempt to remove the main cover from the container. Three flanges in a row had both bolts in place (total of 6 bolts were remaining, see Figure 16). In this side pin drop the pin hit the middle flange (with bolts 11 and 12) in attempt to break the bolts and to cause the container to split open, as there were no bolts around 260° angle opposite the side of impact (Figure 14). After the drop test, all bolts stayed in their place and the main cover did not open.

5.5 Integrity of Thermal Protection

Steady state testing before and after drop tests prove that the container did not lose any of its thermal protection capabilities. Exposing 35 in^2 of the crush foam to the fire is a very small fraction from the total outside surface area (11780 in^2), and is actually beneficial to the heat removal during accidental fire by venting fumes and gasses outside of the package. Additionally, the polyurethane foam when exposed to fire will create an intumescent char that has a very low conductivity.

5.6 Integrity of Containment

Helium leak test after drop test proved that containment was not lost. The dummy sealed source remained leak tight.

5.7 Integrity of Shielding

No weld fractures were observed on the GC-40 irradiator, therefore shielding was not damaged after nine drop tests.

6. CONCLUSION

The F-430 transport container with GC-40 lower head (with additional 1100 lb weight) passed the testing requirements as prescribed by IAEA Safety Standards (Series No. 6, 1990) and complies with the general standards for all packaging as specified in 10 CFR 71 SS 71.43.

APPENDIX 1
AECL Test Report, F-430 Testing, AECL Document No. A-17048-TN-1

AECL EACL

Engineered Products and Services
Design Document

Classification/ Designation CONTROLLED

DOCUMENT TITLE MDS Nordion F-430 Transport Packaging Testing

PROJECT/JOB TITLE F-430 Testing

DOCUMENT TYPE Test Report

Prepared By	R. Birchall	**Date**	99/12/17
Reviewed By	R. J. Lesco	**Date**	99/12/17
Approved By	E. W. Butterworth	**Date**	99/12/17
Accepted By		**Date**	
Accepted By		**Date**	

(Signatories for Rev. 0 only)

REA No. 17048

Document No. A-17048-TN-1

Revision No. 0

Alternate Document No.

CRL-3554-1-Rev. 3

AECL EACL

Engineered Products and Services
Document Status and Revision History

TITLE: Test Report: MDS Nordion F-430 Transport Packaging Testing	REA No. 17048 Doc. No. A-17048-TN-1 Sheet 1 of 1	

Rev. No. / Date	Revision History and ECN Reference	Prepared / Reviewed	Approved / Accepted

Issue No.	Rev. No.	DTS No.	Date	ISSUE/STATUS	BY

1. INTRODUCTION

Vertical drop tests and puncture tests were performed on the F-430 test specimen during October 13-14, 1999, at the AECL drop test facility located at Chalk River, Ontario, Canada.

These tests were witnessed by representatives from MDS Nordion, Menova Engineering, AECB, and USNRC.

Nine drop tests were performed, in a variety of orientations. Tri-axial accelerometer blocks were installed on the F-430 test specimen, in three locations, to record deceleration data.

Visual records were made using a normal video camera, high-speed film camera (500 frames per second), and still camera. Brief qualitative field observations were recorded by the AECL engineer (R. Birchall) after each drop test, and are part of this document. Detailed quantitative and qualitative observations were recorded after each drop test by MDS Nordion and Menova Engineering personnel, as witnessed by the MDS Nordion Quality Assurance engineer, and are not part of this document.

This report references the photographic record, print numbers 9910-23698-1 to 9910-23698-84. The high speed film transfer to AVI file format is referenced by filenames shota.avi to shoti.avi.

2. REFERENCES

MDS Nordion document:

F-430 Test Plan, IN/TP 1493 F430 (1)

3. FACILITIES

AECL (Atomic Energy of Canada Limited) maintains a drop test facility at Chalk River Laboratories (CRL), located at Chalk River, Ontario. The drop test tower is 65 ft high; the maximum drop height is 50 ft. The impact target has a surface area of 48 ft^2.

The impact target consists of a steel plate mounted on a concrete pad with a total mass of approximately 80 ton. The entire target is embedded in granite bedrock to provide an essentially infinite mass. The steel-reinforced concrete pad is 10 ft by 10 ft by 10 ft deep with a compressive strength of 5000 psi. The steel plate is 8 ft by 6 ft by 4 inches thick, ASTM A203 Grade E. Tapped holes are provided in the top plate for the installation of a high strength plate and puncture pin for impact testing. (Ref: AECL Dwg. E-4511-2002).

Puncture pins were supplied by MDS Nordion.

4. TESTING

Test No. 1

Conditions:

Drop height = 1.2m
Orientation: Upright drop
Temperature: 9.6 °C
Time of drop: 9:55 AM, Oct. 13, 1999

Photographic record:

9910-23698-1	**Verification of length of steel rod.**
9910-23698-2	**F-430, pre-drop.**
9910-23698-3 to 9910-23698-9	**F-430, post-drop.**
9910-23698-10 to 9910-23698-13	**Post-drop removal of F-430 upper impact limiter.**
9910-23698-15	**Post-drop removal of F-430 lid.**

Field observations:

1. Skid deformed per photographic record.
2. Bulge on bottom vertical surface as per photographic record.
3. No cracked welds.
4. Removed impact limiter. [*for post-drop inspection*]
5. Removed lid. [*for post-drop inspection*]
6. Inside: 1/2" - 3/4" drop within container. [*refer to photograph* ***9910-23698-15***]

Test No. 2

Conditions:

Drop height = 1.2m
Orientation: Top corner drop
Temperature: 9.4 °C
Time of drop: 11:45 AM, Oct. 13, 1999

Photographic record:

9910-23698-16	**F-430, pre-drop.**
9910-23698-17 to 9910-23698-28	**F-430, post-drop.**

Field observations:

1. [*F-430*] rested on impacted face.
2. Dent as per photographic record.
3. [*F-430*] did not roll after impact, [line of impact] through Centre of Gravity.

Test No. 3

Conditions:

Drop height = 9m
Orientation: Inverted drop
Temperature: 10.0 °C
Time of drop: 1:25 PM, Oct. 13, 1999

Photographic record:

9910-23698-29	**F-430, pre-drop.**
9910-23698-30 to 9910-23698-41	**F-430, post-drop.**

Field observations:

1. Did not tip.
2. Symmetric deformation.
3. Stacking pockets on head compressed as per photographic record.
4. One bolt missing (stripped) from skid.
5. Cracked weld on back left bumper.
6. Crush shield deformed per photographic record.

Test No. 4

Conditions:

Drop height = 9m
Orientation: Top corner drop
Temperature: 10.0 °C
Time of drop: 2:10 PM, Oct. 13, 1999

Photographic record:

9910-23698-42 to 9910-23698-51	**F-430, post-drop.**

Field observations:

1. Crush shield deformed as per photographic record.
2. Five (5) bolts missing [*from crush shield, after drop*].

Test No. 5

Conditions:

Drop height = Impact zone 1m above top of pin
Orientation: Inverted pin drop
Temperature: 10.1 °C
Time of drop: 3:20 PM, Oct. 13, 1999

Photographic record:

9910-23698-52	**F-430, pre-drop.**
9910-23698-53 to 9910-23698-57	**F-430, post-drop.**

Field observations:

1. Dent, no tearing [as per photographic record].

Test No. 6

Conditions:

Drop height = Impact zone 1m above top of pin
Orientation: Side pin drop
Temperature: 10.0 °C
Time of drop: 4:00 PM, Oct. 13, 1999

Photographic record:

9910-23698-58 to 9910-23698-59	**F-430, pre-drop.**
9910-23698-60 to 9910-23698-64	**F-430, post-drop.**

Field observations:

1. Dent by pin [as per photographic record].
2. [Side wall] torn as per photographic record.

Test No. 7

Conditions:

Drop height = 9m
Orientation: Side drop
Temperature: 9.5 °C
Time of drop: 4:46 PM, Oct. 13, 1999

Photographic record:

9910-23698-65	**F-430, pre-drop.**
9910-23698-66 to 9910-23698-73	**F-430, post-drop.**

Field observations:

1. Skid off [detached from F-430 during impact].
2. Gap between upper limiter and body. [refer to photograph **9910-23698-68**]
3. Body flattened on impact side as per photographic record.
4. Additional six bolts missing.
5. Bracket pushed in. [refer to photographs **9910-23698-71, -73**]

Test No. 8

Conditions:

Drop height = Impact zone 1m above top of pin
Orientation: Oblique pin drop
Temperature: 2.2 °C
Time of drop: 9:10 PM, Oct. 14, 1999

Photographic record:

9910-23698-74	**F-430, pre-drop.**
9910-23698-75 to 9910-23698-79	**F-430, post-drop.**

Field observations:

1. Torn [*by pin*] as per photographic record.
2. Split at centre of tear as per photographic record.

Test No. 9

Conditions:

Drop height = Impact zone 1m above top of pin
Orientation: Side pin drop
Temperature: 2.8 °C
Time of drop: 9:50 PM, Oct. 14, 1999

Photographic record:

9910-23698-80	**F-430, pre-drop.**
9910-23698-81 to 9910-23698-84	**F-430, post-drop.**

Field observations:

1. Bracket bent inward. [*as per photographic record*]
2. No [*additional*] broken welds.
3. Cover stayed on.

Appendix 1

DECELERATION MEASUREMENT DURING DROP TESTS OF A F-430 OVERPACK

John Tromp, Vibration and Tribology Unit

1. INTRODUCTION

Impact tests were conducted on a F-430 Overpack containing a GC-40 Lower Head inside. The Vibration and Tribology Unit was asked to gather data during the impact of this package to address structural concerns. All drops were performed as requested onto an unyielding surface using various orientations.

2. INSTRUMENTATION

The package was instrumented with low impedance accelerometers, capable of measuring 2500 g and withstanding a shock load of 5000 g. The accelerometers were tested prior to mounting them in the package to verify their operation, since the majority of them would not be accessible for replacement once the package was closed. After the package was closed, the accelerometers were again tested for signal integrity before the drop test. Deceleration signals were stored on a multi-channel tape recorder (TEAC model XR7000, QA # 456-268) for later analysis. Figure # 1 shows the location of the accelerometers and Figure # 2 shows their orientation on the G-40 Lower Head and F-430 Overpack.

3. CALIBRATION

All accelerometers were calibrated before and after the drops. A hand-held shaker (B&K Calibration Exciter Type 4294, QA # FS1217) was used as an excitation source. This shaker vibrates at 159.0 Hz and produces an acceleration level of 1.0 g. Each accelerometer was mounted on the shaker and connected to an amplifier (Kistler Dual Mode Model 5010, QA # 456-239). The accelerometer sensitivity setting was adjusted and the output voltage measured using a voltmeter (Keithley Multimeter Model 2001, QA # B5871). Results are listed in Table # 1 in the 'as found' columns. The sensitivity setting was then changed till the output read 1.00 Volts. The resulting sensitivity was then noted in the 'as left' column of Table # 1. This procedure was repeated in part and documented in Table # 1, to verify the condition of the accelerometers after the drops were completed

Calibration Certificates for the instruments used are attached in Appendix 2.

Table # 1: Accelerometer Calibration

Accelerometer (Serial #)	Sensitivity (mV/g)		Date of Calibration (before drop test)	Measured Acceleration (g's)		Date of Calibration (after drop test)	Measured Acceleration (g's)
	as found	as left		as found	as left		as found
2500	1.50	1.45	99/09/30	0.97	1.00	99/11/04	0.98
6742	2.16	1.94	99/09/30	0.90	1.00	99/11/04	0.99
6952	2.22	1.82	99/09/30	0.82	1.00	99/11/04	1.00
9745	1.55	1.45	99/09/30	0.94	1.00	99/11/04	1.00
1303	1.70	1.66	99/09/30	0.98	1.00	99/11/04	0.99
1302	1.99	1.78	99/09/30	0.90	1.00	99/11/04	0.99
2503	1.69	1.61	99/09/30	0.95	1.00	99/11/04	1.00
2501	1.70	1.56	99/09/30	0.92	1.00	99/11/04	0.99
2525	1.72	1.59	99/09/30	0.93	1.00	99/11/04	0.99

4. TEST RESULTS

The signals stored on tape contain both the deceleration frequency and all natural frequencies of all parts of the package and contents excited on impact. Natural frequencies are usually higher frequencies having higher amplitudes and should therefore be filtered out to reveal the true deceleration frequency. It was determined, by using various filter settings, that anything above 640 Hz showed these natural frequencies.

IAEA Safety Series No.37, Paragraph A-601.14., suggests a cut-off frequency range of 100 to 200 Hz, multiplied by a factor $(100/m)^{1/3}$, where m = mass of package [Mg]. As per this guideline:

$$(100 \text{ to } 200 \text{ Hz}) \times (100/3.17 \text{ Mg})^{1/3} = 316 \text{ Hz to } 631 \text{ Hz}$$

Therefore the selected 640 Hz filter setting is <1.5% higher than the upper end of the IAEA suggested range.

The recorded data was analyzed using a LabVIEW program which was adapted from a previously developed program. This program was verified by analyzing a previous drop test, where results were acquired using a strip chart recorder (the traditional method).
The graphs on pages 13–29 show the signals after being filtered so that anything above 640 Hz is eliminated.

Analog data from the tape recorder was filtered using a National Instrument SCXI-1141 configurable 8-channel elliptic lowpass filter. The filter was connected to a data acquisition card (National Instruments type AT-MIO-16E-10) installed in a Dell personal computer. The digital sampling rate is 8000 samples/second. Data provided in Excel file format is referenced by filenames "Drop # 1.xls" to "Drop # 9.xls".

Table # 2: Summary of Maximum Measured Deceleration of Drops #1 to #9
[g's]

Accelerometer Location	Accelerometer (Serial #)	Drop #1	Drop #2	Drop #3	Drop #4	Drop #5	Drop #6	Drop #7	Drop #8	Drop #9
Front of GC-40	2500	36	-47	LOS	-60	-18	19	-113	LOS	-20
	6742	30	-17	LOS	-67	9	-10	99	-8	26
	6952	N/A	-15	LOS	-82	N/A	23	-46	-10	24
Back of GC-40	9745	N/A	36	LOS	-37	N/A	20	161	-14	42
	1303	36	-43	LOS	-101	-19	N/A	N/A	11	N/A
	1302	N/A	10	LOS	88	N/A	-23	33	11	-18
Bottom of skid	2503	N/A	Removed from tests							
	2501	N/A	Removed from tests							
	2525	-65	Removed from tests							

Drop # 1: 1.2m upright drop
Drop # 2: 1.2m top corner drop
Drop # 3: 9m inverted drop
Drop # 4: 9m top corner drop
Drop # 5: Inverted pin drop (impact zone 1m above top of pin)
Drop # 6: Side pin drop (impact zone 1m above top of pin)
Drop # 7: 9m Side drop
Drop # 8: Oblique pin drop (impact zone 1m above top of pin)
Drop # 9: Side pin drop (impact zone 1m above top of pin)

Note 1: **N/A** = Accelerometer in transverse orientation.
The sensing element of an accelerometer is oriented along its longitudinal axis. Thus, when an accelerometer is oriented in the transverse direction to the direction of drop, no valid measurement can be made.
The traces for these accelerometer results are not shown in the graphs.

Note 2: **LOS** = Loss Of Signal (see Section 5.1).
The traces for these accelerometer results are not shown in the graphs.

Note 3: Maximum decelerations in this table do not necessarily occur at the same instant in time.

5. COMMENTS

5.1 Losses of signal

Drop test # 1

At some time just prior to the drop cable # 6 connecting to accel. # 1302, developed a short (probably because of rain) thus no data was obtained. This cable was replaced for subsequent drops.

Drop Test # 3

Normally the leads are taped to the package prior to a drop to relieve strain on the leads and connectors during impact. This was not possible at the time of these drops since the package was wet from the rain. Wiping the package dry to make the tape adhere did not work. As a consequence, with the exception of one lead (accel. # 1302), the male connectors were pulled out of their mating connectors when impact occurred and the signals were lost.

Drop Test # 4

For subsequent drops the umbilical leads were taped to the leads on the other side of the connector to minimize strain on the connector. However, the lead from accel. # 9745 was disconnected upon impact during drop # 4. [Result appears valid until point of disconnect]

Drop Test # 8

During drop # 8 the lead from accel. # 2500 developed a short which was repaired prior to the next drop.

5.2 Bottom plate accelerometers

The bottom accelerometers (see Figure # 1) were present only for Drop # 1. While setting up for Drop # 2 it was shown that these accelerometers were going to be damaged without some protection. It was decided by J. Krupka (Menova Engineering) and B. Menna (MDS Nordion) that these would no longer be required.

Placement of Accelerometers on GC-40 and F-430 Overpack

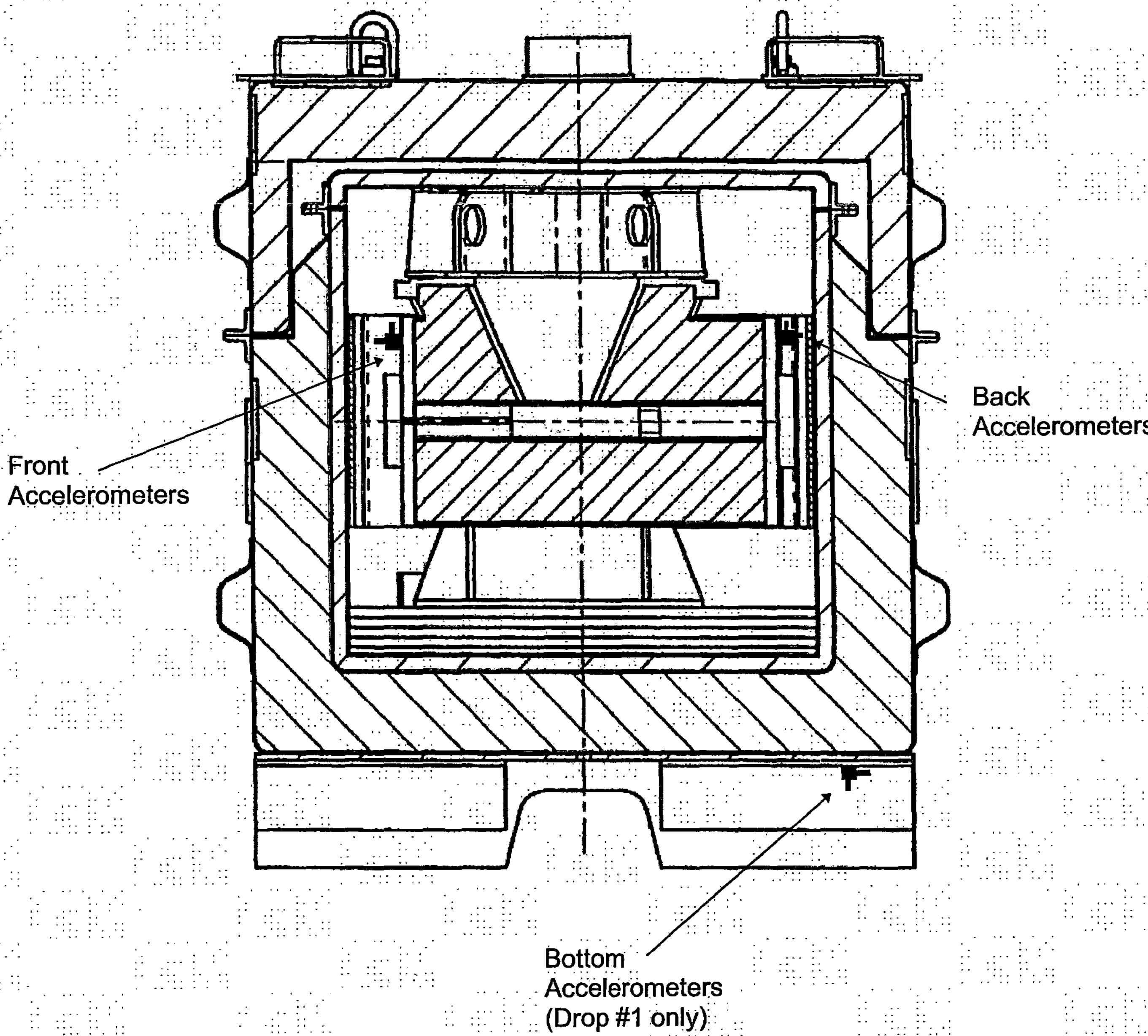


FIGURE #1: Location of Accelerometers

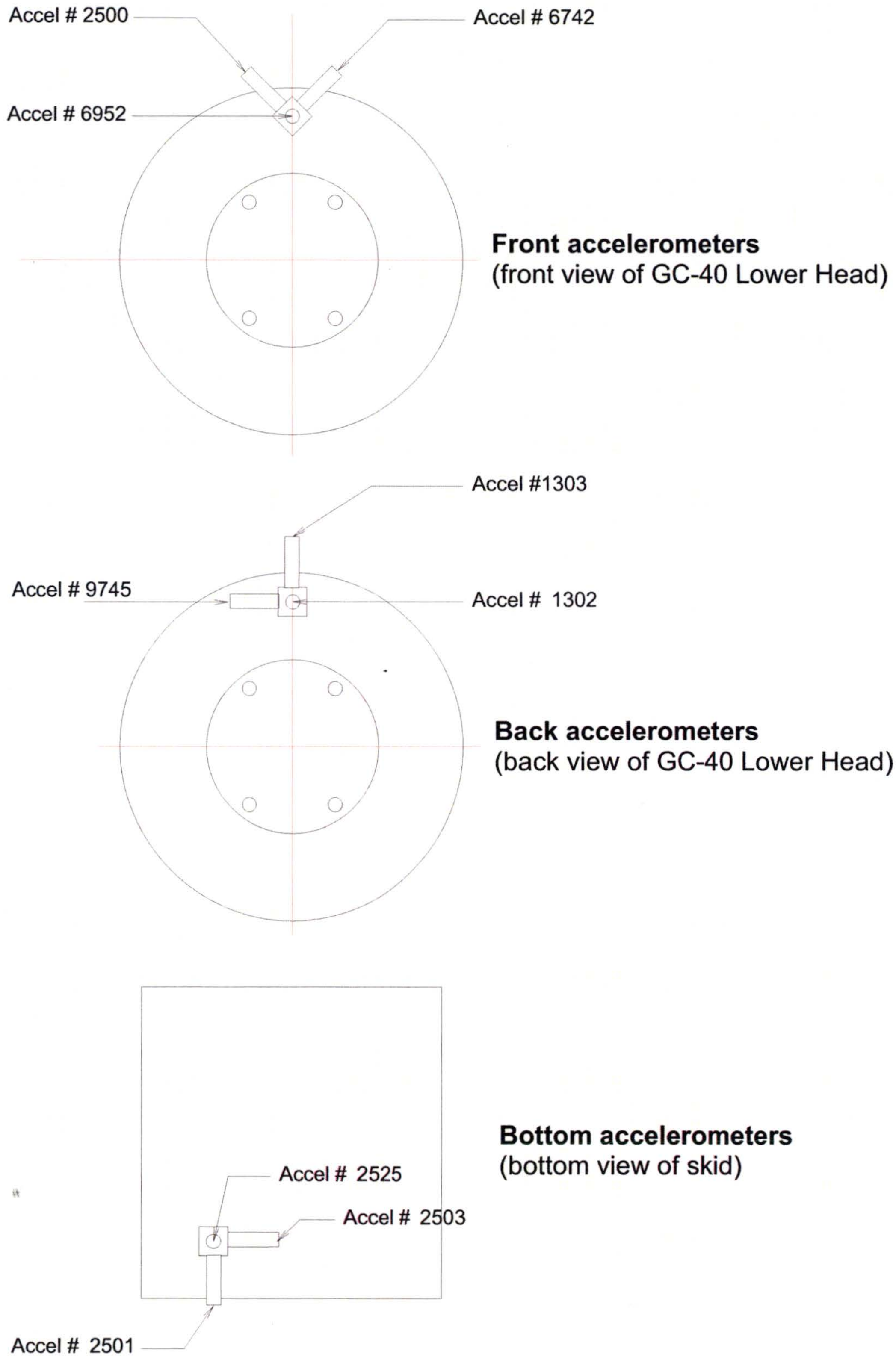
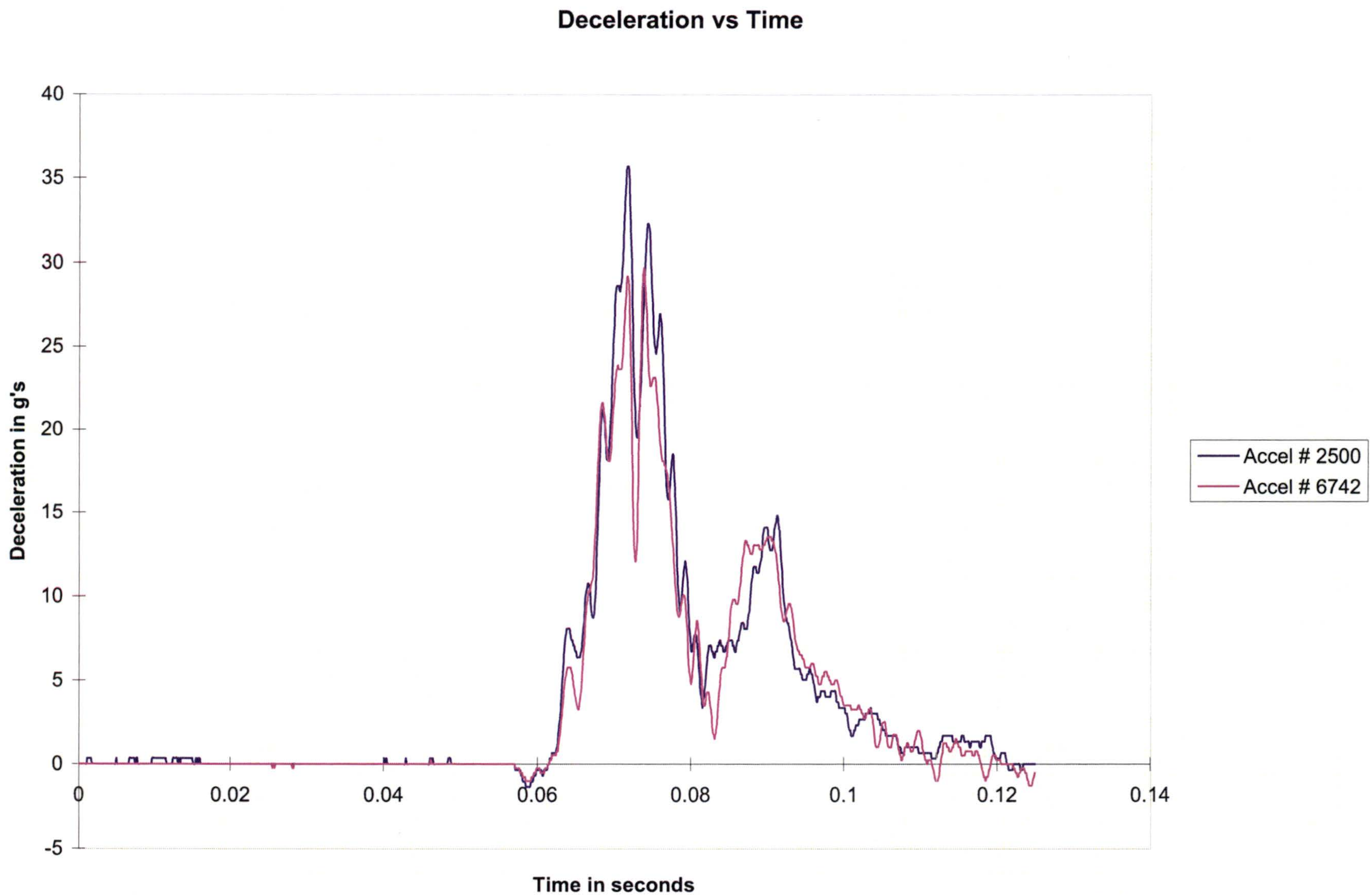
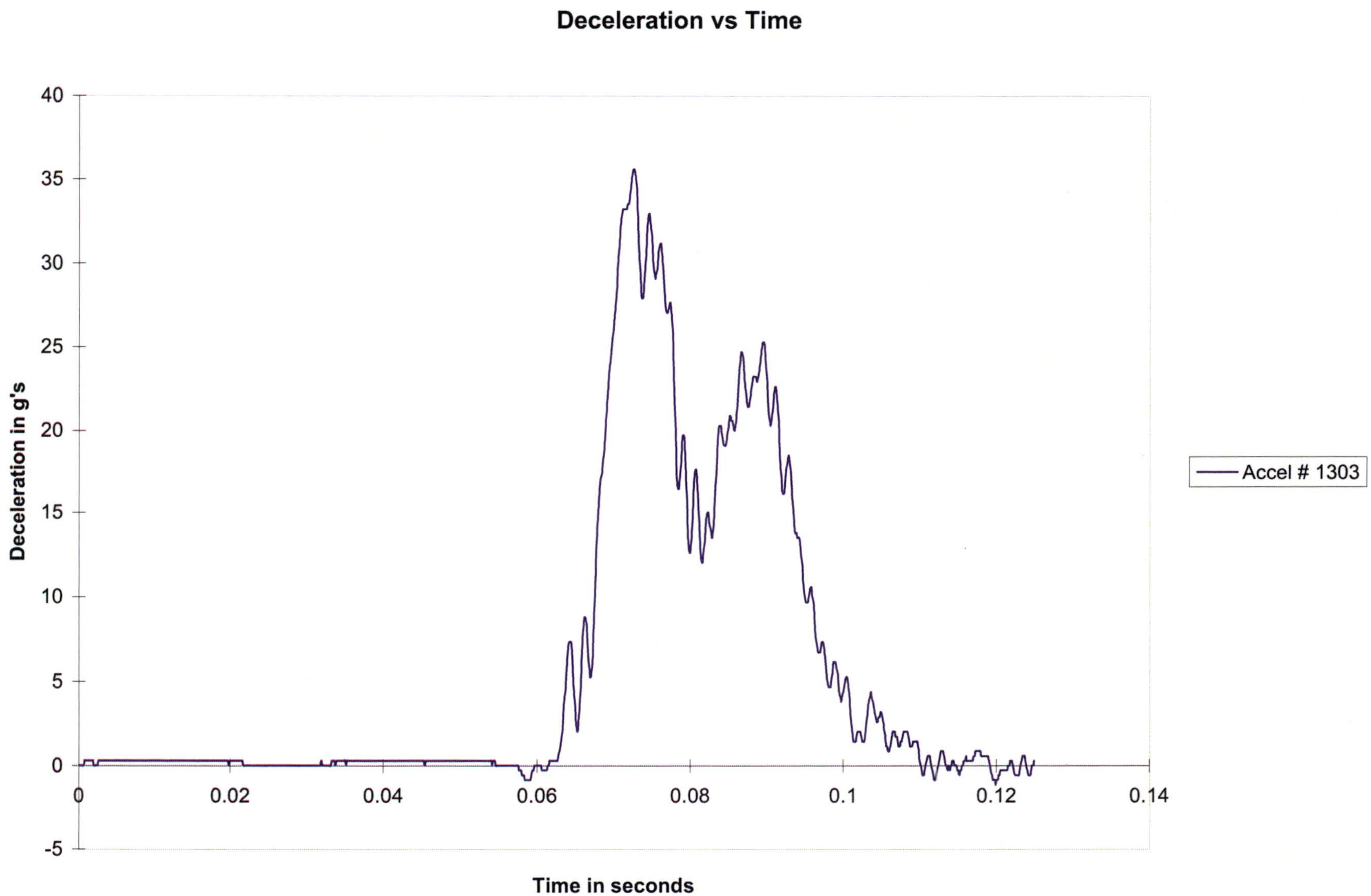
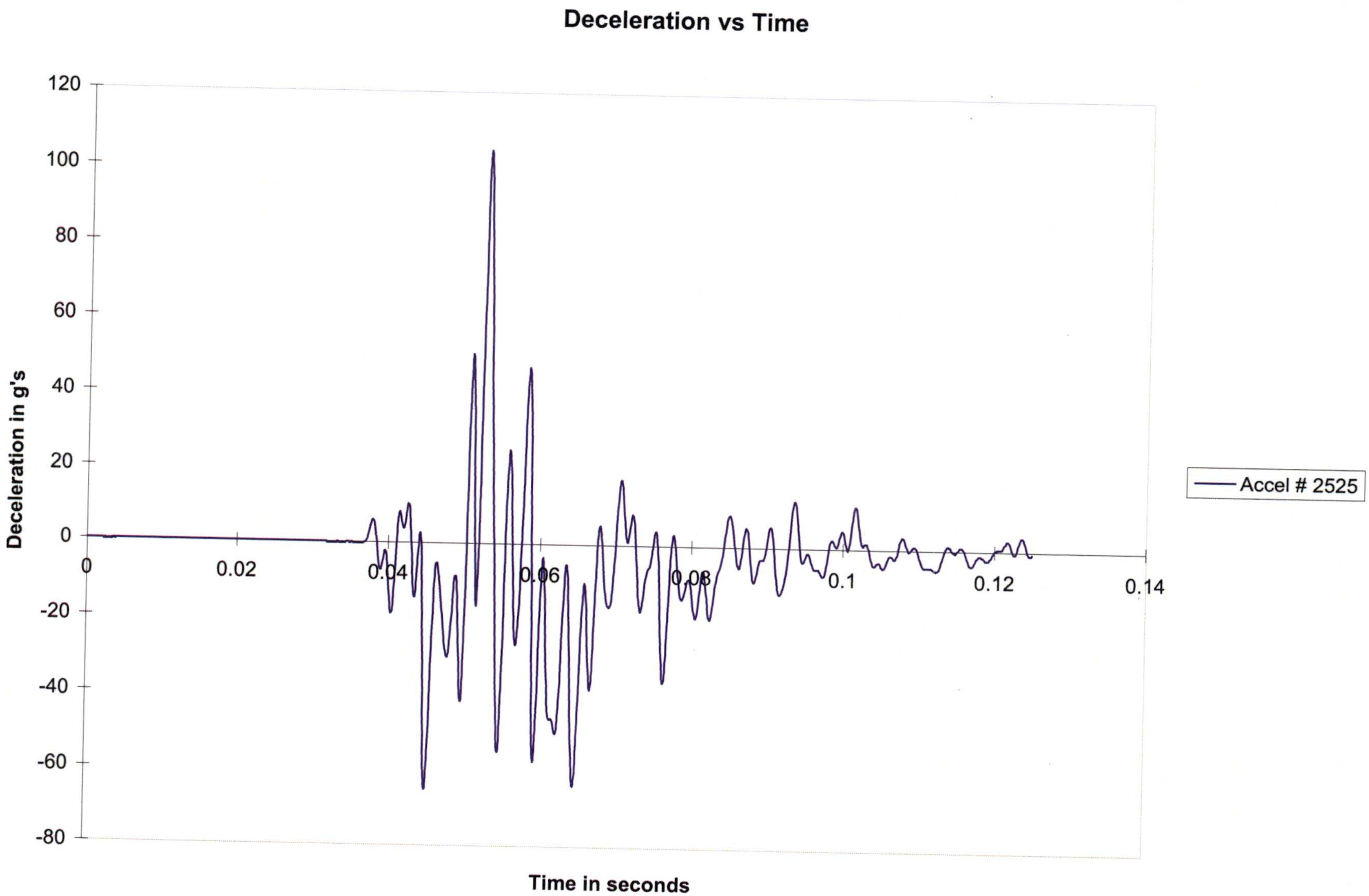
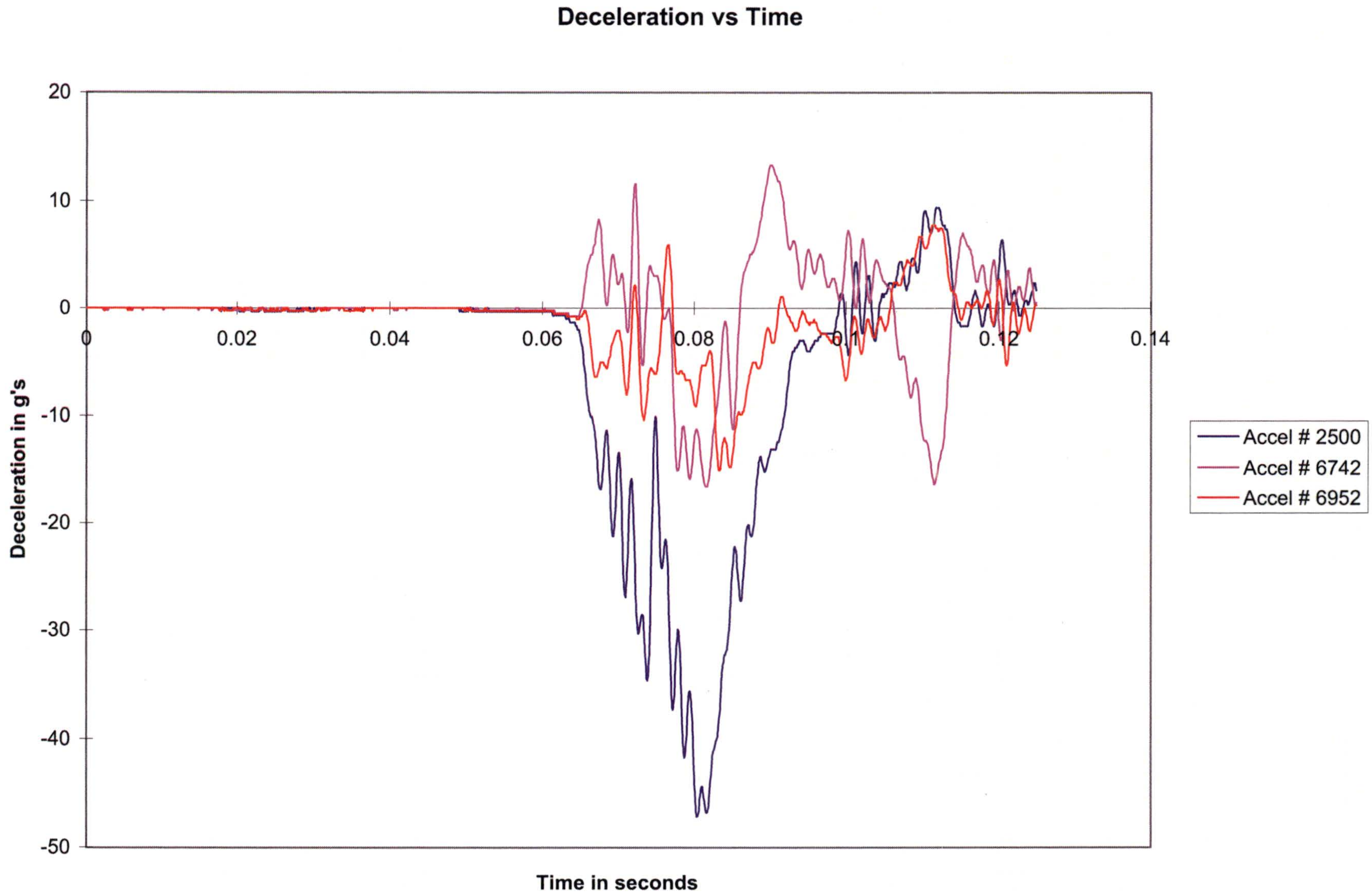


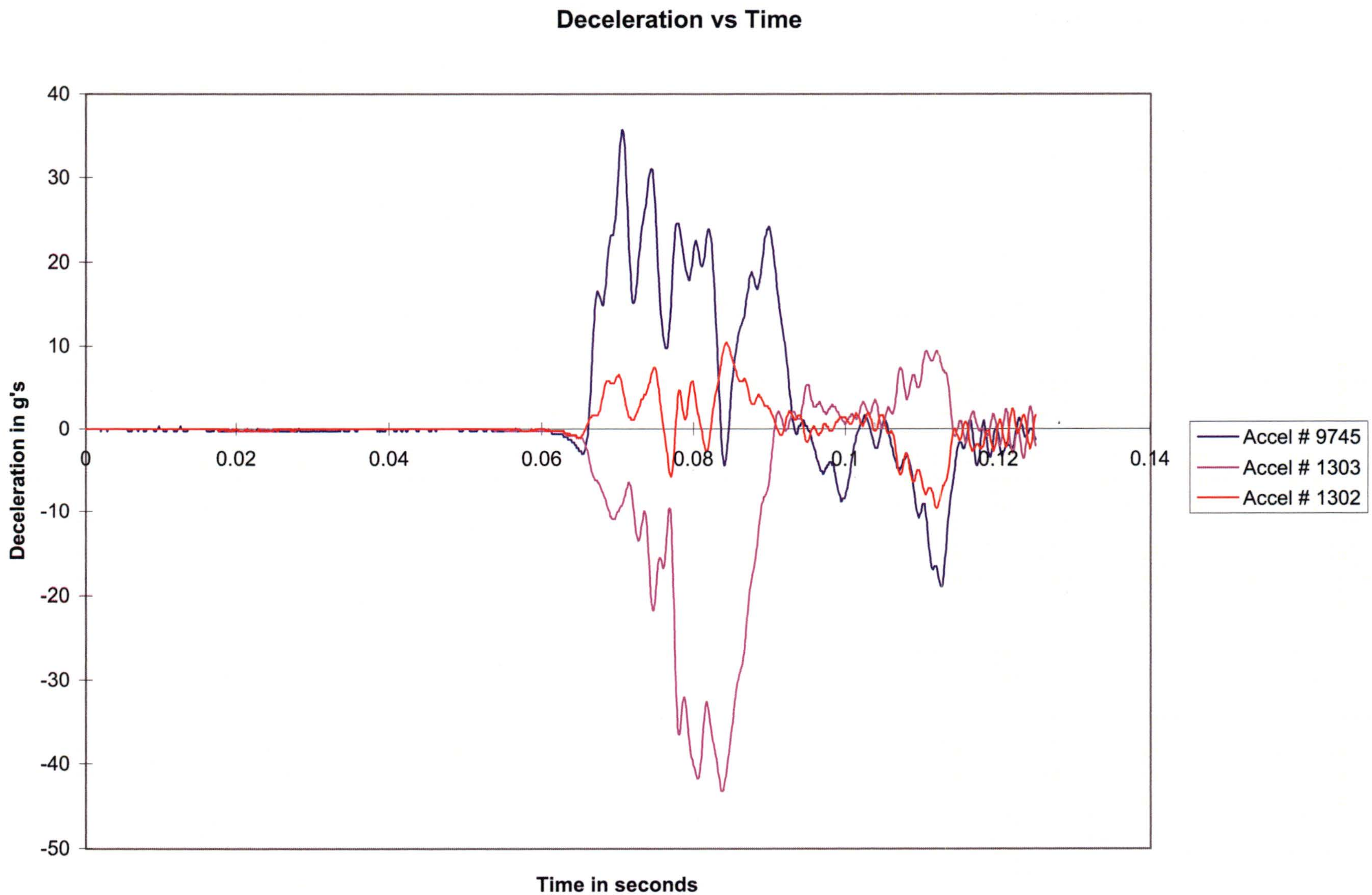
FIGURE #2: Orientation of Accelerometers

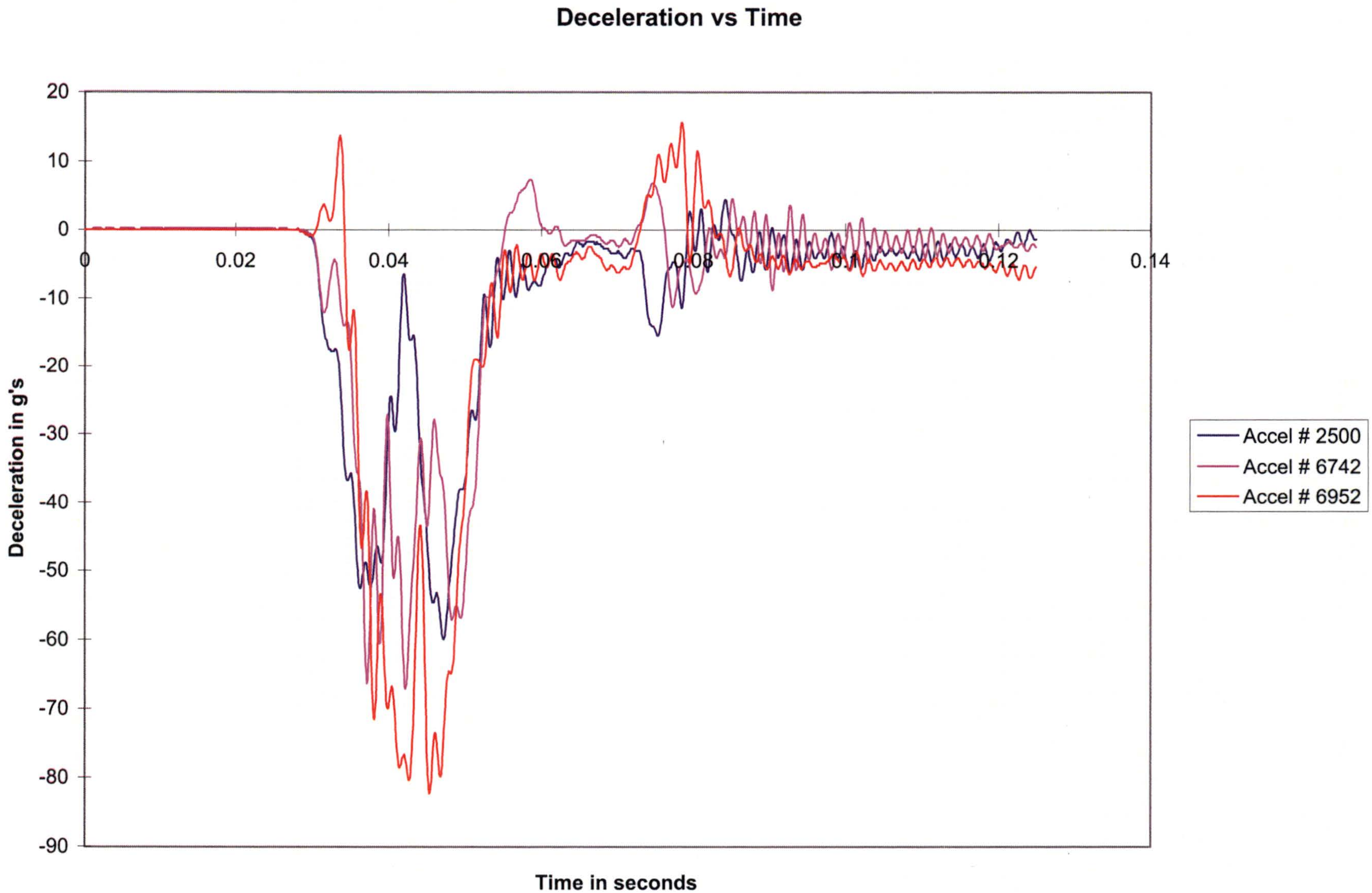

Deceleration vs Time
Deceleration in g's
40
35
30
25
20
15
10
5
0
-5
0
0.02
0.04
0.06
0.08
0.1
0.12
0.14
Time in seconds
Accel # 2500
Accel # 6742

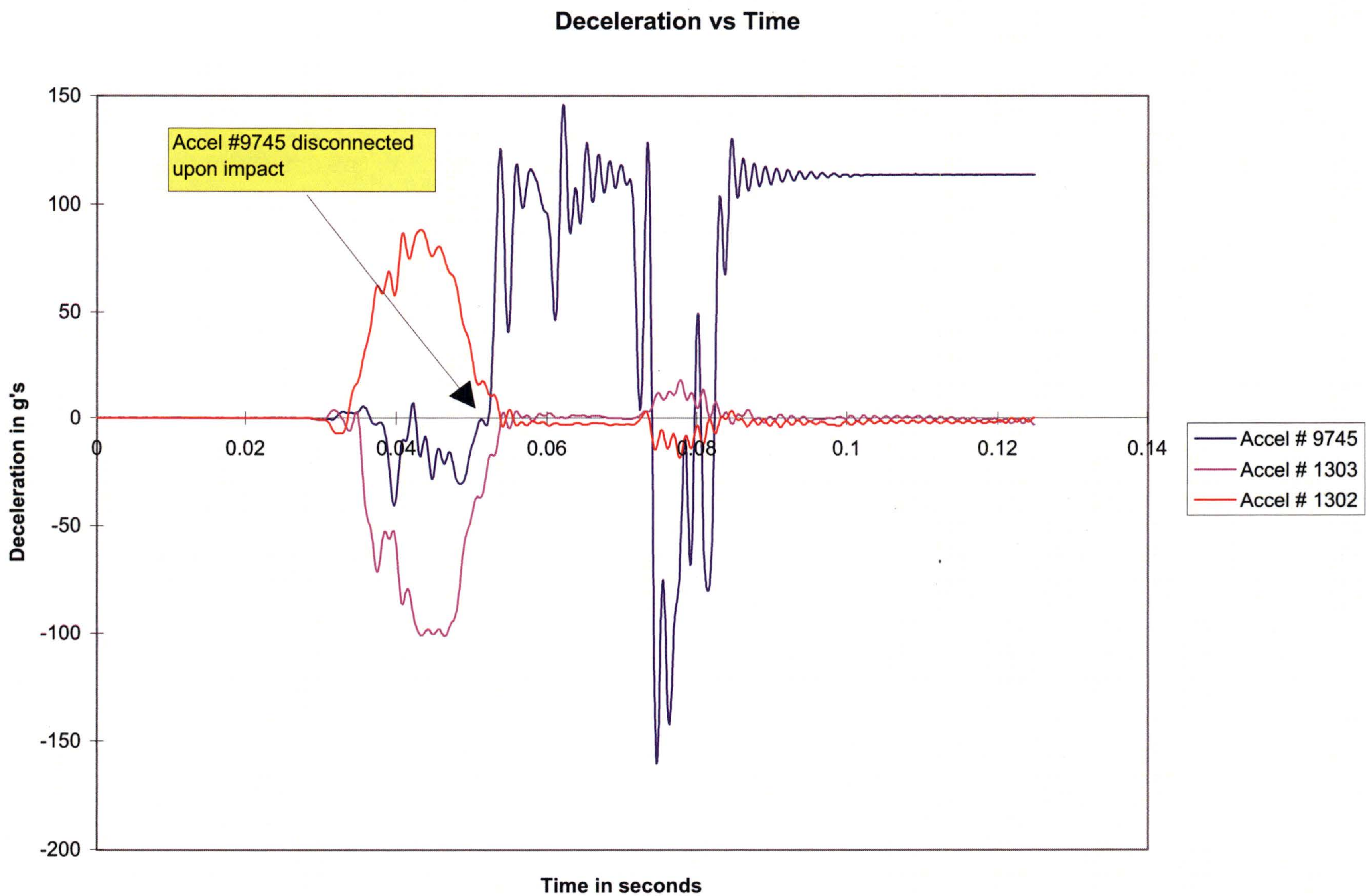

Deceleration vs Time
40
35
30
25
20
15
10
5
0
-5
Deceleration in g's
0
0.02
0.04
0.06
0.08
0.1
0.12
0.14
Time in seconds
Accel # 1303

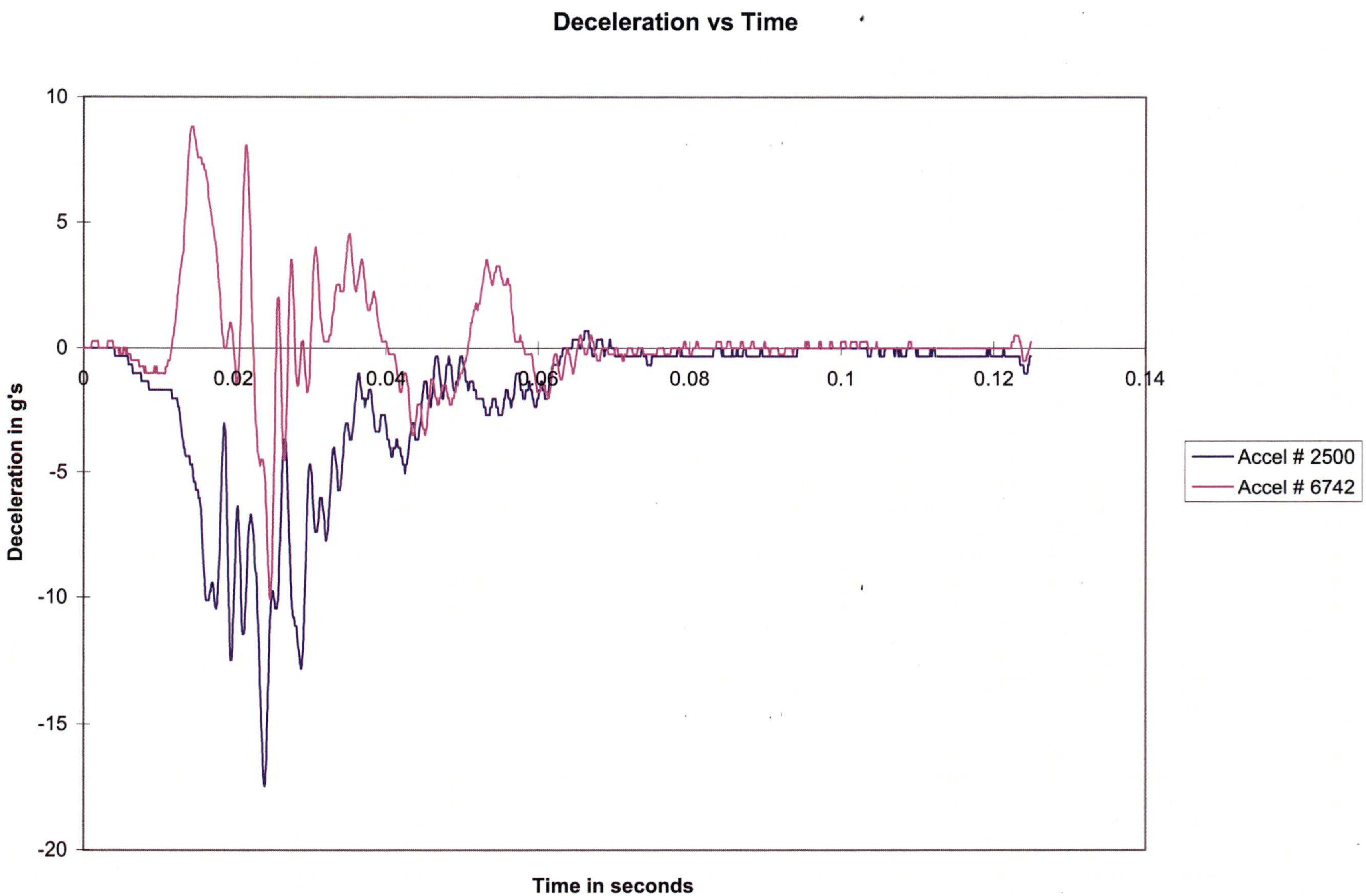

Deceleration vs Time
Deceleration in g's
120
100
80
60
40
20
0
-20
-40
-60
-80
0
0.02
0.04
0.06
0.08
0.1
0.12
0.14
Time in seconds
Accel # 2525

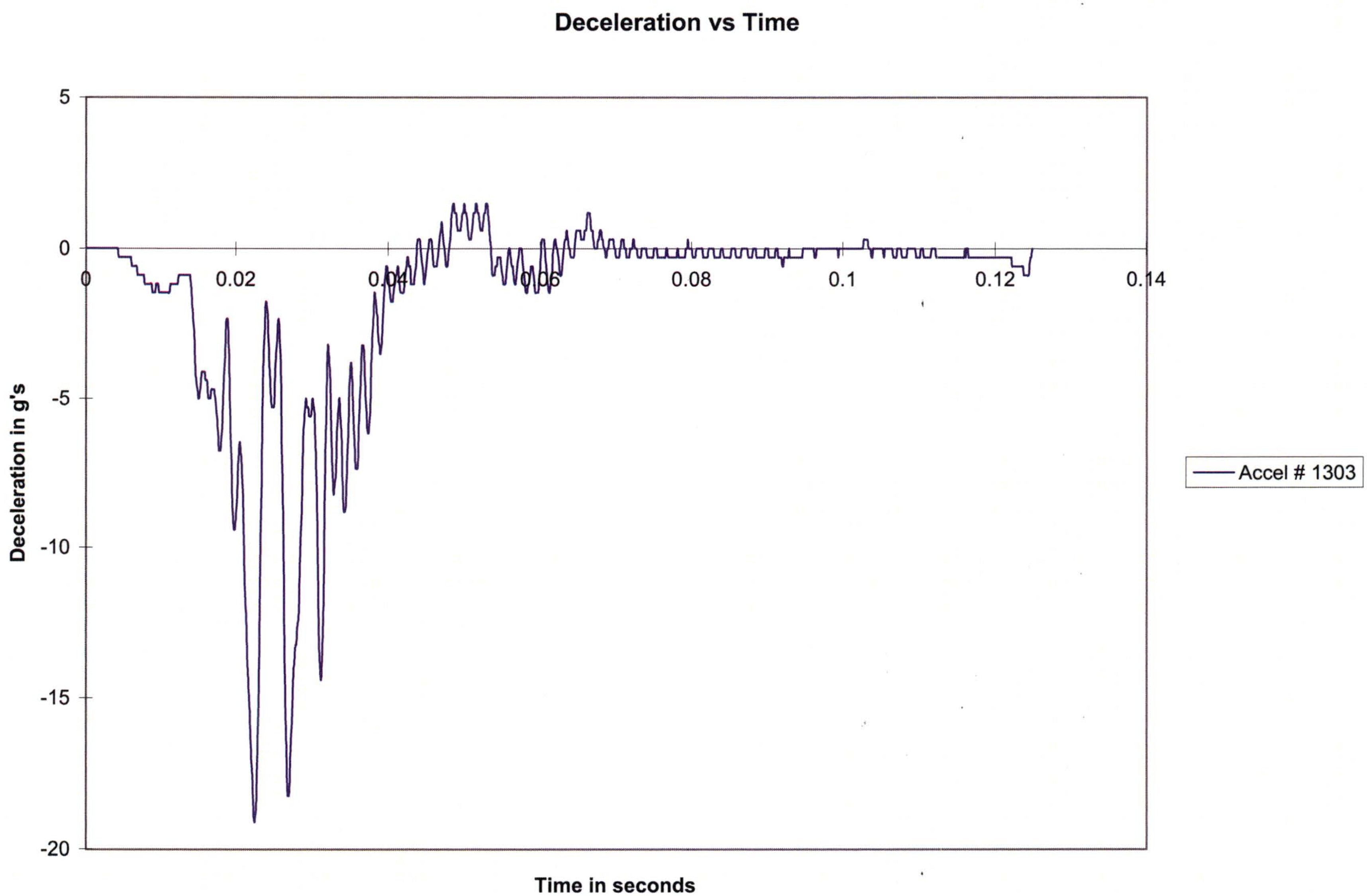

Deceleration vs Time
20
10
0
-10
-20
-30
-40
-50
0
0.02
0.04
0.06
0.08
0.1
0.12
0.14
Deceleration in g's
Time in seconds
Accel # 2500
Accel # 6742
Accel # 6952

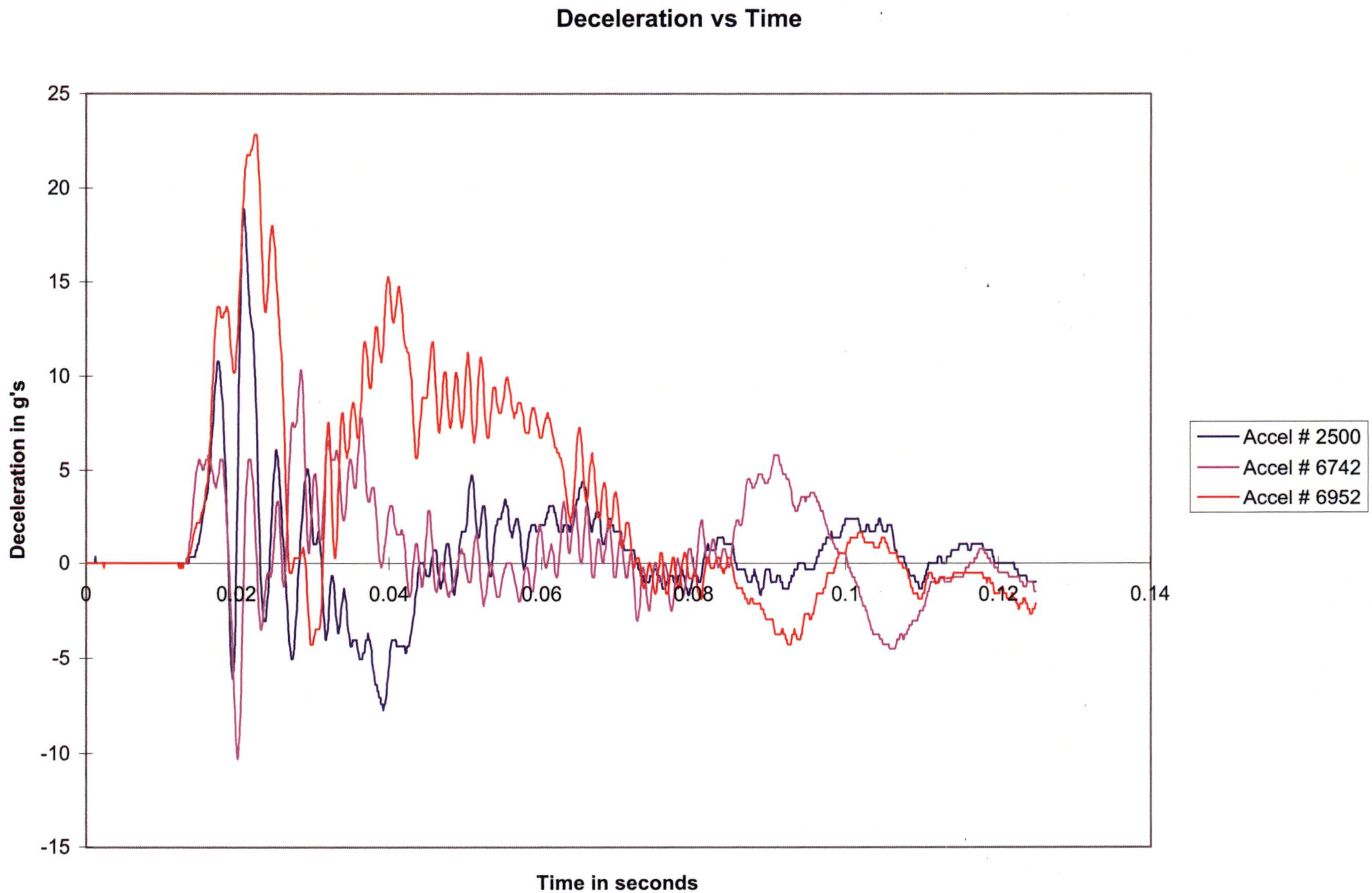

Deceleration vs Time
40
30
20
10
0
-10
-20
-30
-40
-50
Deceleration in g's
0
0.02
0.04
0.06
0.08
0.1
0.12
0.14
Time in seconds
Accel # 9745
Accel # 1303
Accel # 1302

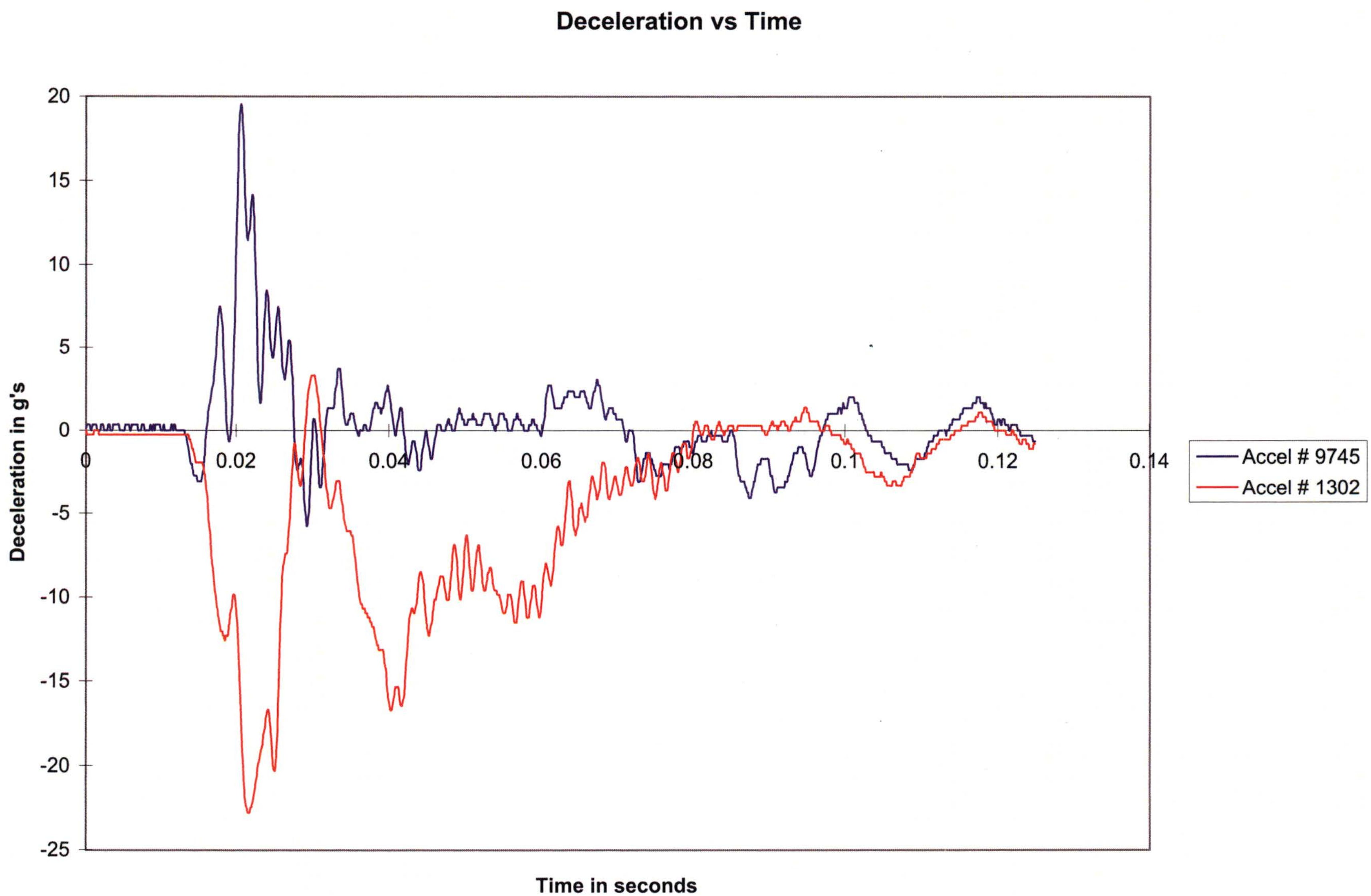

Deceleration vs Time
20
10
0
-10
-20
-30
-40
-50
-60
-70
-80
-90
0
0.02
0.04
0.06
0.08
0.1
0.12
0.14
Deceleration in g's
Time in seconds
Accel # 2500
Accel # 6742
Accel # 6952

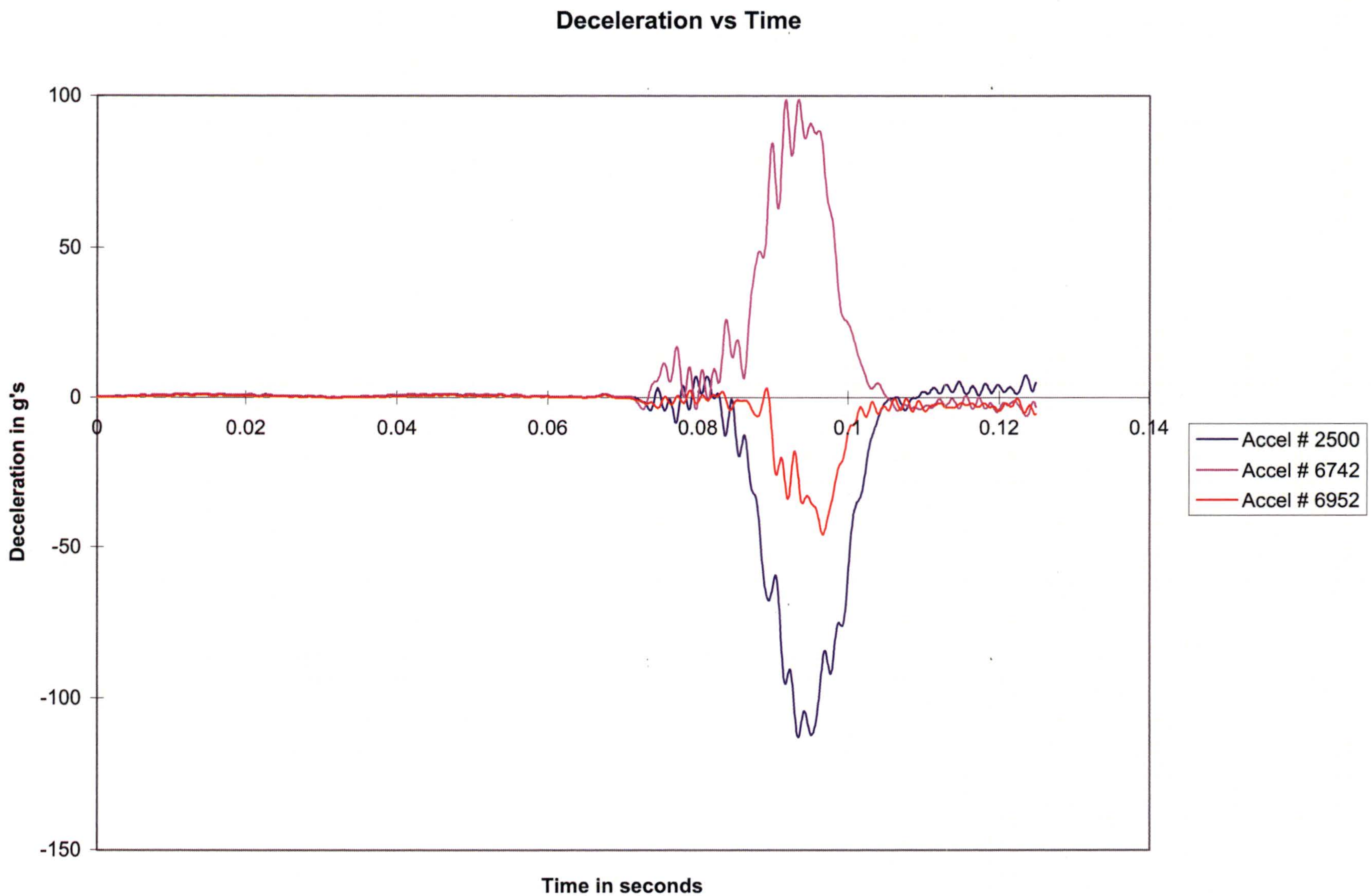

Deceleration vs Time
Accel #9745 disconnected upon impact
150
100
50
0
-50
-100
-150
-200
0
0.02
0.04
0.06
0.08
0.1
0.12
0.14
Deceleration in g's
Time in seconds
Accel # 9745
Accel # 1303
Accel # 1302

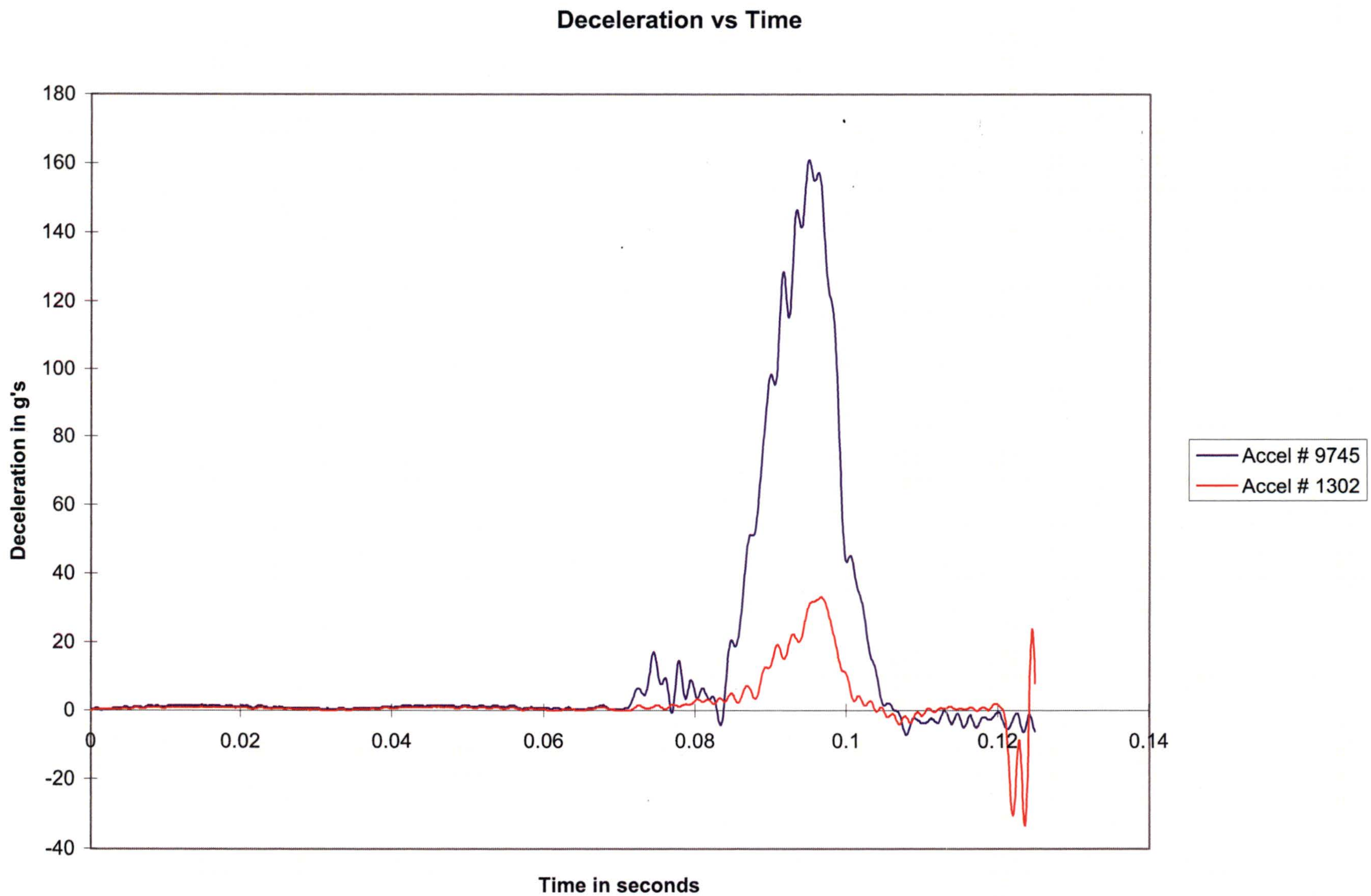

Deceleration vs Time
10
5
0
-5
-10
-15
-20
0
0.02
0.04
0.06
0.08
0.1
0.12
0.14
Deceleration in g's
Time in seconds
Accel # 2500
Accel # 6742

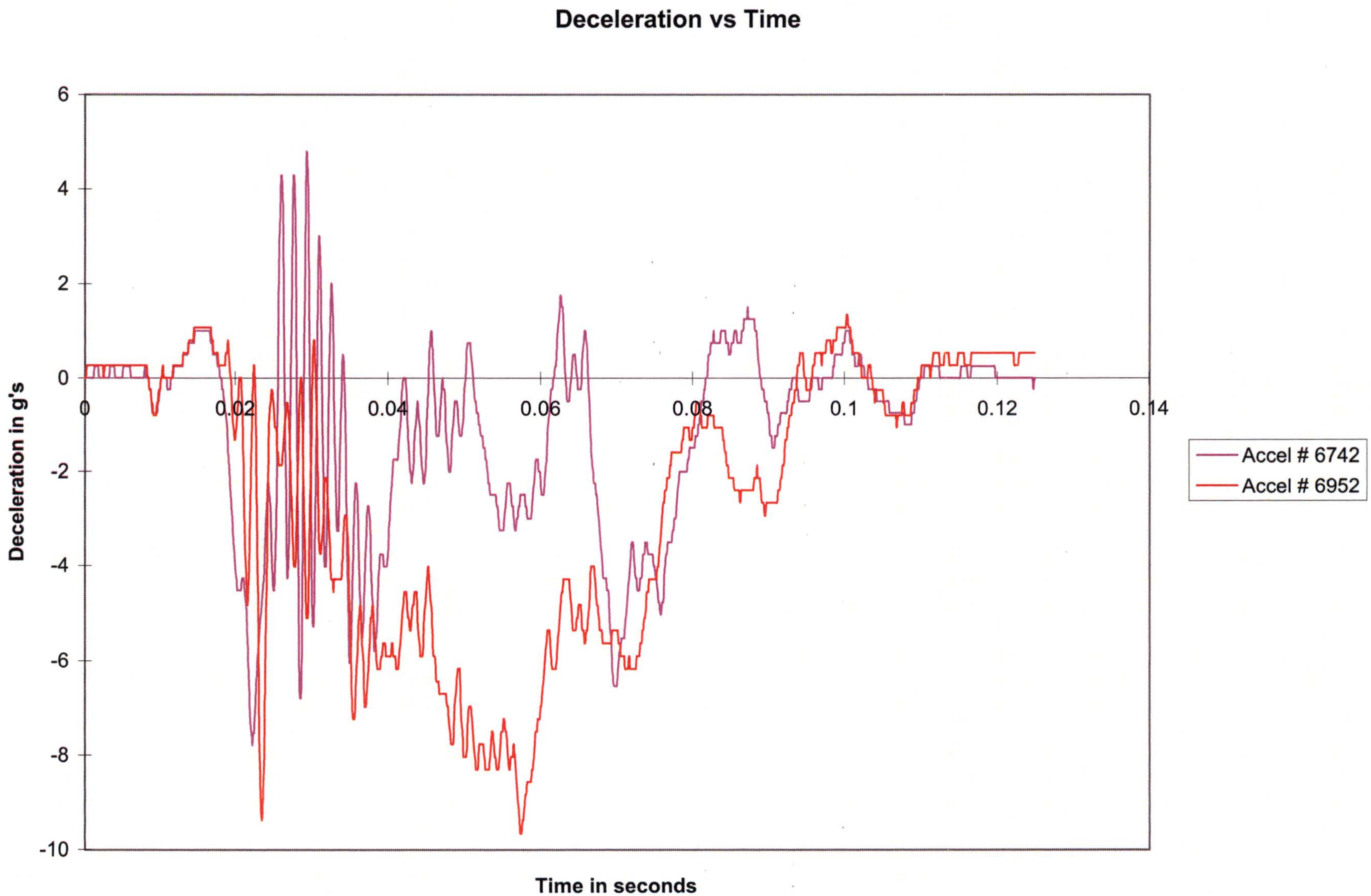

Deceleration vs Time
5
0
-5
-10
-15
-20
0
0.02
0.04
0.06
0.08
0.1
0.12
0.14
Deceleration in g's
Time in seconds
Accel # 1303

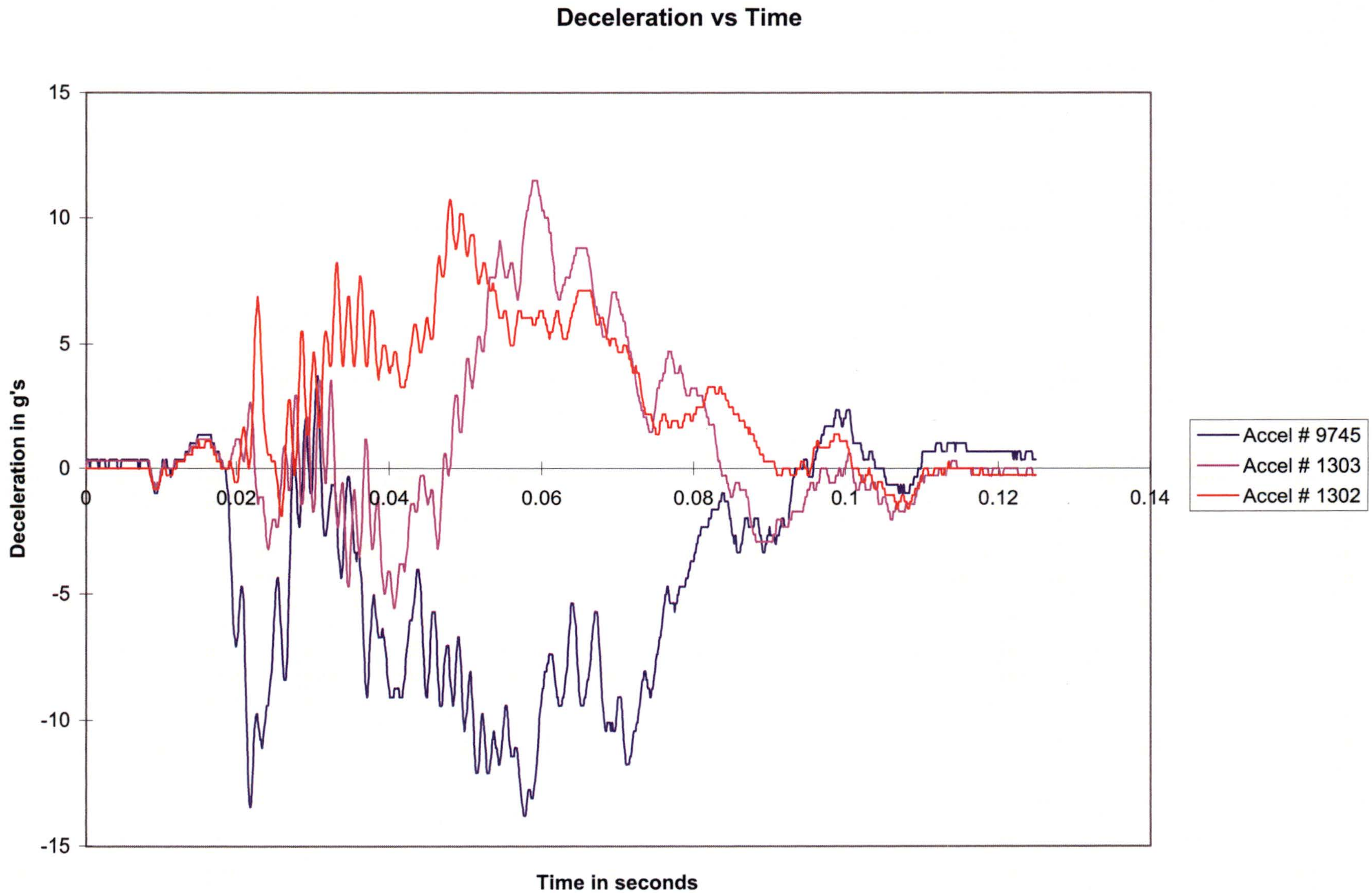

Deceleration vs Time
25
20
15
10
5
0
-5
-10
-15
0
0.02
0.04
0.06
0.08
0.1
0.12
0.14
Deceleration in g's
Time in seconds
Accel # 2500
Accel # 6742
Accel # 6952

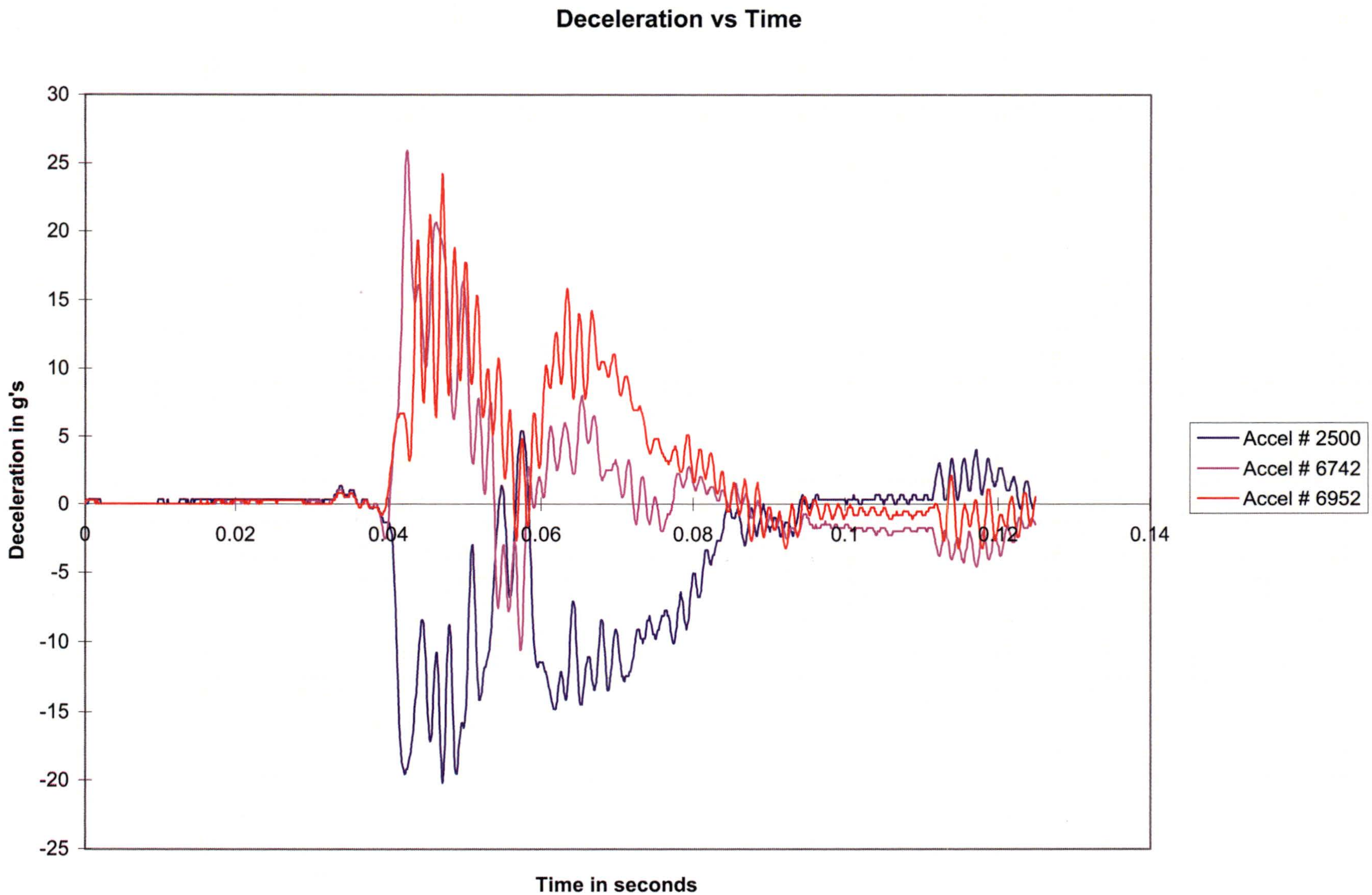

Deceleration vs Time
20
15
10
5
0
-5
-10
-15
-20
-25
Deceleration in g's
0
0.02
0.04
0.06
0.08
0.1
0.12
0.14
Time in seconds
Accel # 9745
Accel # 1302

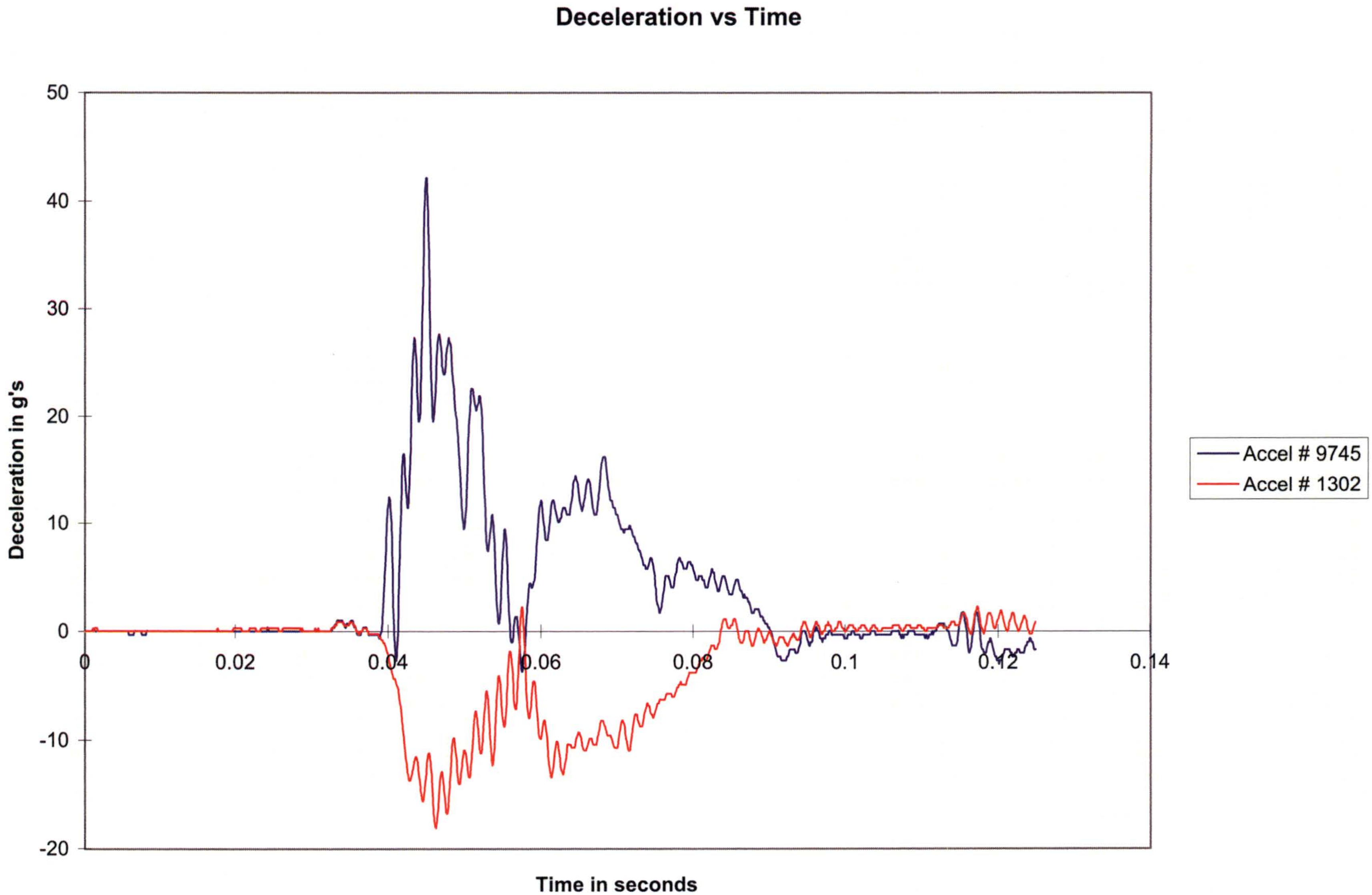

Deceleration vs Time
100
50
0
-50
-100
-150
Deceleration in g's
0
0.02
0.04
0.06
0.08
0.1
0.12
0.14
Time in seconds
Accel # 2500
Accel # 6742
Accel # 6952


Deceleration vs Time
180
160
140
120
100
80
60
40
20
0
-20
-40
Deceleration in g's
0
0.02
0.04
0.06
0.08
0.1
0.12
0.14
Time in seconds
Accel # 9745
Accel # 1302


Deceleration vs Time
6
4
2
0
-2
-4
-6
-8
-10
0
0.02
0.04
0.06
0.08
0.1
0.12
0.14
Deceleration in g's
Time in seconds
Accel # 6742
Accel # 6952


Deceleration vs Time
15
10
5
0
-5
-10
-15
Deceleration in g's
0
0.02
0.04
0.06
0.08
0.1
0.12
0.14
Time in seconds
Accel # 9745
Accel # 1303
Accel # 1302


Deceleration vs Time
30
25
20
15
10
5
0
-5
-10
-15
-20
-25
Deceleration in g's
0
0.02
0.04
0.06
0.08
0.1
0.12
0.14
Time in seconds
Accel # 2500
Accel # 6742
Accel # 6952


Deceleration vs Time
50
40
30
20
10
0
-10
-20
Deceleration in g's
0
0.02
0.04
0.06
0.08
0.1
0.12
0.14
Time in seconds
Accel # 9745
Accel # 1302

Appendix 2

CALIBRATION CERTIFICATES

Description	Make and Model	AECL QA Number
Multi-channel tape recorder	TEAC Model XR7000	# 456-268
Amplifier	Kistler Dual Mode Model 5010	# 456-239
Hand-held shaker	B&K Calibration Exciter Type 4294	# FS 1217
Voltmeter	Keithley Multimeter Model 2001	# B5871

Canadian Instrumentation Services Group Ltd.

957-10896
Work Order Number

Certificate of Calibration

Issued to:
AECL-CHALK RIVER LAB
CENTRAL WAREHOUSE
BLDG 457

CHAULK RIVER, ONT, CAN
K0J 1J0

Calibrated by: Don Cleveland
Calibrated Date: June 24, 1999
Recall Date: June 22, 2000

Description: DATA RECORDER
Manufacturer: TEAC
Model #: XR-7000
Serial #: 772733
Asset #: C00021
Procedure: SEE DATA SHEET
Cal. State: AS FOUND

This certificate attests that this instrument meets or exceeds published specifications for the parameters tested and has been calibrated with standards traceable to one or more of the following: National Institute of Standards and Technology (NIST), the National Research Council (NRC), fundamental or natural physical constants with values assigned or accepted by NIST or NRC, ratio type or self calibration techniques, comparison to consensus standards. Evidence of traceability is on file at our metrology laboratory. The calibration environmental conditions are as recorded. The collective uncertainty of the measurement standards used do not exceed 25% of the applicable tolerance for each characteristic calibrated unless otherwise stated. The results documented in this certificate relate only to the item(s) calibrated or tested. Calibration interval assignment is the responsibility of the end user, when not specified Canadian Instrumentation Services Group will assign an appropriate calibration interval. This certificate may not be reproduced, except in full, without the written approval of Canadian Instrumentation Services Group.

The measurement standards used for this calibration are supported by a quality system which meets the intent of ISO/IEC Guide 25 and the requirements of ~ISO 9002-1994~ (QMI Certificate #002612) and the CISG QA Manual Rev.1.1.

Standards Used:

Tool #	Description	Calibration Due
ST244560	PRECISION DMM	October 14, 1999
ST299961	CALIBRATOR	February 28, 2000

Quality System Registered to ISO 9002 Certificate 002612

Issue Date: June 24, 1999

Approved By: S Collins

1091 Monaghan Road • Peterborough, Ontario K9J 5L4 • Phone: 705-748-5225 • Fax: 705-748-4559 • 1-800-419-3419 • Website: www.cisg.net

West Caldwell Calibration Laboratories Inc.

Certificate of Calibration

for

DUAL MODE AMPLIFIER

Manufactured By: KISTLER
Model No.: 5010 Serial No.: C70224
Calibration Recall No.: C5164

Submitted by:

Customer: Mr. Brain Luloff
Company: ATOMIC ENERGY OF CANADA LTD.

The subject instrument was calibrated to the indicated specification using standards traceable to the National Institute of Standards and Technology or to accepted values of natural physical constants. This document certifies that the instrument met the following specification upon its return to the submitter.

West Caldwell Calibration Laboratories Specification No. 5010 KIST (see attached)

Upon receipt for Calibration, the instrument was found to be:

Within (X)
Outside ( ) see attached data

the tolerance of the indicated specification.

West Caldwell Calibration Laboratories' calibration control system meets the following requirements, MIL-STD-45662A, ANSI/NCSL Z540-1, and ISO 9002

Calibration Date: August 20, 1999
Certificate No: C5164 - 1
Calibration Due: August 20, 2000

Approved by:

Stanley Christopher

West Caldwell Calibration Laboratories, Inc.
uncompromised calibration

Ste. 118
5200 Dixie Road
Mississauga Ont.
L4W 1E4

Telephone
(905) 624-3919
Fax
(905) 624 -3926

Spectris Technologies Inc.
90 Leacock Drive
Pointe-Claire, QC H9R 1H1
Telephone: (514) 695-8225
Fax: (514) 695-4808

CERTIFICATE OF CALIBRATION

Brüel & Kjær
spectris group

CUSTOMER : Atomic Energy of Canada Ltd.

Calibration Exciter Type : 4294 Serial No. : 1218159 Ref. No. : 4319

CALIBRATION CONDITIONS :

Air Temperature : 22 °C Air Pressure : 1013 hPa Relative Humidity : 57 %

PROCEDURE :

The calibration is performed by measurement of the Acceleration Level , using Bruël & Kjaer Standard Calibration Set Type 3506 s.n. 1137339.
The Standard Calibration Set is calibrated by laser-interferometer in accordance with ISO 5347.

RESULTS :

The following documented Acceleration Level result is valid with the instrument under test placed in the **vertical position.** The load mass documented below corresponds to the mass of the measuring accelerometer from the Standard Calibration Set.

Acceleration Level : 9.99 ms^{-2} R.M.S.

Frequency : 159.0 Hz

Load Mass : 40 grams

The above results are traceable to N.I.S.T.

The estimated uncertainty for Acceleration Level is ±0.6 % at 95% confidence level. The calibration standards used are documented below.

CALIBRATION SYSTEM

I.D.	Description	Type No.	Serial No.	Cal. Date	Cal. By
27	Multimeter	3458A	2823A11758	05 Nov 97	Hewlett-Packard
35	Calibration Set (B)	3506	1137339	10 Sep 97	B&K Denmark

Date of Calibration : 22-Jun-98 Certificate issued : 22-Jun-98

Calibrated by : *[signature]* M. Iacobaccio Approved by : *[signature]* S. Tierney

ATOMIC ENERGY OF CANADA LTD.
BUILDING 409 CALIBRATION LAB
REPORT OF CALIBRATION

CUSTOMER WORK ORDER NUMBER: DATE: 19-Jul-99

UNIT UNDER TEST: Keithley 2001 Verify (FRONT) Part 1
PROCEDURE NAME: Keithley 2001 Verify (FRONT) Part 1
SERIAL NUMBER: 0545140
ASSET NUMBER: B5871
CUSTOMER: Bldg. 456 Brian Lulloff
CUSTOMER PURCHASE ORDER NUMBER:

RESULT	PASS
NOTIFY USER (IF > 0)	0
FAILED FINAL TESTS	0
CALIBRATED BY	Joseph Soucy
TEMPERATURE	24.5°C
RELATIVE HUMIDITY	85.0%

STANDARDS USED

Instrument Model	Asset Number	Cal Date	Due Date
Fluke 5700A	409-101	16-Jun-99	13-Dec-99
Fluke 5725A	409-101	16-jun-99	13-Dec-99

REMARKS: As Found/As Left Results

Metrology Technician

Lab Manager

APPENDIX 2.10.3b:
F-430 Supplementary Analysis Report

IN/TR 6088 F430 (C)

Supplementary Safety Analysis Report for the F-430 Transport Package

Signatures

Prepared by: [redacted] Date: 6-Mar-12

Reviewed by: [redacted] Date: MAR 06/2012

Approved by: [redacted] Date: March 8, 2012

Document History

Date	Version	Comments	Prepared by	Reviewed by	Approved by
Oct. 2011	A	DC30761	B. Menna	V. Moga	R. Wassenaar
Feb. 2012	B	DC30806	J. Barroeta Robles	V. Moga	R. Wassenaar
Mar. 2012	C	DC30825			

NOTE: A vertical line in the margin (tracking bar), denotes change. For complete rewrites, tracking bars are not used.

TABLE OF CONTENTS

CHAPTER 1 – GENERAL INFORMATION

1.1 INTRODUCTION

The Best Theratronics F-430 transport package has been developed as a safe means of transporting self-contained irradiators (SCI). The F-430 was designed principally to transport the Gammacell 40 Irradiator (GC40) (see Figure 1).

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

This report describes some changes to the GC40 design due to the incorporation of additional security features and their affect on the safety analysis of the F-430.

The changes to the GC40 were implemented to delay the potential unauthorized access to the sealed sources from the outside of the irradiator. There are two versions of the new design. The first version is intended to be installed on existing devices at licensees' sites (field retrofit) and the second version will be incorporated on new devices during manufacturing (in-house). The design is the same for both versions (see Figure 2). This Safety Analysis Report (SAR) demonstrates that the F-430 overpack can safely transport the new GC40 design.

1.2 PACKAGE DESCRIPTION

1.2.1 Packaging

The design of the F-430 is described in the existing SAR [1]. Except for changes to the payload, the design of the F-430 is unchanged.

The F-430 is a stainless steel drum 1.27 m (50 in.) in outside diameter, 1.27 m (50 in.) in height, placed on a removable steel skid 1.27 x 1.27 x 0.20 m (50 in. x 50 in. x 8 in.). It has a cylindrical cavity 0.914 m (36 in.) in diameter, 0.895 m (35.25 in.) in height. The main materials of construction are 304L stainless steel and rigid polyurethane foam.

1.2.2 Contents

The Gammacell 40 (GC40) is a self-contained irradiator used primarily for research. It consists mainly of an upper and a lower shielding head, each containing one Cs-137 sealed source.

The proposed design changes have no affect on the operation of the GC40 when it is installed in the laboratory. However, the new features added to the device make it harder to dismantle and this has an impact on how the device is prepared for shipment. The different designs of the GC40 and the process of preparing the shielding heads for shipment are discussed in the following paragraphs.

When preparing the GC40 for shipment, the device is partially disassembled from the laboratory configuration. The covers, the drive systems and the mechanical interlock are removed and the shielding heads are separated.

During transport, it is important to secure the source drawer from movement within the head. Currently, this is done with two redundant means. First, the Retaining Ring is removed from one end of each head and a Shipping Tube is installed (Refer to Figure 1). The Shipping Tube has the same outside diameter as the Source Drawer and it fills the length of the bore not occupied by the Source Drawer. When the retaining ring is replaced, the Shipping Tube and Source Drawer are blocked in place.

In order to further secure the source drawer, Shipping Plates are fastened to each end of the shielding heads (Refer to Figure 1). The Shipping Plates block the Source Drawer Assembly inside the bore. The Source Drawer Assembly consists of the Source Drawer and the Drawer Interlock Bar. The Drawer Interlock Bar is part of the GC40 mechanical interlock. This steel bar is 1 inch square and passes through the Retaining Ring during operation of the GC40. However, when the Shipping Plates are installed, the Source Drawer Assembly cannot move.

The proposed new design of the GC40 incorporates many additional fasteners with security features. Because of the new features, it is not practicable to remove the mounting plates for transport (Refer to Figure 2). Therefore the Shipping Tube cannot be installed on upgraded units. However, the Source Drawer Assembly is secured from movement with Shipping Plates. The new Shipping Plates are very similar to the existing Shipping Plates. They fasten to the GC40 shielding head using the same fasteners as before (four 3/8-16 socket head cap screws. Additionally, a ½-20 socket head cap screw fastens through one of the Shipping Plates into the Source Drawer. This further secures the source drawer.

An important feature of the existing Shipping Plate is the fact that it is partly recessed in a cournterbore on the GC40 shielding head. In the event of an impact, the force on the shipping plate is borne by the interface with this counterbore, as well as the fasteners. The new Shipping Plates maintain this feature (refer to Figure 2).

Because the Mounting Plates are left in place for transport, the weight of the GC40 shielding heads each increases by approximately 7 kg (15 lb.). The effect of this slight increase in weight is discussed in Chapter 2.

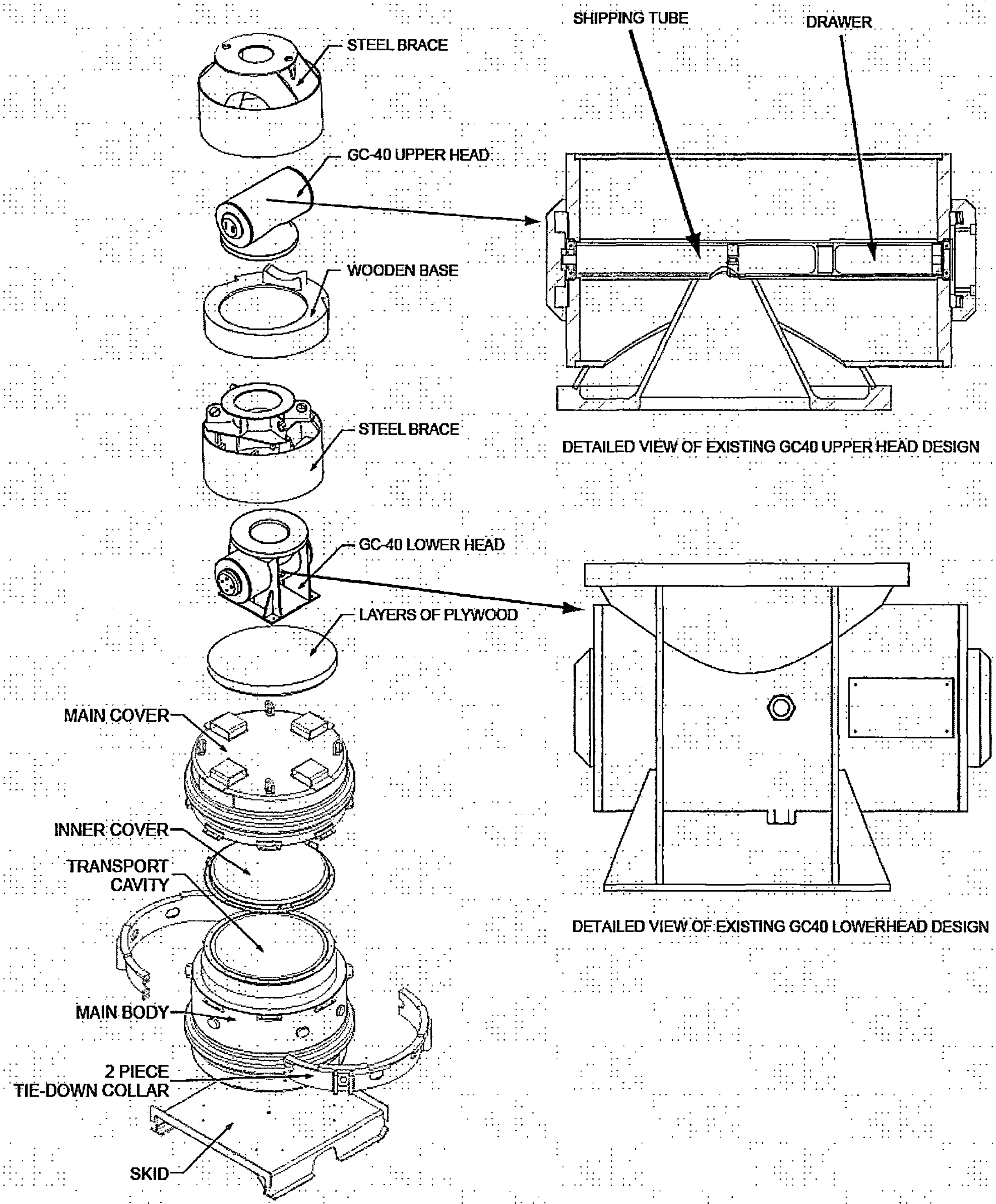


Figure 1: GC40 Existing Design Prepared For Shipment

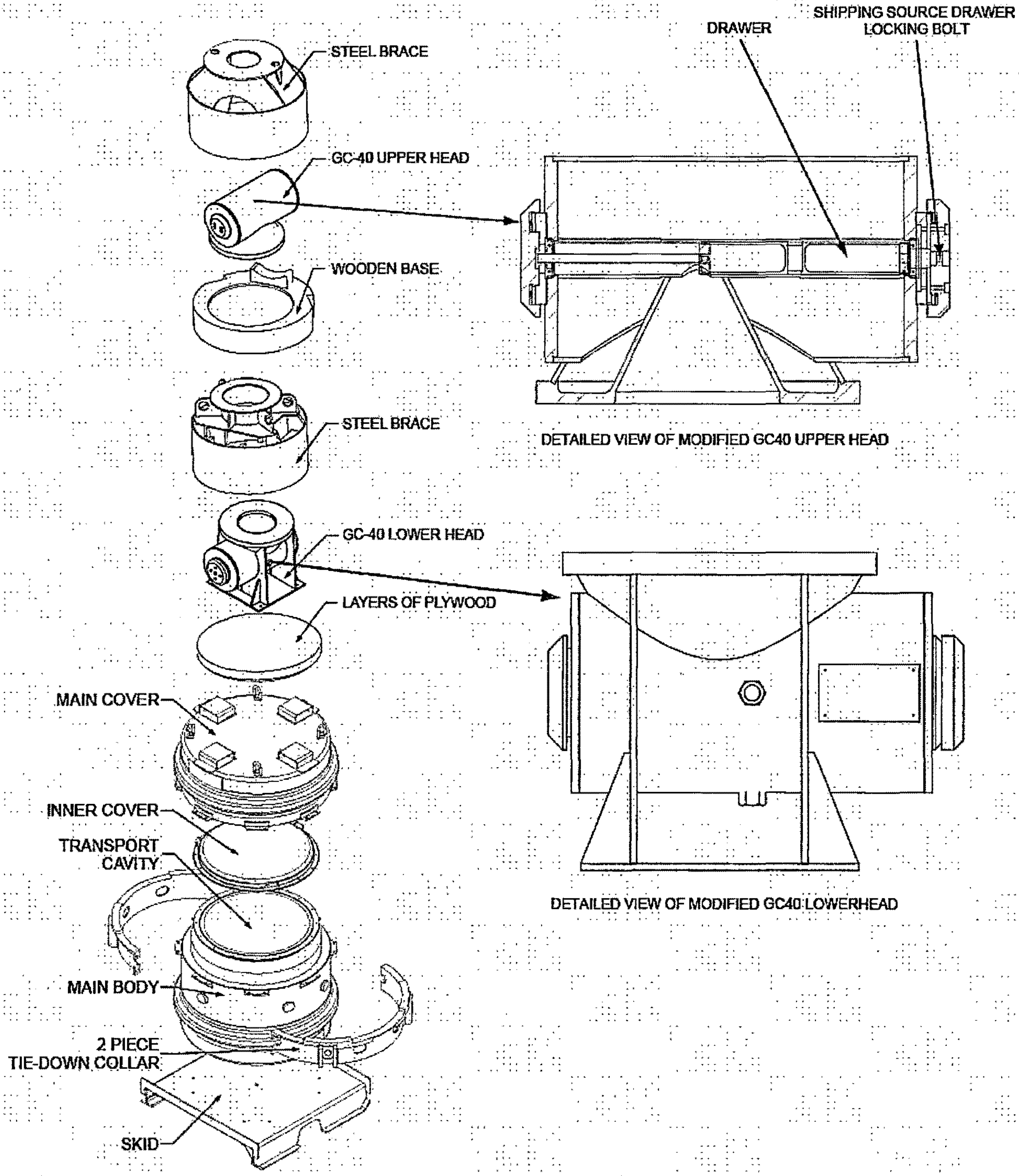


Figure 2: GC40 Modified Design (field retrofit and in-house) Prepared For Shipment

1.2.3 Special Requirements for Plutonium

The F-430 does not contain plutonium, therefore this section is not applicable.

1.2.4 Operational Features

The F-430 is a simple package from an operational perspective. There are no valves or piping. The package consists of a main body, and inner lid and an outer lid. The procedure for preparing the package for shipment is described in Chapter 7.

1.3 REFERENCES

[1] Menna, Blair. Safety Analysis Report for the F-430/GC40 Transport Package, MDS Nordion Technical Report No. IN/TR 1608 F430, March 2010.

1.4 APPENDICES

Appendix 1.4.1 F-430 Engineering Information Drawing

Appendix 1.4.1:
F-430 Engineering Information Drawing
F643001-001 rev P (sheets 1 & 2)

[redacted]

[redacted]

[redacted]

CHAPTER 2 – STRUCTURAL EVALUATION

This chapter presents the structural evaluation that demonstrates that the Best Theratronics F-430/GC40 package design meets all applicable structural criteria. The F-430 SAR [1] presents the overall experimental verification and evaluation of the F-430. This supplementary SAR demonstrates that the proposed design changes for the GC40 also satisfy the regulatory structural requirements.

2.1 DESCRIPTION OF STRUCTURAL DESIGN

The design criteria and the codes and standards for the F-430 package design have not changed.

The principal structural members and components of the F-430 package have not changed. The inner bracing has not changed. Only the means of securing the Source Drawer from movement has changed. The impact of this change is discussed in Section 2.7.

The weight of the new GC40 head design increases by approximately 7 kg (15 lb.). The weights of the various GC40 head configurations are listed in Table 2-1. The F-430 structural analysis in the F-430 SAR was based on a payload weight of 1740 kg (3835 lb.) and a total package weight of 3175 kg (7000 lb.)[1]. Since the weight of the GC40 remains less than that in the original analysis, the existing analysis is still valid.

Table 2.1: GC40 Head Weights

Component	Weight
GC40 Upper Head (Original Design)	1157 kg (2550 lb.)
GC40 Lower Head (Original Design)	1241 kg (2735 lb.)
GC40 Upper Head (New Design)	1164 kg (2565 lb.)
GC40 Lower Head (New Design)	1248 kg (2751 lb.)
GC40 Test Specimen	**1740 kg (3835 lb.)**

2.2 MATERIALS

The mechanical properties of materials are addressed in IN/TR 1608 F430 [1]. The discussion regarding material properties, specification, chemical and galvanic reactions and the effects of radiation are unchanged.

2.3 FABRICATION AND EXAMINATION

The fabrication and examination processes for the F-430 are unchanged from the original SAR [1].

2.4 GENERAL STANDARDS FOR ALL PACKAGES

The proposed design changes to the F-430 contents have no affect on the package's ability to satisfy the general standards for all packages. Therefore the analysis in IN/TR 1608 F430 [1] remains valid.

2.5 LIFTING AND TIE-DOWN STANDARDS FOR ALL PACKAGES

Although the weights of the GC40 Upper and Lower Heads have increased slightly, the original analysis of the F-430 contained a margin for an increase in weight. The existing analysis in IN/TR 1608 F430 [1] is based on a total package weight of 3175 kg (7000 lb.) and a GC40 test specimen weight of 1740 kg (3835 lb). The new maximum weight of GC40 heads is 1248 kg (2751 lb). This is less the weight of the test specimen and therefore the analysis remains valid.

2.6 NORMAL CONDITIONS OF TRANSPORT

The design changes to the GC40 do not affect the performance of the F-430/GC40 under the normal conditions of transport. The original analysis in IN/TR 1608 F430 [1] remains valid and the effectiveness of the package will not be reduced as a result of the normal conditions of transport.

2.7 HYPOTHETICAL ACCIDENT CONDITIONS

The F-430/GC40 was subjected to the hypothetical accident conditions of transport by test and analysis. The test specimen included an additional 500 kg of lead added to the GC40 payload. A single test specimen was subjected to nine drop tests including three drops from 9 meters.

After the drop tests, the GC40 was inspected and found to have suffered very little damage. This is because the F-430 overpack absorbed almost all of the energy and the GC40 is cradled firmly inside the Inner Brace. The Shipping Plates were completely protected during the drop tests. Since these are the only features that have changed as a result of the design change, the new shipping configurations will also survive the drop test without damage.

The changes to the GC40 have no affect on the performance of the F-430/GC40 with respect to thermal or water immersion. Therefore, the original analysis for the Hypothetical Accident Conditions remains valid.

2.8 ACCIDENT CONDITIONS FOR AIR TRANSPORT OF PLUTONIUM

The F-430 does not contain plutonium, therefore these requirement are not applicable.

2.9 ACCCIDENT CONDITIONS FOR FISSILE MATERIAL PACKAGES FOR AIR TRANSPORT

The F-430 does not contain fissile material, therefore these requirement are not applicable.

2.10 SPECIAL FORM

The special form sources inside the F-430 are not changing and therefore the analysis in IN/TR 1608 F430 [1] remains applicable

2.11 FUEL RODS

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

2.12 REFERENCES

[1] Menna, Blair. Safety Analysis Report for the F-430/GC40 Transport Package, MDS Nordion Technical Report No. IN/TR 1608 F430, March 2010.

CHAPTER 3 – THERMAL EVALUATION

This chapter presents a thermal evaluation demonstrating that the Best Theratronics F-430/GC40 package design meets all applicable thermal criteria. The original F-430 SAR [1] presents the overall analysis and evaluation of the F-430.

3.1 DISCUSSION

The proposed changes to the GC40 will have no impact on the thermal evaluation of the F-430.

3.2 SUMMARY OF THERMAL PROPERTIES OF MATERIALS

A summary of the thermal properties of materials is presented in IN/TR 1608 F430 [1] and remains valid.

3.3 TECHNICAL SPECIFICATIONS OF COMPONENTS

Technical specifications of components is addressed in IN/TR 1608 F430 [1] and are unchanged.

3.4 THERMAL EVALUATION FOR NORMAL CONDITIONS OF TRANSPORT

The thermal analysis of the F-430 under the Normal Conditions of Transport is presented in IN/TR 1608 F430 [1]. The original analysis conservatively assumed that the internal heat generation was 100W. The heat generated by the GC40 is unchanged.

Two analyses were performed for the Normal Conditions of Transport; a steady state analysis and a 12 hour transient analysis. Both analyses assumed an ambient temperature of 38°C and solar heat fluxes as defined by the Regulations.

The steady state analysis was conservative and overstated the temperatures inside the F-430. On the top of the F-430, where the solar heat flux was greatest (800 W/m^2), the temperature reached 126°C. On the sides of the F-430, the temperatures were lower (typically around 89 °C), since the solar heat flux was lower (400 W/m^2). Moving from the outside toward the center of the package, the temperatures dropped across the outer layer of low-density foam to around 125°C. Due to the heat generated internally by the Gammacell, the temperature increases across the inner layer of high-density foam, typically to about 133°C. The highest temperature (143°C) occurred inside the GC40 shield. Since the Gammacell shield is made of highly conductive materials (steel and lead), it has a relatively uniform temperature of around 142°C. The new features added to the Gammacells (also steel) will have no impact on the temperatures of the Gammacell shield.

The transient thermal analysis was more realistic. The solar heat fluxes were applied for a duration of 12 hours. The highest temperature (124°C) occurred on the outside top surface of the F-430. On the sides of the F-430, the temperatures were lower (typically around (86°C). The temperature gradients were most significant across the thickness of the top of the F-430 overpack. Across the outer layer of polyurethane foam, the temperature drops to about 80°C. Moving closer to the center of the package, the temperatures start to increase again due to the heat generated by the sealed source. However, temperatures inside the F-430 overpack are relative stable, ranging from 80°C to 96°C. Because the temperatures across the GC40 are very uniform, the new steel components will have no affect on the transient thermal analysis.

3.5 HYPOTHETICAL ACCIDENT THERMAL EVALUATION

The analysis of the F-430 during the hypothetical accident thermal conditions showed that the thick outer layer of polyurethane foam was very effective in insulating the Gammacell inside. At the end of the 30 minute fire, the outside surface of the F-430 overpack was near 800°C, but the temperature dropped to 200°C over the first few inches of the polyurethane foam. Inside the overpack cavity and throughout the Gammacell shield, temperatures were relatively uniform at around 100°C. Since the temperature gradients inside the overpack were very small, the changes to the Gammacell would have very little effect on the temperatures at the end of the 30 minute fire.

Immediately after the fire was extinguished, the outside surfaces of the F-430 began to cool. However the heat absorbed in the outer layers of the overpack continued to flow inward toward the payload. This heat transfer was slow and temperatures inside the Gammacell shield peaked 18 hours after the fire. During this period, the temperature gradient from the inside of the F-430 overpack cavity wall to the inside of the Gammacell shield was only about 10°C. Since the temperature gradient inside the overpack cavity was very low, the small changes to the Gammacell would have no effect on the heat transfer.

3.6 REFERENCES

[1] Menna, Blair. Safety Analysis Report for the F-430/GC40 Transport Package, MDS Nordion Technical Report No. IN/TR 1608 F430, March 2010.

CHAPTER 4 – CONTAINMENT

The containment system for the F-430 is defined as the sealed sources which are located inside the GC40 shielding heads. Since the sealed sources have not changed, the containment analysis presented in IN/TR 1608 F430 remains valid.

CHAPTER 5 – SHIELDING EVALUATION

The F-430 overpack is not intended to serve a shielding function. Shielding is provided by the GC40 shielding heads. The modifications to the GC40 design affect the exterior of the radiation shields and have no affect on the shielding performance. Therefore the shielding analysis presented in IN/TR 1608 F430 remains valid.

CHAPTER 6 – CRITICALITY EVALUATION

The requirements of this chapter are not applicable since the F-430 package does not transport fissile materials.

CHAPTER 7 – PACKAGE OPERATIONS

This chapter describes the procedure for preparing the F-430/GC40 for shipment. The intention is to ship heads without the additional security features (existing design) and with the additional security features (modified design).

7.1 OPERATING PROCEDURE

The original F-430 SAR [1] presents the complete procedure for preparing the F-430/GC40 for shipment.

The process of preparing the GC40/F430 for shipment consists of three main steps:

1. Dismantling the GC40 device
2. Securing the GC40 shielding heads for shipment
3. Loading the GC40 inside the F-430 and preparing the F-430 for shipment.

Only the process for securing the GC40 shielding heads for shipment has changed. The changes are minimal and are described below. The specific changes to the work instructions are listed in Table 7.1.

Because it is not practical to remove the extra security hardware, it is not possible to install the Shipping Tube (or "Tube Spacer") inside the bore of the GC40 heads. On devices that have the new security hardware, the step for installing the Shipping Tube is omitted.

The upgraded GC40 devices will use the new shipping plate. The procedure for installing the new shipping plates is unchanged, except that one additional ½-20 UNF screw is installed.

The process of loading the GC40 into the F-430 and preparing the F-430 for shipment is unchanged.

Table 7.1: Changes to Operating Procedures

Applicable Section of IN/TR 1608 F430	Existing Operation	New Operation
Section 7.2.1, Step 8 Section 7.2.2, Step 9 Section 7.2.3, Step 9	"Install the end Shipping Plate to the source head using the four 3/8-16 UNC x 45 mm long socket head screws provided"	To the current instructions, add "If the GC40 has the upgraded security hardware, install the ½-20 UNF socket head screw provided. Torque to 85 ft-lb."
Section 7.2.1, Step 12 Section 7.2.2, Step 13 Section 7.2.3, Step 13	"Unscrew the upper Source Drawer retaining ring and insert the Tube Spacer over the interlock bar into Source Drawer bore. This tube retains the source in the Safe position during shipment."	To the current instructions, add "If the GC40 has the upgraded security hardware installed, this step is omitted."
Section 7.3.1, Step 2, a)	a) "Insert the drawer shipping spacer in the source tube."	To the current instructions, add "If the GC40 has the upgraded security hardware installed, this step is omitted."
Section 7.3.1, Step 2, b)	b) "Screw the locking rings into the source tube at both ends of the respective heads."	To the current instructions, add "If the GC40 has the upgraded security hardware installed, this step is omitted."
Section 7.3.1, Step 2,c)	c) "Install the drawer shipping plate at both ends using four 3/8-16 UNC x 1.75 in. long ASTM A490 socket head screws or the approved equivalent. Torque each screw to 20 to 22 Nm (180 to 200 in-lb.)"	To the current instructions, add "If the GC40 has the upgraded security hardware, install the ½-20 UNF socket head screw provided. Torque to 85 ft-lb."

7.2 REFERENCES

[1] Menna, Blair. Safety Analysis Report for the F-430/GC40 Transport Package, MDS Nordion Technical Report No. IN/TR 1608 F430, March 2010.

CHAPTER 8 – ACCEPTANCE TESTS AND MAINTENANCE PROGRAM

The Acceptance Tests and Maintenance Program for the F-430 are described in IN/TR 1608 F430 and are unchanged.

CHAPTER 9 – QUALITY ASSURANCE

On May 1, 2008, MDS Nordion sold its teletherapy and self-contained irradiator businesses to Best Medical. The former MDS Nordion operations are now known as Best Theratronics Ltd. At the time of the sale, MDS Nordion transferred to Best Theratronics the F-430 Transport Packages and all of the associated designs and procedures.

9.1 BEST THERATRONICS QUALITY ASSURANCE PROGRAM

Best Theratronics continues to operate and maintain the F-430 transport packages in accordance with the original procedures and drawings that were transferred from MDS Nordion.

Best Theratronics' Quality Assurance has been approved by the USNRC. The approval certificate is attached in Appendix 9.2.1.

9.2 APPENDICES

Appendix 9.2.1 USNRC Quality Assurance Program Approval

APPENDIX 9.2.1:
USNRC Quality Assurance Program Approval For Radioactive Material Packages

NRC FORM 311 (10-2006) 10 CFR 71 U.S. NUCLEAR REGULATORY COMMISSION

QUALITY ASSURANCE PROGRAM APPROVAL
FOR RADIOACTIVE MATERIAL PACKAGES

1. APPROVAL NUMBER: 943

REVISION NUMBER: 0

Pursuant to the Atomic Energy Act of 1954, as amended, the Energy Reorganization Act of 1974, as amended, and Title 10, Code of Federal Regulations, Chapter 1, Part 71, and in reliance on statements and representations heretofore made in Item 5 by the organization named in Item 2, the Quality Assurance Program identified in Item 5 is hereby approved. This approval is issued to satisfy the requirements of Section 71.101 of 10 CFR Part 71. This approval is subject to all applicable rules, regulations, and orders of the Nuclear Regulatory Commission now or hereafter in effect and to any conditions specified below.

2. NAME			3. EXPIRATION DATE
Best Theratronics			April 30, 2019
STREET ADDRESS			4. DOCKET NUMBER
413 March Road			71-0943
CITY	STATE	ZIP CODE	
Ottawa, Ontario	CAN	K2K 0E4	

5. QUALITY ASSURANCE PROGRAM APPLICATION DATE(S)

February 27, 2009

6. CONDITIONS

1. Activities conducted regarding transportation packagings are to be executed under applicable criteria of 10 CFR Part 71, Subpart H. Authorized activities include: design, procurement, fabrication, assembly, testing, modification, maintenance, repair, and use of transportation packagings.

2. Records shall be maintained in accordance with the provisions of 10 CFR Part 71. Specifically:

   a. Records of each shipment of licensed material shall be maintained for 3 years after that shipment [10 CFR 71.91(a)].

   b. Records providing evidence of packaging quality shall be maintained for 3 years after the life of the packaging [10 CFR 71.91(d)].

   c. Records describing activities affecting packaging quality shall be maintained for 3 years after this Quality Assurance Program Approval is terminated [10 CFR 71.135].

3. Planned and periodic audits of all aspects of the Quality Assurance Program shall be conducted in accordance with written procedures or checklists by appropriately trained personnel not having direct responsibility in the areas being audited, in accordance with 10 CFR 71.137.

FOR THE U.S. NUCLEAR REGULATORY COMMISSION

SIGNATURE: [signature]

DATE: 6/4/2009

DAVID W. PSTRAK, CHIEF
RULES, INSPECTIONS, AND OPERATIONS BRANCH
DIVISION OF SPENT FUEL STORAGE AND TRANSPORTATION
OFFICE OF NUCLEAR MATERIAL SAFETY AND SAFEGUARDS

APPENDIX 2.10.4:
Test Report for GC3000 Removable Plug

IN/TR 1691 GC3000 (1)

Note: the following report discusses two test specimens.
Only the bare GC3000 specimen is relevant to the F-431 safety analysis.

Test Report for the GC-3000 Removable Plug

Signatures

Prepared by: [redacted] Date: 03/04/03

Reviewed by: Date: APR 10, 2003

Approved by: Date: 03 April 11

Document History

Date	Version	Comments	Prepared by	Reviewed by	Approved by
April 2003	1	DCN A1297-D-08A			

[redacted]

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

TABLE OF CONTENTS

1. INTRODUCTION

To simplify the removal of the source holder from GC-1000 and GC-3000 irradiators, housings can be modified to accommodate two internal retaining rings which keep the source plug in place. This eliminates the need to grind off the V-groove weld in order to remove the source plugs on current irradiators.

To prove the strength of this new plug closure design, the GC-3000 was selected for drop testing. GC-3000 s/n 119 and 120 were selected for drop testing. These units both included a tungsten plate cast inside the lead shielding. The tungsten plates slightly increased the weight of the GC-3000 shielding head relative to the current design. The drop tested configuration is described in Appendix F.

The first test specimen, s/n 119, was subjected to a 9 m inverted drop on the bare GC-3000 shielding head. The second test specimen, s/n 120, was tested inside the current drum-style overpack. It was subjected to one 9 m drop and two 1 m pin drops.

Tests were conducted according to IN/TP 1559 GC3000 (1) test plan on October 14, 1999.

2. PRE-DROP TESTS

2.1 Inspect GC-3000 Test Specimens for Fit

2.1.1 Test Details

GC-3000 (s/n 119 and 120) plug closure areas were inspected by visually observing the fillet weld, closure plug fit, and internal snap ring fit.

2.1.2 Observations

The outside diameter on both plugs (s/n 119 and 120) had to be turned down to minimum clearance with the plug seat since the plug seat slightly deformed after welding.

2.1.3 Results

Both specimens are suitable for drop testing to verify strength of plug closure.

2.1.4 Conclusions

Provisions must be made for this new plug closure design to avoid plug interference with the housing. For production units welding should be done prior to machining. In this case, both specimens were modifications of existing units.

2.2 Weigh Test Specimens

The GC-3000 components were weighed in Industrial Operations at MDS Nordion.

2.2.1 Equipment

2.2.1.1 Measurement System International Digital Scale (overhead load cell)

Portaweigh Model 4300, Serial No: 40524/67782, MDSN Inventory No: 13531
Calibrated: 03/07/1997 (recalibrated in April 2000 without correction)
Capacity: 20,000 lb., Accuracy: +/- 5lb.

2.2.1.2 *Mettler Balance*

Type P3, Serial No: 230493, MDSN Inventory No: 6-745-006
Calibrated: 13 May, 1999
Capacity: 3000 g +/- 1g

2.2.1.3 *Toledo Scale*

Model 2184, Serial No: 585 5524-5TL, MDSN Inventory No: 6-745-85
Calibrated: 9 August, 1999
Capacity: 400 lb. +/- 0.1 lb.

2.2.2 Results

GC-3000 (s/n 119) (excluding two dummy sources) = 2,270 lb.
Plug for s/n 119 = 28 lb.
Source holder for s/n 119 = 3.2 lb.
Dummy Sources (stainless steel round bars, 0.69 in. dia., 10.67 in. long) = 1.13 lb. each

GC-3000 (s/n 120) (excluding two dummy sources) = 2,255 lb.
Plug for s/n 120 = 28 lb.
Source holder for s/n 120 = 3.2 lb.

GC-3000 (s/n 120) inside metal drum (s/n 43) = 2,940 lb.

2.2.3 Conclusions

The total weight of the GC-3000 (s/n 119) bare specimen was 2,272 lb., and of the GC-3000 (s/n 120) inside metal drum (s/n 43) was 2,942 lb.

2.3 Radiation Survey

The following is a summary of the pre-drop surveys done on the GC-3000 (s/n 119 and 120). For more details refer to Appendix A.

GC-3000 Irradiator	Total Source Activity	Max. Contact Reading	Max. Reading at 1m From Surface
s/n 119	1,423 + 1,434 = 2,857 Ci	100 mR/h (back, under plate)	3.0 mR/h (back, under plate)
s/n 120	1,434 + 1,463 = 2,897 Ci	100 mR/h (back, under plate)	4.0 mR/h (back, under plate)

3. DROP TESTS

The drop tests were performed at Chalk River Laboratories (CRL) on October 14, 1999. See Appendix D for AECL Test Report, GC-3000 Testing.

The order of the drop tests deviated from the test plan as follows:

Test #1: 9 m inverted drop with bare GC-3000 (s/n 119).
Test #2: 1 m pin drop with GC-3000 (s/n 120) inside metal drum (s/n 43).
Test #3: 9 m inverted corner drop with GC-3000 (s/n 120) inside metal drum (s/n 43).
Test #4: 1 m pin drop with GC-3000 (s/n 120) inside metal drum (s/n 43).

The drop tests were documented with observations, photographs and video tapes.

4. POST-DROP TESTS

4.1 Damage Assessment of GC-3000 (s/n 119)

4.1.1 Test Details

Upon receiving the specimens from the drop test facilities at CRL (October 19, 1999), they were brought to MDS Nordion's Cobalt Operations area for inspection.

4.1.2 Results/Observations

Maximum deceleration was measured at 180g (refer to Appendix D).

One screw from the plug cover plate broke off (see Figure 1). The two retaining rings kept the source plug in place (see Figure 2). Side view of the impacted surface is shown in Figure 3.

The upper retaining ring bent slightly and was difficult to remove with the retaining ring pliers. The lower retaining ring remained flat.

The plug jammed inside the cavity and could not be removed using the existing threaded hole (#10-24) or by tapping a larger threaded hole to pull the plug out using the weight of the GC-3000. The initial attempt to remove the shielding plug was abandoned in October 1999.

In December 2002, another attempt was made to remove the shielding plug. The GC-3000 was fastened in an intra-site shipping frame, and the frame was clamped to the shop floor. A 5 ton hoist was used to pull out the shielding plug. A bulge approximately 2 mm high was observed in the wall of the plug cavity, nearest the axial centre line of the GC-3000. Correspondingly, a small dent was observed in the side of the shielding plug.

The source holder was also found to be jammed. It was removed with the 5 ton hoist. A bulge in the source cavity approximately 2 mm high was observed about 5 cm from the top of the cavity and nearest the axial centre line of the GC-3000.

The source holder was found to be bent by less than 0.5 mm. Except for a burr on one of the upper source openings (see Figure 4), there was no other damage.

The dummy sealed sources were neither bent nor damaged.

4.1.3 Conclusions

The design of the removable plug using two retaining rings (1/8 in. thick, 5.75 in. bore diameter) proved to be strong enough to keep the plug in place during the 9 m accidental drop of the bare GC-3000. The bare GC-3000 suffered moderate damage, but there was no damage to the dummy sources.

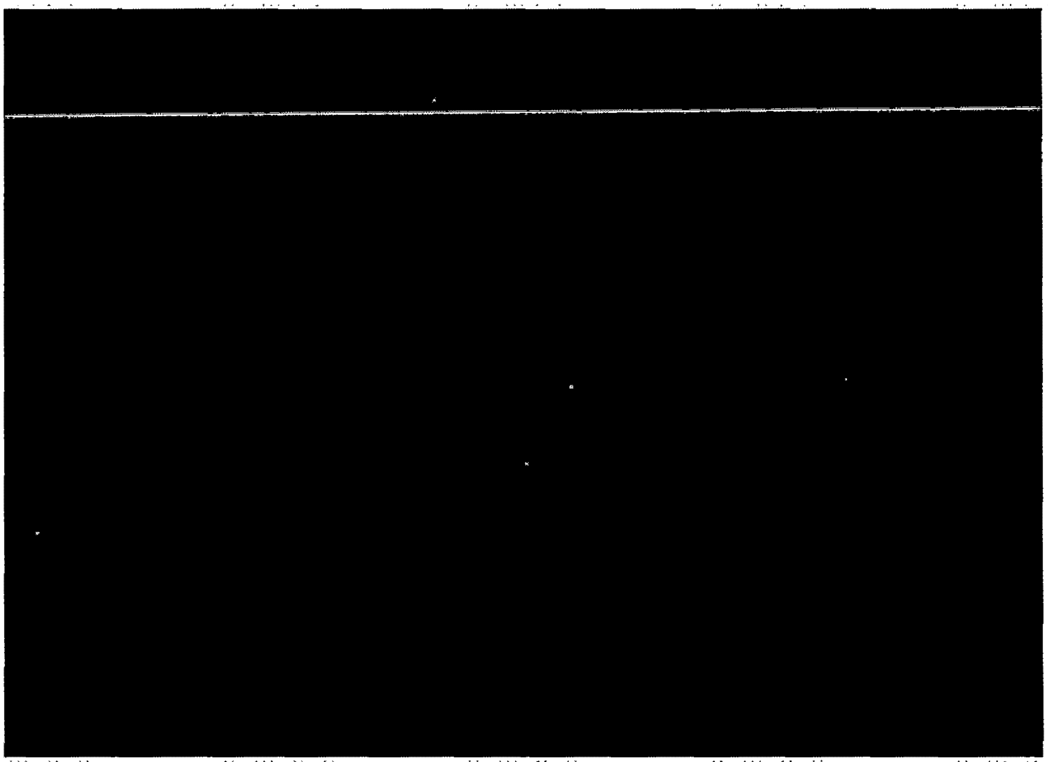


Figure 1
GC-3000 (s/n 119) After 9m Drop Test
(on a shipping frame)

1. Four socket head cap screws holding the axial bearing retaining plate were flattened.
2. Hoist rings bent and fractured (came off during loading of GC-3000 back onto the shipping frame).
3. Plug cover plate remained in place. One bolt on the plug cover plate broke off.
4. Rotor stop was also damaged as it impacted the target (steel plate).

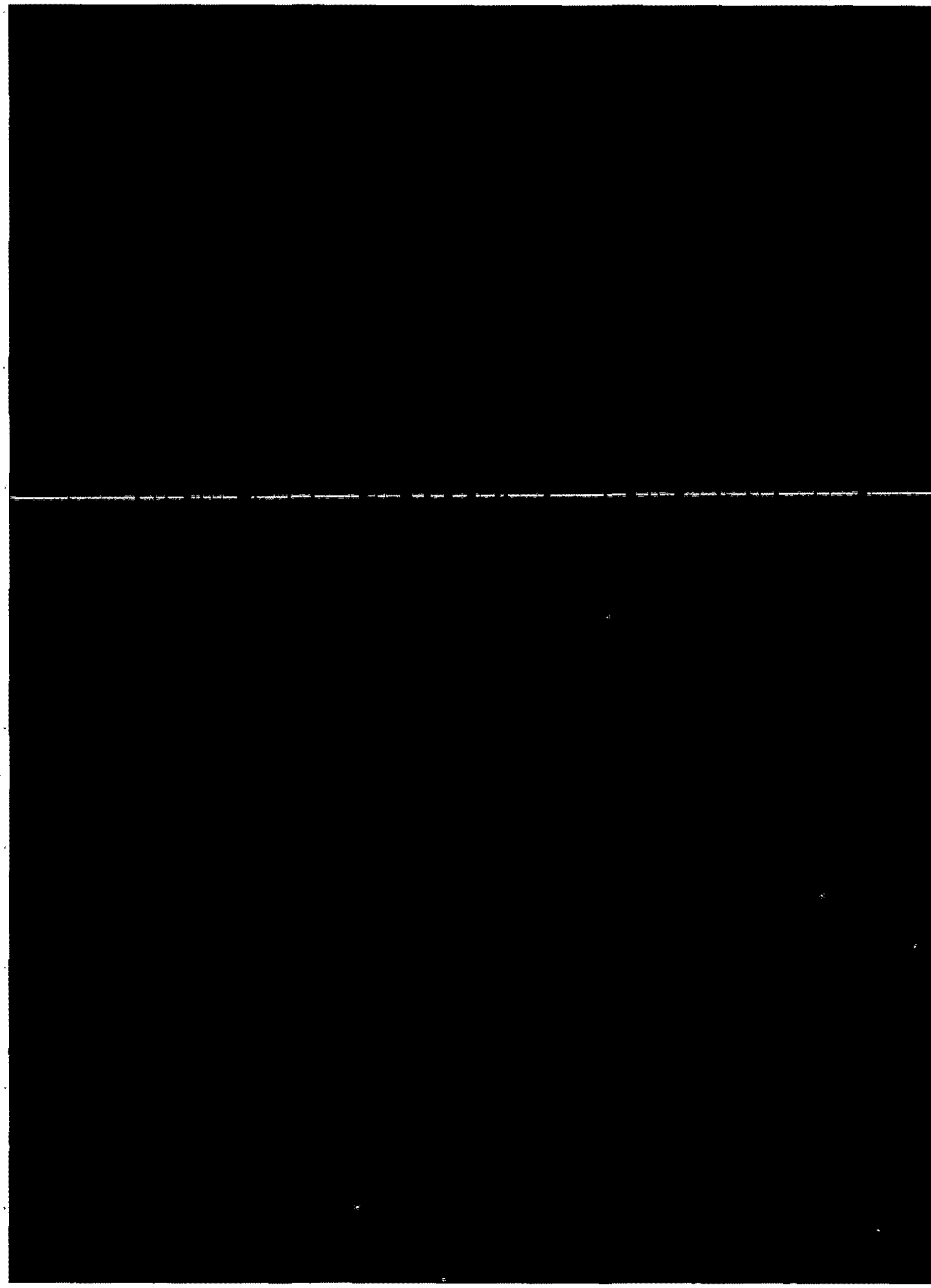


Figure 2
GC-3000 (s/n 119) Plug Detail
(cover removed)

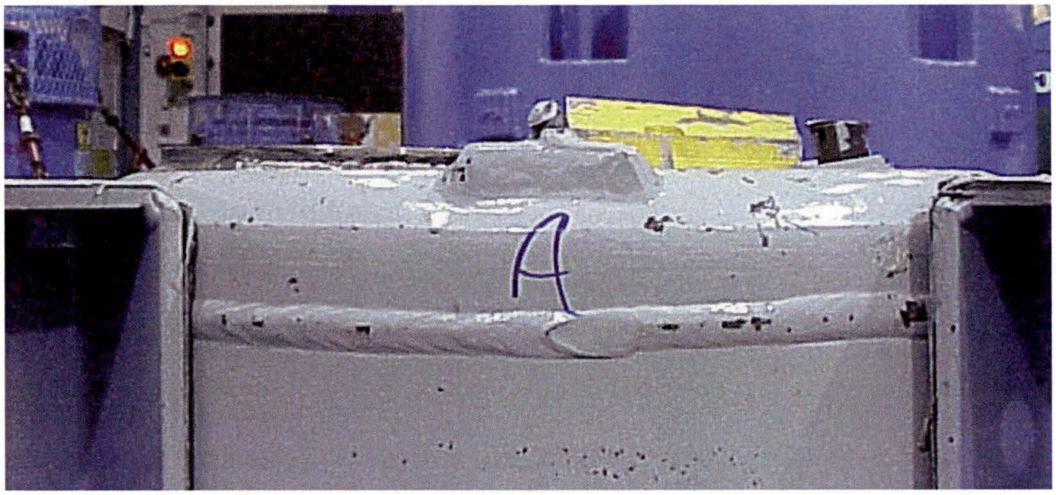


Figure 3
GC-3000 (s/n 119) Impacted Surface
(Side View)

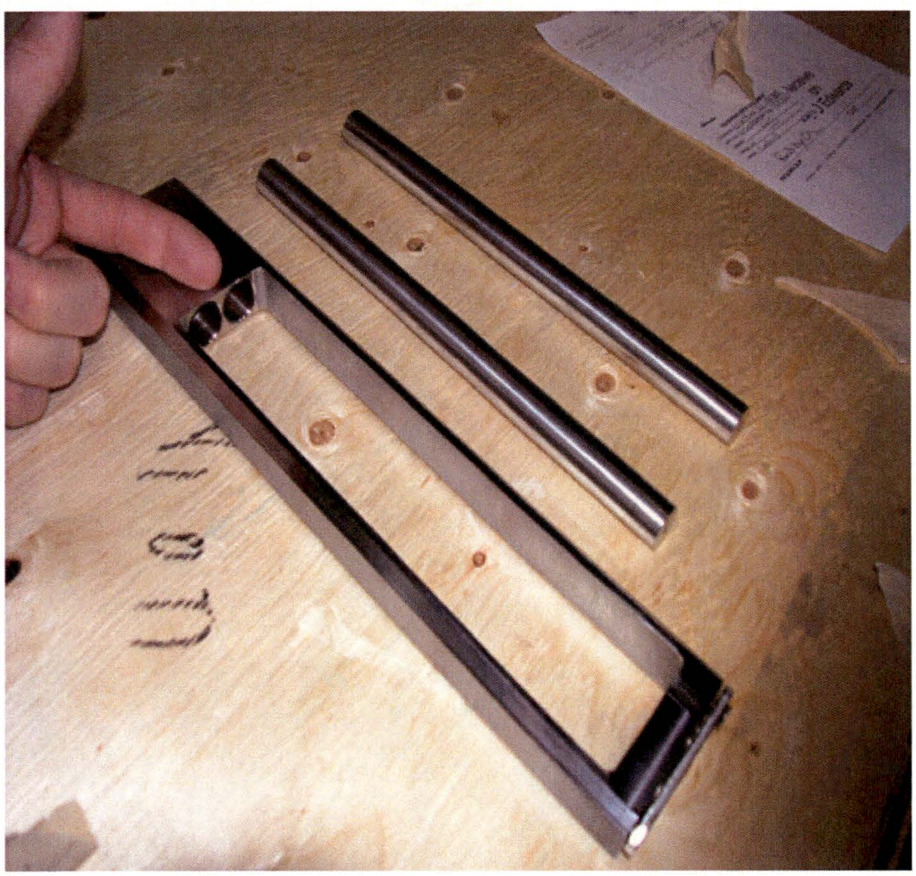


Figure 4
GC-3000 (s/n 119) Dummy Sources and Source Holder

4.2 Damage Assessment of Metal Drum (s/n 43) and GC-3000 (s/n 120)

4.2.1 Test Details

Upon receiving the specimens from the drop test facilities at CRL (October 19, 1999), they were brought to MDS Nordion's Cobalt Operations area for inspection.

4.2.2 Results/Observations

The following series of pictures describes the test specimen's condition following the three drop tests. The first 1m pin drop test following the 9 m drop missed the pin and had to be repeated. This, however, caused no significant damage to the package that would adversely affect the subsequent drop tests.

Figure 5 Telephoto View of GC-3000 (s/n 120) Inside Metal Drum (s/n 43).

Figure 6 Right View of GC-3000 (s/n 120) Inside Overpack (s/n 43): steel rope came off as hoist rings fractured after 9 m drop test.

Figure 7 Metal Drum Closure Bolt Detail: closure ring ends were touching before drop testing.

Figure 8 Metal Drum Flame Cut Opened (Front View). Deformed crush shield is seen in top section of drum on the floor to the left.

Figure 9 Metal Drum Flame Cut Opened (Rear View)

Figure 10 GC-3000 (s/n 120) Inside Metal Drum (s/n 43)

Figure 11 Top Detail after Uncovering Thermal Layer.

Figure 12 Removing GC-3000 (s/n 120) from Metal Drum (s/n 43)

Figure 13 Bottom View of GC-3000 (Thermal Layer Removed): the GC-3000's surface is burned from the torch used to cut open the metal drum.

Figure 14 Lower Crush Shield inside

Figure 15 Top Surface of GC-3000 (s/n 120): three of five plug cover bolts were sheared by crush shield.

Figure 16 GC-3000 (s/n 120), Plug Cover Removed: Both internal retaining rings still in place after drop testing.

Figure 17 GC-3000 (s/n 120), Plug and Source Holder with Dummy Sources Removed: After removal of two retaining rings, the source plug, source holder and source dummies were removed freely with no sign of damage.

4.2.3 Conclusions

The metal drum and upper crush shield and thermal blanket were damaged by the drop tests. The GC-3000 shielding head suffered superficial damage. The source holder and dummy sources were undamaged.

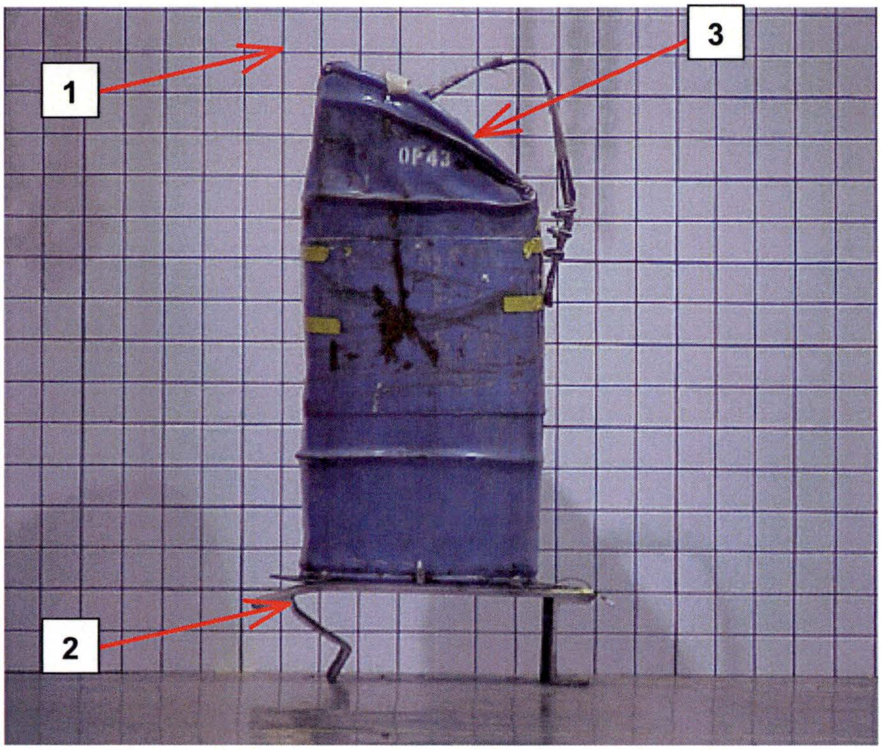


Figure 5
Telephoto View of GC-3000 (s/n 120) Inside Metal Drum (s/n 43)
(Background with 4 in. squares)

1. Point of impact in drop test #2 (1 m oblique drop, the first drop with s/n120 inside metal drum).
2. Damage after 1 m oblique pin drop (test #2) when skid impacted the drop test target.
3. Point of impact and damage after drop test #3 (9 m inverted corner drop).

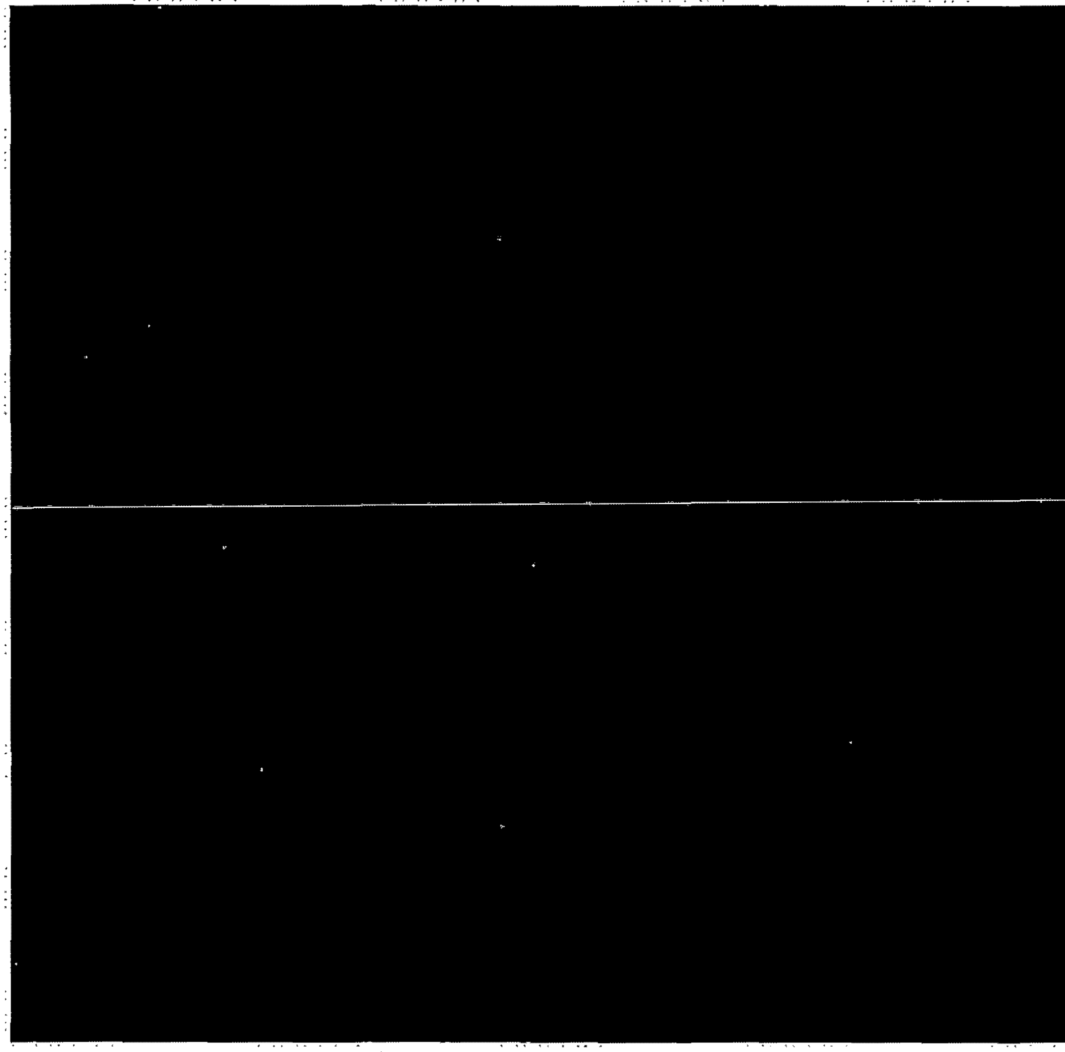


Figure 6
Right View of GC-3000 (s/n 120) Inside Overpack (s/n 43)

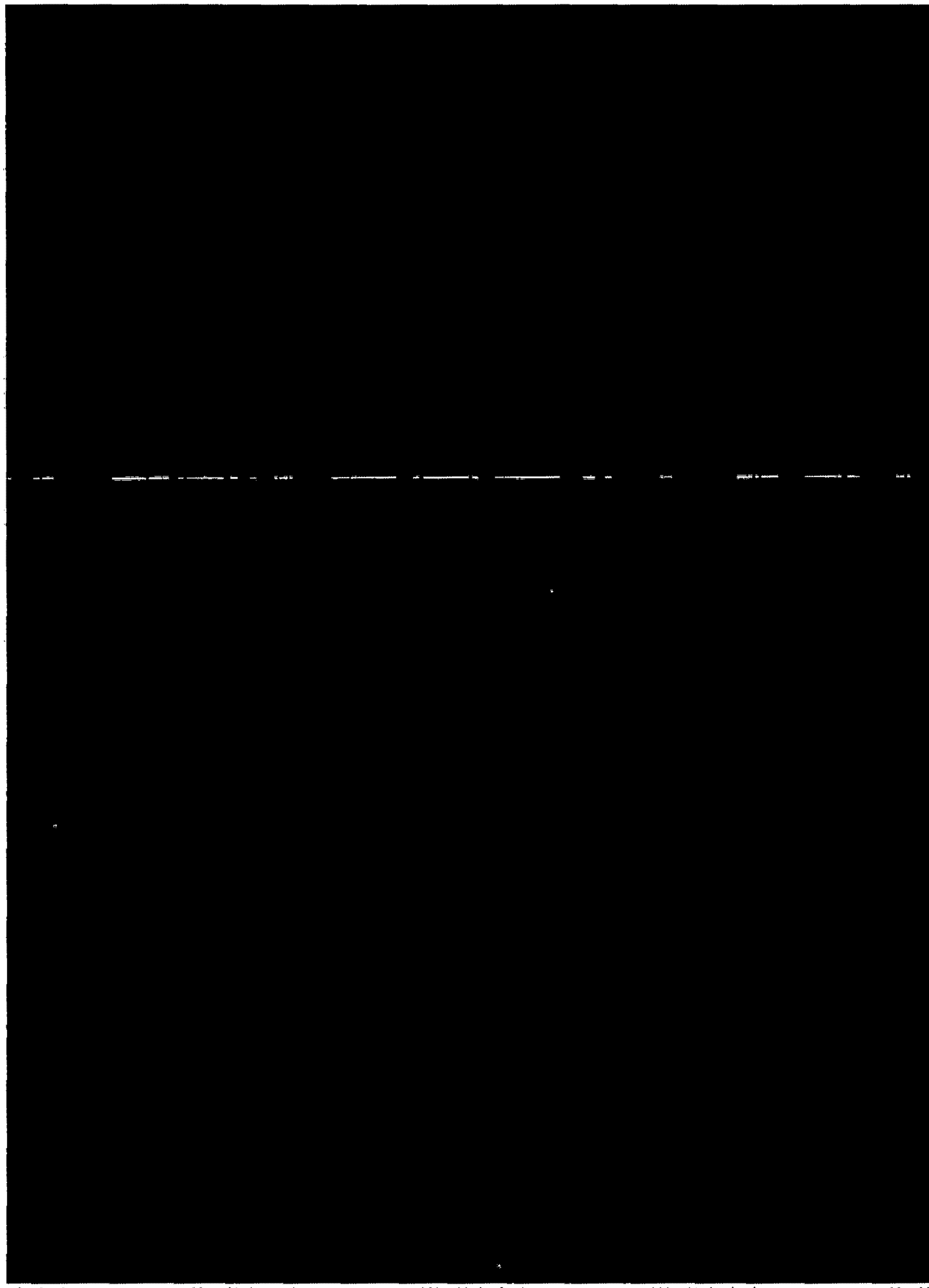


Figure 7
Metal Drum Closure Bolt Detail

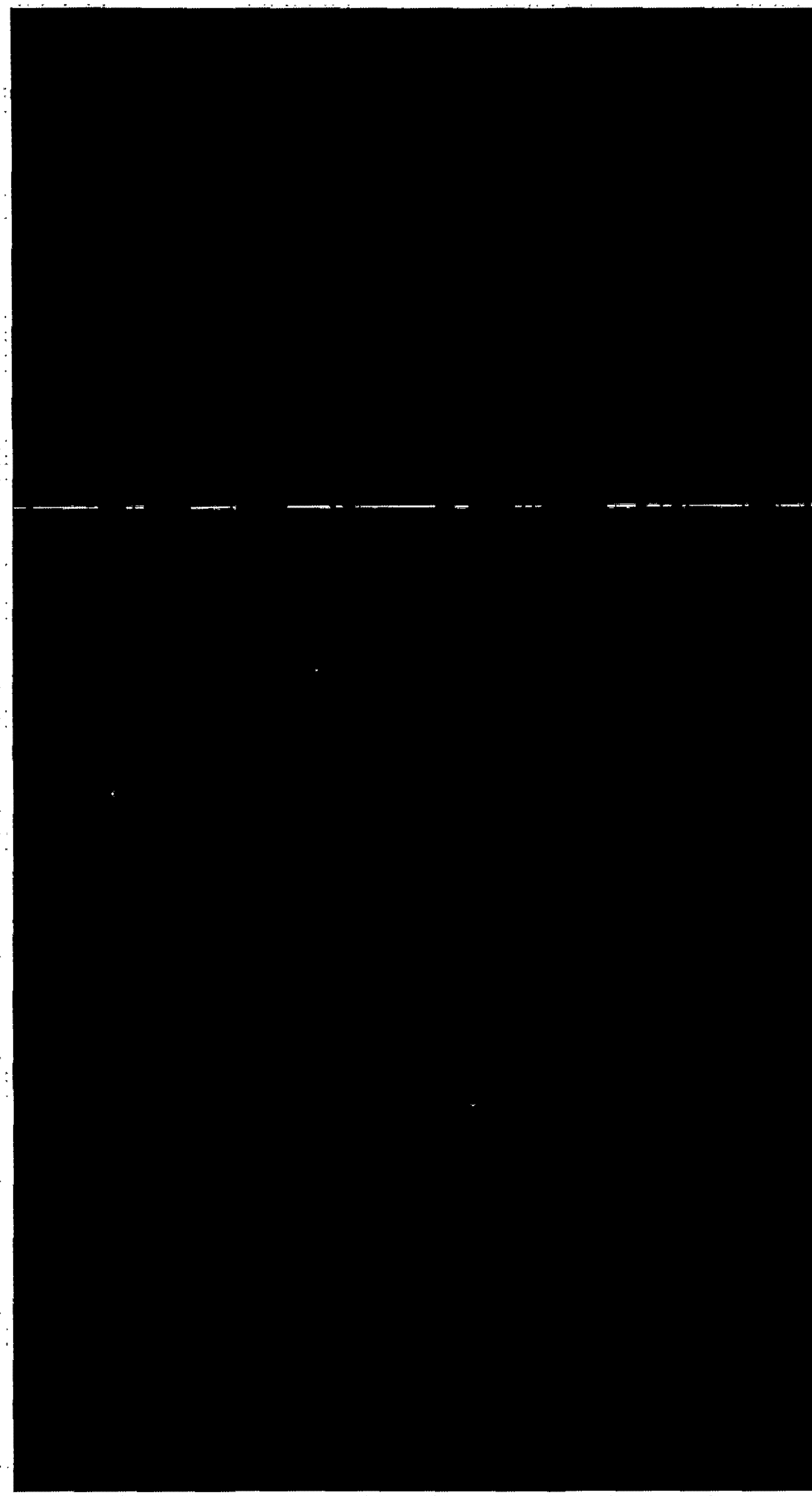


Figure 9
Metal Drum Flame Cut Opened (Rear View)

[redacted]

Figure 11
Top Detail after Uncovering Thermal Layer

Figure 12
Removing GC-3000 (s/n 120) from Metal Drum (s/n 43)

Figure 13
Bottom View of GC-3000
(Thermal Layer Removed)

[redacted]

Figure 14
Lower Crush Shield inside

[redacted]

Figure 15
Top Surface of GC-3000 (s/n 120)

[redacted]

Figure 16
GC-3000 (s/n 120), Plug Cover Removed

[redacted]

Figure 17
GC-3000 (s/n 120), Plug and Source Holder
with Dummy Sources Removed

4.3 Radiation Survey

The following is a summary of the radiation surveys done on the GC-3000 (s/n 119 and 120). For more details refer to Appendix A.

GC-3000 Radiation Survey Results				
GC-3000 Irradiator	Test	Total Source Activity	Max. Contact Reading	Max. Reading at 1 m From Surface
s/n 119	Pre-drop test	1,423 + 1,434 = 2,857 Ci	100 mR/h	3.0 mR/h
	Post-drop test	1,415 + 1,419 = 2,834 Ci	90 mR/h	3.5 mR/h
s/n 120	Pre-drop test	1,434 + 1,463 = 2,897 Ci	100 mR/h	4.0 mR/h
	Post-drop test	1,407 + 1,405 = 2,812 Ci	90 mR/h	2.5 mR/h

The radiation survey results show that there is no measurable shielding concern with the GC-3000. It is found that after the drop test, the integrity of the shielding material remained intact and radiation field levels are well below regulatory limits.

5. DISCUSSION OF RESULTS

5.1 Drop Tests

The removable plug on the GC-3000 withstood 9 m drop testing without any crush protection (metal drum and crush shield). The same performance is expected with the plugs on the GC-1000 as they are lighter than that of the GC-3000.

When the GC-3000 was tested inside the steel drum overpack, the crush shield performed well and the GC-3000 was retained in the drum.

5.2 Integrity of Containment

There was no visible damage to the dummy sources.

5.3 Integrity of Shielding

No weld fractures were observed on the GC-3000 irradiator even when it was dropped bare. Radiation surveys demonstrated that the lead and tungsten did not shift sufficiently inside the specimens to cause an increase in radiation levels.

6. CONCLUSIONS

The design of the removable plug using two retaining rings (1/8 in. thick, 5.75 in. bore diameter) proved to be strong enough to keep the plug in place during the 9 m accidental drop of the bare GC-3000. The design change is equally suitable for the GC-1000.

The steel drum overpack provides additional protection during the drop tests and the crush shields absorb much of the impact.

When a bare GC-3000 shielded head is subjected to the regulatory drop tests, there is no significant damage and no decrease in shielding or containment.

APPENDIX A:
Pre-Drop Test Radiation Survey

Re-Issued Report for GC-3000 Regulatory Test
S/N: 119 & 120

Radiation Survey Before The Drop Test

Prepared By:	B. Prieur, Industrial QC	Date:	2001/02/14
Reviewed By:	D. Whitby, Senior Industrial QC	Date:	2001·02·14
Approved By:	K. O'Hara, Senior Radiation Physicist	Date:	2001 Feb. 15

Radiation Survey Before the Drop Test

The GC-3000 s/n 119 and 120 were loaded with two Caesim-137 sources:

GC-3000 S/N	Source S/N	Source Activity (1)	Source S/N	Source Activity (2)
119	A1099	1454 Ci	A1086	1466 Ci
120	A1090	1466 Ci	A1092	1495 Ci

Sources were measured as of October 16 1998, the caesium sources are in three powder form caesium-137 capsules, which are then double encapsulated resulting in one capsule. C-30001 source drawing number: GA61600 (refer to QC Source Document). The capsules were loaded as per GC-1000 and GC-3000 loading procedure CO-C6/OP-0009 (7) in Cell 06 within Industrial operations, MDS Nordion, Kanata on 1999 September 21.

The GC-3000 was surveyed first in accordance with procedure IN/IM 0209 GC3000E (6). The reading and location of high activity readings "Hot spots" are listed. Both GC's were surveyed on September 27 1999, the decayed source curie content to survey date:

GC-3000 S/N	Source S/N	Source Activity (1)	Source S/N	Source Activity (2)
119	A1099	1423 Ci	A1086	1434 Ci
120	A1090	1434 Ci	A1092	1463 Ci

The GC's were consecutively placed on the levelator for the survey, each GC had their shipping stand fastened at the time of the surveys.

Both GC's were surveyed with two calibrated instruments as outlined in the Radiation Integrity for New Transport Packaging Procedure CO-QC/TP-0001 (2). Met or exceeded radiation requirements listed in Functional and Final Assembly Inspection of the GC-3000 Elan procedure IN/IM 0517 GC1000/3000 (8) and Radiation Survey Report for the GC-3000 Elan IN/IM 0209 GC3000E (6). Based on the type of instrumentation and the last calibration data, all readings would be within +/- 5% of the actual. Each section top, bottom, front, back, Side A&B of the GC was divided into four areas, the highest reading for each location on both GC's were recorded, see attached.

Note: The shipping stands were fastened at the time of the survey, which made the location of the sections easier to identify. The GC chamber on both units were in the open position during the survey, a reading was recorded on the inside of the chamber.

Equipment used:

Meter	**Serial Number**	**Calibration Date**
Victoreen 471	1432	October 22 1999
Bicron Surveyor 2000	A054Q	November 28 1999

GC3000 S/N: 119
Surface: Top

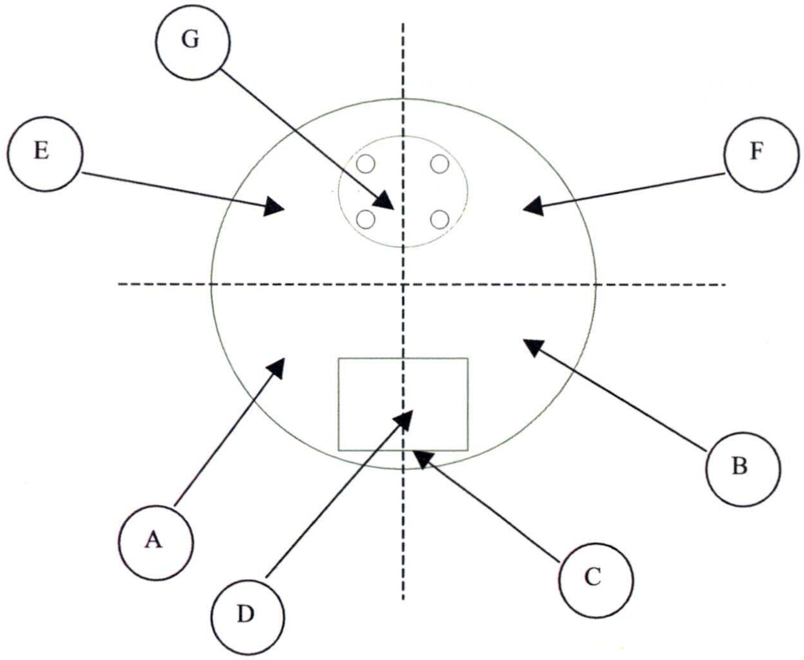


Figure 1. GC3000 Radiation Survey Top.

		Contact Reading		1 meter Reading	
Description	Location	Victoreen (mR/h)	Bicron (mR/h)	Victoreen (mR/h)	Bicron (mR/h)
L.F. Quadrant	A	0.0	0.10	0.26	0.50
R.F. Quadrant	B	0.0	0.15	0.40	0.50
R.F. Quadrant	C	0.0	0.01	0.18	0.40
Over Plate	D	1.0	0.03	0.42	0.62
L.B. Quadrant	E	2.0	1.00	0.52	0.60
R.B. Quadrant	F	2.2	1.20	0.52	0.65
Over Chamber	G	16.0	30.0	0.50	0.60

Table 1. GC3000 Radiation Survey Readings.

GC3000 S/N: 119
Surface: Bottom

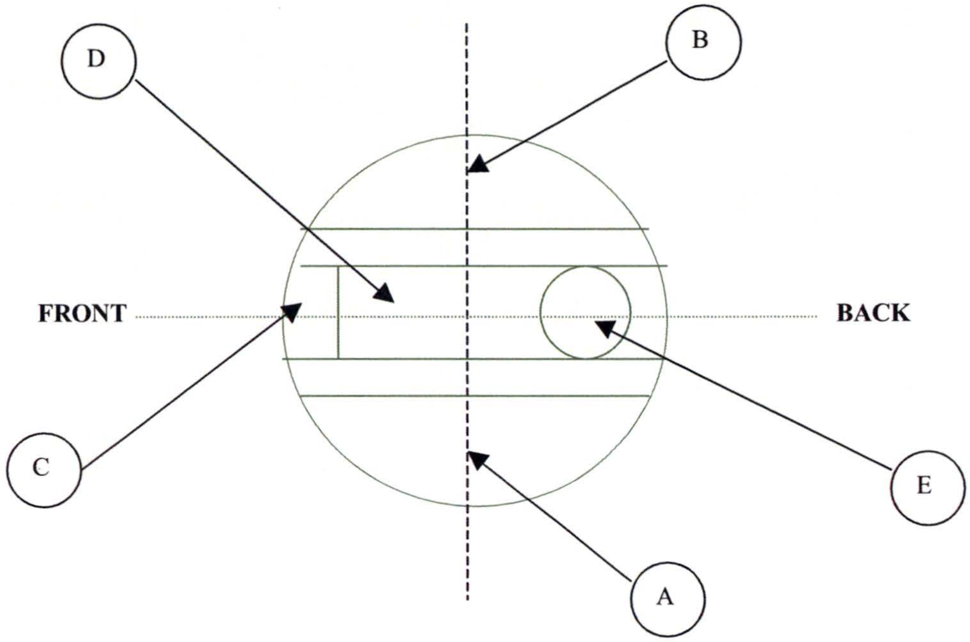


Figure 2. GC3000 Radiation Survey Bottom.

		Contact Reading		1 meter Reading	
Description	Location	Victoreen (mR/h)	Bicron (mR/h)	Victoreen (mR/h)	Bicron (mR/h)
L.B. Quadrant	A	0.0	0.05	0.0	0.03
U.B. Quadrant	B	0.0	0.04	0.0	0.03
U.F. Quadrant	C	0.0	0.14	0.0	0.04
U.F. Quadrant	D	0.0	0.04	0.0	0.01
Under Chamber	E	0.0	0.03	0.0	0.02

Table 2. GC3000 Radiation Survey Readings.

GC3000 S/N: 119
Surface: Back

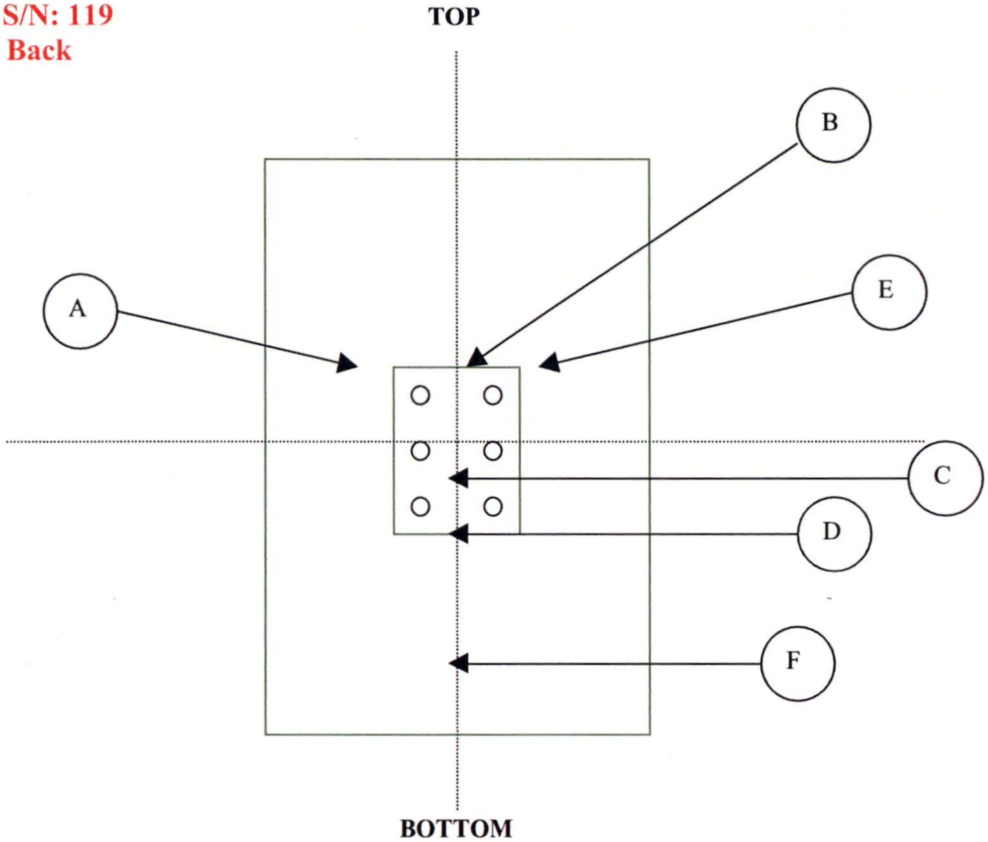


Figure 3. GC3000 Radiation Survey Back.

		Contact Reading		1 meter Reading	
Description	Location	Victoreen (mR/h)	Bicron (mR/h)	Victoreen (mR/h)	Bicron (mR/h)
L.T. Quadrant	A	28	30	1.0	1.3
R.T. Quadrant	B	40	40	2.0	2.0
Front Plate	C	70	80	2.4	3.0
Under Plate	D	62	100	2.2	3.0
R.T. Quadrant	E	30	30	1.4	2.0
R.B. Quadrant	F	20	30	2.0	2.0

Table 3. GC3000 Radiation Survey Readings.

GC3000 S/N: 119
Surface: Front

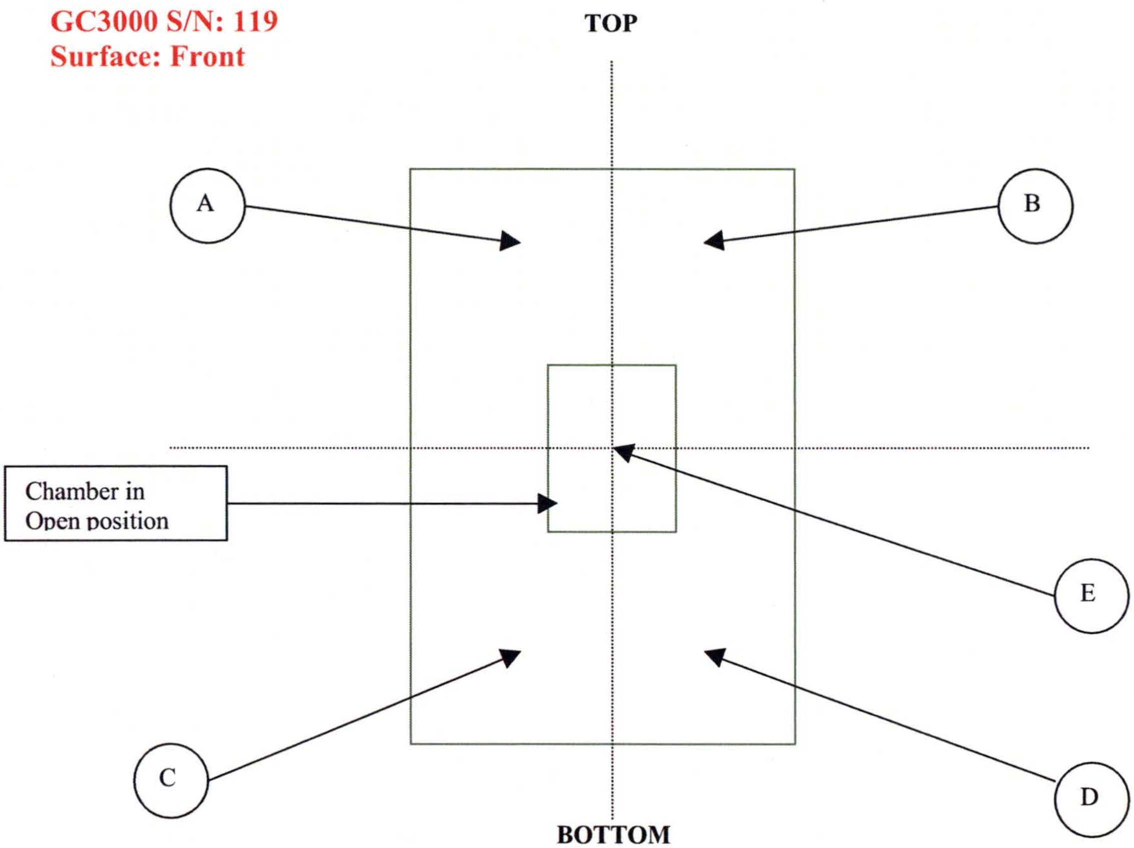


Figure 4. GC3000 Radiation Survey Front.

		Contact Reading		1 meter Reading	
Description	Location	Victoreen (mR/h)	Bicron (mR/h)	Victoreen (mR/h)	Bicron (mR/h)
L.T. Quadrant	A	0.0	0.01	0.0	0.02
R.T. Quadrant	B	0.0	0.01	0.0	0.02
L.B. Quadrant	C	0.0	0.01	0.0	0.02
R.B. Quadrant	D	0.0	0.01	0.0	0.00
Inside Chamber	E	0.0	0.09	0.0	0.02

Table 4. GC3000 Radiation Survey Readings.

GC3000 S/N: 119
Surface: Side A

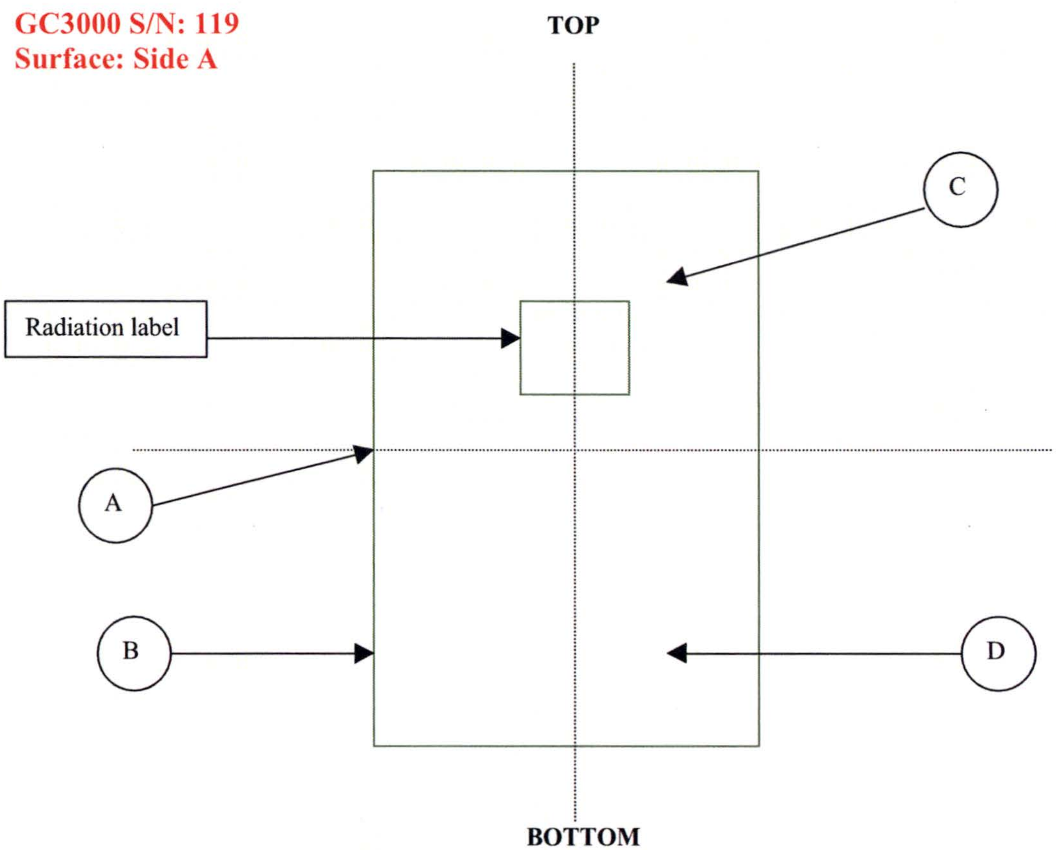


Figure 5. GC3000 Radiation Survey Side A.

		Contact Reading		1 meter Reading	
Description	Location	Victoreen (mR/h)	Bicron (mR/h)	Victoreen (mR/h)	Bicron (mR/h)
L.B. Quadrant	A	1.0	1.5	0.22	0.50
L.B. Quadrant	B	0.3	0.5	0.10	0.30
R.T. Quadrant	C	0.0	0.1	0.00	0.04
R.B. Quadrant	D	0.0	0.1	0.00	0.03

Table 5. GC3000 Radiation Survey Readings.

GC3000 S/N: 119
Surface: Side B

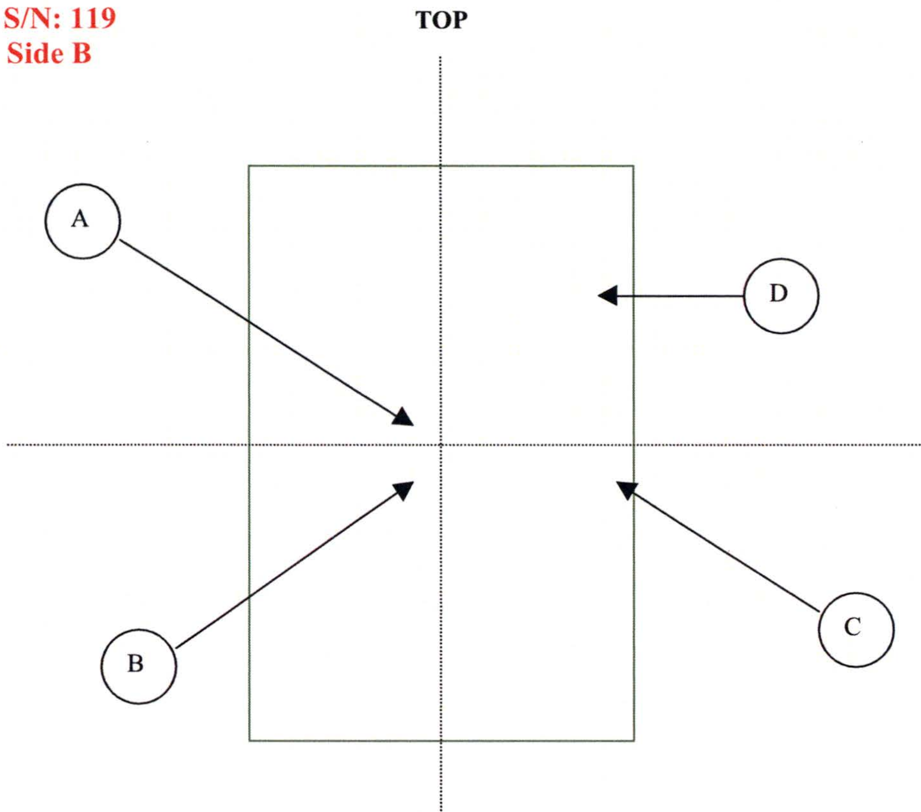


Figure 6. GC3000 Radiation Survey Side B.

		Contact Reading		1 meter Reading	
Description	Location	Victoreen (mR/h)	Bicron (mR/h)	Victoreen (mR/h)	Bicron (mR/h)
L.T. Quadrant	A	0.0	0.2	0.00	0.03
L.B. Quadrant	B	0.0	0.3	0.00	0.03
R.B. Quadrant	C	1.4	2.0	0.22	0.45
R.T. Quadrant	D	0.9	1.0	0.22	0.40

Table 6. GC3000 Radiation Survey Readings.

GC3000 S/N: 120
Surface: Top

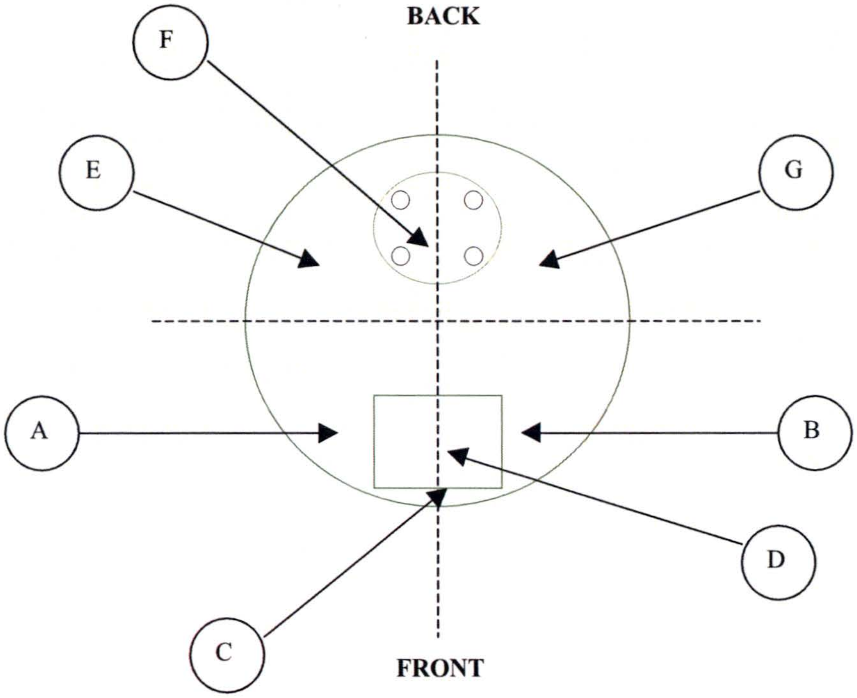


Figure 7. GC3000 Radiation Survey Top.

		Contact Reading		1 meter Reading	
Description	Location	Victoreen (mR/h)	Bicron (mR/h)	Victoreen (mR/h)	Bicron (mR/h)
L.F. Quadrant	A	0.0	0.12	0.40	0.70
R.F. Quadrant	B	0.0	0.11	0.40	0.60
R.F. Quadrant	C	0.0	0.03	0.10	0.45
Over Plate	D	1.2	0.50	0.40	0.60
L.B. Quadrant	E	1.9	2.00	0.50	0.70
Over Chamber	F	18.0	30.00	0.45	1.00
R.B. Quadrant	G	1.8	2.00	0.40	0.90

Table 7. GC3000 Radiation Survey Readings.

GC3000 S/N: 120
Surface: Bottom

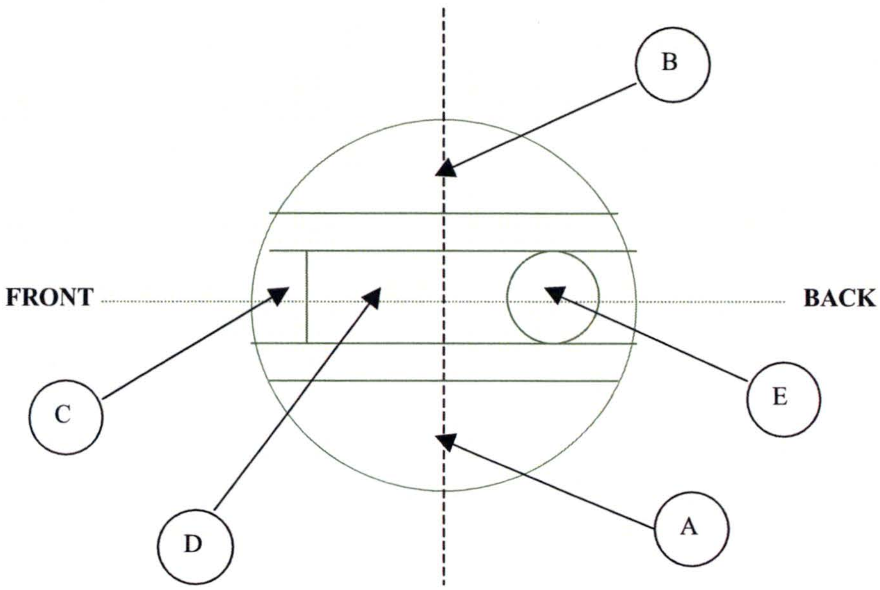


Figure 8. GC3000 Radiation Survey Bottom.

		Contact Reading		1 meter Reading	
Description	Location	Victoreen (mR/h)	Bicron (mR/h)	Victoreen (mR/h)	Bicron (mR/h)
L.F. Quadrant	A	0.0	0.02	0.0	0.02
U.F. Quadrant	B	0.0	0.04	0.0	0.30
U.F. Quadrant	C	0.0	0.20	0.0	0.03
U.F. Quadrant	D	0.0	0.09	0.0	0.03
Under Chamber	E	0.0	0.04	0.0	0.02

Table 8. GC3000 Radiation Survey Readings.

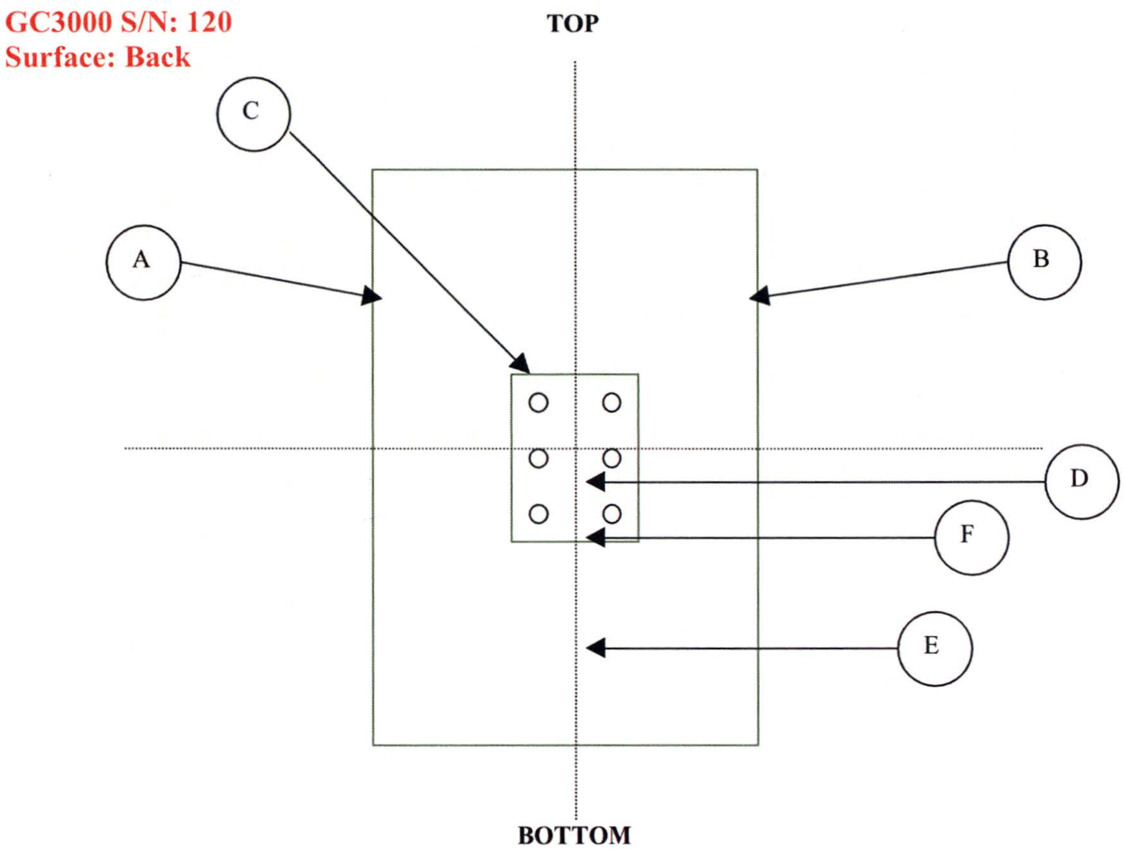


Figure 9. GC3000 Radiation Survey Back.

		Contact Reading		1 meter Reading	
Description	Location	Victoreen (mR/h)	Bicron (mR/h)	Victoreen (mR/h)	Bicron (mR/h)
L.T. Quadrant	A	19.0	30.0	1.5	1.5
R.T. Quadrant	B	18.0	30.0	1.2	2.0
L.T. Quadrant	C	21.0	40.0	2.2	3.0
Front Plate	D	70.0	90.0	2.5	3.0
R.B. Quadrant	E	16.0	20.0	2.1	3.0
Under Plate	F	70.0	100.0	2.6	4.0

Table 9. GC3000 Radiation Survey Readings.

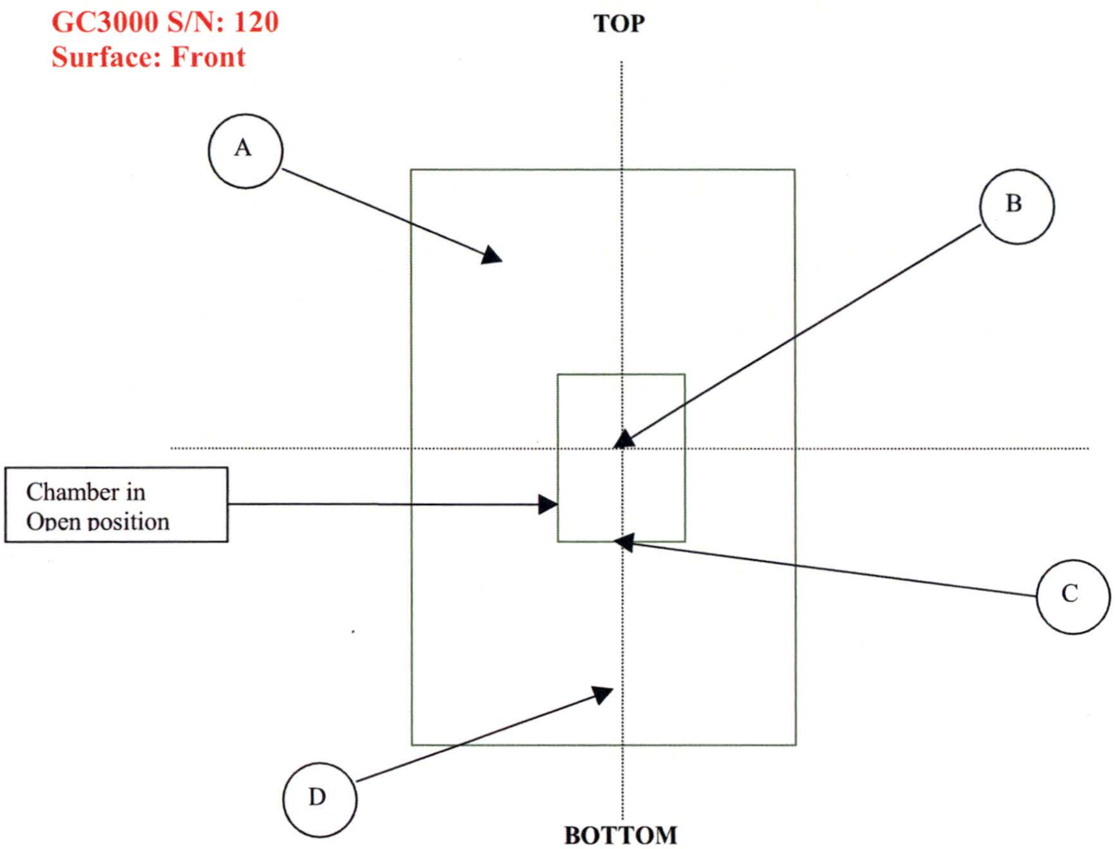


Figure 10. GC3000 Radiation Survey Front.

		Contact Reading		1 meter Reading	
Description	Location	Victoreen (mR/h)	Bicron (mR/h)	Victoreen (mR/h)	Bicron (mR/h)
R.T. Quadrant	A	0.0	0.02	0.0	0.02
Inside Chamber	B	0.0	0.30	0.0	0.03
L.B. Quadrant	C	0.0	0.03	0.0	0.03
L.B. Quadrant	D	0.0	0.02	0.0	0.02

Table 10. GC3000 Radiation Survey Readings.

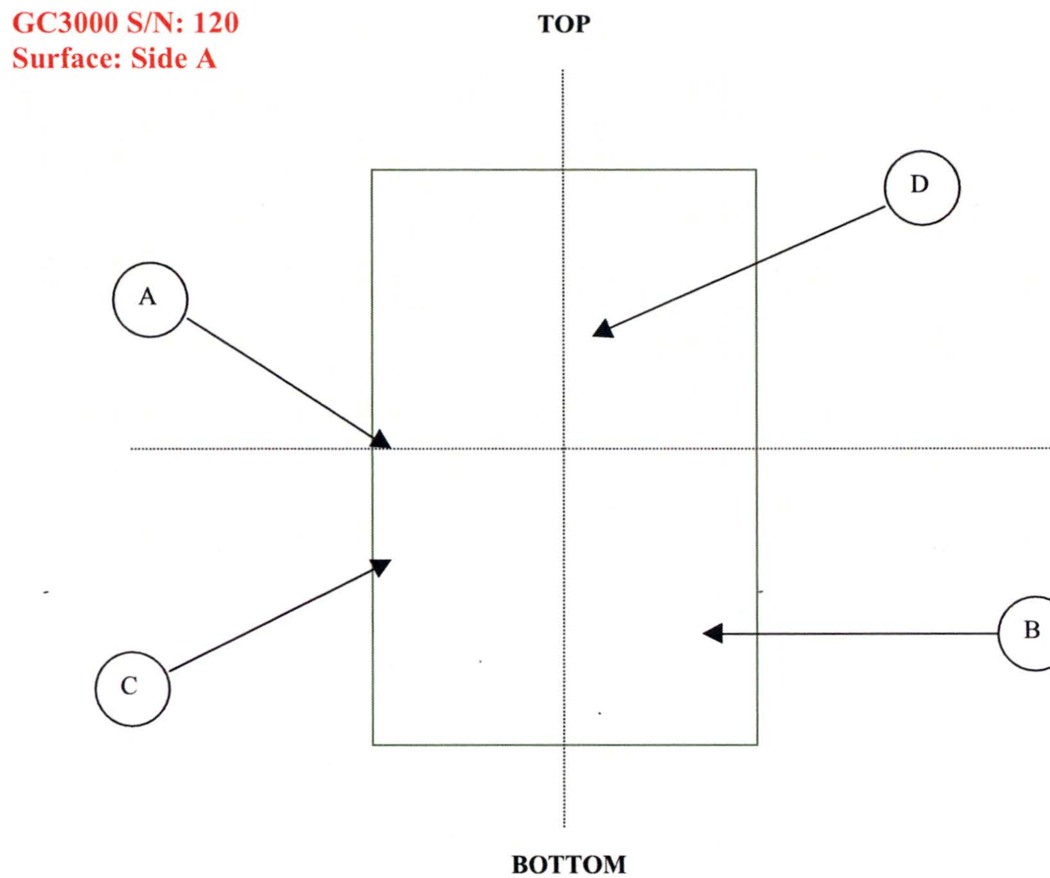


Figure 11. GC3000 Radiation Survey Side A.

		Contact Reading		1 meter Reading	
Description	Location	Victoreen (mR/h)	Bicron (mR/h)	Victoreen (mR/h)	Bicron (mR/h)
L.T. Quadrant	A	0.70	2.00	0.10	0.18
R.B. Quadrant	B	0.00	0.05	0.00	0.04
L.B. Quadrant	C	0.30	1.50	0.00	0.15
L.T. Quadrant	D	0.05	0.30	0.00	0.05

Table 11. GC3000 Radiation Survey Readings.

GC3000 S/N: 120
Surface: Side B

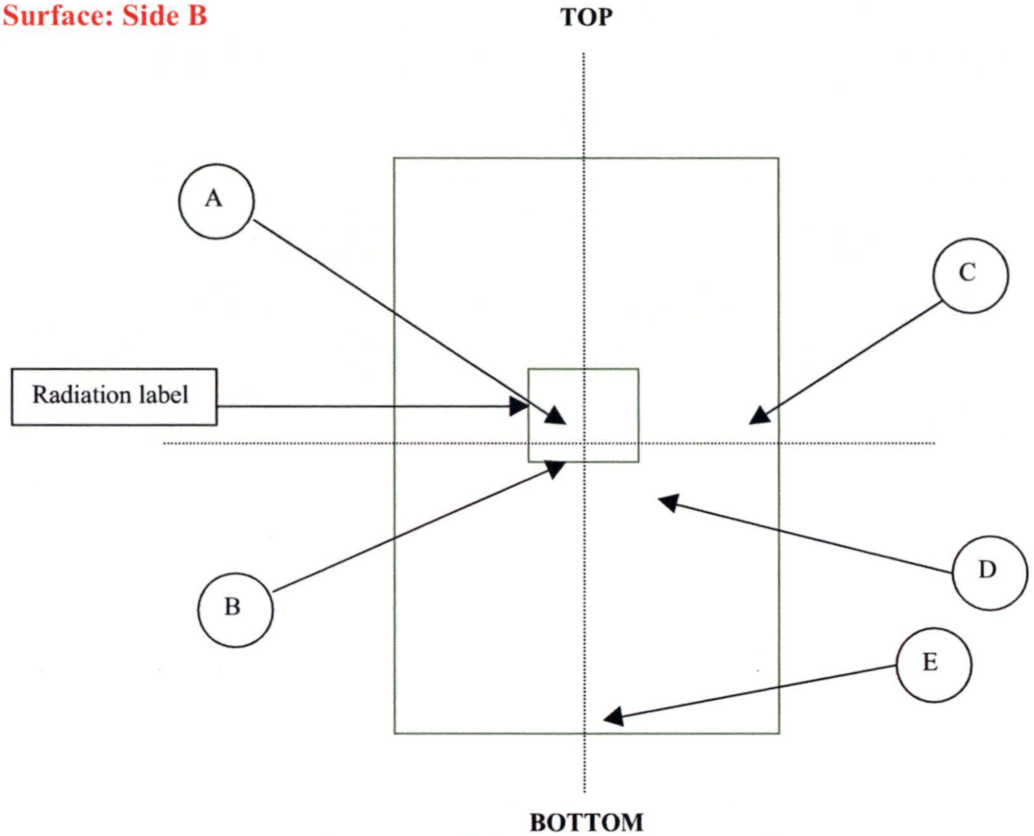


Figure 12. GC3000 Radiation Survey Side B.

		Contact Reading		1 meter Reading	
Description	Location	Victoreen (mR/h)	Bicron (mR/h)	Victoreen (mR/h)	Bicron (mR/h)
L.T. Quadrant	A	0.00	0.30	0.0	0.03
L.B. Quadrant	B	0.00	0.30	0.0	0.03
R.T. Quadrant	C	0.70	2.00	0.0	0.40
R.B. Quadrant	D	0.20	0.30	0.0	0.13
R.B. Quadrant	E	0.00	0.04	0.0	0.04

Table 12. GC3000 Radiation Survey Readings.

APPENDIX B:
Post-Drop Test Radiation Survey for GC-3000 s/n 119

Report for GC-3000 Regulatory Test

S/N: 119

Radiation Survey After Drop Test

Prepared By: Blaine Menna Date: 03/02/07

B. Menna, Package Engineering

Measured By: Sandi Rheubottom Date: 03.02.17

S. Rheubottom, Radiation Safety

Approved By: K. O'Hara Date: 2003 Feb 27

K. O'Hara, Senior Radiation Physicist

Introduction:

GC3000 s/n 119 was subjected to a 9m drop test with no protective overpack. The unit was dropped inverted, and as a result of the impact, the steel shell and lead shielding were deformed.

The initial attempt to remove the shielding plug, shortly after the drop test, was unsuccessful. The impact of the drop test caused the lead to slump, and the shielding plug was jammed. The weight of the entire GC3000 shield (2200 lb), was not enough to pull the plug free.

The next attempt to remove the plug was successful. The GC3000 was loaded in an intra-site shipping frame, and the frame was clamped to the floor. A 5-ton hoist was used to pull out the plug. The shielding plug cavity was inspected and a bulge was identified closest to the centreline of the GC3000 shielding head. The source holder containing the dummy sources was also jammed. It was removed in the same way. A bulge was identified closest to the centreline of the GC3000 shielding head, about 5 cm down from the top of the source cavity. The GC3000, the source plug and the source holder were machined in order to remove the interference in order to facilitate re-assembly. The amount of steel removed from each part was approximately 2 mm.

The post-drop test survey is similar to the test survey conducted before the drop test, on 1999 September 27. The measurement locations are the same as those surveyed before the drop test.

The GC-3000 s/n 119 was loaded with two Caesim-137 sources, Model C-3001, as described in Table 1.

Table 1. C-3001 Measured Activity		
Source Serial Number	Source Activity	Measurement Date
A1493	53.13 TBq (1,436 Ci)	2002/05/24
A1501	53.28 TBq (1,440 Ci)	2002/05/24

The sources were loaded as per GC-1000 and GC-3000 Loading Procedure CO-C6/0P-0009 (7) in Cell 06 within Ion Technologies Operations, MDS Nordion, Kanata on 2003 January 9. The GC-3000 was fastened in its intra-site shipping frame and was placed on the Levelator for the survey. The radiation survey was performed on 2003 January 10. The source activities as of the survey date are listed in Table 2.

Table 2. C-3001 Decayed Activity		
Source Serial Number	Source Activity	Reference Date
A1493	52.4 TBq (1415 Ci)	2003/01/10
A1501	52.5 TBq (1419 Ci)	2003/01/10

The GC-3000 was surveyed with two calibrated instruments as outlined in the Radiation Integrity for New Transport Packaging Procedure CO-QC/TP-0001 (2). The measurement error for the readings is +/- 5%. Each face (top, bottom, front, back, left and right side) of the GC3000 was divided into four quadrants. The highest reading for each quadrant was recorded.

Note: The shipping frame defined each of the quadrants. The square top frame was bolted to the top of the GC-3000 and partially obscured points F and D on the top of the GC3000, as was the case with the pre-drop test survey. The shipping adapter was fastened to the top of the rotor during the survey. This also limited the proximity of the meters to the surface of the radiation shield during the survey. No chamber guard was affixed to the GC3000 at the time of the radiation survey. The chamber was in the Load position.

Equipment:

Meter	Serial Number	Calibration Date	Calibration Due Date
Victoreen 471	1432	2002 Sept 17	2003 Sept 17
Bicron Surveyor 2000	C311H	2002 Dec 22	2003 Jun 22

Results:

The measurements results are listed in Tables 3 through 8.

Conclusion:

The measurement data shows that there was no significant increase in the radiation fields from the GC3000. It is found that after the drop test, the integrity of the shielding material remained intact and radiation fields levels are well below regulatory limits.

GC3000 S/N: 119

Surface: Top

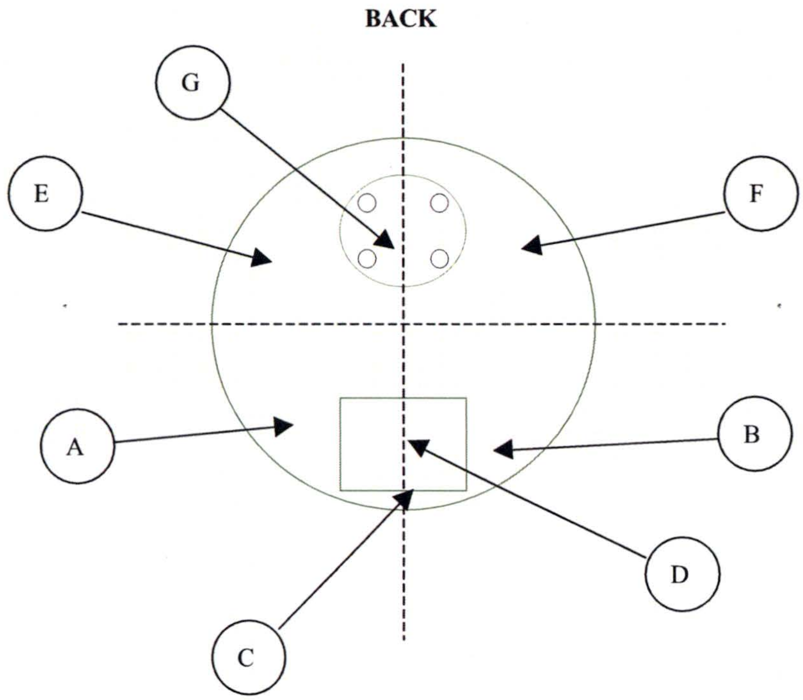


Figure 1. GC3000 Radiation Survey Top.

Table 3. Radiation Measurements on Top of GC3000 s/n 119					
		Contact Reading		Reading at 1m from Surface	
Description	Location	Victoreen (mR/h)	Bicron (mR/h)	Victoreen (mR/h)	Bicron (mR/h)
L.F. Quadrant	A	0.7	0	0.5	0.8
R.F. Quadrant	B	0.3	0	0.5	0.8
Front of Plate	C	0.2	0	0.5	0.8
Over Plate	D	2.0	0.5	0.5	0.8
L.B. Quadrant	E	3.0	0.4	0.6	1.0
R.B. Quadrant	F	2.0	0.4	0.6	1.0
Over Plug	G	13	30	0.6	1.1

GC3000 S/N: 119

Surface: Bottom

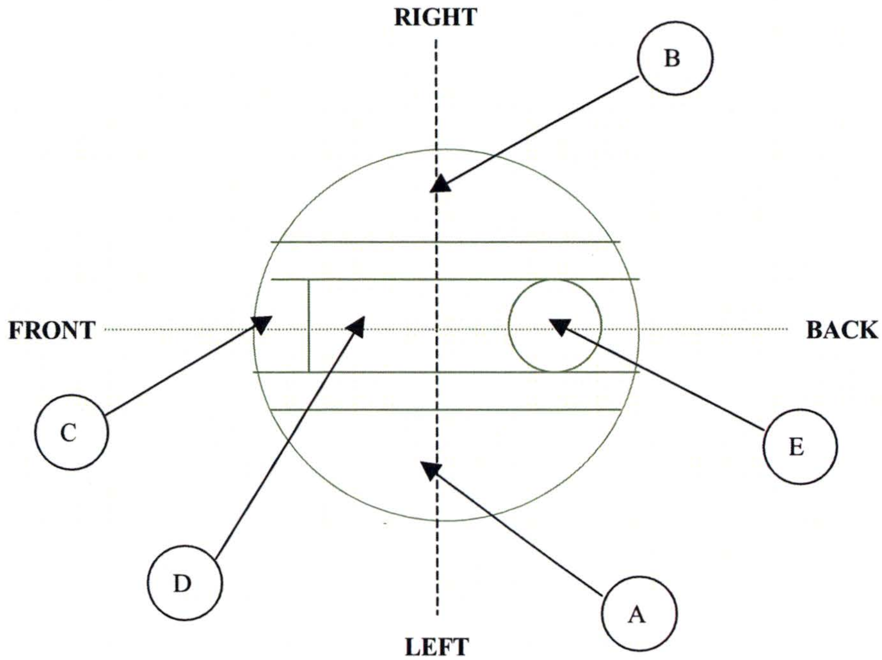


Figure 2. GC3000 Radiation Survey Bottom.

Table 4. Radiation Measurements on Bottom of GC3000 s/n 119					
		Contact Reading		Reading at 1m from Surface	
Description	Location	Victoreen (mR/h)	Bicron (mR/h)	Victoreen (mR/h)	Bicron (mR/h)
Left Side	A	0.0	0.0	0.0	0.0
Right Side	B	0.0	0.0	0.0	0.0
Front	C	0.0	0.0	0.0	0.0
Front Centre	D	0.0	0.0	0.0	0.0
Under Chamber (Back)	E	0.0	0.0	0.0	0.0

GC3000 s/n: 119

Surface: Back

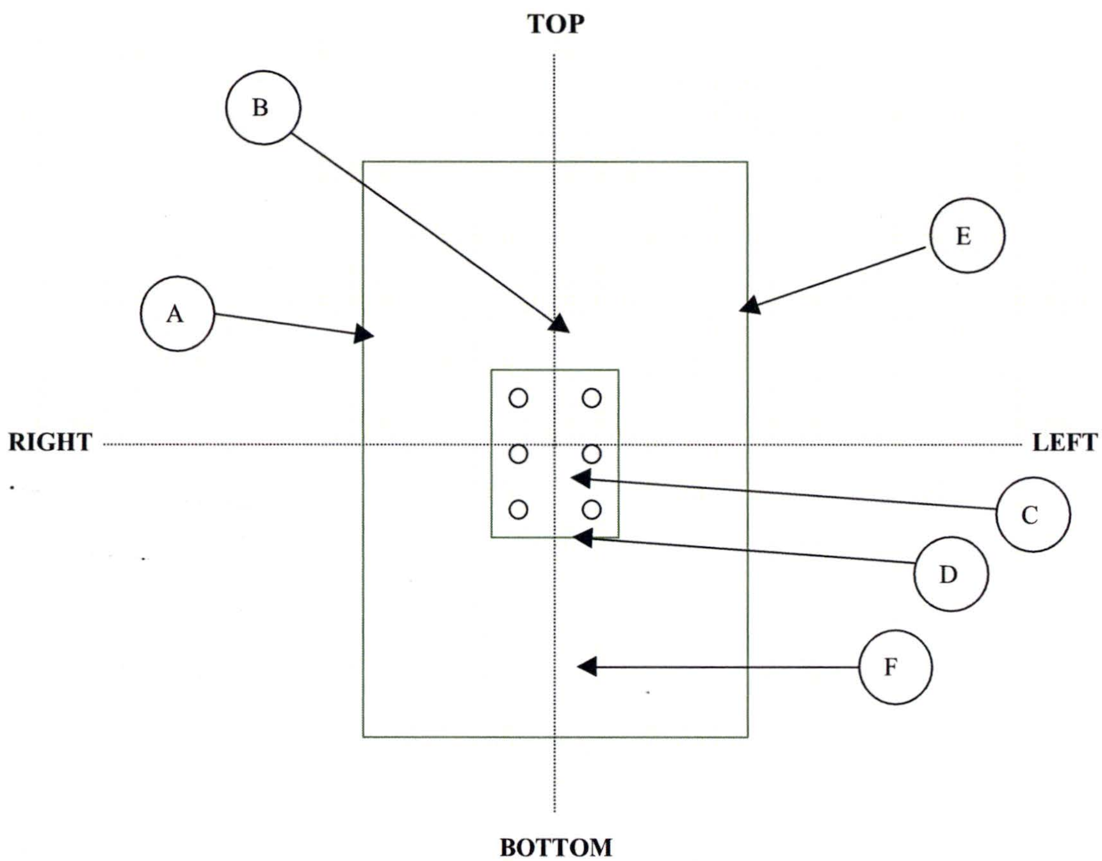


Figure 3. GC3000 Radiation Survey Back.

Table 5. Radiation Measurements on Back of GC3000 s/n 119					
		Contact Reading		Reading at 1m from Surface	
Description	Location	Victoreen (mR/h)	Bicron (mR/h)	Victoreen (mR/h)	Bicron (mR/h)
R.T. Quadrant	A	27	25	2.0	2.0
Top Centre	B	10	13	2.0	2.0
Face of Plate	C	58	75	2.2	3.5*
Bottom of Plate	D	60*	90*	2.4*	3.0
L.T. Quadrant	E	6	3	2.0	2.0
Bottom Centre	F	25	50	2.0	3.0

* denotes exact location of maximum reading measured over entire area.

GC3000 S/N: .119

Surface: Front

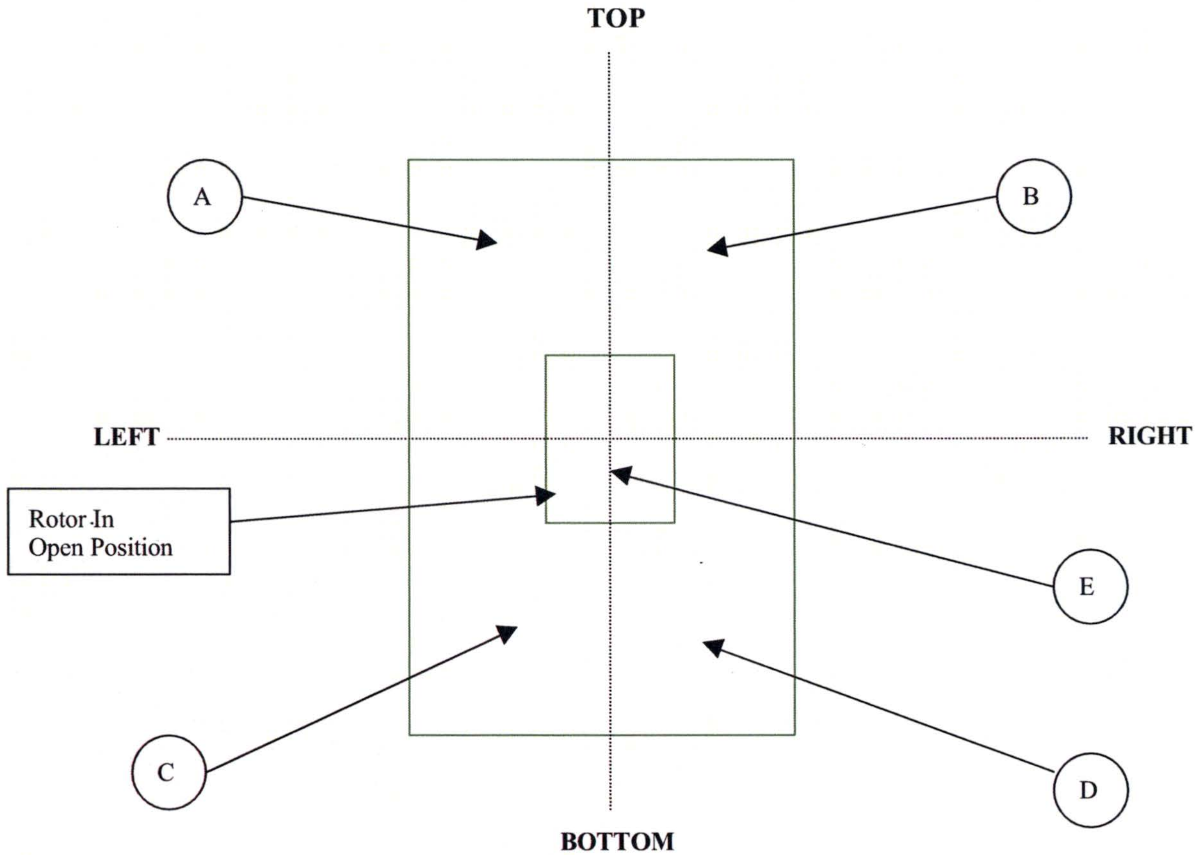


Figure 4. GC3000 Radiation Survey Front.

Table 6. Radiation Measurements on Front of GC3000 s/n 119					
		Contact Reading		Reading at 1m from Surface	
Description	Location	Victoreen (mR/h)	Bicron (mR/h)	Victoreen (mR/h)	Bicron (mR/h)
L.T Quadrant	A	0.0	0.0	0.0	0.0
R.T. Quadrant	B	0.0	0.0	0.0	0.0
L.B. Quadrant	C	0.0	0.0	0.0	0.0
R.B. Quadrant	D	0.0	0.0	0.0	0.0
Front of Chamber	E	0.0	0.0	0.0	0.0

GC3000 S/N: 119

Surface: Left Side

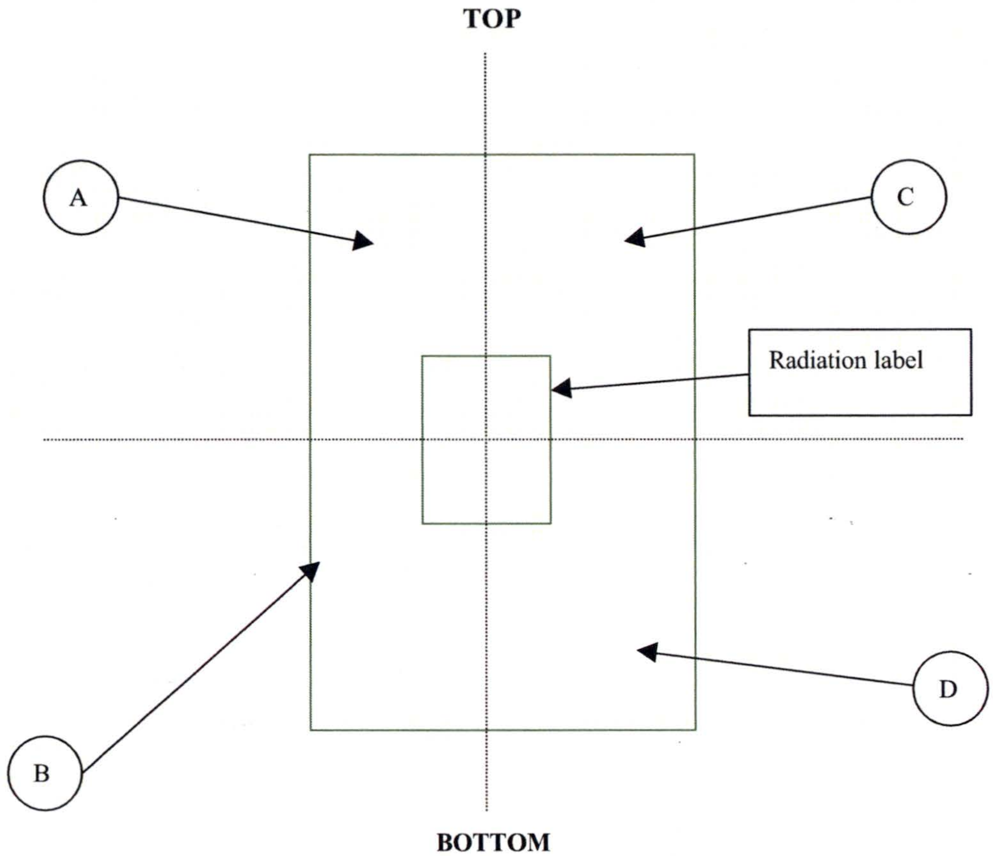


Figure 5. GC3000 Radiation Survey on Left Side.

Table 7. Radiation Measurements on Left Side of GC3000 s/n 119					
		Contact Reading		Reading at 1m from Surface	
Description	Location	Victoreen (mR/h)	Bicron (mR/h)	Victoreen (mR/h)	Bicron (mR/h)
L.T Quadrant	A	0.1	0.5	0.0	0.0
L.B. Quadrant	B	0.3	0.3	0.0	0.0
R.T. Quadrant	C	0.0	0.0	0.0	0.0
R.B. Quadrant	D	0.0	0.0	0.0	0.0

GC3000 S/N: 119

Surface: Right Side

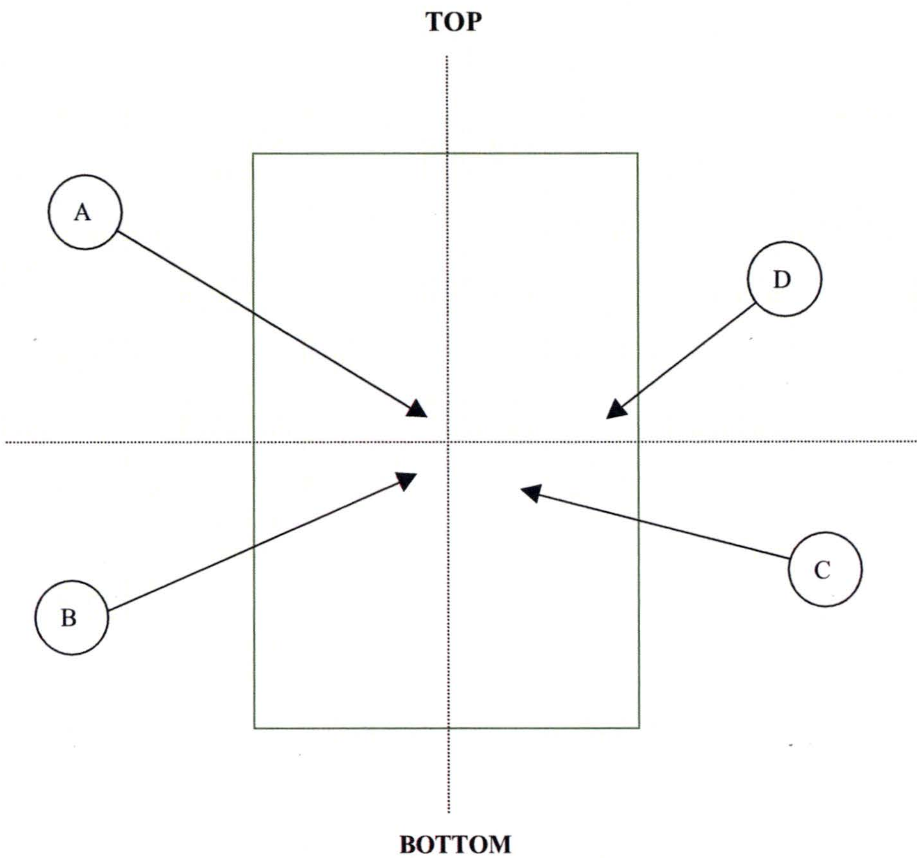


Figure 6. GC3000 Radiation Survey Right Side.

Table 8. Radiation Measurements on Right Side of GC3000 s/n 119					
		Contact Reading		Reading at 1m from Surface	
Description	Location	Victoreen (mR/h)	Bicron (mR/h)	Victoreen (mR/h)	Bicron (mR/h)
L.T Quadrant	A	0.0	0.0	0.0	0.0
L.B. Quadrant	B	0.0	0.0	0.0	0.0
R.B. Quadrant	C	0.4	0.6	0.0	0.0
R.T. Quadrant	D	0.3	0.2	0.0	0.0

APPENDIX C:
Post-Drop Test Radiation Survey for GC-3000 s/n 120

Report for GC-3000 Regulatory Test
S/N: 120

Radiation Survey After Drop Test

Prepared By:	B. Prieur, Industrial QC	Date:	2000/11/23
Reviewed By:	D. Whitby, Senior Industrial QC	Date:	2000 · 11 · 23
Approved By:	K. O'Hara, Senior Radiation Physicist	Date:	2000 Dec. 01

Radiation Survey After the Drop Test

After the regulatory drop test, there was minimum to zero deformation to the shielding material. The GC-3000 has undergone modifications since the drop test, therefore there are shielding variations between the before and after drop tests.
This survey is similar to the before drop test survey conducted on 1999 September 27, the target points initially surveyed on the before drop test were surveyed again on the GC-3000 after the drop test.
The GC-3000 s/n 120 was loaded with two Caesim-137 sources:

GC-3000 S/N	Source S/N	Source Activity (1)
120	A1185	1447 Ci
120	A1188	1445 Ci

Sources were measured 1999 September 07, each cesium source contains three powder form caesium-137 capsules, which are then double encapsulated in one C-30001 source, drawing number: GA61600 (refer to QC Source Document). The sources were loaded as per GC-1000 and GC-3000 loading procedure CO-C6/OP-0009 (7) in Cell 06 within Industrial operations, MDS Nordion, Kanata on 2000 November 20.

The GC-3000 was surveyed first in accordance with procedure IN/IM 0209 GC3000E (6). The reading and location of high activity readings " Hot spots" are listed. The GC-3000 was surveyed on 2000 November 22, the decayed source curie content to survey date:

GC-3000 S/N	Source S/N	Source Activity (1)
120	A1185	1407 Ci
120	A1188	1405 Ci
		Total: 2812 Ci

The GC-3000 was placed on the elevator for the survey, the GC-3000 had it's shipping stand fastened at the time of the surveys.

The GC-3000 was surveyed with two calibrated instruments as outlined in the Radiation Integrity for New Transport Packaging Procedure CO-QC/TP-0001 (2) which met or exceeded radiation requirements listed in Functional and Final Assembly Inspection of the GC-3000 Elan procedure IN/IM 0517 GC1000/3000 (8) and Radiation Survey Report for the GC-3000 Elan IN/IM 0209 GC3000E (6). Based on the type of instrumentation and the last calibration data, all readings would be within +/- 5% of the actual. Each section top, bottom, front, back, Side A&B of the GC was divided into four areas, the highest reading for each location on the GC-3000 was recorded, see attached.

Note: The shipping stand was fastened at the time of the survey, which made the location of the sections easier to identify. A square steel frame was bolted down to the top of the GC-3000 at the time of the survey which partially covered points F and D. The shipping adapter was fastened to the top of the chamber during the survey, this will affect the result of the radiation field. A 3/8" thick plate was fastened to the front of the GC-3000, the plate covers the opening of the chamber, couldn't identify whether the chamber was open or closed at time of survey.

Equipment used:

Meter	Serial Number	Calibration Date	Cal. Due Date
Victoreen 471	1368	December 20 2000	January 20 2001
Bicron Surveyor 2000	A054Q	May 2 2001	November 2 2001

Conclusion

After the review of the survey results, there are no measurable shielding concerns with the GC-3000. It is found that after the drop test, the integrity of the shielding material remained intact and radiation fields levels are well below regulatory limits.

GC3000 S/N: 120
Surface: Top

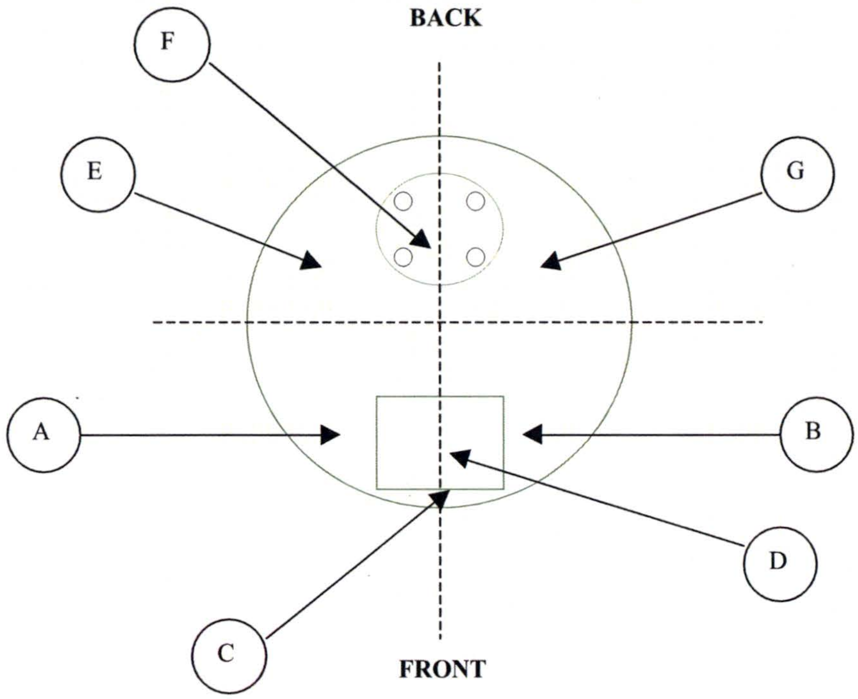


Figure 1. GC3000 Radiation Survey Top.

		Contact Reading		1 meter Reading	
Description	Location	Victoreen (mR/h)	Bicron (mR/h)	Victoreen (mR/h)	Bicron (mR/h)
L.F. Quadrant	A	1.3	0.6	0.8	0.5
R.F. Quadrant	B	1.1	0.7	0.76	1.0
R.F. Quadrant	C	1.2	1.5	0.6	0.8
Over Plate	D	13	20	0.7	0.5
L.B. Quadrant	E	0.26	0.04	0.4	0.6
Over Chamber	F	1.4	0.4	0.52	0.8
R.B. Quadrant	G	0.24	0.05	0.58	0.7

Table 1. GC3000 Radiation Survey Readings.

GC3000 S/N: 120
Surface: Bottom

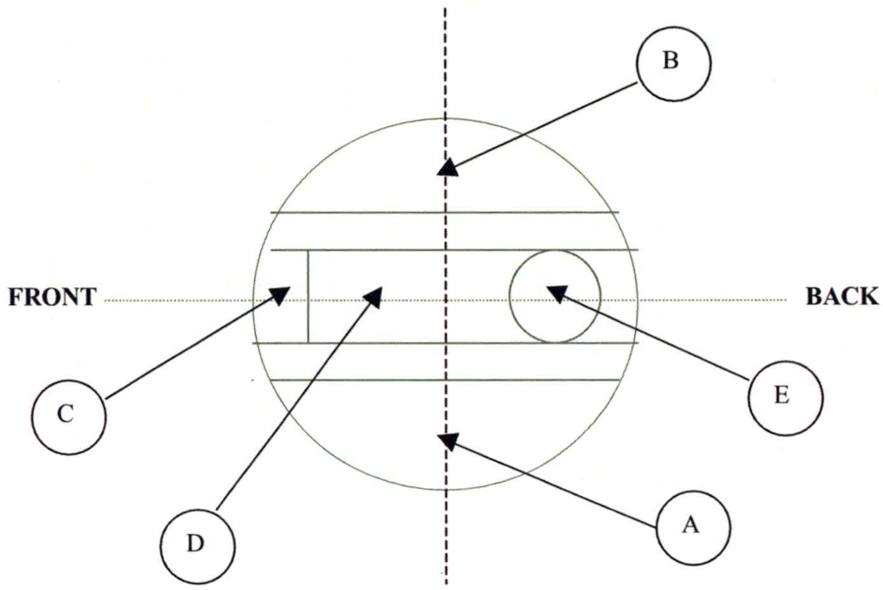


Figure 2. GC3000 Radiation Survey Bottom.

		Contact Reading		1 meter Reading	
Description	Location	Victoreen (mR/h)	Bicron (mR/h)	Victoreen (mR/h)	Bicron (mR/h)
L.F. Quadrant	A	0.1	0.03	0.22	0.05
U.F. Quadrant	B	0.18	0.05	0.2	0.04
U.F. Quadrant	C	0.2	0.09	0.22	0.07
U.F. Quadrant	D	0.28	0.01	0.2	0.04
Under Chamber	E	0.2	0.04	0.18	0.08

Table 2. GC3000 Radiation Survey Readings.

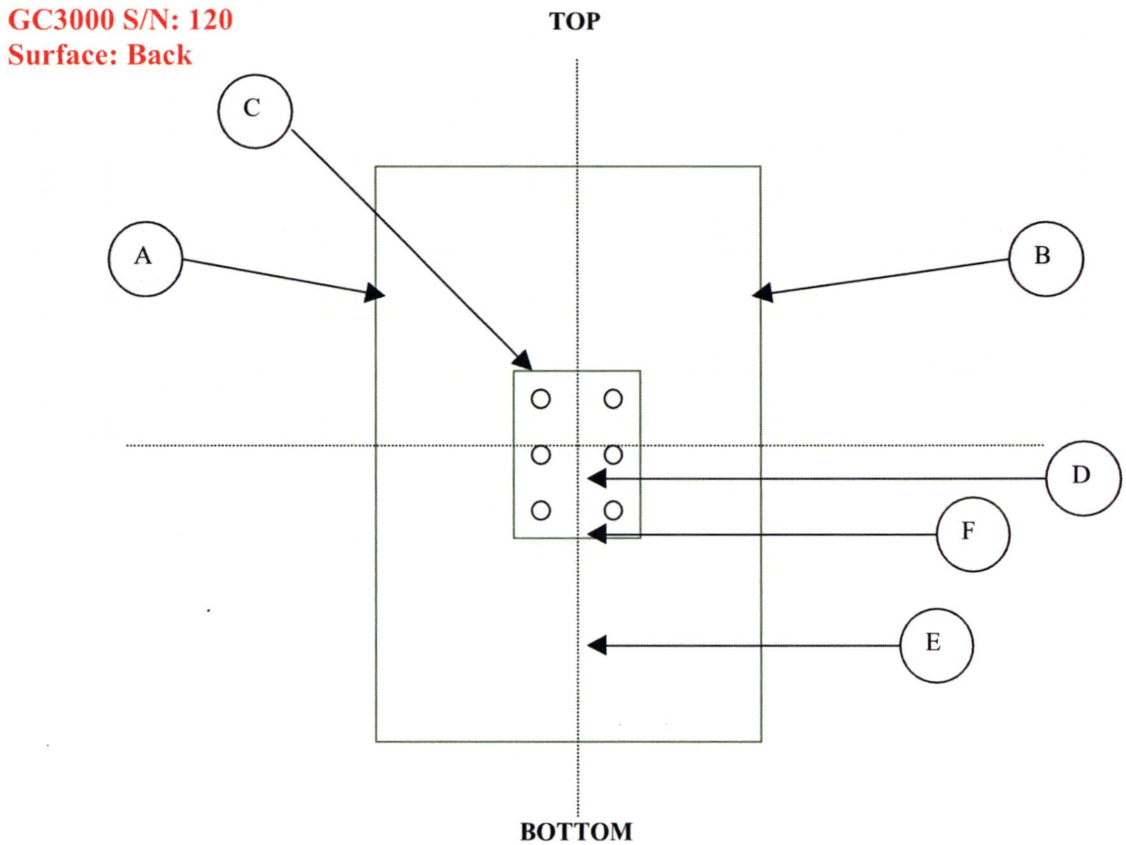


Figure 3. GC3000 Radiation Survey Back.

Description	Location	Contact Reading Victoreen (mR/h)	Contact Reading Bicron (mR/h)	1 meter Reading Victoreen (mR/h)	1 meter Reading Bicron (mR/h)
L.T. Quadrant	A	7.0	7.0	1.6	2.0
R.T. Quadrant	B	8.0	6.5	1.8	2.0
L.T. Quadrant	C	14	20	2.2	2.5
Front Plate	D	64	65	2.5	2.0
R.B. Quadrant	E	6.2	9.0	2.2	2.0
Under Plate	F	50	90	2.4	2.0

Table 3. GC3000 Radiation Survey Readings.

GC3000 S/N: 120
Surface: Front

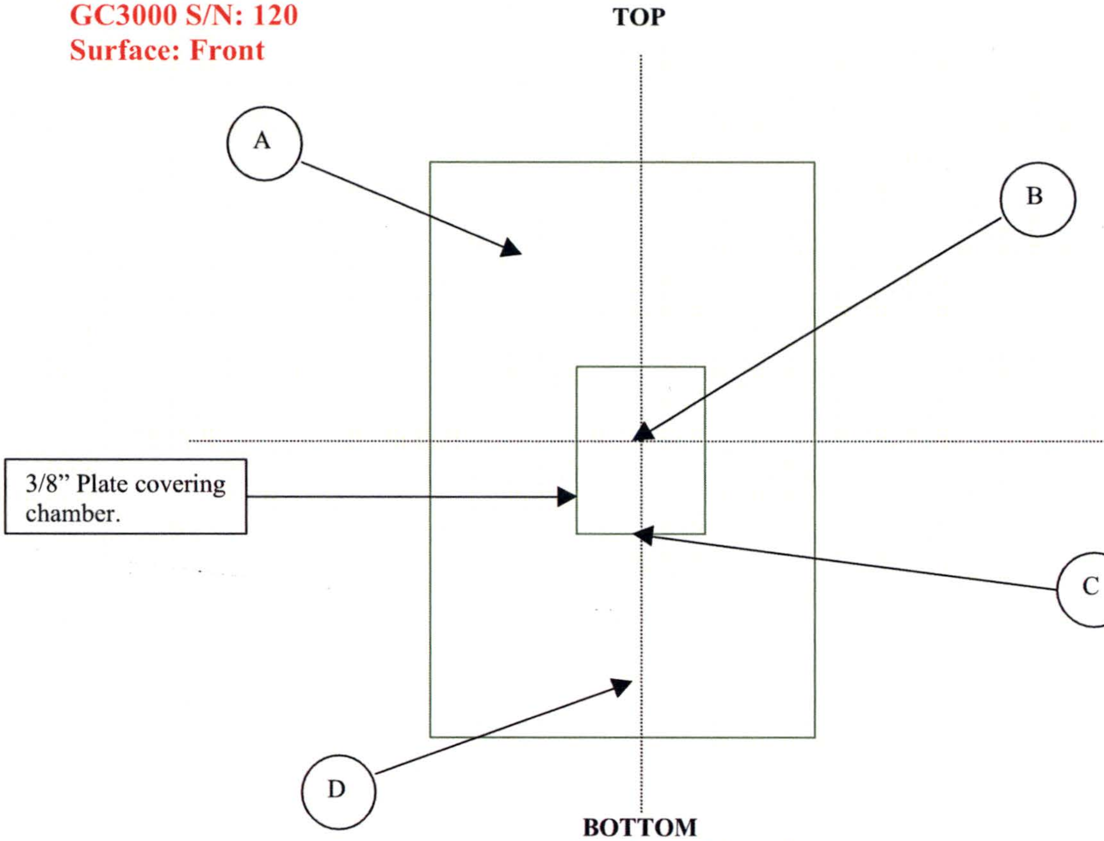


Figure 4. GC3000 Radiation Survey Front.

		Contact Reading		1 meter Reading	
Description	Location	Victoreen (mR/h)	Bicron (mR/h)	Victoreen (mR/h)	Bicron (mR/h)
R.T. Quadrant	A	0.01	0.0	0.02	0.07
Inside Chamber	B	0.02	0.05	0.02	0.08
L.B. Quadrant	C	0.02	0.07	0.02	0.06
L.B. Quadrant	D	0.02	0.07	0.01	0.06

Table 4. GC3000 Radiation Survey Readings.

GC3000 S/N: 120
Surface: Side A

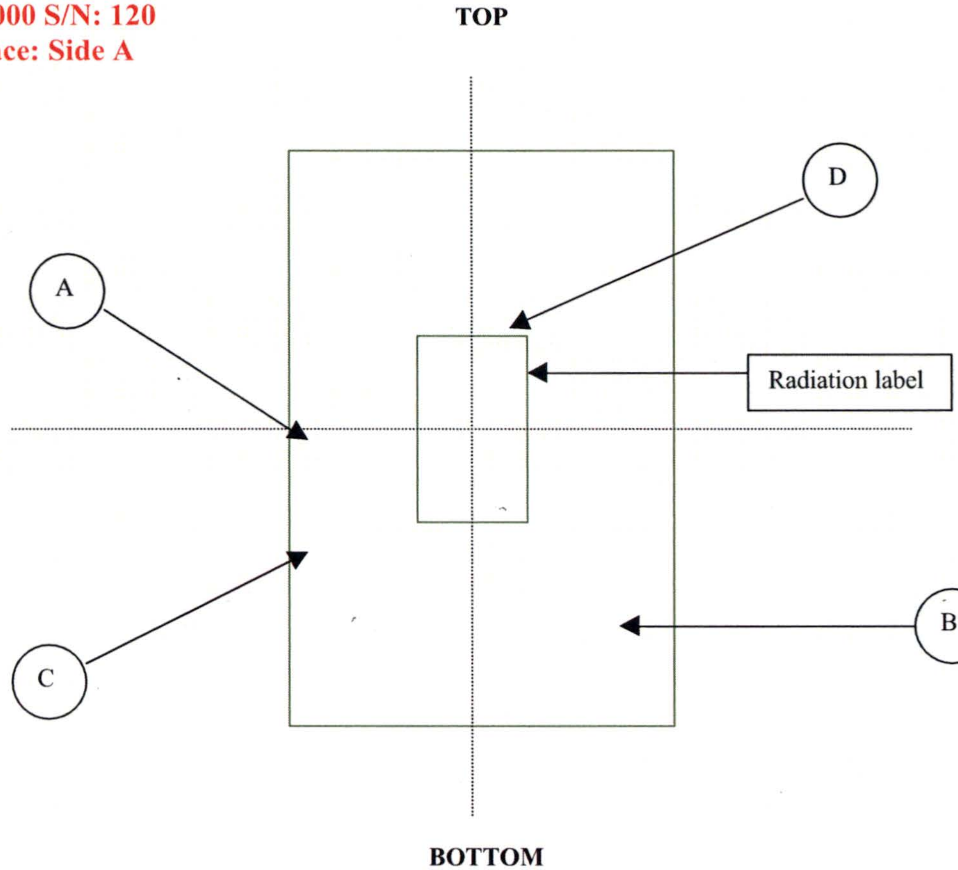


Figure 5. GC3000 Radiation Survey Side A.

		Contact Reading		1 meter Reading	
Description	Location	Victoreen (mR/h)	Bicron (mR/h)	Victoreen (mR/h)	Bicron (mR/h)
L.T. Quadrant	A	0.6	1.1	3.6	0.5
R.B. Quadrant	B	1.0	0.4	1.2	0.0
L.B. Quadrant	C	0.8	0.3	3.0	0.3
L.T. Quadrant	D	1.8	0.02	1.0	0.0

Table 5. GC3000 Radiation Survey Readings.

GC3000 S/N: 120
Surface: Side B

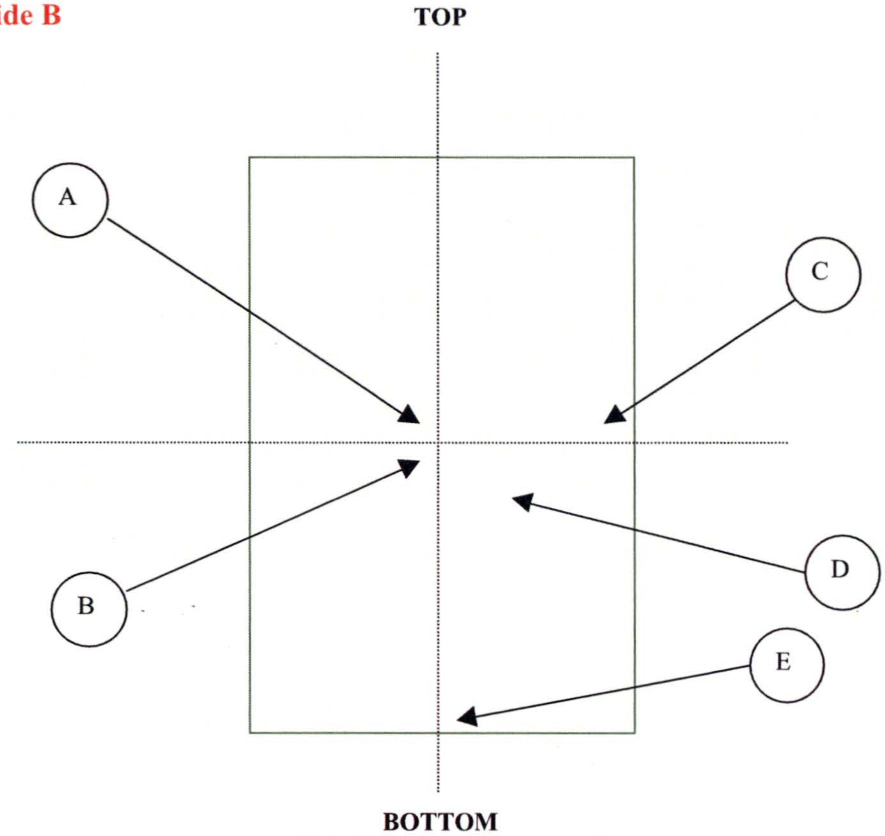


Figure 6. GC3000 Radiation Survey Side B.

		Contact Reading		1 meter Reading	
Description	Location	Victoreen (mR/h)	Bicron (mR/h)	Victoreen (mR/h)	Bicron (mR/h)
L.T. Quadrant	A	0.24	0.12	0.2	0.3
L.B. Quadrant	B	0.3	0.12	0.2	0.5
R.T. Quadrant	C	0.7	1.4	0.2	0.6
R.B. Quadrant	D	0.4	0.1	0.2	0.16
R.B. Quadrant	E	0.3	0.03	0.2	0.15

Table 6. GC3000 Radiation Survey Readings.

APPENDIX D:
AECL Test Report – GC-3000 Testing

AECL EACL

Engineered Products and Services
Design Document

Classification/ Designation CONTROLLED

DOCUMENT TITLE MDS Nordion GC-3000 Testing

PROJECT/JOB TITLE GC-3000 Testing

DOCUMENT TYPE Test Report

Prepared By	R. Birchall	**Date**	99/12/01
Reviewed By	R. J. Lesco	**Date**	99/12/02
Approved By	for E. W. Butterworth	**Date**	99/12/02
Accepted By		**Date**	
Accepted By		**Date**	

(Signatories for Rev. 0 only)

REA No. 17048

Document No. A-17048-TN-2

Revision No. 0

Alternate Document

CRL-3554-1-Rev. 3

AECL EACL

Engineered Products and Services
Document Status and Revision History

TITLE: Test Report: MDS Nordion GC-3000 Testing	REA No. 17048 Doc. No. A-17048-TN-2 Sheet 1 of 1

Rev. No. / Date	Revision History and ECN Reference	Prepared / Reviewed	Approved / Accepted

Issue No.	Rev. No.	DTS No.	Date	ISSUE/STATUS	BY

1. INTRODUCTION

Vertical drop tests were performed on two MDS Nordion test specimens, a bare GC-3000 irradiator and a second GC-3000 irradiator inside its transport container (steel drum), on October 14, 1999, at the AECL drop test facility located at Chalk River, Ontario, Canada.

These tests were witnessed by representatives from MDS Nordion and Menova Engineering.

Five drop tests were performed, in a variety of orientations. An accelerometer was installed on each test specimen to record deceleration data.

Visual records were made using a normal video camera, high-speed film camera (500 frames per second), and still camera. Brief qualitative field observations were recorded by the AECL engineer (R. Birchall) after each drop test, and are part of this document. Detailed quantitative and qualitative observations were recorded after each drop test by MDS Nordion and Menova Engineering personnel, as witnessed by the MDS Nordion Quality Assurance engineer, and are not part of this document.

This report references the photographic record, print numbers 9910-23698-1 and 9910-23698-85 to 9910-23698-107. The high speed film transfer to AVI file format is referenced by filenames shotj.avi to shotn.avi.

2. REFERENCES

MDS Nordion document:

Drop Test Plan for Removable Plug on GC-3000, IN/TP 1559 GC3000 (1)

3. FACILITIES

AECL (Atomic Energy of Canada Limited) maintains a drop test facility at Chalk River Laboratories (CRL), located at Chalk River, Ontario. The drop test tower is 65 ft high; the maximum drop height is 50 ft. The impact target has a surface area of 48 ft^2.

The impact target consists of a steel plate mounted on a concrete pad with a total mass of approximately 80 ton. The entire target is embedded in granite bedrock to provide an essentially infinite mass. The steel-reinforced concrete pad is 10 ft by 10 ft by 10 ft deep with a compressive strength of 5000 psi. The steel plate is 8 ft by 6 ft by 4 inches thick, ASTM A203 Grade E. Tapped holes are provided in the top plate for the installation of a high strength plate and puncture pin for impact testing. (Ref.: AECL Dwg. E-4511-2002).

The puncture pin was supplied by MDS Nordion.

4. TESTING

Note on test numbering: These drop tests were done immediately after testing of the MDS Nordion F-430 (nine drop tests), and the original test numbering (starting at Test No.10) has been retained.

Test No. 10

Conditions:

Drop height = 9m
Orientation: Inverted drop of bare GC-3000
Time of drop: 10:30 AM, Oct. 14, 1999

Photographic record:

9910-23698-85	**Bare GC-3000, pre-drop.**
9910-23698-86 to 9910-23698-87	**Bare GC-3000, post-drop.**

Field observations:

1. Depressed top surface [*as per photographic record*].
2. [*Sample chamber*] plate came off.
3. Bolts flattened [*as per photographic record*].
4. Lifting rings bent [*as per photographic record*].

Deceleration record:

The trace for Accel #7228 shows a deceleration peak of 180 g.

Test No. 11

Conditions:

Drop height = Impact zone 1m above top of pin
Orientation: Oblique angle pin drop of GC-3000 inside the Transport Container
Temperature: 3.6 °C
Time of drop: 11:30 AM, Oct. 14, 1999

Photographic record:

9910-23698-1	**Verification of length of steel rod.**
9910-23698-88	**GC-3000 inside the Transport Container, pre-drop.**
9910-23698-89 to 9910-23698-94	**GC-3000 inside the Transport Container, post-drop.**

Field observations:

1. Lid did not come off.
2. Lid retaining bolt pushed in as per photographic record.
3. Skid bent.
4. Pin hits first [*before the skid hit ground*].

Deceleration record:

The trace for Accel #4713 shows the first deceleration peak of -14 g when the container hits the pin, and a second deceleration peak of -38 g, occurring 0.0159 seconds later, when the skid hits the ground. This interval can also be seen in the AVI file (shotk.avi) in Frames 228 to 234.

Test No. 12

Conditions:

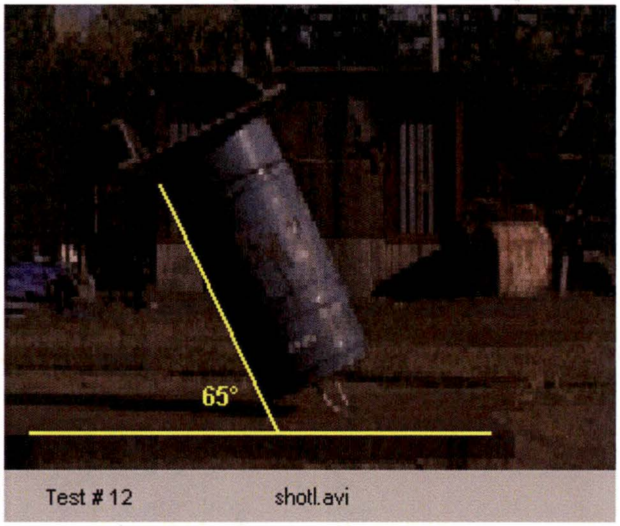
Drop height = 9m
Orientation: Oblique angle (65°) drop of GC-3000 inside the Transport Container
Temperature: 4.5 °C
Time of drop: 1:10 PM, Oct. 14, 1999

Photographic record:

9910-23698-95	**GC-3000 inside the Transport Container, pre-drop.**
9910-23698-96 to 9910-23698-102	**GC-3000 inside the Transport Container, post-drop.**

Field observations:

1. Top section of drum [*upper crush shield*] depressed as per photographic record.
2. Lid did not come off.
3. No new openings in drum.



Deceleration record:

The trace for Accel #4713 shows a deceleration peak of 56 g.

Test No. 13

Conditions:

Drop height = Impact zone 1m above top of pin
Orientation: Side pin drop of GC-3000 inside the Transport Container
Time of drop: 1:45 PM, Oct. 14, 1999

Photographic record:

9910-23698-103	**GC-3000 inside the Transport Container, pre-drop.**

Field observations:

1. Impact [*target*] on lid bolt.

1. Missed pin. [*Test redone as Test No. 14*]

Deceleration record:

The trace for Accel #4713 shows a deceleration peak of 41 g when the skid hits the ground.

Test No. 14

Conditions:

Drop height = Impact zone 1m above top of pin
Orientation: Side pin drop of GC-3000 inside the Transport Container
Temperature: 4.8 °C
Time of drop: 2:00 PM, Oct. 14, 1999

Photographic record:

9910-23698-104 to 9910-23698-107	**GC-3000 inside the Transport Container, post-drop.**

Field observations:

[*None made. Lid did not come off, as per photographic record.*]

Deceleration record:

The trace for Accel #4713 shows the first deceleration peak of 17 g when the container hits the pin, and a second deceleration peak of 40 g, occurring 0.0813 seconds later, when the skid hits the ground. This interval can also be seen in the AVI file (shotn.avi) in Frames 169 to 207.

Appendix 1

DECELERATION MEASUREMENT DURING DROP TESTS OF TWO GC-3000 IRRADIATOR TEST SPECIMENS

John Tromp, Vibration and Tribology Unit

1. INTRODUCTION

Impact tests were conducted on two MDS Nordion test specimens, a bare GC-3000 irradiator and a second GC-3000 irradiator inside its transport container. The Vibration and Tribology Unit was asked to gather data during the impact of these packages to address structural concerns. All drops were performed as requested onto an unyielding surface using various orientations.

2. INSTRUMENTATION

The packages were instrumented with low impedance accelerometers, capable of measuring 2500 g and withstanding a shock load of 5000 g. The accelerometer inside the transport container was tested prior to mounting it in the package to verify its operation, since it would not be accessible for replacement once the package was closed. After the transport container was closed, the accelerometer was again tested for signal integrity before the drop test. Deceleration signals were stored on a multi-channel tape recorder (TEAC model XR7000, QA # 456-268) for later analysis. Figure # 1 shows the GC-3000 inside its transport container and the placement of the accelerometer, and Figure # 2 shows the bare GC-3000 and the placement of the accelerometer.

3. CALIBRATION

All accelerometers were calibrated before and after the drops. A hand-held shaker (B&K Calibration Exciter Type 4294, QA # FS1217) was used as an excitation source. This shaker vibrates at 159.0 Hz and produces an acceleration level of 1.0 g. Each accelerometer was mounted on the shaker and connected to an amplifier (Kistler Dual Mode Model 5010, QA # 456-239). The accelerometer sensitivity setting was adjusted and the output voltage measured using a voltmeter (Keithley Multimeter Model 2001, QA # B5871). Results are listed in Table # 1 in the 'as found' columns. The sensitivity setting was then changed till the output read 1.00 Volts. The resulting sensitivity was then noted in the 'as left' column of Table # 1. This procedure was repeated in part and documented in Table # 1, to verify the condition of the accelerometers after the drops were completed

Calibration Certificates for the instruments used are attached in Appendix 2.

Table # 1: Accelerometer Calibration

Accelerometer (Serial #)	Sensitivity (mV/g)		Date of Calibration (before drop test)	Measured Acceleration (g's)		Date of Calibration (after drop test)	Measured Acceleration (g's)
	as found	as left		as found	as left		as found
7228	2.22	2.10	99/09/30	0.95	1.00	99/11/04	0.98
4713	2.02	1.92	99/09/30	0.95	1.00	99/11/04	0.99

4. TEST RESULTS

The signals stored on tape contain both the deceleration frequency and all natural frequencies of all parts of the package and contents excited on impact. Natural frequencies are usually higher frequencies having higher amplitudes and should therefore be filtered out to reveal the true deceleration frequency. It was determined, by using various filter settings, that anything above 640 Hz showed these natural frequencies.

IAEA Safety Series No.37, Paragraph A-601.14., suggests a cut-off frequency range of 100 to 200 Hz, multiplied by a factor $(100/m)^{1/3}$, where m = mass of package [Mg]. As per this guideline:

Bare GC-3000: (100 to 200 Hz) $\times$ $(100/1.04\ \text{Mg})^{1/3}$ = 458 Hz to 916 Hz

GC-3000 in container: (100 to 200 Hz) $\times$ $(100/1.50\ \text{Mg})^{1/3}$ = 405 Hz to 810 Hz

Therefore the 640 Hz filter setting falls within the IAEA suggested range.

The recorded data was analyzed using a LabVIEW program which was adapted from a previously developed program. This program was verified by analyzing a previous drop test, where results were acquired using a strip chart recorder (the traditional method).
The graphs on pages 11–15 show the signals after being filtered so that anything above 640 Hz is eliminated.

Analog data from the tape recorder was filtered using a National Instrument SCXI-1141 configurable 8-channel elliptic lowpass filter. The filter was connected to a data acquisition card (National Instruments type AT-MIO-16E-10) installed in a Dell personal computer. The digital sampling rate is 8000 samples/second. Data provided in Excel file format is referenced by filenames "Drop # 10.xls" to "Drop # 14.xls".

Table # 2 is a summary of the deceleration data.

Table # 2: Summary of Maximum Measured Deceleration of Drops #10 to #14
[g's]

Accelerometer Location	Accelerometer (Serial #)	Drop #10	Drop #11	Drop #12	Drop #13	Drop #14
Bare GC-3000 (SN 119)	7228	180				
GC-3000 inside transport container (SN 120)	4713		-38	56	41	17

Drop # 10: 9m inverted drop of bare GC-3000.

Drop # 11: Oblique angle pin drop of GC-3000 inside the Transport Container.

Drop # 12: 9m oblique angle (65°) drop of GC-3000 inside the Transport Container.

Drop # 13: Side pin drop of GC-3000 inside the Transport Container. **(Missed the pin)**

Drop # 14: Side pin drop of GC-3000 inside the Transport Container.

5. COMMENTS

The first deceleration graph (Page 10) shows the signal for the bare GC-3000 drop. The next four deceleration graphs (Pages 11–14) show the signals for the GC-3000 inside its transport container.

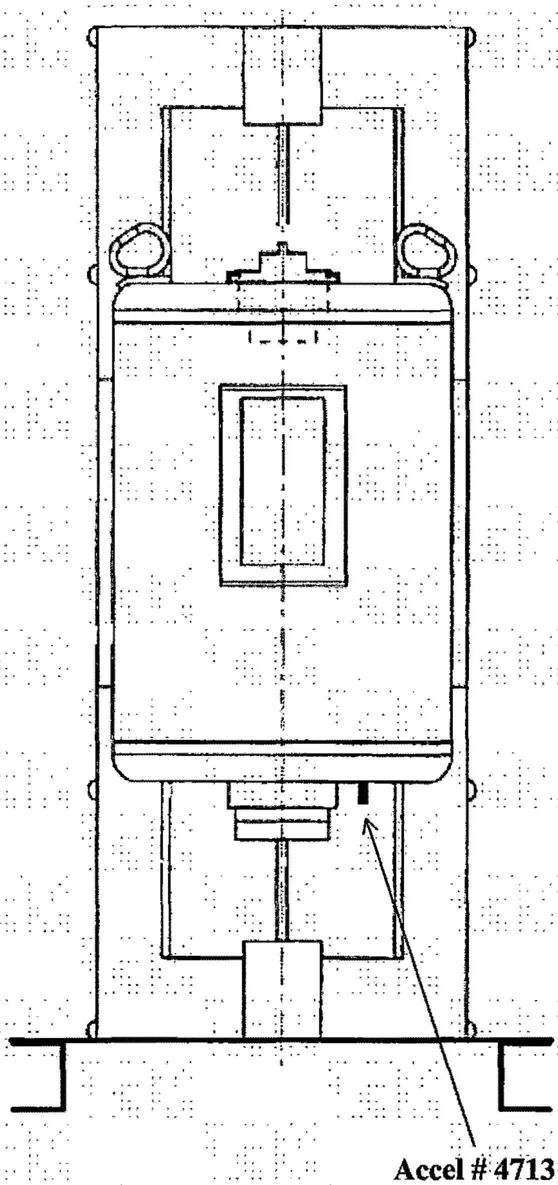


Figure #1: GC-3000 inside its transport container

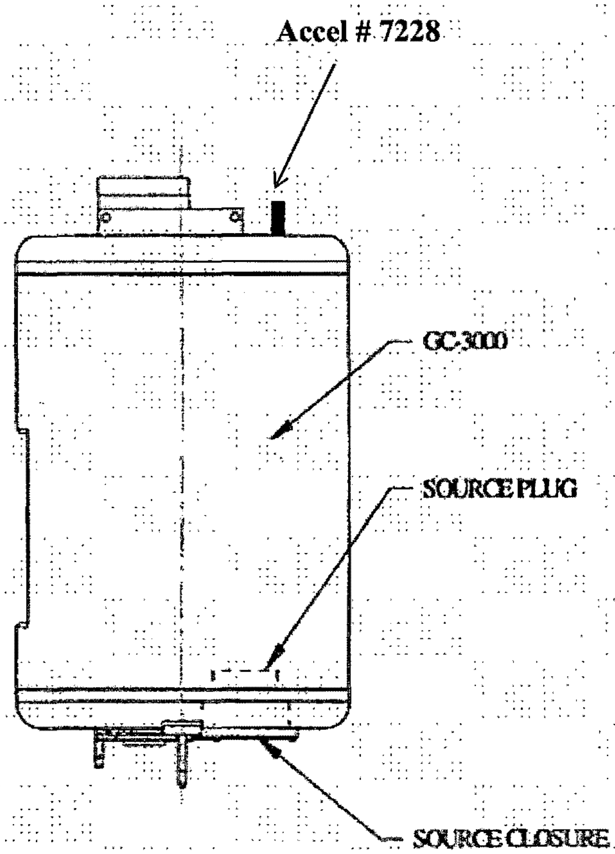
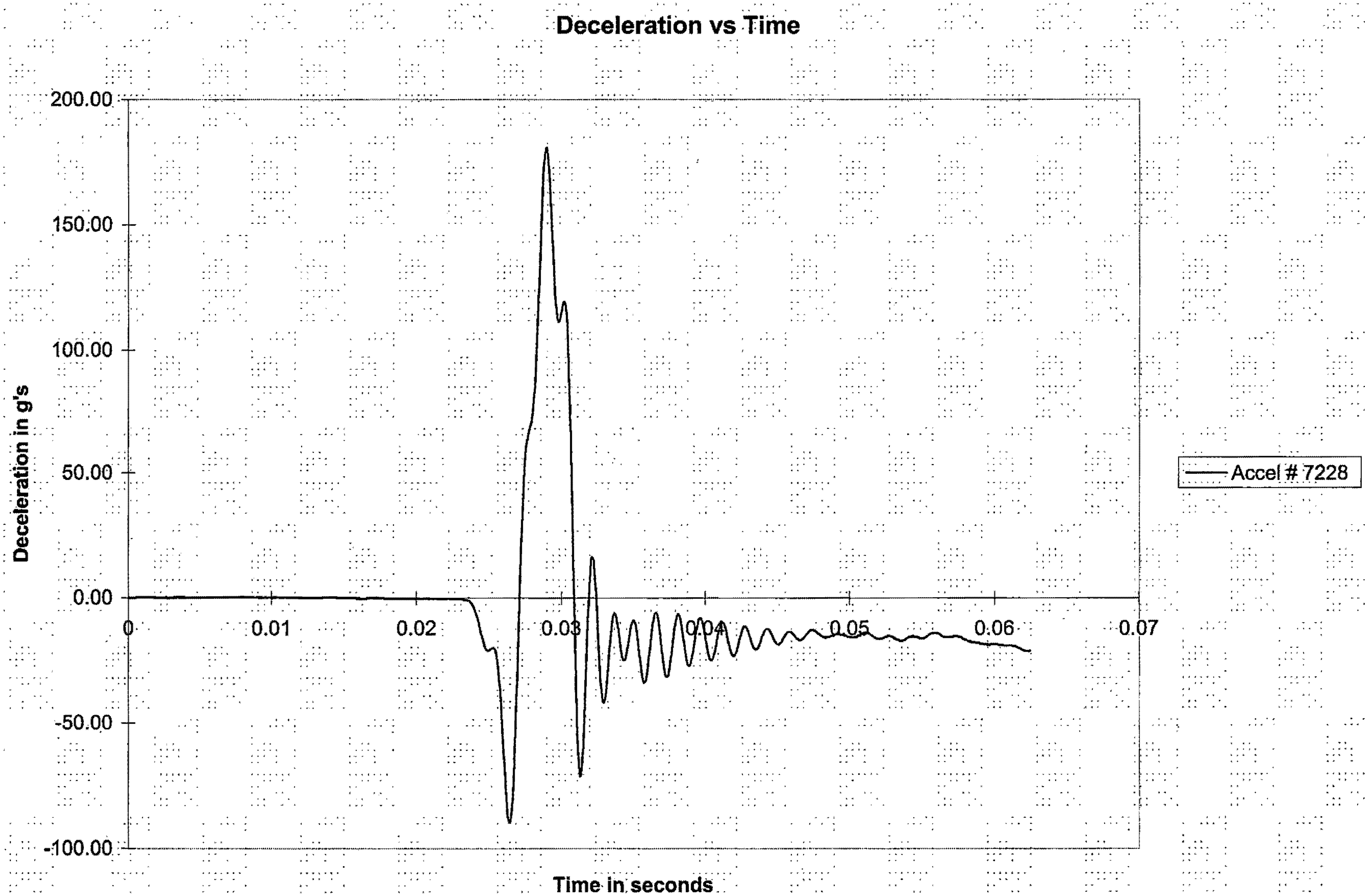
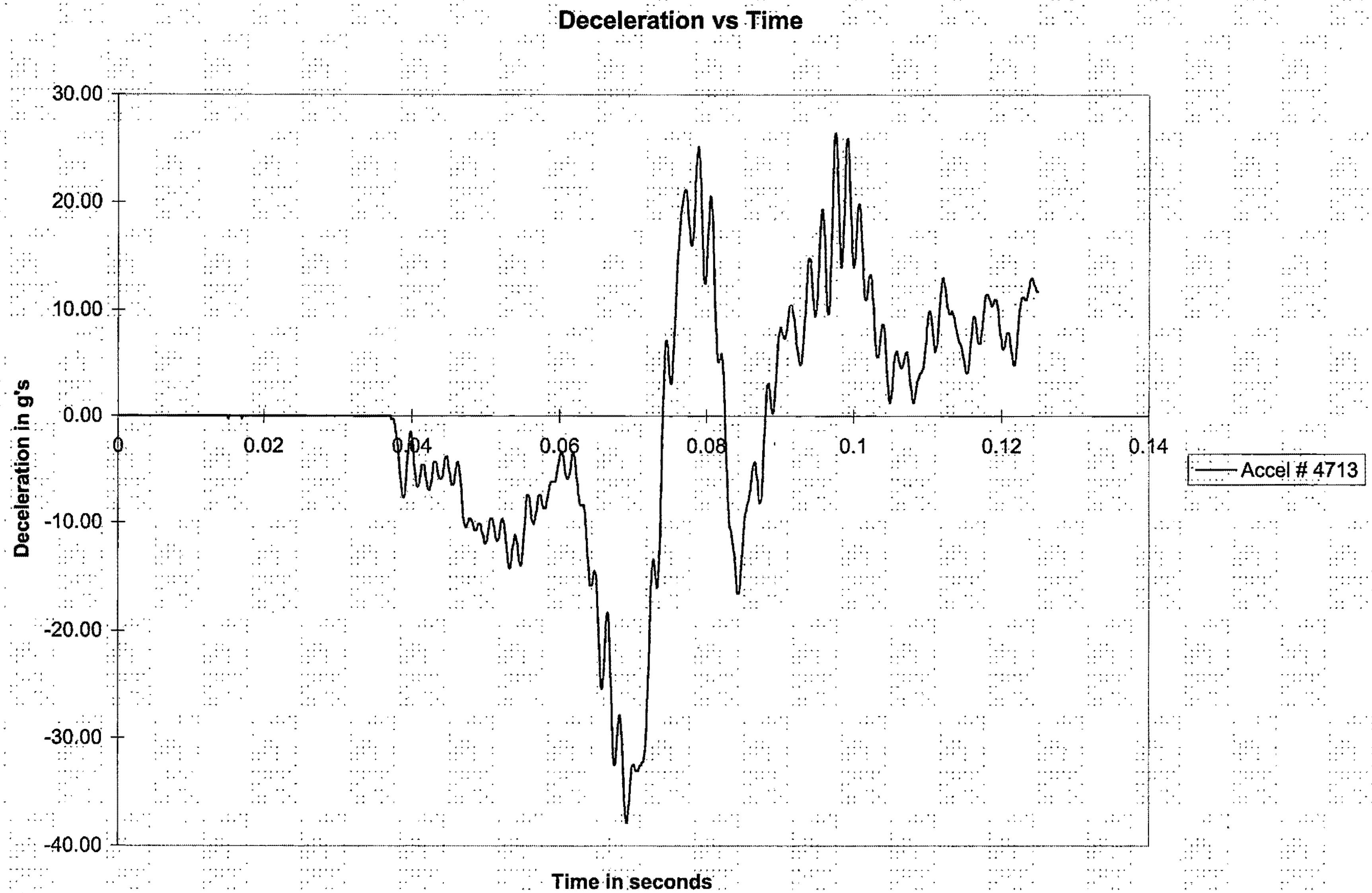
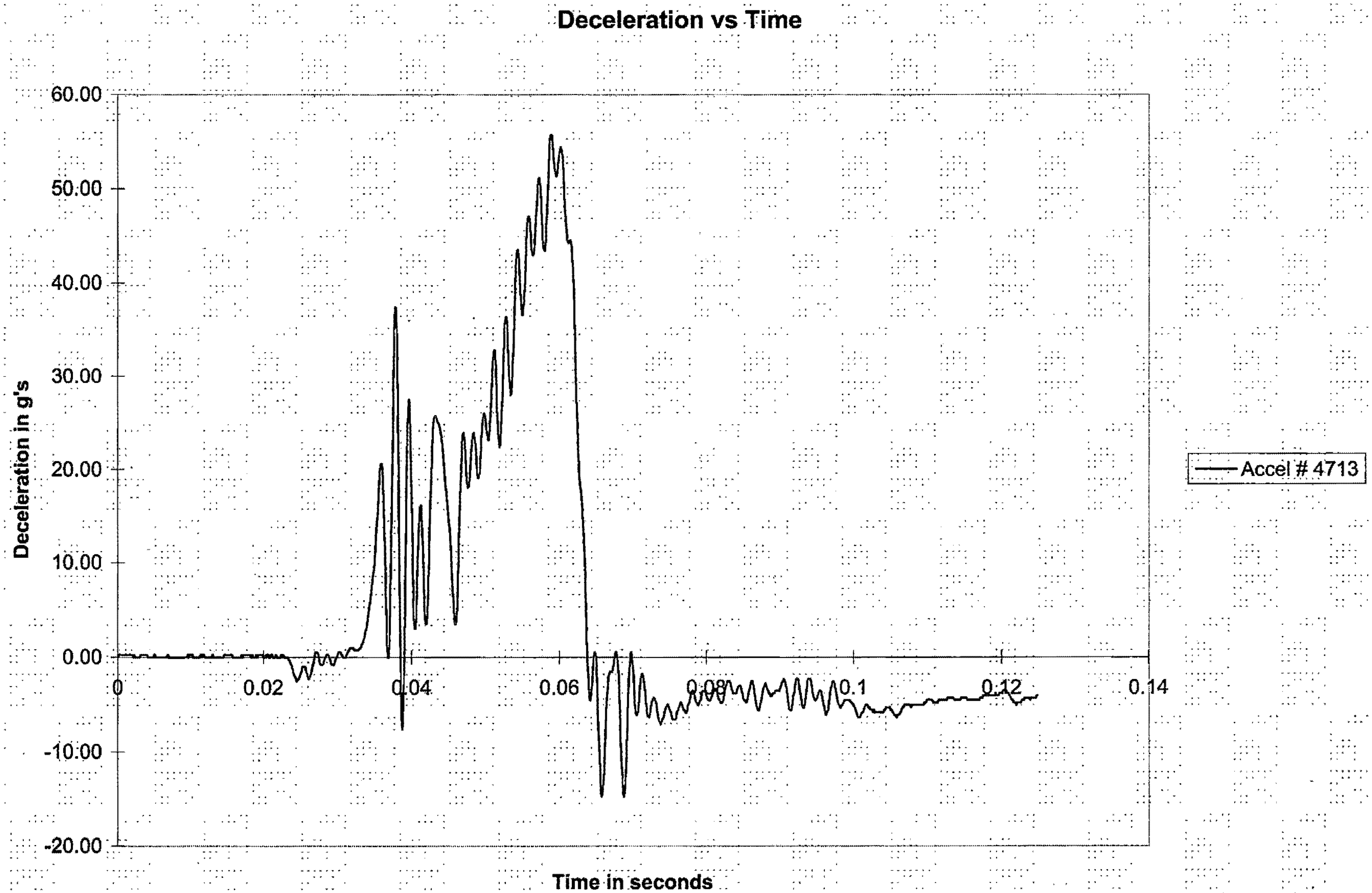


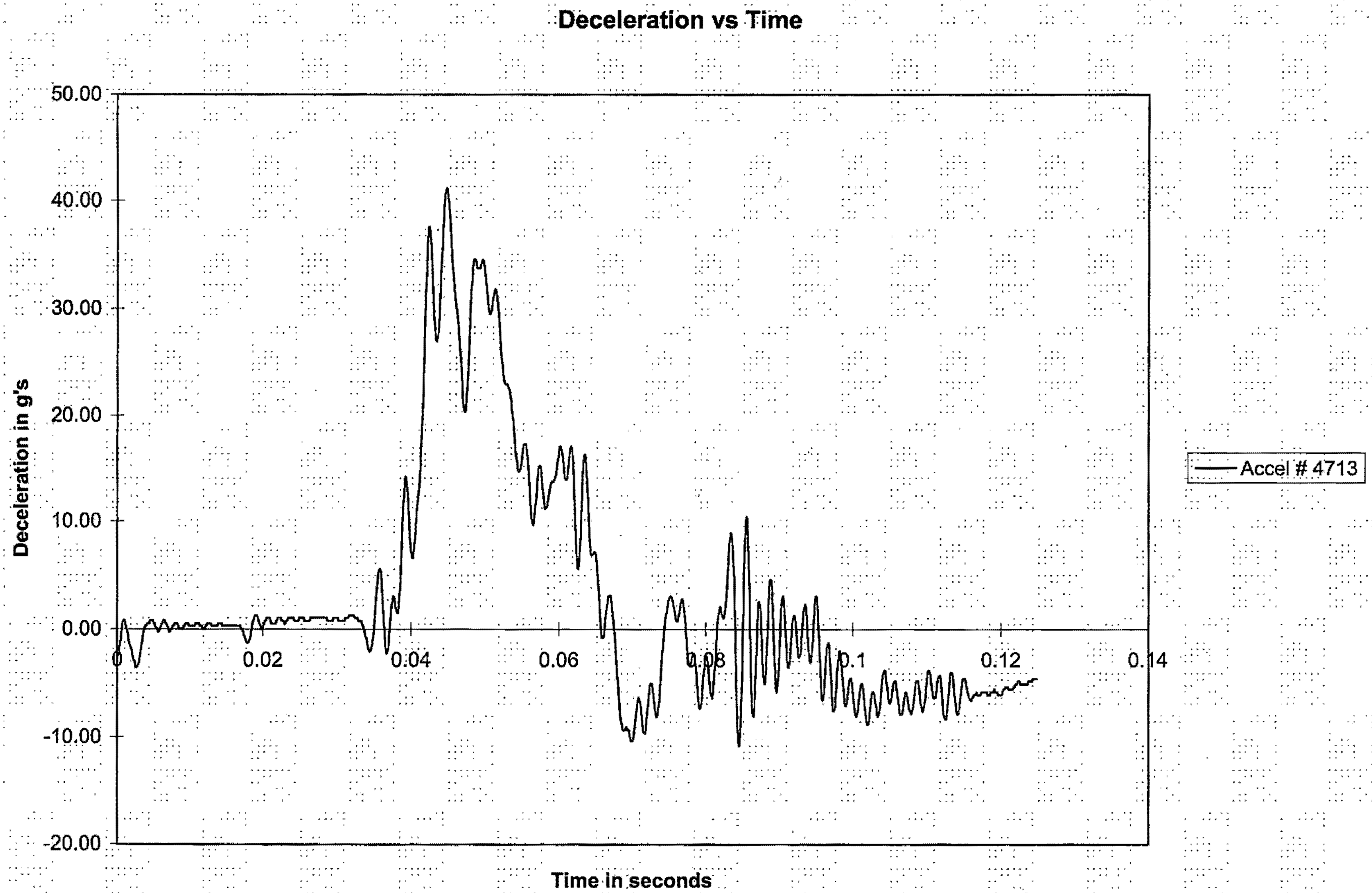
Figure #2: Bare GC-3000


Deceleration vs Time
200.00
150.00
100.00
50.00
0.00
-50.00
-100.00
Deceleration in g's
0
0.01
0.02
0.03
0.04
0.05
0.06
0.07
Time in seconds
Accel # 7228

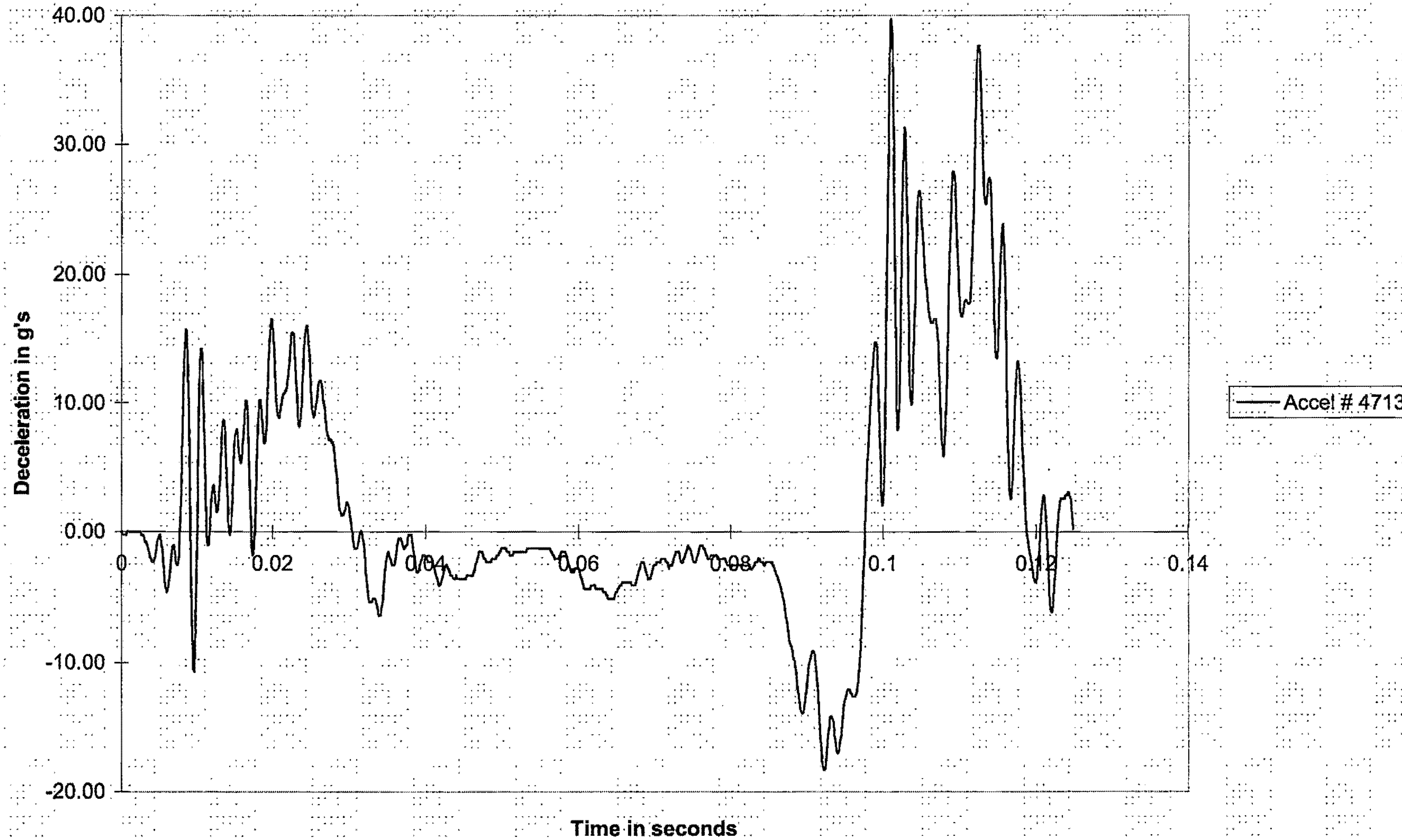

Deceleration vs Time
30.00
20.00
10.00
0.00
-10.00
-20.00
-30.00
-40.00
Deceleration in g's
0
0.02
0.04
0.06
0.08
0.1
0.12
0.14
Time in seconds
Accel # 4713

Accel 4713 Drop # 12




Deceleration vs Time
50.00
40.00
30.00
20.00
10.00
0.00
-10.00
-20.00
Deceleration in g's
0
0.02
0.04
0.06
0.08
0.1
0.12
0.14
Time in seconds
Accel # 4713

Deceleration vs Time



Appendix 2

CALIBRATION CERTIFICATES

Description	Make and Model	AECL QA Number
Multi-channel tape recorder	TEAC Model XR7000	# 456-268
Amplifier	Kistler Dual Mode Model 5010	# 456-239
Hand-held shaker	B&K Calibration Exciter Type 4294	# FS 1217
Voltmeter	Keithley Multimeter Model 2001	# B5871

Canadian Instrumentation Services Group Ltd.

957-10896
Work Order Number

Certificate of Calibration

Issued to:
AECL-CHALK RIVER LAB
CENTRAL WAREHOUSE
BLDG 457

CHAULK RIVER, ONT, CAN
K0J 1J0

Calibrated by: Don Cleveland
Calibrated Date: June 24, 1999
Recall Date: June 22, 2000

Description: DATA RECORDER
Manufacturer: TEAC
Model #: XR-7000
Serial #: 772733
Asset #: C00021
Procedure: SEE DATA SHEET
Cal. State: AS FOUND

This certificate attests that this instrument meets or exceeds published specifications for the parameters tested and has been calibrated with standards traceable to one or more of the following: National Institute of Standards and Technology (NIST), the National Research Council (NRC), fundamental or natural physical constants with values assigned or accepted by NIST or NRC, ratio type or self calibration techniques, comparison to consensus standards. Evidence of traceability is on file at our metrology laboratory. The calibration environmental conditions are as recorded. The collective uncertainty of the measurement standards used do not exceed 25% of the applicable tolerance for each characteristic calibrated unless otherwise stated. The results documented in this certificate relate only to the item(s) calibrated or tested. Calibration interval assignment is the responsibility of the end user, when not specified Canadian Instrumentation Services Group will assign an appropriate calibration interval. This certificate may not be reproduced, except in full, without the written approval of Canadian Instrumentation Services Group.

The measurement standards used for this calibration are supported by a quality system which meets the intent of ISO/IEC Guide 25 and the requirements of ~ISO 9002-1994~ (QMI Certificate #002612) and the CISG QA Manual Rev.1.1.

Standards Used:

Tool #	Description	Calibration Due
ST244560	PRECISION DMM	October 14, 1999
ST299961	CALIBRATOR	February 28, 2000

Quality System Registered to ISO 9002 Certificate 002612

Issue Date: June 24, 1999

Approved By: S Collins

1091 Monaghan Road • Peterborough, Ontario K9J 5L4 • Phone: 705-748-5225 • Fax: 705-748-4559 • 1-800-419-3419 • Website: www.cisg.net

11

West Caldwell Calibration Laboratories Inc.

Certificate of Calibration

for

DUAL MODE AMPLIFIER

Manufactured By: KISTLER
Model No.: 5010 **Serial No.:** C70224
Calibration Recall No.: C5164

Submitted by:

Customer: Mr. Brain Luloff
Company: ATOMIC ENERGY OF CANADA LTD.

The subject instrument was calibrated to the indicated specification using standards traceable to the National Institute of Standards and Technology or to accepted values of natural physical constants. This document certifies that the instrument met the following specification upon its return to the submitter.

West Caldwell Calibration Laboratories Specification No. 5010 KIST (see attached)

Upon receipt for Calibration, the instrument was found to be:

Within (X)
Outside ( ) see attached data

the tolerance of the indicated specification.

West Caldwell Calibration Laboratories' calibration control system meets the following requirements, MIL-STD-45662A, ANSI/NCSL Z540-1, and ISO 9002

Calibration Date: August 20, 1999
Certificate No: C5164 - 1
Calibration Due: August 20, 2000

Approved by:

Stanley Christopher

West Caldwell Calibration Laboratories, Inc.
uncompromised calibration

Ste. 118
5200 Dixie Road
Mississauga Ont.
L4W 1E4

Telephone
(905) 624-3919
Fax
(905) 624 -3926

Spectris Technologies Inc.
90 Leacock Drive
Pointe-Claire, QC H9R 1H1
Telephone: (514) 695-8225
Fax: (514) 695-4808

CERTIFICATE OF CALIBRATION

Brüel & Kjær
spectris group

CUSTOMER : Atomic Energy of Canada Ltd.

Calibration Exciter Type : 4294 Serial No. : 1218159 Ref. No. : 4319

CALIBRATION CONDITIONS :

Air Temperature : 22 °C Air Pressure : 1013 hPa Relative Humidity : 57 %

PROCEDURE :

The calibration is performed by measurement of the Acceleration Level , using Bruël & Kjaer Standard Calibration Set Type 3506 s.n. 1137339.
The Standard Calibration Set is calibrated by laser-interferometer in accordance with ISO 5347.

RESULTS :

The following documented Acceleration Level result is valid with the instrument under test placed in the **vertical position.** The load mass documented below corresponds to the mass of the measuring accelerometer from the Standard Calibration Set.

Acceleration Level : **9.99** ms^{-2} R.M.S.

Frequency : **159.0** Hz

Load Mass : **40** grams

The above results are traceable to N.I.S.T.

The estimated uncertainty for Acceleration Level is ±0.6 % at 95% confidence level. The calibration standards used are documented below.

CALIBRATION SYSTEM

I.D.	Description	Type No.	Serial No.	Cal. Date	Cal. By
27	Multimeter	3458A	2823A11758	05 Nov 97	Hewlett-Packard
35	Calibration Set (B)	3506	1137339	10 Sep 97	B&K Denmark

Date of Calibration : 22-Jun-98 Certificate issued : 22-Jun-98

Calibrated by : Mario Iacobaccio
M. Iacobaccio

Approved by : ST.
S. Tierney

ATOMIC ENERGY OF CANADA LTD.
BUILDING 409 CALIBRATION LAB
REPORT OF CALIBRATION

CUSTOMER WORK ORDER NUMBER: DATE: 19-Jul-99

UNIT UNDER TEST: Keithley 2001 Verify (FRONT) Part 1
PROCEDURE NAME: Keithley 2001 Verify (FRONT) Part 1
SERIAL NUMBER: 0545140
ASSET NUMBER: B5871
CUSTOMER: Bldg. 456 Brian Lulloff
CUSTOMER PURCHASE ORDER NUMBER:

RESULT	PASS
NOTIFY USER (IF > 0)	0
FAILED FINAL TESTS	0
CALIBRATED BY	Joseph Soucy
TEMPERATURE	24.5°C
RELATIVE HUMIDITY	85.0%

STANDARDS USED

Instrument Model	Asset Number	Cal Date	Due Date
Fluke 5700A	409-101	16-Jun-99	13-Dec-99
Fluke 5725A	409-101	16-jun-99	13-Dec-99

REMARKS: As Found/As Left Results

Metrology Technician

Lab Manager

APPENDIX E:
AECL Photographs – No's 9910-23698-85 through to 107

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

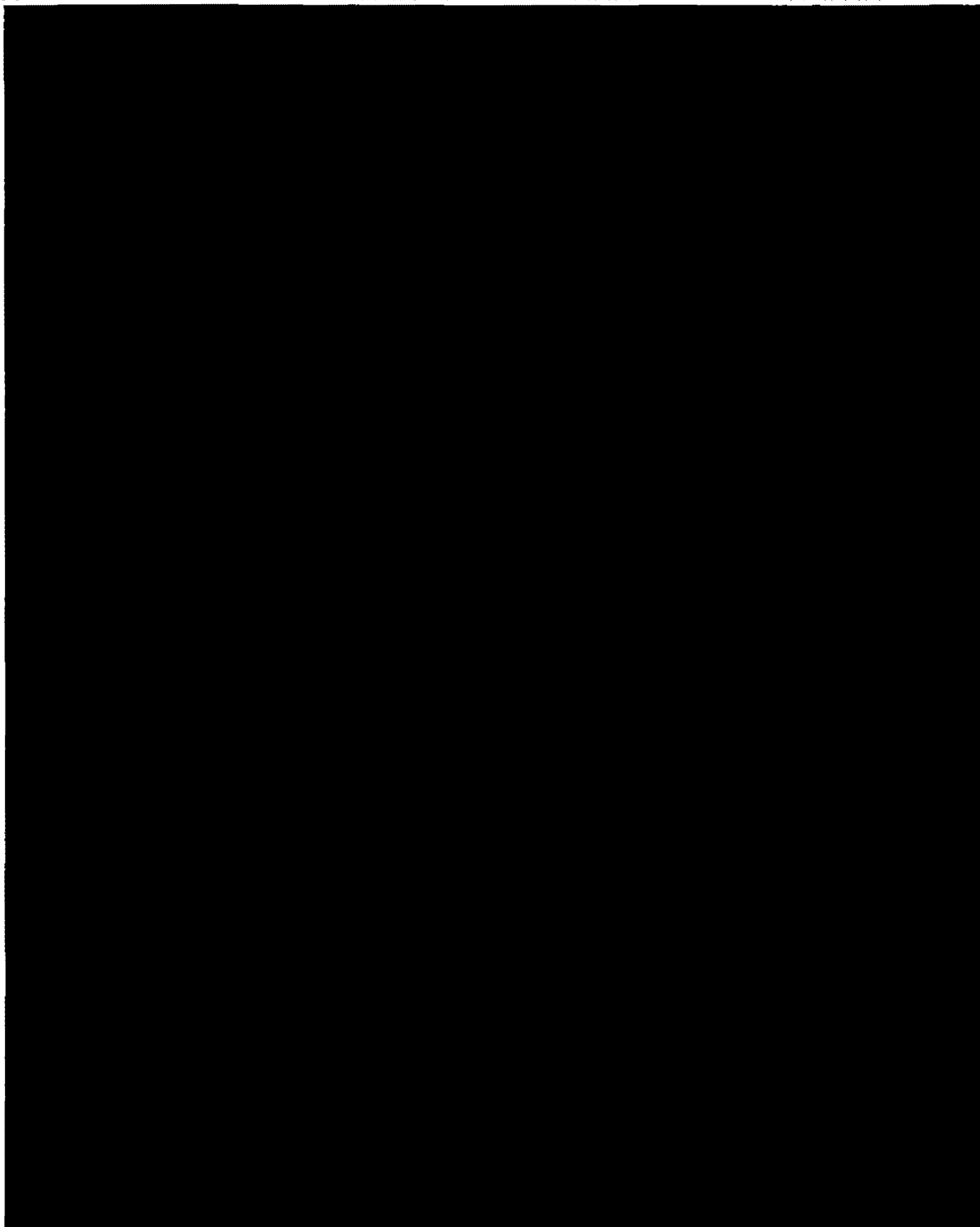
[redacted]

[redacted]

[redacted]

[redacted]

[redacted]



ATOMIC ENERGY OF CANADA LTD 9910-23698-101

[redacted]

ATOMIC ENERGY OF CANADA LTD

9910-23698-102 1

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

APPENDIX F:
Drop Tested Configuration

[redacted]

[redacted]

Security-Related Information
Figure Withheld Under
10 CFR 2.390

APPENDIX 2.10.5:

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

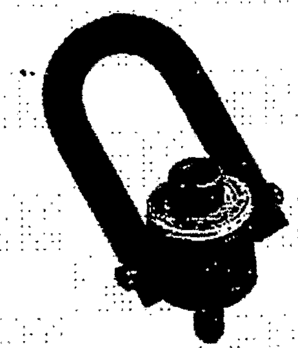
[redacted]

[redacted]

APPENDIX 2.10.6:
Hoist Rings

Page 146

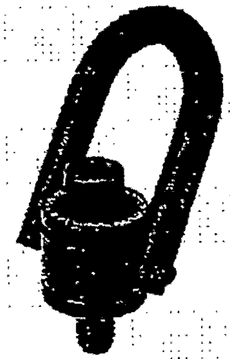
Color coded to distinguish between UNC (Red) and Metric (Silver) thread types



U.S. Patent 5,352,056

Load Rated

Fatigue Rated



HR-125 M
Patented

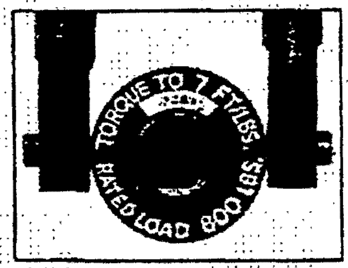
HR-125
Patented

- Rated at 100% at 90° angle
- Each product has a Product Identification Code (PIC) for material traceability along with a Working Load Limit and the name Crosby or "CG" stamped into it.
- All components are Alloy Steel - Quenched and Tempered.
- Available in UNC and Metric thread sizes.
- UNC threads available in sizes from 800 pounds to 30,000 pounds Working Load Limit, with a design factor of 5 to 1.
- Metric threads available in sizes from 400 kg to 16,900 kg and dual rated in both a 4 to 1 and 5 to 1 design factor.
- 360° swivel and 180° pivot action.
- 100% individually proof tested to 2-1/2 times the Working Load Limit with certification and Statistically Magnetic Particle inspected. (Can be furnished 100% Magnetic Particle inspected when requested at time of order).
- Fatigue rated to 20,000 cycles at 1-1/2 times the Working Load Limit.
- Individually packaged along with proper application instructions and warning information.
- Bolt is secured with patented retaining ring which requires no modification to threads. This method allows for easy disassembly and assembly of hoist ring for thorough examination of all components. Replacement kits are available.
- Bolts are individually Proof Tested.
- Multiple Bolt lengths available to meet specific application requirements.

Swivel Hoist Ring

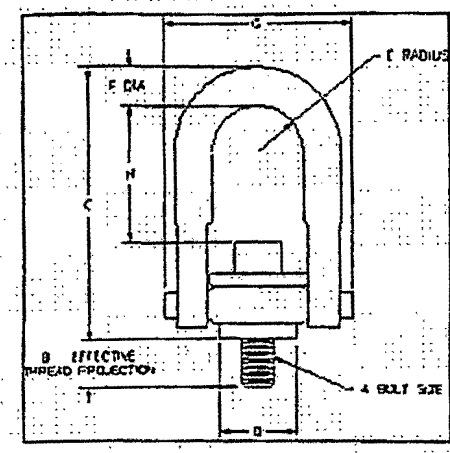
UNC THREADS

SEE APPLICATION AND WARNING INFORMATION
See Pages 144 - 145



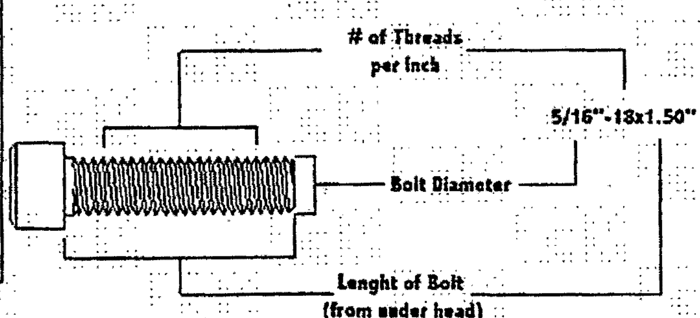
Top washer has the following features:

- The Working Load Limit and Recommended Torque value are permanently stamped into each washer.
- Washer is color coded for easy identification
  Red - UNC thread



BOLT SIZE IDENTIFICATION

The size of the bolt will be stated as in the following example. Illustration shows meaning of each dimension given.



HR-125 Stock No.	Working Load Limit* (lbs.)	Torque in Ft. Lbs.	Dimensions (in.)								Est. Weight Each (lbs.)
			Bolt Size †† A	Effective Thread Projection Length B	C	D	Radius E	Diameter F	G	H	
1016887†	800	7	5/16 - 18 x 1.50	.59	2.69	1.00	.46	.38	1.69	1.11	.43
1016898†	1000	12	3/8 - 16 x 1.50	.59	2.69	1.00	.46	.38	1.69	1.09	.43
1016909	2500	28	1/2 - 13 x 2.00	.71	4.82	2.00	.88	.75	3.30	2.29	2.49
1016912†	2500	28	1/2 - 13 x 2.50	1.21	4.82	2.00	.88	.75	3.30	2.29	2.52
1016920	4000	60	5/8 - 11 x 2.00	.71	4.82	2.00	.88	.75	3.30	2.21	2.55
1016924†	4000	60	5/8 - 11 x 2.75	1.46	4.82	2.00	.88	.75	3.30	2.21	2.70
1016931	5000	100	3/4 - 10 x 2.25	.96	4.82	2.00	.88	.75	3.30	2.05	2.65
1016935†	5000	100	3/4 - 10 x 2.75	1.46	4.82	2.00	.88	.75	3.30	2.05	3.00
1016942	7000	100	3/4 - 10 x 2.75	.90	6.55	3.00	1.37	1.00	4.73	2.98	7.00
1016946†	7000	100	3/4 - 10 x 3.50	1.65	6.55	3.00	1.37	1.00	4.73	2.98	7.00
1016953	8000	160	7/8 - 9 x 2.75	.90	6.55	3.00	1.37	1.00	4.73	2.95	7.00
1016957†	8000	160	7/8 - 9 x 3.50	1.65	6.55	3.00	1.37	1.00	4.73	2.95	7.00
1016964	10000	230	1 - 8 x 3.00	1.15	6.55	3.00	1.37	1.00	4.73	2.73	7.50
1016969†	10000	230	1 - 8 x 4.00	2.15	6.55	3.00	1.37	1.00	4.73	2.73	7.50
1016975	15000	470	1-1/4 - 7 x 4.50	2.22	8.70	3.75	1.75	1.25	6.00	3.94	14.79
1016986	24000	800	1-1/2 - 6 x 6.50	2.98	12.39	4.75	2.25	1.75	8.00	5.93	33.00
1016997	30000	1100	2 - 4-1/2 x 6.50	2.98	12.39	4.75	2.25	1.75	8.00	5.43	36.00

* Ultimate load is 5 times the Working Load Limit.
† Long bolts are designed to be used with soft metal (i.e., aluminum) work piece. While the long bolts may also be used with ferrous metal (i.e., steel & iron) work piece, short bolts are designed for ferrous work pieces only.
†† Bolt specification is a Grade 8 Alloy socket head cap screw to ASTM A 574. All threads listed are UNC - 3A.

NOTE: For Special Applications see page 149.

CROSBY SWIVEL HOIST RING

WARNINGS AND APPLICATION INSTRUCTIONS

WARNING

- Loads may slip or fall if proper Hoist Ring assembly and lifting procedures are not used.
- A falling load may cause serious injury or death.
- Use only genuine Crosby parts as replacements.
- Read, understand and follow all instructions, diagrams and chart information before using swivel hoist ring assembly.

U.S. Patented 5,352,056

HR-125 (Red Washer)

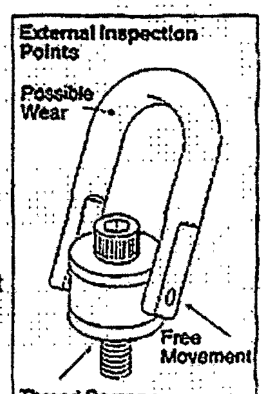
HR-125 M (Silver Washer)

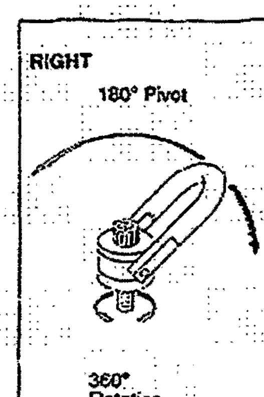
Hoist Ring Application Assembly Safety

- Use swivel hoist ring only with a ferrous metal (steel, iron) or soft metal (i.e., aluminum) loads (work piece).
  Do not leave threaded end of hoist ring in aluminum loads for long time periods due to corrosion.
- After determining the loads on each hoist ring, select the proper size hoist ring using the working Load Limit ratings in Table 1 for UNC threads and Table 2 for Metric threads.
- Drill and tap the work piece to the correct size to a minimum depth of one-half the threaded shank diameter plus the threaded shank length. See rated load limit and bolt torque requirements imprinted on top of the swivel trunnion. (see Table 1 and/ or table 2)
- Install hoist ring to recommended torque with a torque wrench making sure the bushing flange meets the load (work piece) surface.
- Never use spacers between bushing flange and mounting surface.
- Always select proper load rated lifting device for use with Swivel Hoist Ring.
- Attach lifting device ensuring free fit to hoist ring bail (lifting ring). (Fig. 1)
- Apply partial load and check proper rotation and alignment. There should be no interference between load (work piece) and hoist ring bail. (Fig. 2)
- **Special Note:** when a Hoist Ring is installed with a retention nut, the nut must have full thread engagement and must meet one of the following standards to develop the Working Load Limit (WLL).
  1. ASTM A-563 (A) Grade D Hex Thick
     (B) Grade DH Standard Hex
  2. SAE Grade 8 — Standard Hex

Hoist Ring Inspection Maintenance

- Always inspect hoist ring before use.
- Regularly inspect hoist ring parts. (Fig. 3)
- Never use hoist ring that shows signs of corrosion, wear or damage.
- Never use hoist ring if bail is bent or elongated.
- Always be sure threads on shank and receiving holes are clean, not damaged, and fit properly.
- Always check with torque wrench before using an already installed hoist ring.
- Always make sure there are no spacers (washers) used between bushing flange and the mounting surface. Remove any spacers (washers) and retorque before use.
- Always ensure free movement of bail. The bail should pivot 180° and swivel 360°. (Fig. 4)
- Always be sure total work piece surface is in contact with hoist ring bushing mating surface. Drilled and tapped hole must be 90° to load (work piece) surface.



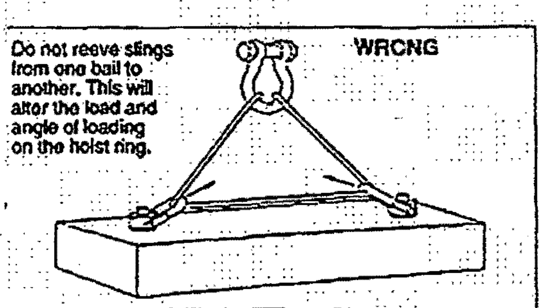


Operating Safety

Page 145

OPERATING SAFETY

- Never exceed the capacity of the swivel hoist ring, see Table 1 for UNC threads and Table 2 Metric threads.
- When using lifting slings of two or more legs, make sure the forces in the legs are calculated using the angle from the vertical to the leg and select the proper size swivel hoist ring to allow for the angular forces. (Note: Sling angles will de-rate sling members (chain, rope, or webbing) but will not de-rate swivel hoist ring capacity.)



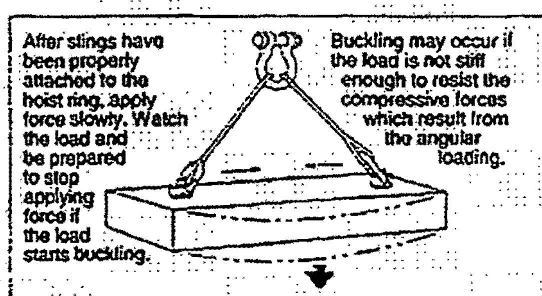


Table 1
HR-125 Swivel Hoist Rings

Working Load Limit* (lbs.)	Torque** in Ft. Lbs.	Bolt Size†† (in.)	Effective Thread Projection Length (in.)
800+	7	5/16 - 18 x 1.50	.59
1000+	12	3/8 - 16 x 1.50	.59
2500	28	1/2 - 13 x 2.00	.71
2500+	28	1/2 - 13 x 2.50	1.21
4000	60	5/8 - 11 x 2.00	.71
4000+	60	5/8 - 11 x 2.75	1.46
5000	100	3/4 - 10 x 2.25	.96
5000+	100	3/4 - 10 x 2.75	1.46
7000	100	3/4 - 10 x 2.75	.90
7000+	100	3/4 - 10 x 3.50	1.65
8000	160	7/8 - 9 x 2.75	.90
8000+	160	7/8 - 9 x 3.50	1.65
10000	230	1 - 8 x 3.00	1.15
10000+	230	1 - 8 x 4.00	2.15
15000	470	1-1/4 - 7 x 4.50	2.22
24000	800	1-1/2 - 6 x 6.50	2.98
30000	1100	2 - 4-1/2 x 6.50	2.98

* Ultimate load is 5 times the Working Load Limit. Individually proof tested to 2-1/2 times the working Load Limit.
** The tightening torque values shown are based upon threads being clean, dry and free of lubrication.
† Long bolts are designed to be used with soft metal (i.e., aluminum) work piece. While the long bolts may also be used with ferrous metal (i.e., steel & iron) work pieces, short bolts are designed for ferrous work pieces only.
†† Bolt specification is a Grade 8 Alloy socket head cap screw to ASTM A 574. All threads are UNC-3A.

Table 2
HR-125M Metric Swivel Hoist Rings*

Working Load Limit (Kg) At a 5:1 Design Factor†	Working Load Limit (Kg) At a 4:1 Design Factor†	Torque** in Nm	Bolt Size†† (mm)	Effective Thread Projection Length (mm)
400	500	10	M8 x 1.25 x 40	16.9
450	550	16	M10 x 1.50 x 40	16.9
1050	1300	38	M12 x 1.75 x 50	17.2
1900	2400	81	M16 x 2.00 x 60	27.2
2150	2700	136	M20 x 2.50 x 65	31.2
3000	3750	136	M20 x 2.50 x 75	28.1
4200	5250	312	M24 x 3.00 x 80	33.1
7000	8750	637	M30 x 3.50 x 100	45.1
11000	13750	1005	M36 x 4.00 x 150	60.6
12500	15600	1005	M42 x 4.50 x 160	70.6
13500	16900	1350	M48 x 5.00 x 160	70.6

* Designed to be used with ferrous work piece only.
** The tightening torque values shown are based upon threads being clean, dry and free of lubrication.
† Individually proof tested to 2-1/2 times the Working Load Limit based on the 4:1 design factor.
†† Bolt specification is a Grade 12.9 Alloy socket head cap screw to DIN 912. All threads are metric (ASME/ANSI B18.3.1 m).

APPENDIX 2.10.7:
Lifting Analysis for the F-431 Overpack

1. INTRODUCTION

The F-431 transport package has a maximum weight of 5000 lb. The package can be lifted using four hoist rings or two forklift pockets located on the main lid assembly. The general arrangement of the package is shown in Figure A2.10.7-1. The internal construction of the main lid assembly is shown in Figure A2.10.7-2.

2. LIFTING FORCES

The package can be lifted using the four hoist rings and a sling. The tension in each leg of the sling will be equal.

Resolve forces vertically: $\Sigma F_Y = 0$

W = 4F cos α

where

W = weight of the container = 5000 pounds.

α = 45°, angle of sling with the vertical

Therefore

F = W/[4 cos α]

= 5000/[4 x cos 45°] = 1768 lb.

Horizontal component, Fx

Fx = F sin α

= 1768 x sin 45° = 1250 lb.

Vertical component, Fy

Fy = F cos α

= 1768 x cos 45° = 1250 lb.

The package also can be lifted using two of the forklift pockets on the main lid. In this case the load on the forklift pocket will be vertical, and shared equally between each pocket.

Fy = W/2

= 2500 lb.

3. STRESS ANALYSIS

3.1 Stresses in Hoist Rings

The ultimate load for the hoist rings is five times the working load (refer to Appendix 2.10.6). Each hoist ring has a working load limit of 7000 lb. When four hoist rings are used to lift the package, the total ultimate load is 140,000 lb. Therefore, the hoist rings have a Safety Factor of 28 against failure.

3.2 Stresses in Lifting Brace

The forces in the hoist rings are transferred to the lifting lug blocks. These are welded to the lifting brace (refer to Figure A2.10.7-2). Normal yield stress S_Y [redacted]

3.2.1 Lifting Lug Block

The lifting lug block weld is under tension due to force Fy. The area under tension, AT, is the fillet weld, [redacted]. The support provided by [redacted].

[redacted]

Average tensile stress, σ

σ $= Fy/AT$

$=$ [redacted]

The lifting lug block weld is under shear due to force Fx. The sheared area, AS, is the [redacted]

[redacted]

Average shear stress, τ

τ $= Fx/AS$

$=$ [redacted]

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

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

σ_n $=$ [redacted]

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

σ_s $=$ [redacted]

3.2.2 Inner Brace With Inner Ring

Where the inner brace attaches to the inner ring, the loading can be approximated by a cantilever beam simply loaded with force F and supported at the outside wall of the overpack. The area under shear resulting from force Fy is:

[redacted]

Average shear stress, τ

τ $= Fy/AS$

$=$ [redacted]

Tensile stress due to force Fx is assumed to be borne entirely by the weld between the inner brace and the inner ring.

Average bending stress, σ

σ $= 6LFy/[bh^2]$
= [redacted]

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

σ_n $= 1/2\ [\sigma + \sqrt{(\sigma^2 + 4\tau^2)}]$
[redacted]
σ_s $= 1/2\sqrt{(\sigma^2 + 4\tau^2)}]$
[redacted]

3.3 Stresses in Flange Segment

The main lid is bolted to the main body with [redacted]

Average shear stress, τ (in the flange fillet weld) is

[redacted]

Average tensile stress, σ [redacted]
= [redacted]

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

σ_n $= 1/2\ [\sigma + \sqrt{(\sigma^2 + 4\tau^2)}]$
[redacted]
σ_s $= 1/2\sqrt{(\sigma^2 + 4\tau^2)}]$
[redacted]

3.4 Stresses in Flange Bolts

[redacted]

Average tensile stress, σ

= [redacted]

3.5 Stresses in Forklift Pocket

The forklift pocket has three highly stressed fillet welds during normal lifting. Each pocket will carry half of the overpack weight.

3.5.1 Pocket With Base

[redacted]

Average tensile stress, σ

= [redacted]

3.5.2 Pocket Base With Skin

[redacted]

Average tensile stress, σ

= [redacted]

3.5.3 Gusset With Inner Ring

Where the gussets attach to the inner ring, the loading can be approximated by a cantilever beam simply loaded with force W/2 and supported at the outside wall of the overpack. Force W/2 is equally distributed to the pocket base plate (two forces W/4) as shown in Figure A2.10.7-2. The weld area under shear resulting from force Fy is:

[redacted]

Average shear stress, τ

τ = W/2/AS

= [redacted]

Average bending stress, σ

σ = 6(L + L) W/4 / [bh²]

= [redacted]

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

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

[redacted]

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

[redacted]

3.6 Failure Under Excessive Load

If excessive load were applied when the F-431 is lifted using the hoist rings, failure would occur in the main lid. Specifically, if the F-431 were restrained and the lifting load were increased beyond 27 tons (11 times the weight of the F-431), the package could be damaged in one or more of the following ways

[redacted]

If the load continued to increase, eventually [redacted]

A similar result would occur if excessive load were applied to two of the forklift pockets.

This would be a very unusual occurrence during handling, and would be considered to be an emergency. The shipment would not proceed any further. Best Theratronics would be contacted for disposition.

Nevertheless, the damaged F-431 would continue to satisfy the requirements of the regulations. Specifically, shielding and containment would be maintained, as these functions are independent of the overpack. Furthermore, the damaged package would be able to survive the accident conditions of transport. The main lid would remain attached to the main body. [redacted] Chapter 3 shows that the F-431 can survive the 30 minute fire test without the protection provided [redacted]

Therefore, the F-431 would continue to satisfy the regulations after failure of the hoist rings or the forklift pockets due to excessive loading.

4. SUMMARY

The analysis has shown that the F-431 can be lifted safely. Table A2.10.7-1 summarizes the results of the lifting analysis. All of the Safety Factors are greater than three, and therefore the F-431 satisfies the requirements of 10 CFR 71.45 (a).

Table A2.10.7-1: Summary of Lifting Stresses						
	Calculated Stress (psi)		Yield Stress (psi)		Safety Factor	
Location	Normal	Shear	Normal	Shear	Normal	Shear
Hoist Ring					28	28
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]		[redacted]		[redacted]	
[redacted]	[redacted]		[redacted]	[redacted]	[redacted]	
[redacted]	[redacted]		[redacted]	[redacted]	[redacted]	
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]

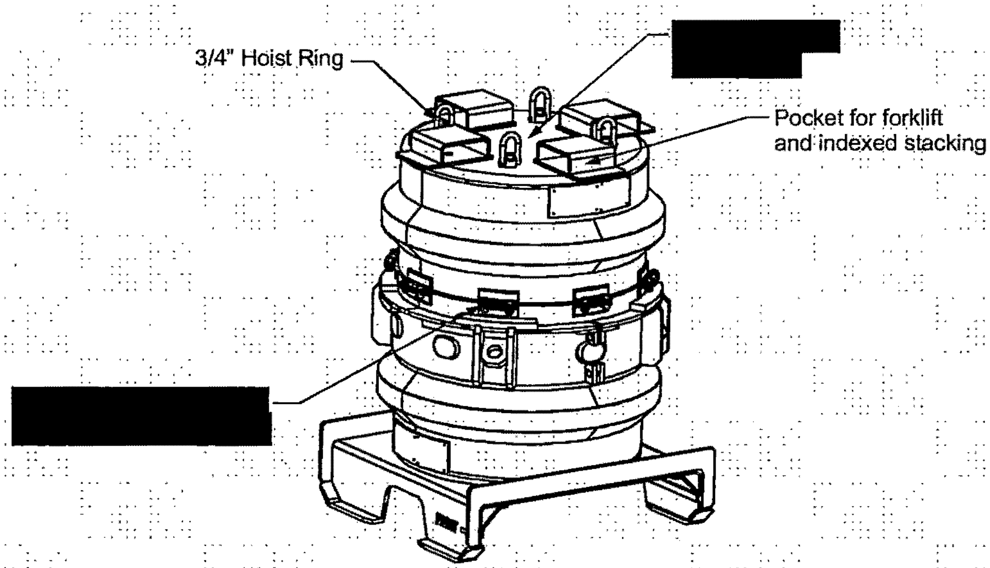


Figure A2.10.7-1: F-431 Overpack

[redacted]

Figure A2.10.7-2: [redacted]

APPENDIX 2.10.8:
Assessment of the F-430 Tie-down Collar Bolted Connection

ML042150352

71-9290 + 71-9310

447 March Road
Ottawa, ON K2K 1X8
Canada

Tel: +1 613 592 2790
Fax: +1 613 592 6937
www.mds.nordion.com

MDS Nordion
Science Advancing Health

July 23, 2004

Your file: 71-9290, 71-9310

Mr. Shawn A. Williams
Project Manager
Licensing Section
Spent Fuel Project Office
Office of Nuclear Material Safety and Safeguards
Mail Stop: 13 D13
United States Nuclear Regulatory Commission
One White Flint North
11555 Rockville Pike
Rockville, MD
20852-2738

RE: Request for Additional Information Related to the Certificate of Compliance No. 9290 MDS Nordion's Model No. F-430 and Certificate of Compliance No. 9310, MDS Nordion's Model F-431

Dear Mr. Williams:

This letter is in response to the U.S. Nuclear Regulatory Commission's (NRC) Request for Additional Information (RAI) dated July 22, 2004. The additional information requested relates to the need for an analysis of the bolt stresses considering the gap in the tiedown collar joint. Please find attached a report, which analyses the bolt stresses in the tiedown collar joint.

Please note that the original design as submitted February 20, 2003 included a gap in the tie-down collar.

I trust this information will enable the staff to complete their review.

If you have any questions or require further information please feel free to contact me by telephone at (613) 592-3400 extension 2421 or by email at mcharette@mds.nordion.com.

Yours sincerely

Marc-André Charette

Marc-André Charette
International Transport & Nuclear Initiatives
Manager, Regulatory Affairs

Attached: ASSESSMENT OF F-430 TIE-DOWN COLLAR BOLTED CONNECTION

Copy to: Mike Krzaniak, Blair Menna, Luc Desgagne, MDS Nordion

NMSS01

ASSESSMENT OF F-430 TIE-DOWN COLLAR BOLTED CONNECTION

The stresses in the bolts that fasten together the two halves of the tie-down collar were considered.

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, there is no vertical force borne by the bolted connection. The horizontal tie-down force, however, can potentially exert tension, shear and bending stresses on the bolted connection. These stresses are considered as follows;

<u>Tension</u>

The component of the horizontal tie-down force acting in the direction of the axis of the bolts applies tension on the bolts. As a worst-case condition, the entire horizontal tie-down force is considered to act along the axis of the bolts (see Figure 1).

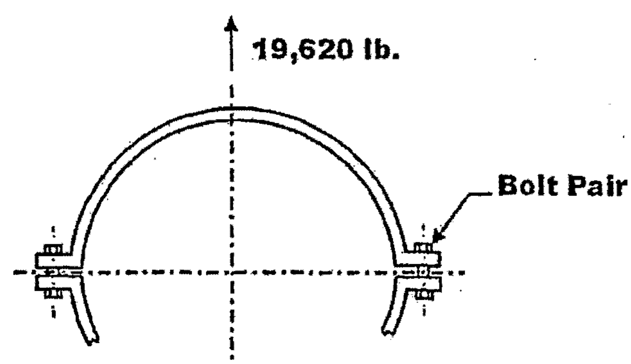


Figure 1: Tension on Tie-Down Collar

The tensile stress in the bolts, σ_t, is calculated from;

$$\sigma_t = F_t/A_t$$

Where,

F_t = the load on the bolts = 19,620 lb.

A_t = tensile stress area of the bolts, based on the root diameter (d = 0.741 in)

$= \pi d^2/4 * 4 \text{ bolts} = \pi(0.741)^2/4 * 4 \text{ bolts} = 1.725 \text{ in}^2$

Therefore,

$$\sigma_t = F_t/A_t = 19{,}620/1.725 = 11{,}374 \text{ psi}$$

The bolts (ASTM A193 Grade B8 Class2) have a yield strength, σ_y, of 80,000 psi. Therefore, the safety factor for the bolts in tension, SF_t, is;

$$SF_t = \sigma_y/\sigma_t = 80{,}000/11{,}374 = 7$$

Shear

The component of the horizontal tie-down force acting in the direction perpendicular to the axis of the bolts applies shear on the bolts. As a worst-case condition, the entire horizontal tie-down force is considered to act perpendicular to the axis of the bolts (see Figure 2).

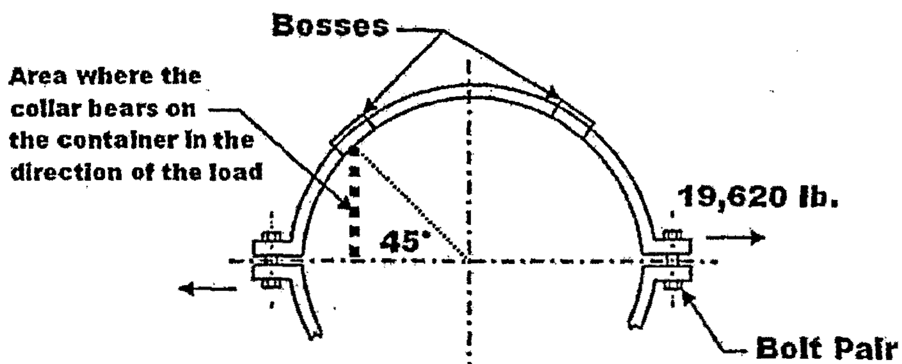


Figure 2: Shear on Tie-Down Collar

The shear is also borne by the oblong boss welds and by the tie-down collar bearing onto the container itself. The total area bearing the shear force, A_s, is calculated by;

$$A_s = A_{bolts} + A_{boss} + A_{container}$$

Where,

A_{bolts} = shear area of bolts = A_t = 1.725 in^2

A_{boss} = shear area of boss welds

= $(2.0*\pi*1.5 + 1.5*2.0)*(0.12)$weld size*2 bosses = 2.982 in^2

$A_{container}$ = area where the tie-down collar bears on the container, which is conservatively assumed to be over a 45° arc in a plane perpendicular to the load (see Figure 2), where the radius of the container is 25.14 in. and the height of the collar is 9.0 inches.

= $\sin(45°)*25.14*9.0 = 159.990\ in^2$

Therefore, the total shear area is,

$A_s = 1.725 + 2.982 + 159.99 = 164.697\ in^2$

The shear stress across the section, τ_s, is calculated from;

$$\tau_s = F_s/A_s$$

Where,

F_s = the shear load = 19,620 lb.

Thus,

$$\tau_s = F_s/A_s = 19{,}620/164.697 = 119\ psi$$

Note that almost all the shear load is borne by the tie-down collar bearing on the container. If it is conservatively assumed that the yield strength of the section to be the yield strength of the compressed foam, which has a yield strength, σ_{yf} of 198 psi, the safety factor for the section in compression, SF_{sc}, is calculated as;

$$SF_{sc} = \sigma_{yf}/\tau_s = 198/119 = 1.7$$

If one considers the yield strength of the shell, the safety factor will be higher.

The bolts have a yield strength, σ_y, of 80,000 psi. Therefore, the safety factor for the bolts under the shear stress, SF_s, is;

$$SF_s = \sigma_y*0.6/\tau_s = 80{,}000*0.6/119 = 403$$

Bending

As there is a gap at the bolted connection, the shear force calculated above applies a bending moment on the bolts.

Conservatively assuming the entire shear stress to act on a pair of bolts, the bending force, F_b, can be calculated as;

$$F_b = \tau_s * A_b$$

Where,

τ_s = 119 psi from the previous section
A_b = cross-sectional area of 2 bolts = = $\pi d^2/4 * 2 = \pi(0.741)^2/4 * 2 = 0.863$ in^2

Therefore,

$$F_b = 119*0.863 = 103 \text{ lb.}$$

The bending stress in the bolts, σ_b, can then be calculated by,

$$\sigma_b = Mc/I$$

Where,

M = moment at the root of the bolts (see Figure 3)
= F_b* (maximum gap between bolts + thickness of bolt flanges)
= 103*(1.0+2.0) = 309 lb-in
c = radius of bolts = (0.741/2) = 0.371 in
I = section modulus of bolts = $\pi d^4/64*2 = \pi(0.741)^4/64*2 = 0.03$ in^4

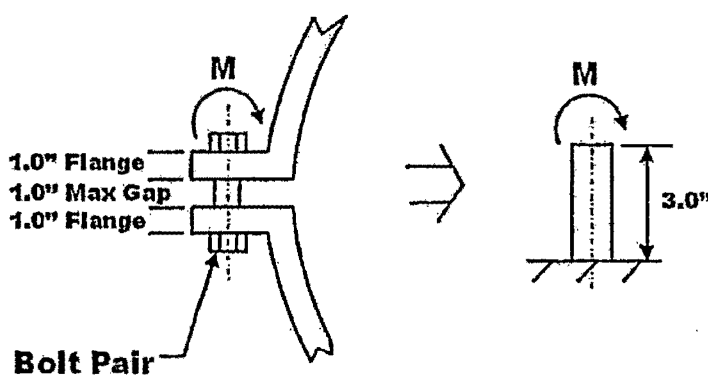


Figure 3: Bending on Tie-Down Collar Bolts

Thus, the bending stress in the bolts is;

$$\sigma_b = 309*0.371/0.03 = 3{,}821 \text{ psi}$$

The bolts have a yield strength of, σ_y of 80,000 psi. Therefore, the safety factor for the bolts in bending, SF_b, is;

$$SF_b = \sigma_y/\sigma_b = 80{,}000/3{,}821 = 21$$

Summary

The safety factors on the bolts in tension, shear and bending were conservatively calculated to be 7, 403, and 21, respectively. It should be noted that a large amount of conservatism was used in the calculation of the load imparted to the bolts in shear and in bending. The container would absorb most of the shear and bending forces and the bolts would be subjected mainly to tension load. The minimum safety factor for the tie-down collar and container under the tie-down force is governed by the compressive strength of the foam resisting the load.

CHAPTER 3 – THERMAL EVALUATION

This chapter presents thermal evaluation demonstrating that the Best Theratronics F-431 package design meets all applicable regulatory criteria for thermal design. The F-431 package is evaluated and shown to provide adequate thermal protection for the payload. Normal and hypothetical accident condition evaluations are performed in accordance with regulatory requirements. The evaluation of the F-431 is based on analysis and tests that were performed on the Best Theratronics F-430 transport package. The analysis and test data for the F-430 are presented as Appendices.

3.1 DISCUSSION

3.1.1 Thermal Design Features

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

3.1.2 Thermal Analysis results

The thermal analysis of the F-431 is detailed in Appendix 3.7.1. The significant results of the thermal analysis are:

1. Temperatures of all accessible surfaces of the package will be less than 50°C in the shade with an ambient temperature of 38°C.
2. An insolation heat load of 800 W/m^2 on the top surface of the package, 400 W/m^2 on the sides, and an ambient temperature of 38°C will not damage the containment and shielding systems.
3. The package is able to survive the regulatory fire test without damage to the shielding or containment systems.

3.1.3 Decay Heat

The F-431 has as a maximum capacity of 113 TBq (3,050 Ci) of Cesium-137. This is equivalent to 15W of decay heat generated as follows [1]:

113e12 dis/s * 816 keV/dis * (1.602e-16) J/keV = 14.8 W

In order to make the analysis conservative, a decay heat of 50W generally was used in the thermal analysis (see Appendix 3.7.1). The decay heat is discussed in detail in section 3.5.6.1.

3.2 SUMMARY OF THERMAL PROPERTIES OF MATERIALS

The thermal properties of the materials used in the F-431 packaging as a function of temperature are given in Table 3.1. This table is reproduced from Appendix 3.7.1.

Table 3.1: Thermal Properties of F-431 Materials

#	Material Description	Density ρ (kg/m³)				Thermal Conductivity k (W/m°C)				Specific Heat c (J/kg°C)			
1	Mild Steel [2]	8131				°C	k	°C	k	°C	c	°C	c
						-73	41.0	127	42.2	-73	434	127	487
						327	39.7	527	35.0	327	559	527	685
						727	27.6	927	27.6	727	1090	927	1090
8	[redacted]	°C	ρ	°C	ρ	°C	k	°C	k	[redacted]			
		0	128	260	128	0	0.038	260	0.038				
		[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]				
		[redacted]	[redacted]			[redacted]	[redacted]						
2	[redacted]	°C	ρ	°C	ρ	°C	k	°C	k	[redacted]			
		[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]				
		[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]				
		[redacted]	[redacted]			[redacted]	[redacted]						
3	Air [2]	°C	ρ	°C	ρ	°C	k	°C	k	°C	c	°C	c
		-73	1.75	127	0.87	-73	0.018	127	0.034	-73	1007	127	1014
		327	0.58	527	0.44	327	0.047	527	0.057	327	1051	527	1099
		727	0.35	927	0.29	727	0.067	927	0.076	727	1141	927	1175
5	[redacted]	[redacted]				°C	k	°C	k	°C	c	°C	c
						[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
						[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
						[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
6	Air With Conduction and Convection Steady State [App. 3.7.1]	°C	ρ	°C	ρ	°C	k	°C	k	°C	c	°C	c
		-73	1.75	127	0.87	-73	1.02	127	1.04	-73	1007	127	1014
		327	0.58	527	0.44	327	0.99	527	0.90	327	1051	527	1099
		727	0.35	927	0.29	727	0.75	927	0.75	727	1141	927	1175
6	Air With Conduction and Convection Transient [App. 3.7.1]	°C	ρ	°C	ρ	°C	k	°C	k	°C	c	°C	c
		-73	1.75	127	0.87	-73	1.51	127	1.53	-73	1007	127	1014
		327	0.58	527	0.44	327	1.48	527	1.39	327	1051	527	1099
		727	0.35	927	0.29	727	1.24	927	1.24	727	1141	927	1175
7	Lead [4]	°C	ρ	°C	ρ	°C	k	°C	k	°C	c	°C	c
		20	11340	327	11005	-273	35	-27	35	-23	127	27	129
		330	10686	800	10686	123	34	227	33	127	132	227	136
						327	31	527	19	327	142	328	6188
						727	22	927	24	331	6188	332	159
12	Mild Steel Including Lead-Steel Contact Resistance [2, 5]	8131				°C	k	°C	k	°C	c	°C	c
						-73	0.53	127	0.99	-73	434	127	487
						327	1.35	527	1.63	327	559	527	685
						727	1.86	927	2.11	727	1090	927	1090

3.3 TECHNICAL SPECIFICATIONS OF COMPONENTS

3.3.1 Standard Construction Materials

The steel, lead, and neoprene are commercially available and meet the requirements of the standards specified in Table 3.2.

3.3.2 [redacted]

[redacted]

Table 3.2: Standards for F-431 Materials of Construction	
Material	**Applicable Standards**
Structural Steel	ASTM A36, CSA G40.21-50W
[redacted]	[redacted]
[redacted]	[redacted]
Pure Lead	ASTM B29
Neoprene	ASTM D2000

3.4 THERMAL EVALUATION FOR NORMAL CONDITIONS OF TRANSPORT

3.4.1 Thermal Model

3.4.1.1 Analytical Model

The Finite Element Model for the F-431 is based on the model used for the F-430 (refer to Appendix 3.7.2). The two packages share almost identical designs. The materials of construction are identical. The main difference between the containers is their size.

No physical testing was performed on the F-431. Rather, the analysis of the F-431 is performed by modifying the geometry used in the F-430 model.

The F-430 thermal analysis and results are included in Appendix 3.7.2. The first step in this model was to validate the FEM steady state model by comparing its output to the results obtained during the steady state temperature test on the full scale prototype. The next step was to run the "validated" F-430 FEM under the different regulatory conditions.

The F-431 finite element model was created by scaling the dimensions in the F-430 model. The same assumptions, material properties and boundary conditions were used as in the F-430 analysis.

3.4.1.2 Test Model

The thermal analysis of the F-431 was based on the analysis of the F-430. A full-scale F-430 prototype was built and tested. The Test Report, including the steady state thermal testing is included in Appendix 2.10.3. This testing was used to validate the F-430 thermal model.

The F-431 is a cylindrical package (107 cm diameter, 128 cm tall) on a square skid. [redacted]

[redacted]

3.4.2 Maximum Temperatures

The analysis of the F-431 is presented in Appendix 3.7.1. The thermal results for the Normal Conditions of Transport are summarized here.

With an ambient temperature of 38°C, 50 W of internal heat load, and no insolation heat loads, the maximum temperatures are 71°C inside the Gammacell cavity, 68°C inside the transport cavity, and 39°C on the outside of the F-431. The maximum source temperature is conservatively assumed to be the same as under the Accident Conditions of Transport (326°C).

Since the surface temperature of the overpack in the shade is not greater than 50°C, the F-431 can be transported as a "non-exclusive use" shipment, and may be shipped by air.

3.4.3 Minimum Temperatures

As there is no minimum activity specified, a minimum temperature of -40°C is defined.

3.4.4 Maximum Internal Pressure

There will be no pressure build up in the F-431 cavity as the covers are not pressure tight.

3.4.5 Maximum Thermal Stresses

The maximum thermal stresses during the normal conditions of transport arise from the temperature distribution given in section 3.4.2 above. As the temperature gradients are very low there will be no significant thermal stresses in the F-431 overpack during normal conditions of transport.

3.4.6 Evaluation of the Package Performance for Normal Conditions of Transport

Temperature sensitive materials used in the Best Theratronics F-431 package [redacted]

The sealed sources are defined as the containment system of the F-431 package. The double encapsulated sealed sources have been demonstrated to meet Special Form requirements and, in particular, the 800°C (1,472°F) temperature test. Since there is a large margin of safety between the maximum source temperature and the Special Form temperature test, containment is assured under the Normal Conditions of Transport.

The maximum temperature of the lead is 117°C. This is safely below the melting point, 327°C, and shielding will not be compromised under the Normal Conditions of Transport.

Finally, as the accessible surface temperatures of the F-431 do not exceed 50°C, the F-431 can be transported as a non-exclusive use shipment.

3.5 HYPOTHETICAL ACCIDENT THERMAL EVALUATION

3.5.1 Thermal Model

3.5.1.1 Analytical Model

The Finite Element Model for the F-431 was summarized in section 3.4.1.1 and is described in detail in Appendix 3.7.1. The following additional features were added to the model for the analysis of the Accident Conditions of Transport.

The output temperatures from the Normal Conditions of Transport (steady state solar, Load Case 2A) became the input for the 30-minute fire transient thermal analysis.

[redacted]

[redacted]

3.5.1.2 Test Model

The thermal analysis of the F-431 was based on the analysis of the F-430. A full-scale F-430 prototype was built and tested. The Test Report, including the steady state thermal testing is included in Appendix 2.10.3. This testing was used to validate the F-430 thermal model. The F-430 thermal analysis is included in Appendix 3.7.2.

The F-431 is a cylindrical package (107 cm diameter, 128 cm tall) on a square skid. [redacted]

[redacted]

3.5.2 Package Conditions and Environment

[redacted]

3.5.3 Package Temperatures

The results of the transient analyses are presented in Appendix 3.7.1. Temperature histories for selected nodes are plotted in this Appendix. The maximum lead temperature was found to be 151°C. The model used a series of conservative assumptions. In spite of these assumptions, a substantial margin of safety exists relative to the 327°C melting point of lead.

The maximum source temperature is estimated to be 326°C in section 3.5.6.1. This is a very conservative estimate. Nevertheless, the sources will continue to provide containment at this temperature.

See Table 3.3 for temperatures at various locations of the F-431.

Table 3.3: [redacted]

[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]

* Temperatures are taken at end of 12 hour transient.
** Temperatures are maximum values during the fire transient at the given time in parentheses.

The effects of the conservative factors used in the analysis is discussed in Appendix 3.7.1. The most significant of these are the assumptions of zero contact resistance at the start of the fire, unimpeded flow of hot gases over the shielding vessel and [redacted]

The results indicate a substantial margin of safety in the design. Therefore the F-431 meets the thermal requirements of the regulations under the normal and hypothetical accident conditions of transport.

3.5.4 Maximum Internal Pressures

In the cavity of the F-431 there will be no pressure build up during accidental fire as the covers are not pressure-tight.

[redacted]

3.5.5 Maximum Thermal Stresses

The maximum thermal stresses will occur during the fire, when the exterior temperatures have reached a maximum and the internal temperatures are still rising. However, no significant thermal stresses are expected as the package is free to expand and contract, [redacted]

3.5.6 Evaluation of Package Performance for the Hypothetical Accident Thermal Conditions

Transient analysis has shown the F-431 to complete the regulatory fire test without the initiation of lead melt. In all cases, peak lead temperatures were found to be significantly less than the melting point, particularly in light of the conservative assumptions used in the model.

The results of the thermal analysis show a substantial margin of safety in the design. Therefore the F-431 meets the thermal requirements of the regulations under the normal and hypothetical accident conditions of transport.

3.5.6.1 Sealed Source

The thermal model in Appendix 3.7.1 does not include the Cs-137 sources. (The sources were simulated by applying the appropriate heat generation to the walls of the gammacell cavity). Since no source temperatures are available, these will be calculated below based on the wall temperature of the gammacell cavity.

The decay energy from Cs-137 consists of 566 keV gamma photons, 62 keV of atomic electron energy and 188 keV of beta radiation [1]. The majority of the gamma photons are shielded in the lead shielding in the gammacell. However some of this energy is attenuated and converted to heat in the sealed source itself. For slender sources such as the ones used in the GC1000 and GC3000, the self absorption is about 4% and the wall absorption (in the stainless steel capsule tubes) is also about 4%. Therefore, the total absorption in the source capsule is 8% of 566 keV, or 45 keV. The balance of the gamma photons, 521 keV, are transmitted through to the gammacell.

Assuming that 100% of the atomic electron energy and 100% of the beta energy are attenuated in the source capsule, the total heat generated in the capsule is 295 keV, or 36% of the total energy. The following analysis will conservatively assume that 50% of the total energy is converted to heat inside the source capsule.

The rated capacity for the F-431 is 113 TBq (3,050 Ci) of Cs-137. This activity generates 15 W of heat. Therefore, the heat generated inside the source will be 50% of 15 W or 7.5 W.

The heat flow from the sealed sources to the gammacell is via convection, conduction and radiation. To be conservative, only convection will be considered here. Also, since concentrating the total activity of Cs-137 inside a single source represents the worst case, only one source will be considered.

The convective heat transfer from the source to the air inside the gammacell cavity is given by:

$$Q = hA_s(T_s - T_a)$$

Where h = convection heat transfer coefficient
A_s = surface area of the source = 0.01 m^2
T_s = source temperature
T_a = air temperature

Similarly, the heat transfer from the air to the gammacell cavity walls is given by

$$Q = hA_w(T_a - T_w)$$

Where A_w = surface area of the gammacell cavity = 0.06 m^2
T_w = cavity wall temperature

Combining the two equations and rearranging gives

$$T_s - T_w = \frac{Q}{h}\left(\frac{1}{A_s} + \frac{1}{A_w}\right)$$

Typical values for h for free convection fall in the range of 5 –25 W/m^2K [2]. For this analysis, h will be taken to be 5 W/m^2K.

Substituting into the equation gives

$T_s - T_w = 175°C$

In appendix 3.7.1, the maximum gammacell cavity wall temperature was found to be 151°C. Therefore the maximum source temperature is 326°C.

This is a very conservative estimate of the source temperature for the following reasons:

1. Conduction heat transfer through the source holder was neglected.
2. Radiation heat transfer from the sealed source was neglected. If the source temperature were this high in reality, the radiation heat transfer would be significant.
3. 50% of the source's energy was assumed to be converted to heat inside the source capsule.

The source capsules meet the requirements for Special Form Radioactive Material and are capable of withstanding a temperature test at 800°C (1,472°F). Therefore, the integrity of the source capsules is sound.

The maximum source temperature in the hypothetical thermal test is 326°C, which is less than the melting point of SS316L (1,260°C). Therefore, the SS316L encapsulation will not melt.

Internal pressure build up due to temperature increase is calculated as follows:

$$\Delta P = P_1\left(\frac{T_2}{T_1}\right) - P_1 = 101.3\left(\frac{273+326}{273+20}\right) - 101.3$$

$$\Delta P = 106kPa = 15psi$$

This is a very low pressure, which will not cause the capsule to fail.

Based on the above arguments, the integrity of the sealed sources is maintained during the fire test.

3.5.6.2 The Containment System

The Special Form sealed source is defined as the containment system of the F-431 package, and these were discussed in the previous section.

3.5.6.3 Shielding

For 50 W of decay heat, the thermal model calculates no lead melt. Consequently there is no loss of lead shielding from the F-431.

Therefore, the integrity of the lead shielding of the F-431 is sound.

3.6 LIST OF REFERENCES FOR CHAPTER 3

[1] Browne, E., Firestone, R.B. *Tables of Radioactive Isotopes*. John Wiley and Sons. New York. 1986.

[2] Incropera, F.P. and Dewitt, D.P. "Fundamentals of Heat and Mass Transfer". John Wiley and Sons, Inc. New York. 1985.

[3] [redacted]

[4] Lead Industries Association. *Lead in Modern Industry* p.184. New York City, New York. 1952.

[5] E7515, Euratom Contract No. 024-65-ECIC, Transnucleaire. "Report on the Implications of the Test Requirements".

3.7 APPENDICES

This section contains the following appendices.

Appendix 3.7.1: Thermal Analysis of the F-431

Appendix 3.7.2: Thermal Analysis of the F-430

Appendix 3.7.3: [redacted]

APPENDIX 3.7.1: Thermal Analysis of F-431 Overpack

IN/TR 1922 F-431 (1)

Thermal Analysis of the F-431 Overpack

Signatures

Prepared by: [redacted] Date: 03.04.23

Reviewed by: Date: 03/04/24

Approved by: Date: 03/04/29

Document History

Date	Version	Comments	Prepared by	Reviewed by	Approved by
April 2003	1	DCN A1297-D-25A			

[redacted]

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

TABLE OF CONTENTS

1. INTRODUCTION

This report is a summary of the analysis performed to determine the thermal behaviour of the F-431 overpack, loaded with a Gammacell, before, during and after the IAEA regulatory fire test [1]. A three-dimensional eighth-section model was constructed, using the ANSYS finite element code Version 6.0 [2], to simulate the fire test. The solid model, finite element mesh, material properties, boundary conditions and load cases used in the ANSYS simulations are discussed. Results of physical testing and finite element simulations previously performed on a similar package design, the F-430 overpack [3], are discussed and compared to verify the thermal model.

The finite element model for the F-431 is based on the model used for the F-430 [3]. The two packages share almost identical designs. The materials of construction are identical. The main difference between the containers is their size.

The finite element analysis of the F-430 was validated against the thermal testing performed on a full scale prototype [3]. No physical testing was performed on the F-431. Rather, the analysis of the F-431 is performed by modifying the geometry used in the F-430 model. The same approach was used in determining the assumptions, material properties and boundary conditions for the F-431 analysis. These are discussed in the following sections.

The results of the analysis show there is no lead melt in the Gammacell contained in the F-431 overpack when it is subjected to the regulatory fire test.

2. SOLID MODEL GEOMETRY

The F-431 overpack loaded with a Gammacell is shown in Figure 1. A three-dimensional, eighth-section solid model of the main components of the F-431 overpack and Gammacell was constructed, as shown in Figures 2 and 3. This model was generated from boolean solids and boolean operations (subtractions, unions) created within ANSYS. These solids were then assigned material properties, meshed, and boundary conditions and loading applied as described in the following sections. A one-eighth section was modelled to take advantage of the symmetry of the package and reduce the size and complexity of the model.

The model for the F-431 was based on the previously verified model of the F-430 overpack [3], which is similar in size and construction. The two overpacks are compared in Figure 4.

3. MATERIAL PROPERTIES

Material properties were required for mild steel, stainless steel, lead, air and foam insulation as shown in Table 1. The properties required included density, thermal conductivity and specific heat. The specific heat of lead incorporated the latent heat of fusion (24,750 J/g) to simulate the phase change when the material melts (note that lead melt was not encountered in any of the load case scenarios).

Convection coefficients and surface emissivities required to define the heat transfer by convection and radiation on the outside of the overpack are discussed in Section 4.3. The conduction, convection and radiation heat transfer across the air space between the Gammacell and the overpack, and the required material properties, are discussed in Section 4.2.

The lead-to-steel contact resistance at the Gammacell outer shell was modelled by modifying the conduction coefficient of the steel outer shell to include an equivalent air gap of 0.02 in. [4 and Appendix A]. The contact resistance was removed for the fire simulation to allow the maximum amount of heat to penetrate into the centre of the package.

Above 465°C, [redacted] [10]. To account for this, the foam was assumed to take on the conduction properties of air at temperatures above 465°C.

4. FINITE ELEMENT MESH, BOUNDARY AND LOAD CONDITIONS

4.1 Three-Dimensional Eighth-Section Model Mesh

The solid model was meshed using thermal three-dimensional tetragonal elements [2 and Appendix B], as shown in Figure 5. The optimal mesh density shown in the figures was achieved by refining the mesh to the point where the temperature results were not dependent on the mesh density. The mesh used for the simulations presented in this report contained 25,388 elements and 4,689 nodes. The integrity of the elements (connectivity, aspect ratios and internal angles) is automatically checked by ANSYS prior to the run.

4.2 Heat Transfer Across the Internal Air Space

The heat transfer across the air space between the Gammacell and the overpack inner frame is comprised of conduction, convection and radiation.

Heat transfer by conduction occurs through the air and through the support structure of the Gammacell. Convection heat transfer through the air is accounted for by an effective thermal conductivity [5], as calculated in Appendix C. The air inside the package will tend to circulate due to the temperature gradients across the air space transferring additional heat by free convection. The effective thermal conductivity is the thermal conductivity that a stationary fluid should have to transfer the same amount of heat as the moving fluid. A total thermal conductivity for the air space is calculated (Appendix C) to combine the contribution of the conduction and convection across the air space.

Radiation across the air space is modelled by a radiation enclosure [2 and Appendix B], as shown in Figure 6. The Gammacell surface, painted grey, was given an emissivity of 0.8, while the stainless steel surfaces of the inner frame and floor of the overpack were assigned an emissivity of 0.5 [5]. The symmetry surfaces of the radiation enclosure are given a very low emissivity of 0.01, such that they behave as mirrored surfaces, reflecting heat back into the enclosure.

The actual radiation heat transfer across the air space will be less than that modelled, since the blocking effects of the Gammacell support structure are neglected. The radiation heat transfer is, therefore, conservatively modelled.

4.3 Convection and Radiation Boundary Conditions

Convection and radiation boundary conditions used in the model are shown in Figure 7.

Convection was applied on the outer surface of the overpack by selecting the external nodes and applying a convection coefficient (calculated in Appendix D) and ambient temperature as a surface load.

To model the radiation on the outer surface of the overpack, surface elements [2 and Appendix B] were used to define a radiation matrix with view factors conservatively set to 1.0. A space node external to the model was used to define the ambient temperature for the radiating surface elements. For the steady state condition, an emissivity of 0.5 was used for the stainless steel surface elements [8]. For the fire condition an emissivity of 1.0 was conservatively used for the surface elements.

4.4 Internal Heat Generation

The decay of the Cs-137 carried inside the F-431 overpack generates 4.84 W of heat per kCi, based on 566 keV of photon energy, 62 keV of atomic electron energy and 188 keV of continuous radiation [6], as calculated below:

1000 Ci/kCi * 3.7e+10 dis/s/Ci * 816 keV/dis * 1.602e-16 J/keV * 1 W/J/s = 4.84 W/kCi

The maximum allowable activity in the F-431 is 3.05 kCi of Cs-137 [7] for a total heat output of 14.8 W (4.84*3.05). Over three times this heat load, or 50 W, was applied for all load cases, including the simulation of the regulatory fire, as a worst-case internal heat load.

The internal heat generated in the Gammacell was applied as a uniform heat generation on the inside of the Gammacell source cavity. The heated elements and the applied heat generation rates are shown in Figure 8. Self-attenuation of the capsules generally results in lower radiation fields in the axial dimension and higher radial fields. This effect was ignored in the model due to the small size of the cavity and the low heat generation of the source.

4.5 Solar Heat Load

Figure 8 shows the elements that were subjected to the solar heat flux required by the regulations [1]. A heat flux of 400 W/m^2 was applied to the side of the overpack and a heat flux of 800 W/m^2 was applied to the top of the overpack as per the regulations. This heat flux was applied both as a steady state load, and as a transient load over 12 hours as specified in the regulations for the Normal Conditions of Transport, to determine the response of the overpack to both conditions.

4.6 Fire Test Transient Load

The IAEA fire test [1] was applied by defining a transient temperature curve for the ambient temperature as shown in Figure 9. This curve was applied to the convection boundary conditions and the node representing the ambient temperature for the external radiation matrix (Section 4.3). The 30 minute, 800°C fire was followed by a one minute ramp-down to pre-fire ambient temperatures, followed by a 21.5 hour (1,288 minute) cool-down period. This 1,288 minutes of cooling was sufficient to allow all temperatures to reach their maximum values.

The solar heat flux discussed in Section 4.5 was applied for 12 of the 21.5 hour cool down period as required by the regulations [1].

To simulate the effects of increased convection to the environment, the convection heat transfer coefficient on the outside of the overpack was set to 19 $W/m^2{}^\circ C$, as calculated in Appendix D.

To maximise the radiation heat transfer during the fire, a conservative emissivity of 1.0 was used for the outside stainless steel surface of the overpack.

Also to simulate a worst-case fire condition, the lead-to-steel contact resistance at the Gammacell outer shell was removed.

5. LOAD CASES

The ANSYS input files for all of the following load case scenarios considered are listed in Appendix E.

5.1 Load Case 1: Steady State, 50 W Cs-137, No Solar Load, 38°C Ambient

This load case was used to determine the steady state behaviour of the model with no insolation. Steady state conditions were used with 50 W (Section 4.4) of cesium-137 loaded into the Gammacell. The ambient temperature outside of the overpack was assumed to be 38°C as per the regulations [1].

5.2 Load Case 2: Steady State/Transient, 50 W Cs-137, Solar Load, 38°C Ambient

This load case is identical to Load Case 1, except that the solar heat load discussed in Section 4.5 was applied.

This load case shows the effect of the solar load with a 38°C ambient temperature under steady state conditions and applied as a 12 hour transient as required by the regulations [1].

5.3 Load Case 3: Fire Transient, 50 W Cs-137, Solar Load, 38°C Ambient

This load case shows the response of the F-431 overpack and Gammacell to the IAEA regulatory fire test [1].

Transient conditions were used with initial temperatures from the steady state analysis in Load Case 2, with the ambient temperature outside of the overpack assumed to be 38°C as per the regulations [1].

The transient loading consisted of the IAEA regulatory fire loading [1], as discussed in Section 4.6. The model was loaded with 50 W of cesium-137 (Section 4.4) and had the solar load (Section 4.5) applied after the fire, during the cool-down of the overpack, as required by the regulations.

5.4 Load Case 4: [redacted]

This load case is identical to Load Case 3, except that the thermal conductivity of the outer foam was increased to a value of 35 W/m°C, similar to lead. This change simulates a very conservative worst-case scenario where all of the outer foam is crushed so as to provide no thermal insulation to the fire. The remainder of the material properties and loading are identical to Load Case 3 in that the inner foam and air spaces remain to provide resistance to the fire and solar load.

6. RESULTS AND DISCUSSION

6.1 Load Case 1: Steady State, 50 W Cs-137, No Solar Load, 38°C Ambient

The calculated steady state temperature distribution in the overpack for this load case is shown in Figure 11. Temperature results at various points within the model are listed in Table 2.

6.2 Load Case 2: Steady State/Transient, 50 W Cs-137, Solar Load, 38°C Ambient

The calculated steady state temperature distribution in the overpack for this load case is shown in Figure 12. Temperature results at various points in the model are compared to those of Load Case 1, which is the same model without the solar load, in Table 2. The results show an approximately 46°C increase in the internal temperatures, a 79°C increase on the top and a 44°C increase on the side of the overpack when the solar load is applied. Therefore, the solar heat flux applied as a steady state load has a significant effect on the internal temperatures of the overpack. Note, however, that even for this worst-case condition, the maximum temperature in the lead shielding, 117°C, is still well below the melting point of lead, 327°C [9].

The regulations only require the solar load to be applied over a 12 hour period, or during daylight hours. So the solar heat flux was also applied as a transient load (Section 4.5) to determine how the maximum temperature reached in 12 hours compares to the steady state temperatures calculated.

Figure 13 shows the temperature distribution in the overpack at the end of the 12 hour transient. The maximum temperature reached in the lead shielding is 76°C, much lower than for the steady state case (117°C). The maximum surface temperature reached, 117°C, is virtually the same as that for the steady state case (118°C), however.

Therefore, the steady state model of the solar heat flux overestimates the internal overpack temperatures that would be reached in a 12 hour insolation period. The temperatures for the steady state model, however, are still all well below lead melt (maximum temperature of 117°C as compared to 327°C for lead melt), and therefore, show unequivocally that the overpack meets the requirements of the regulations under solar load.

6.3 Load Case 3: Fire Transient, 50 W Cs-137, Solar Load, 38°C Ambient

The calculated temperature distribution in the overpack 30 minutes into the transient (as the fire is turned off) is shown in Figure 14. The calculated temperature distribution in the overpack at the time of maximum lead temperature (39,600 s, 11 hrs) is shown in Figure 15. The calculated temperature distribution in the lead elements only, at the time of maximum lead temperature (39,600 s, 11 hrs), is shown in Figure 16. Maximum temperature results at various points within the model are listed in Table 2.

The transient temperature results at the key locations shown in Figure 10 are shown in Figures 17 through 23. All of the temperature transients show temperatures below the melting temperature of lead, 327°C. The maximum temperature reached in the lead, 123°C at 39,600 s (11 hrs), was at the Gammacell cavity.

6.4 Load Case 4: Simulation of Damaged Outer Foam Under Fire Transient

The calculated temperature distribution in the overpack at the time of maximum lead temperature (10,800 s, 3 hrs) is shown in Figure 24. The calculated temperature distribution in the lead elements only, at the time of maximum lead temperature (10,800 s, 3 hrs) is shown in Figure 25. Maximum temperature results at various points within the model are listed in Table 2.

As expected, the maximum lead temperature was higher and peaked earlier than in Load Case 3, since the outer foam provided no resistance to the heat of the fire. The maximum temperature reached in the lead was 151°C, which is 28°C higher than in Load Case 3, but still well below the melting temperature of lead, 327°C, even in such a worst-case scenario.

7. CONCLUSIONS

The results of the simulated IAEA fire test showed no lead melt in the Gammacell modelled inside the F-431 overpack. The maximum lead temperature reached was 151°C, well below 327°C, the melting point of lead. In reality, the maximum lead temperature expected during such a regulatory fire would be much lower than this, considering the extremely conservative assumptions used in the model.

The F-431 overpack and Gammacell analysed in this report passed the IAEA regulatory fire test.

8. REFERENCES

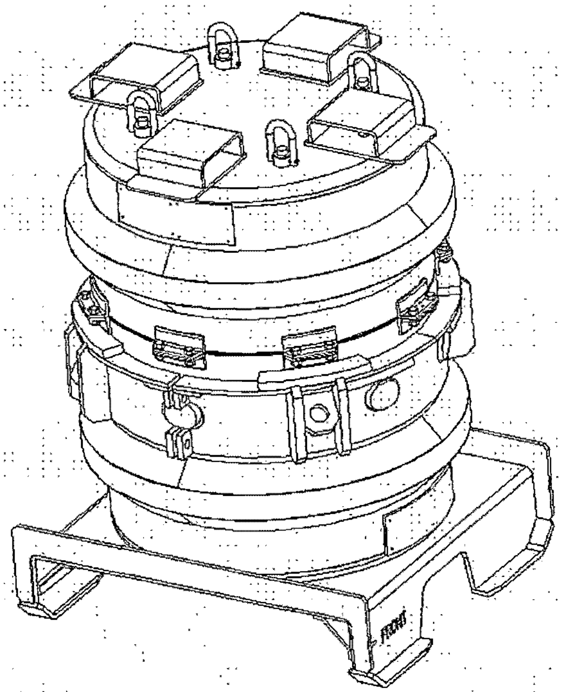
1. IAEA Safety Standard, TS-R-1, "Regulations for the Safe Transport of Radioactive Material", 1996 Revised Edition. Vienna, 2000.
2. ANSYS User's Manual, Revision 6.0. ANSYS Inc. Houston, PA, 2001.
3. Ramsay, J. "Thermal Analysis of F-430 Overpack". MDS Nordion Inc. Report IN/TR 1645 F430, Revision 2. October, 2001.
4. E7515, Euratom Contract No. 024-65-ECIC, Transnucleaire, "Report on the Implications of the Test Requirements for Type B Packagings and a Study of Practical Solutions". Transnucleaire. Paris, France, Part II.
5. Incropera, F.P. and Dewitt, D.P. "Fundamentals of Heat and Mass Transfer". John Wiley and Sons, Inc. New York, 1985.
6. Browne, E., Firestone, R.B. "Tables of Radioactive Isotopes". John Wiley and Sons, Inc. New York, 1986.
7. MDS Nordion Inc. Specification Sheet, "F-431 Transport Package", IN/SS 1915 F431, Revision 1. April, 2003.
8. Holman, J.P. "Heat Transfer". McGraw-Hill Book Company, 5th Edition. New York, 1981.
9. Lead Industries Association. "Lead in Modern Industry". New York City, New York, 1952.
10. General Plastics Manufacturing Company. "General Plastics Last-A-Foam FR-3700 for Crash and Fire Protection of Nuclear Material Shipping Containers". June, 1997.
11. IAEA Safety Standard, TS-G-1.1 (ST-2). "Advisory Material for the IAEA Regulations for the Safe Transport of Radioactive Material Safety Guide". 2002.

Table 1: Thermal Properties of F-431 Materials

#	Material Description	Density ρ (kg/m³)				Thermal Conductivity k (W/m°C)				Specific Heat c (J/kg°C)			
1	Mild Steel [5]	8131				°C	k	°C	k	°C	c	°C	c
						-73	41.0	127	42.2	-73	434	127	487
						327	39.7	527	35.0	327	559	527	685
						727	27.6	927	27.6	727	1090	927	1090
[redacted]	[redacted]	°C	ρ	°C	ρ	°C	k	°C	k	[redacted]			
		[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]				
		[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]				
		[redacted]	[redacted]			[redacted]	[redacted]						
[redacted]	[redacted]	°C	ρ	°C	ρ	°C	k	°C	k	[redacted]			
		[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]				
		[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]				
		[redacted]	[redacted]			[redacted]	[redacted]						
3	Air [5]	°C	ρ	°C	ρ	°C	k	°C	k	°C	c	°C	c
		-73	1.75	127	0.87	-73	0.018	127	0.034	-73	1007	127	1014
		327	0.58	527	0.44	327	0.047	527	0.057	327	1051	527	1099
		727	0.35	927	0.29	727	0.067	927	0.076	727	1141	927	1175
[redacted]	[redacted]	[redacted]				°C	k	°C	k	°C	c	°C	c
						[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
						[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
						[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
6	Air With Conduction and Convection Steady State [App. C]	°C	ρ	°C	ρ	°C	k	°C	k	°C	c	°C	c
		-73	1.75	127	0.87	-73	1.02	127	1.04	-73	1007	127	1014
		327	0.58	527	0.44	327	0.99	527	0.90	327	1051	527	1099
		727	0.35	927	0.29	727	0.75	927	0.75	727	1141	927	1175
6	Air With Conduction and Convection Transient [App. C]	°C	ρ	°C	ρ	°C	k	°C	k	°C	c	°C	c
		-73	1.75	127	0.87	-73	1.51	127	1.53	-73	1007	127	1014
		327	0.58	527	0.44	327	1.48	527	1.39	327	1051	527	1099
		727	0.35	927	0.29	727	1.24	927	1.24	727	1141	927	1175
7	Lead [9]	°C	ρ	°C	ρ	°C	k	°C	k	°C	c	°C	c
		20	11340	327	11005	-273	35	-27	35	-23	127	27	129
		330	10686	800	10686	123	34	227	33	127	132	227	136
						327	31	527	19	327	142	328	6188
						727	22	927	24	331	6188	332	159
12	Mild Steel Including Lead-Steel Contact Resistance [4, 5 and App. F]	8131				°C	k	°C	k	°C	c	°C	c
						-73	0.53	127	0.99	-73	434	127	487
						327	1.35	527	1.63	327	559	527	685
						727	1.86	927	2.11	727	1090	927	1090

Table 2: Comparison of Load Cases 1 Through 4							
Description	ANSYS Node (Fig. 10)	Load Case 1 Steady State, 50 W Cs-137, No Solar Load, 38°C Ambient	Load Case 2A Steady State, 50 W Cs-137, Solar Load, 38°C Ambient	Load Case 2B Transient, 50 W Cs-137, Solar Load*, 38°C Ambient	Load Case 3 Fire Transient, 50 W Cs-137, Fire/Solar Load**, 38°C Ambient	Load Case 4 Simulation of Damaged Outer Foam Under Fire Transient**
Inside Gammacell cavity	3330/3336/ 3323	71°C/70°C /70°C	117°C /117°C /116°C	76°C/75°C /75°C	123°C/123°C /122°C (39,600 s)	151°C/150°C /150°C (10,800 s)
Outside Gammacell on top surface	68	68°C	114°C	72°C	121°C (36,000 s)	152°C (10,800 s)
Outside Gammacell on side surface	119	69°C	115°C	73°C	121°C (36,000 s)	147°C (8,400 s)
Inside inner shell – top	1373	65°C	111°C	71°C	120°C (25,200 s)	168°C (8,400 s)
Inside inner shell – side	1363	68°C	114°C	72°C	120°C (36,000 s)	174°C (3,000 s)
Inside intermediate shell	971	55°C	105°C	69°C	126°C (18,000)	759°C (1,860 s)
Outside overpack – top	2506	39°C	118°C	117°C	794°C (1,860 s)	774°C (1,860 s)
Outside overpack – side	2518/ 2705	39°C/39°C	83°C/83°C	81°C /81°C	794°C/794°C (1,860 s)	745°C/745°C (1,860 s)

* Temperatures are taken at end of 12 hour transient.
** Temperatures are maximum values during the fire transient at the given time in parentheses.



[redacted]

Figure 1: F-431/Gammacell Transport Package

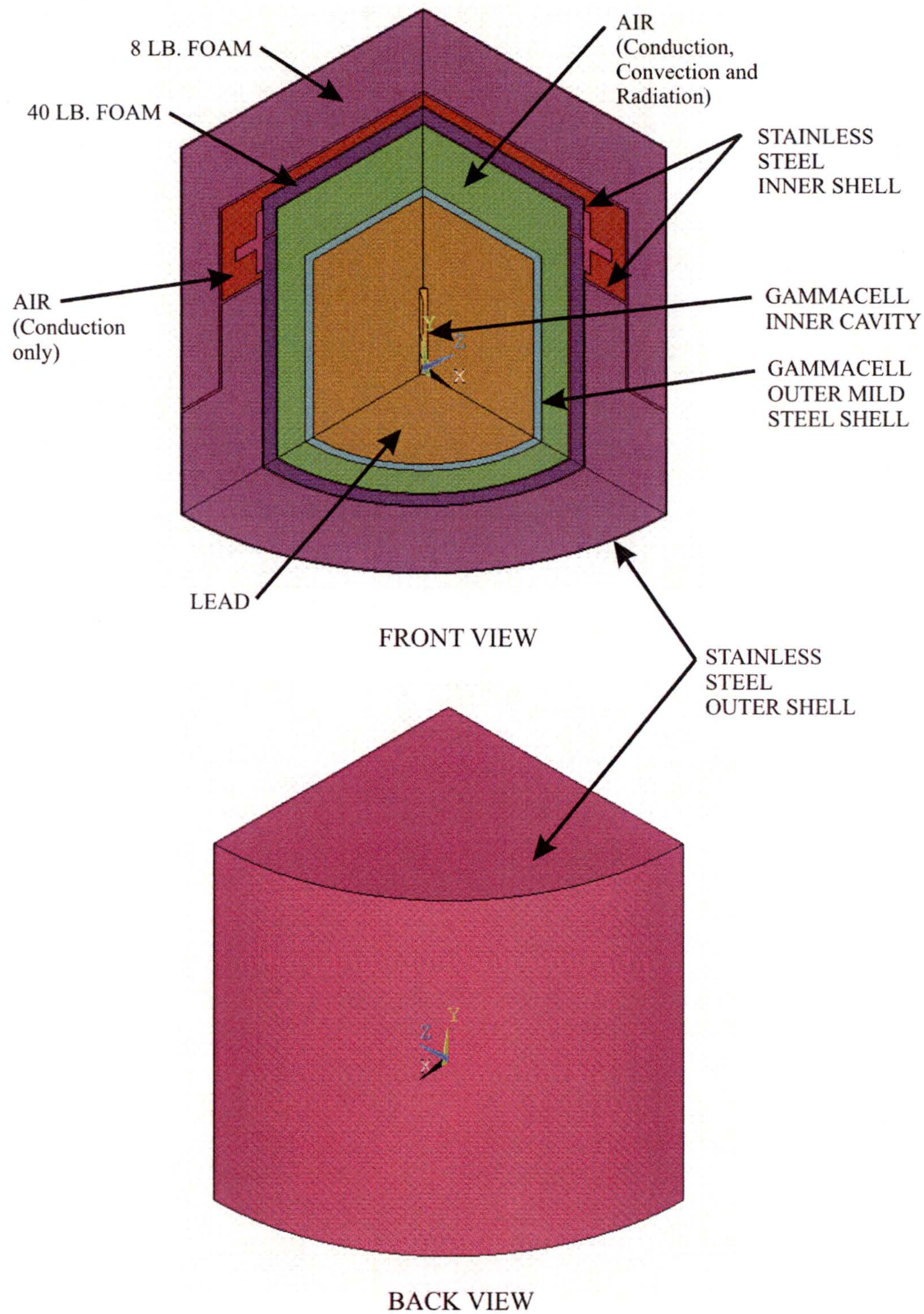


Figure 2: F-431 Overpack Solid Model

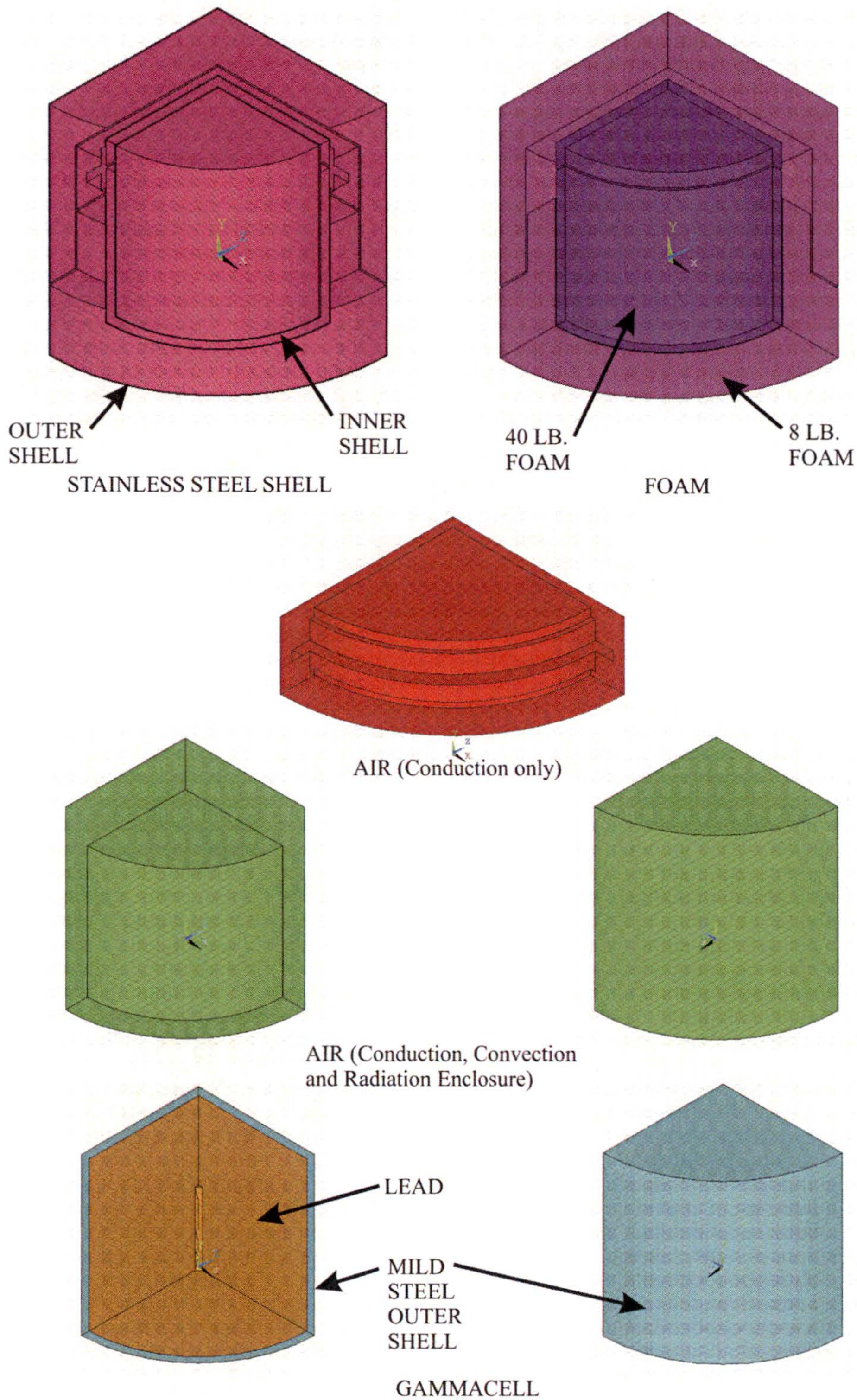


Figure 3: F-431 Overpack Solid Model Components

[redacted]

Figure 4: Comparison of F-430 and F-431 Overpacks

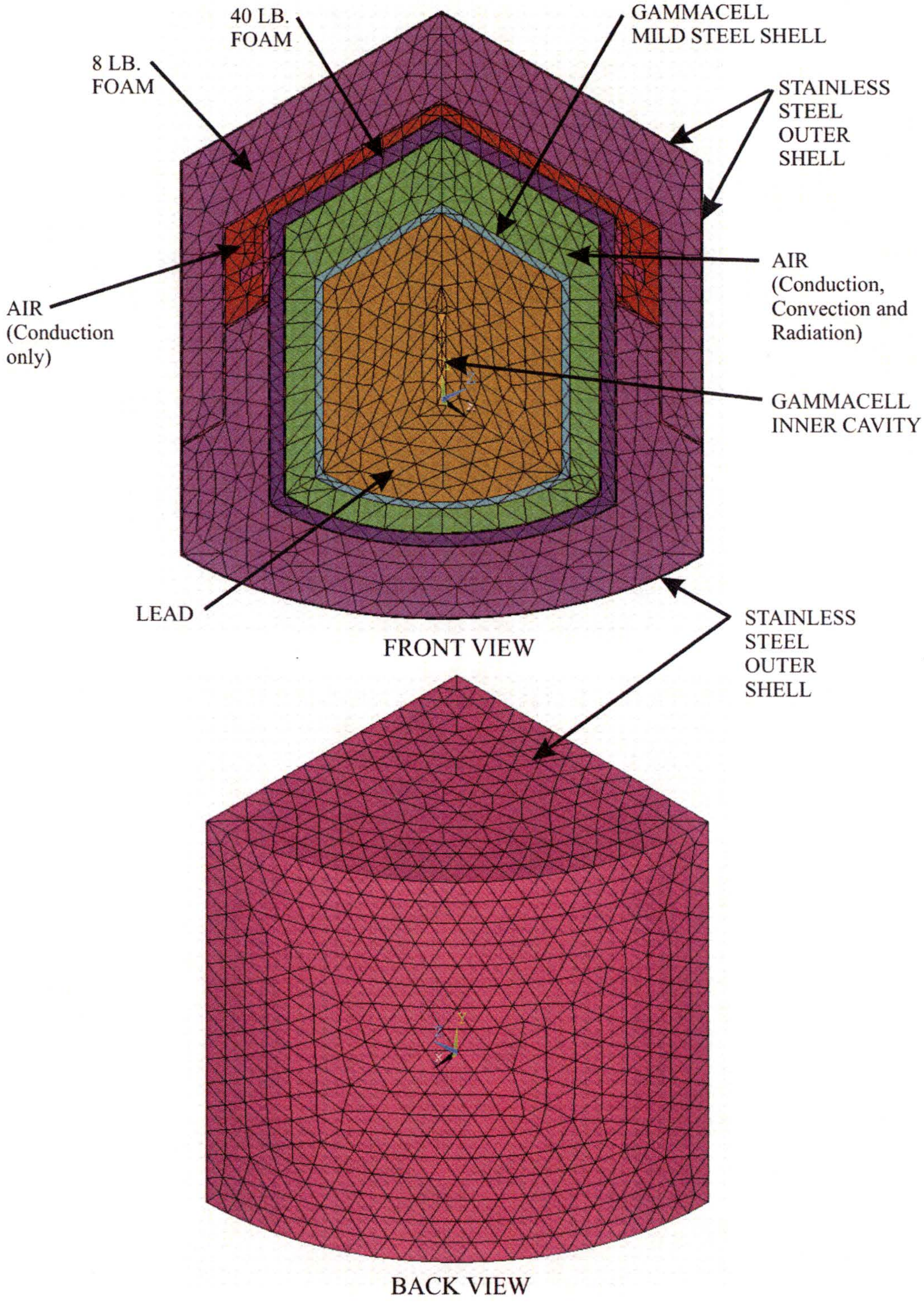
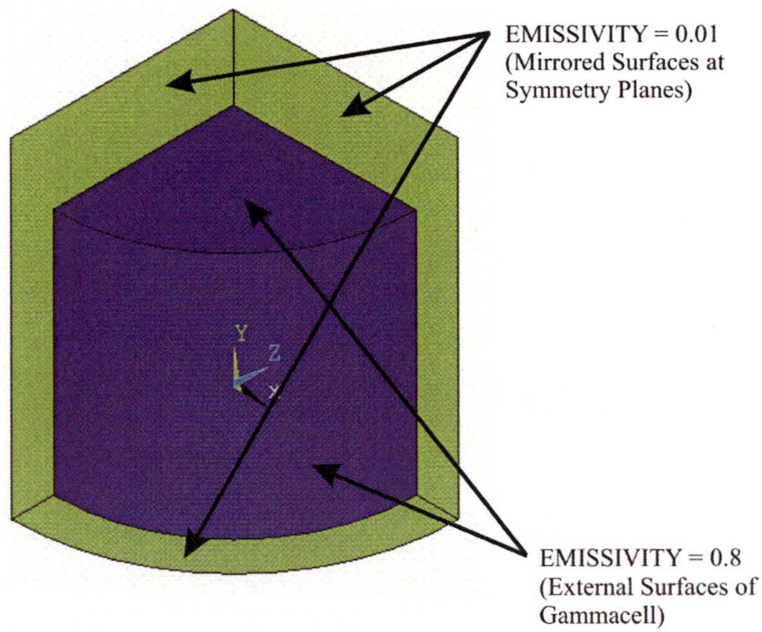
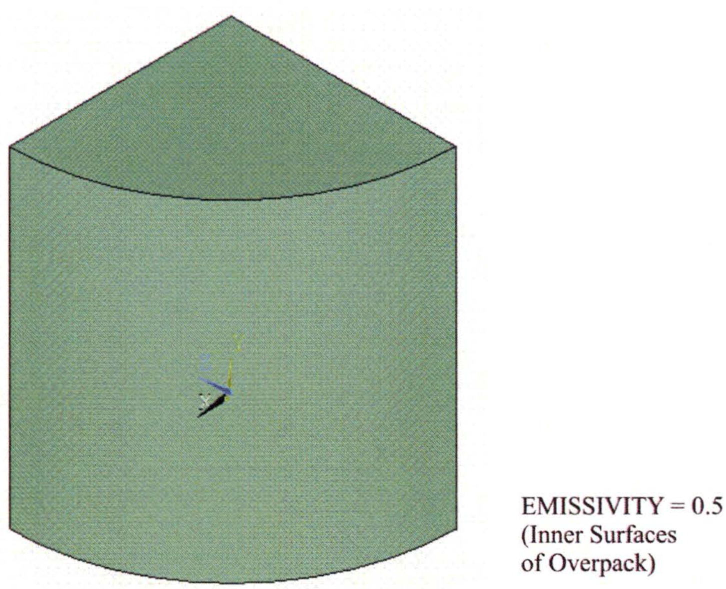


Figure 5: F-431 Overpack Finite Element Mesh



FRONT VIEW OF ENCLOSURE



BACK VIEW OF ENCLOSURE

Figure 6: Radiation Enclosure for Internal Air Space

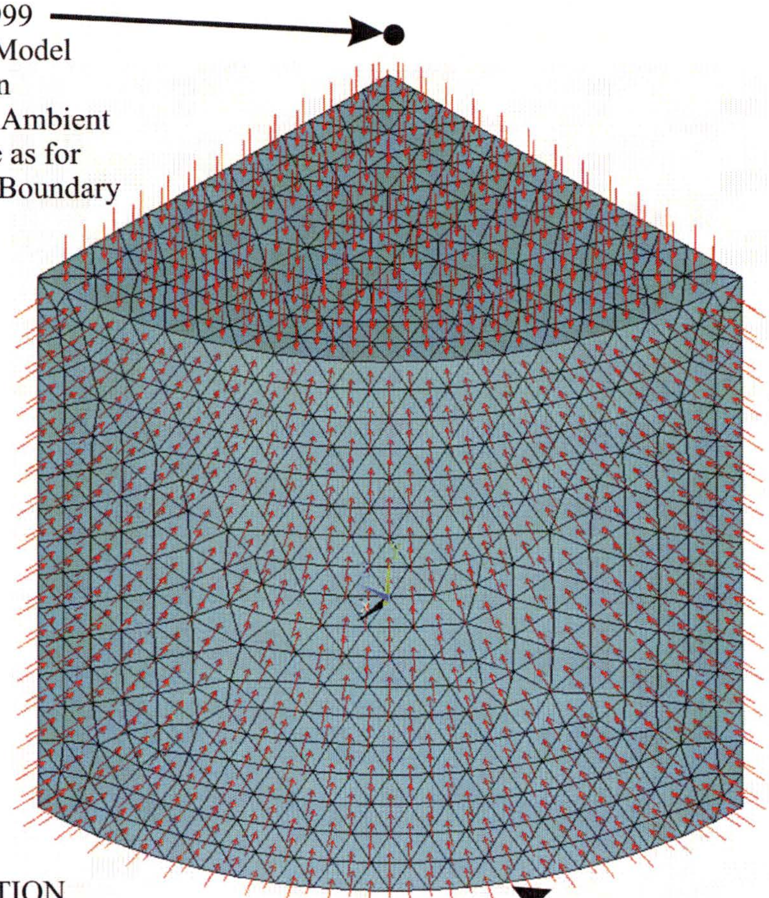


Figure 7: Radiation and Convection Boundary Conditions

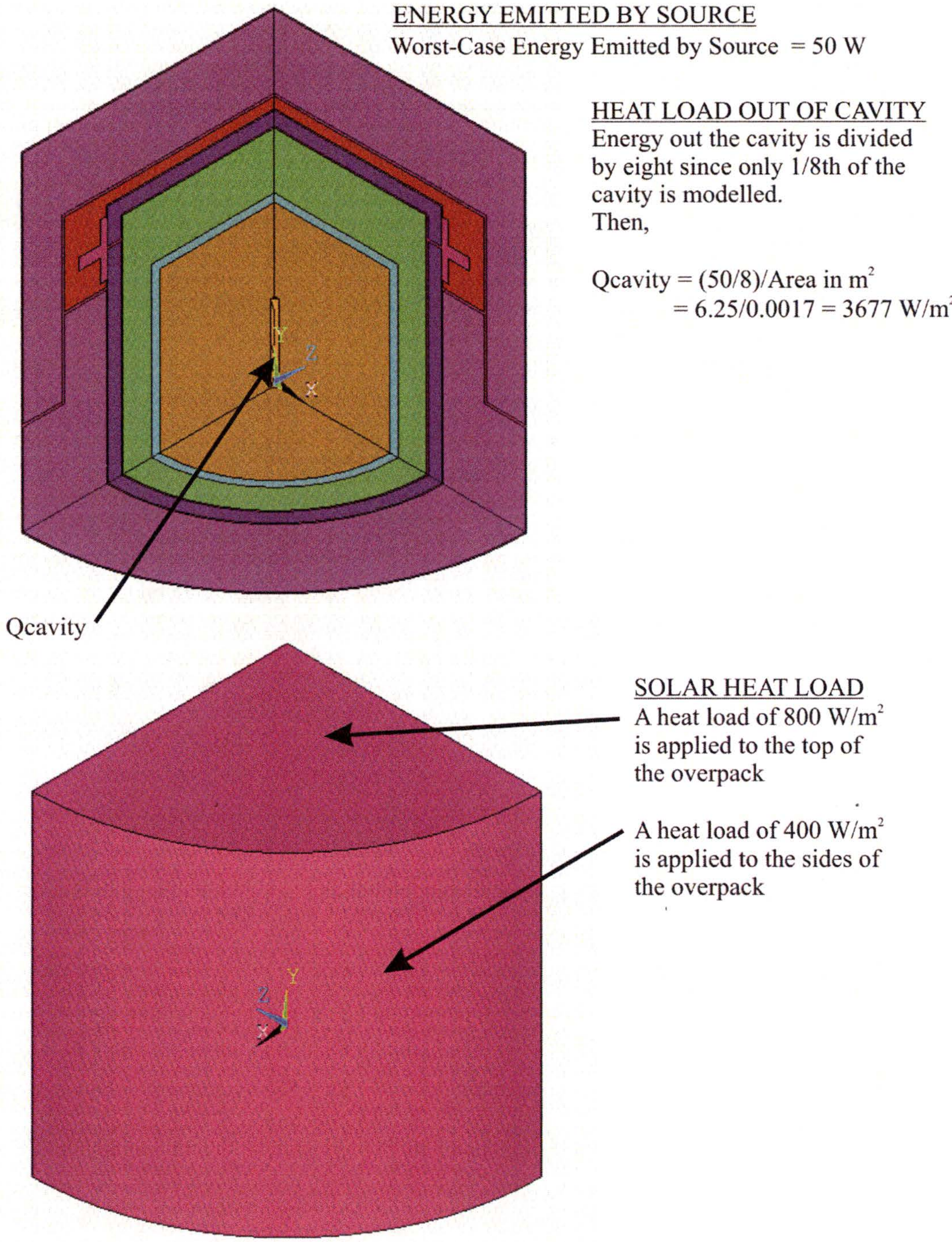


Figure 8: Internal Heat Generation and Solar Heat Load

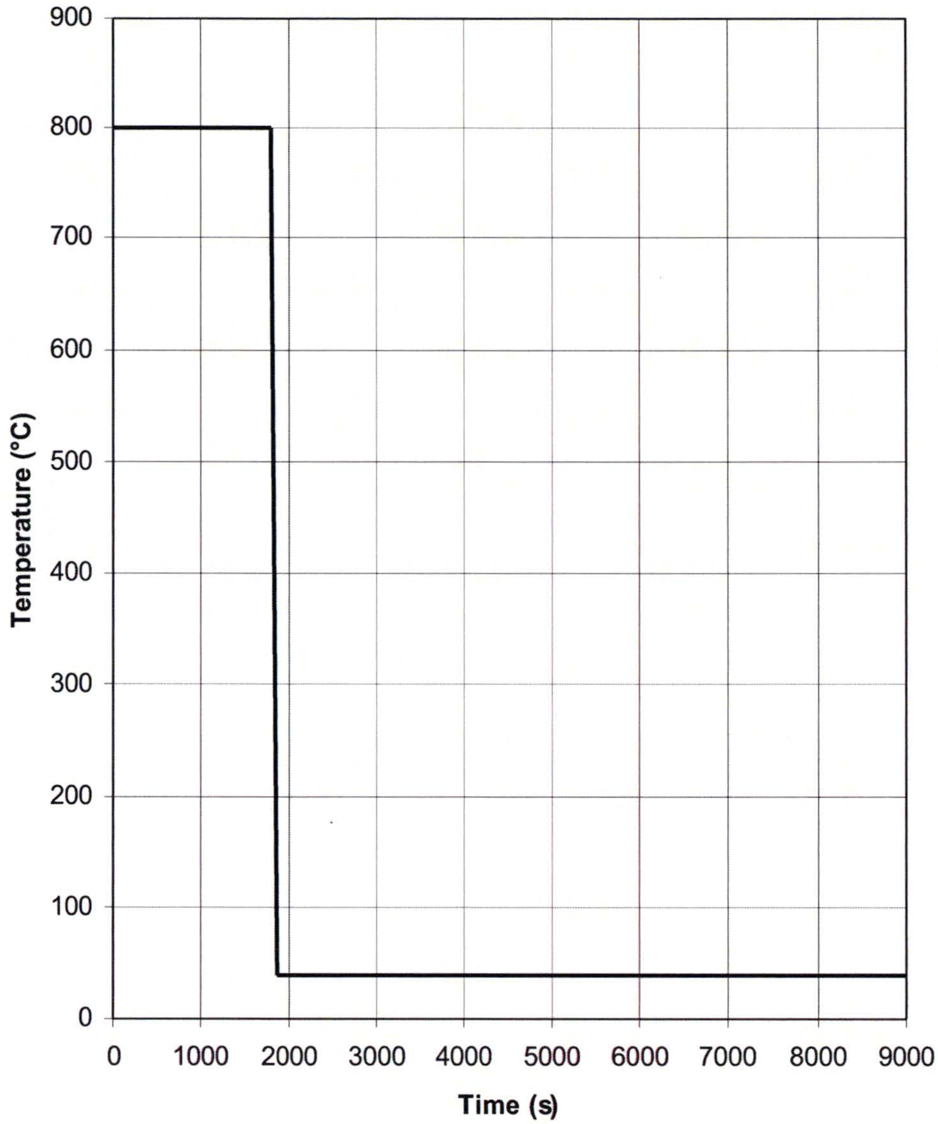


Figure 9: IAEA Regulatory Fire Curve

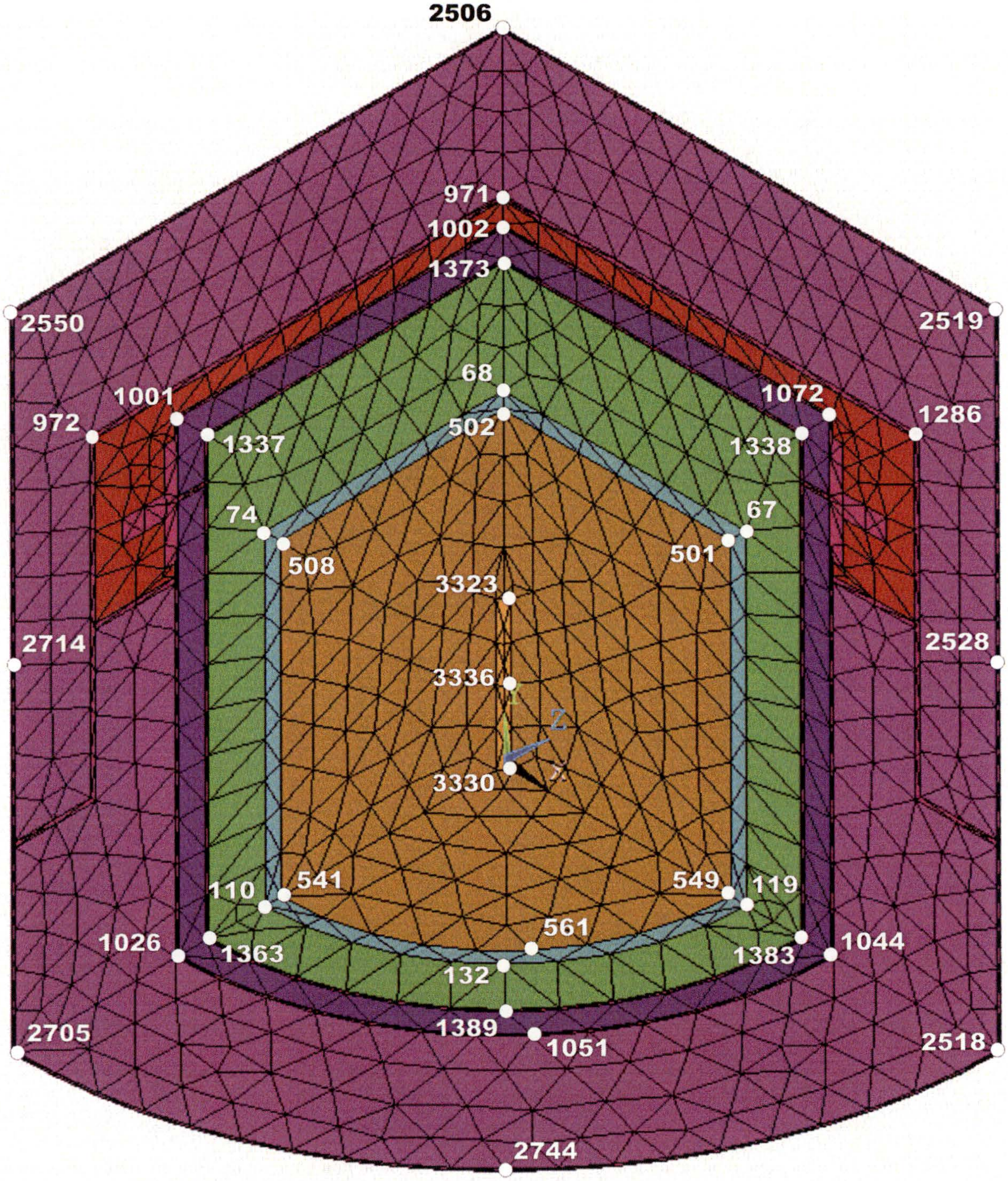


Figure 10: Key Nodal Temperature Locations

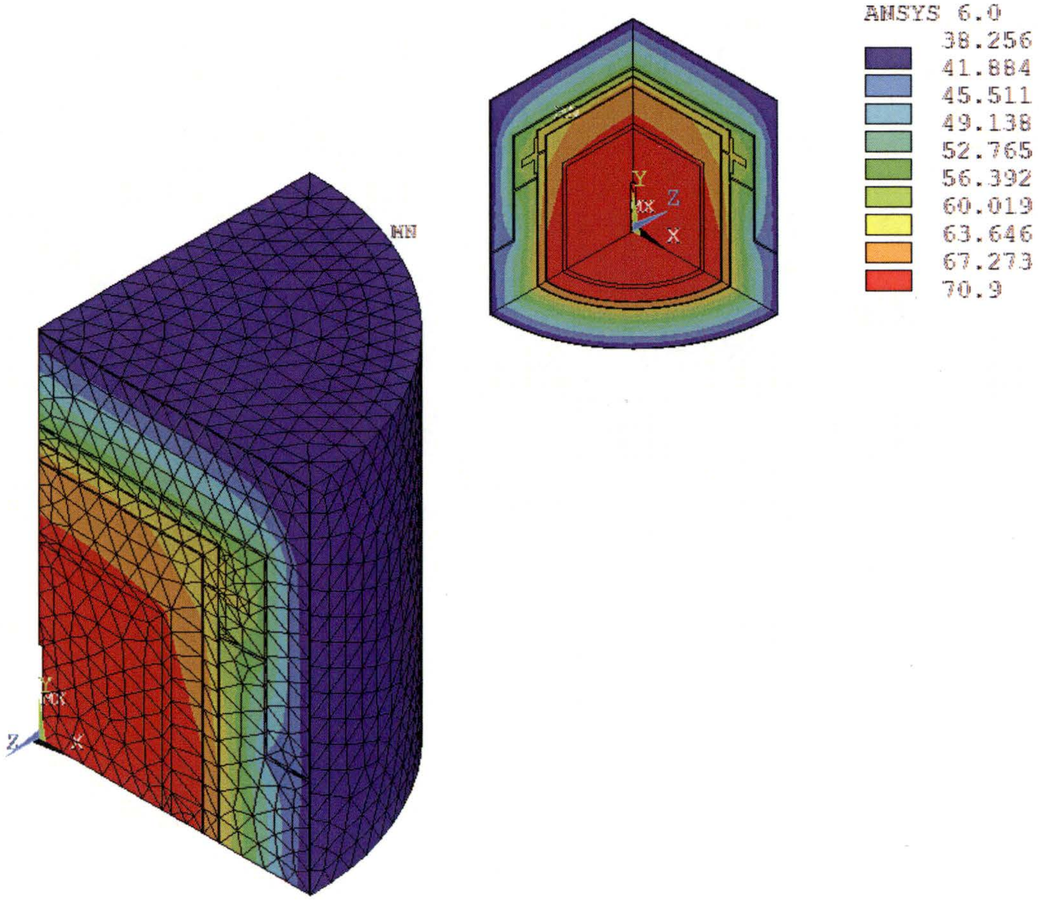


Figure 11: Steady State Temperature Distribution for F-431 Model With 50 W Cs-137, No Solar Load and 38°C Ambient: Load Case 1

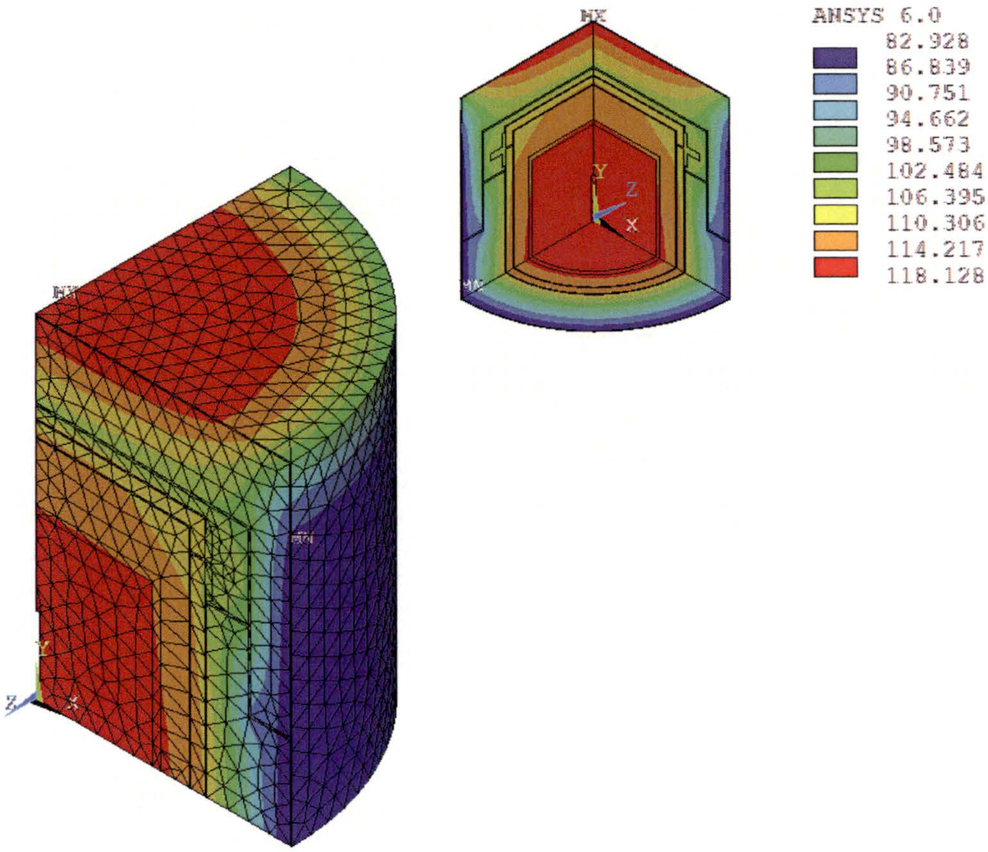


Figure 12: Steady State Temperature Distribution for F-431 Model With 50 W Cs-137, Solar Load and 38°C Ambient: Load Case 2

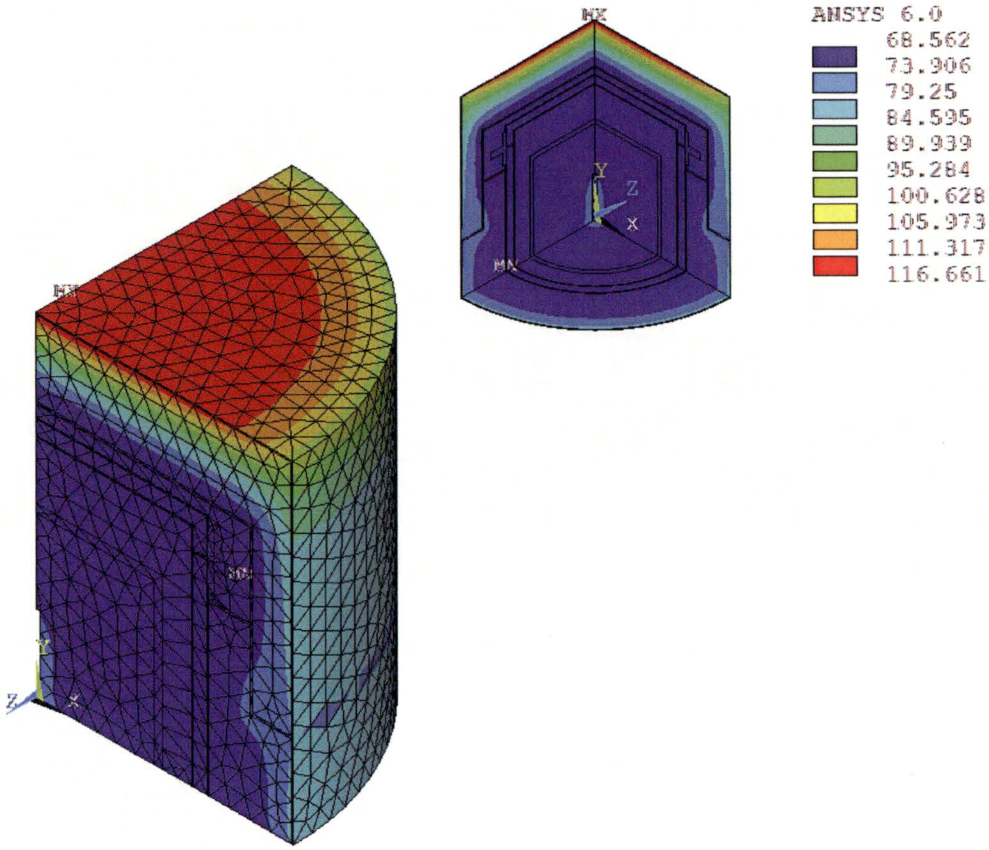


Figure 13: Temperature Distribution for F-431 Model With 50 W Cs-137, Solar Load and 38°C Ambient After 12 Hour Transient: Load Case 2

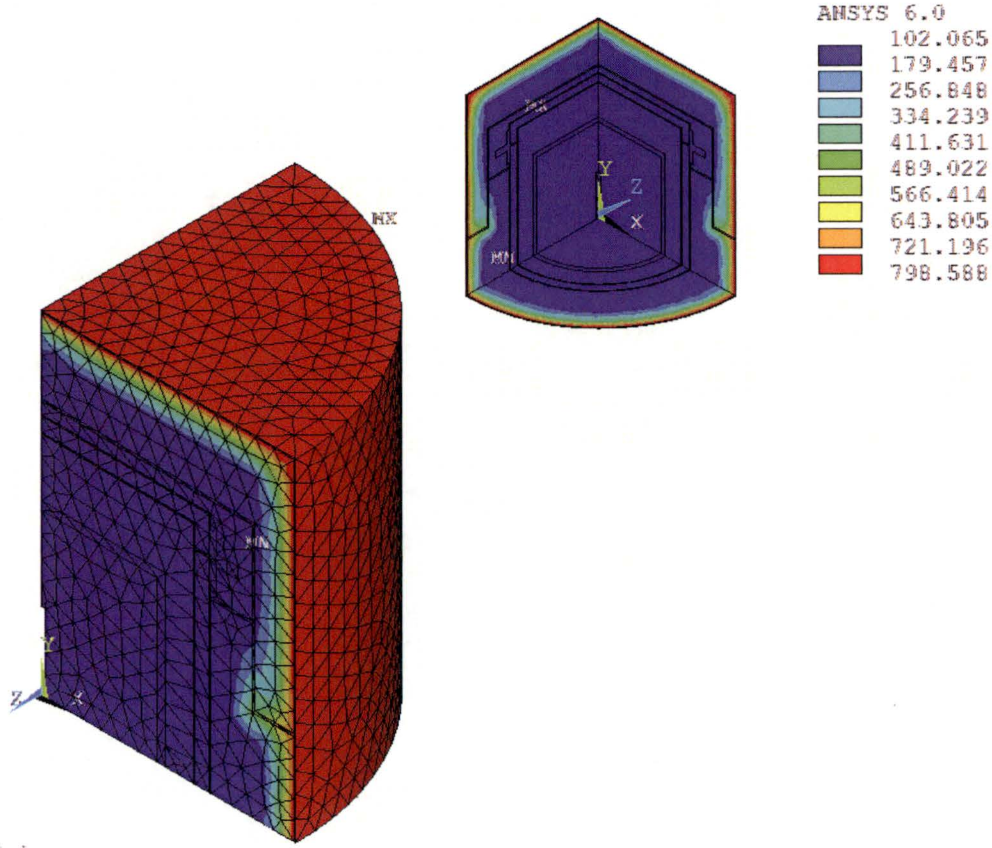


Figure 14: Temperature Distribution at End of Fire (1860 s)
for F-431 Model: Load Case 3

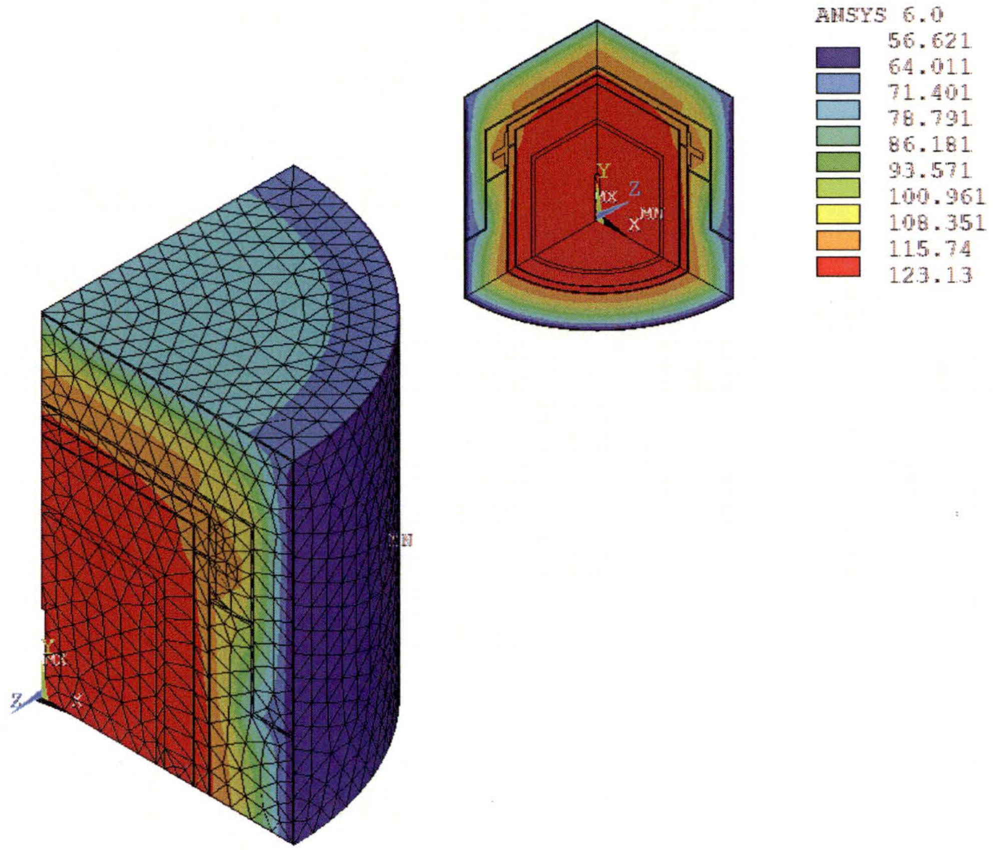


Figure 15: Temperature Distribution at Maximum Lead Temperature (39,600 s, 11 hrs) for F-431 Model: Load Case 3

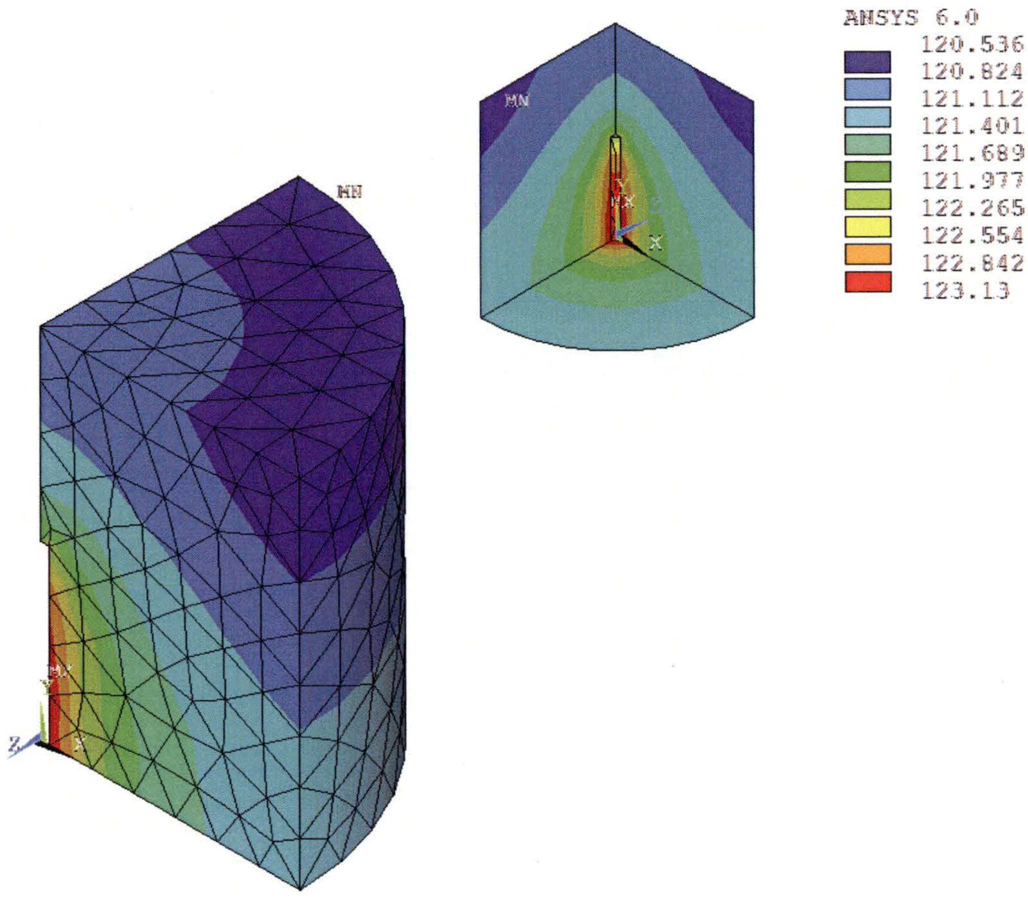


Figure 16: Temperature Distribution in Lead Elements at Maximum Lead Temperature (39,600 s, 11 hrs) for F-431 Model: Load Case 3

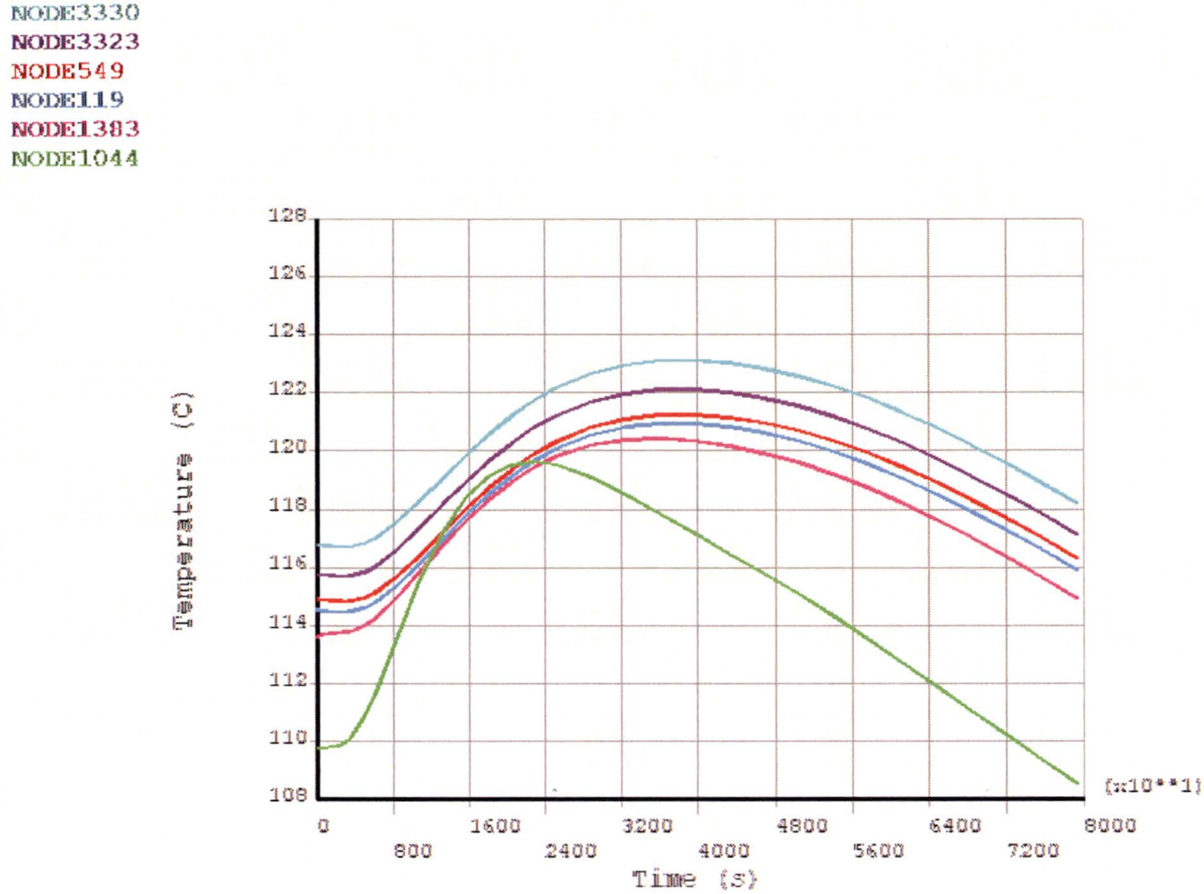


Figure 17: Temperature Transients for Selected Nodes from Figure 10

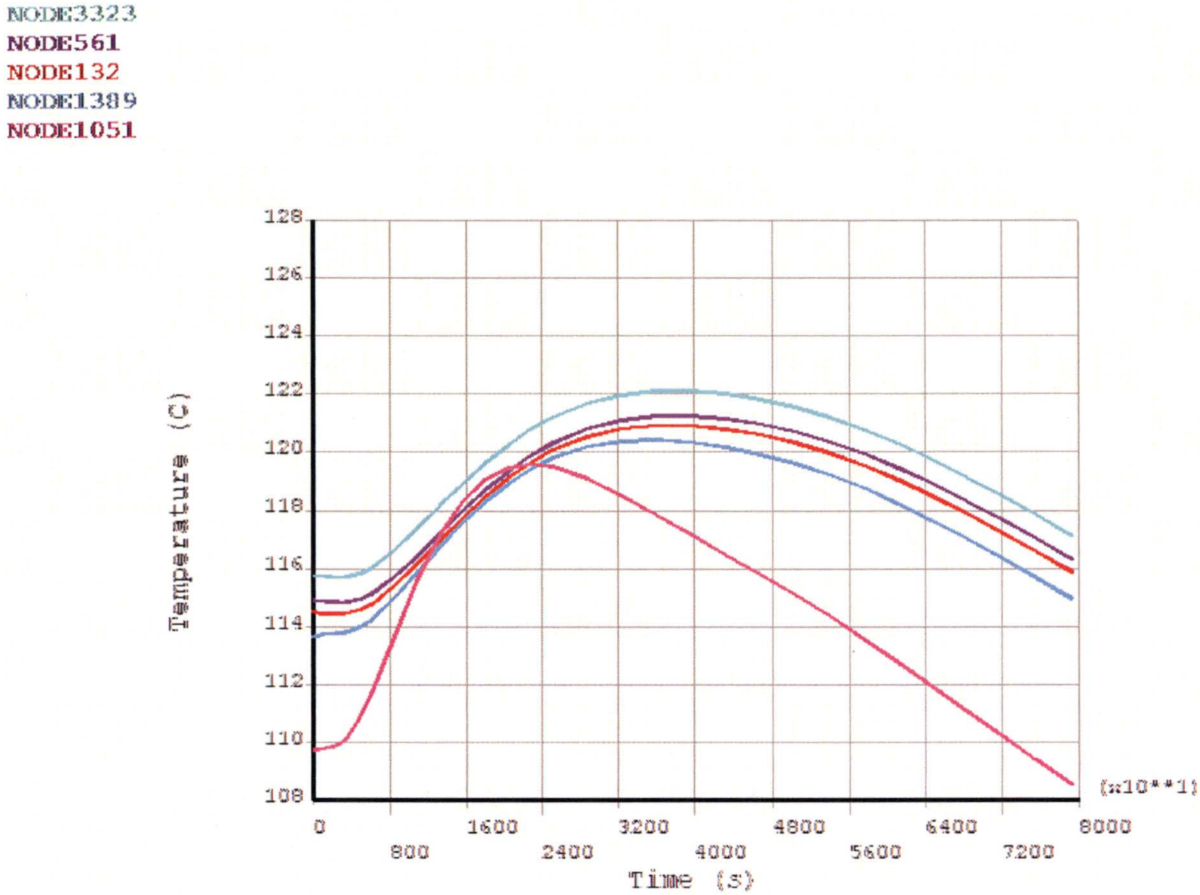


Figure 18: Temperature Transients for Selected Nodes from Figure 10

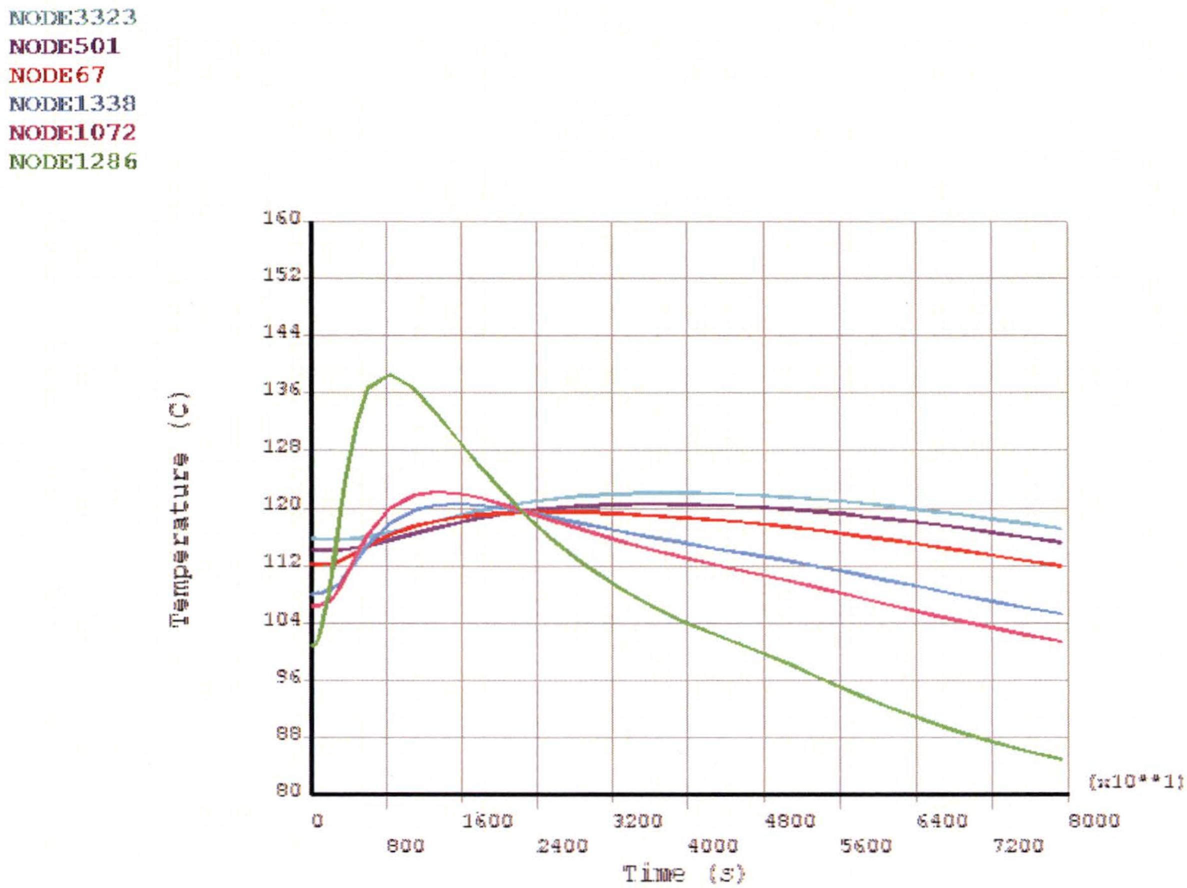


Figure 19: Temperature Transients for Selected Nodes from Figure 10

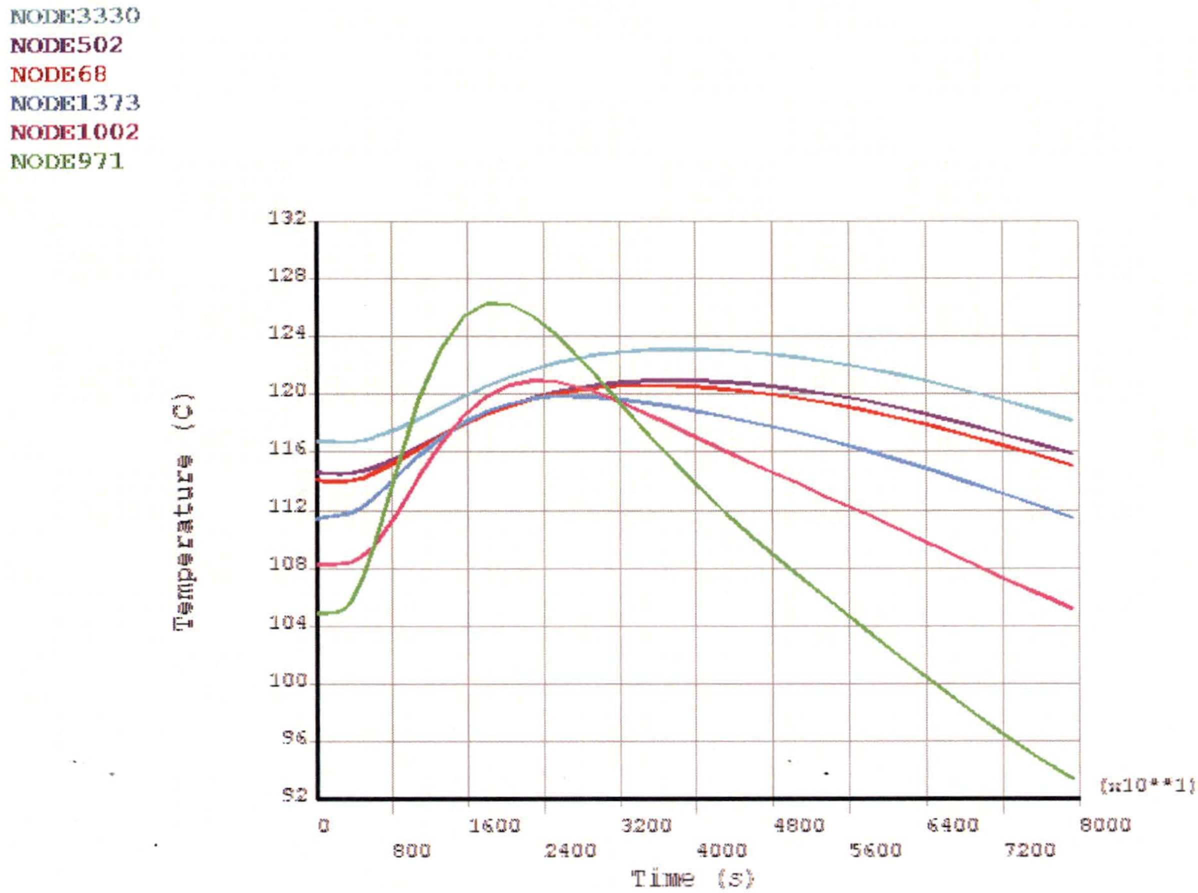


Figure 20: Temperature Transients for Selected Nodes from Figure 10

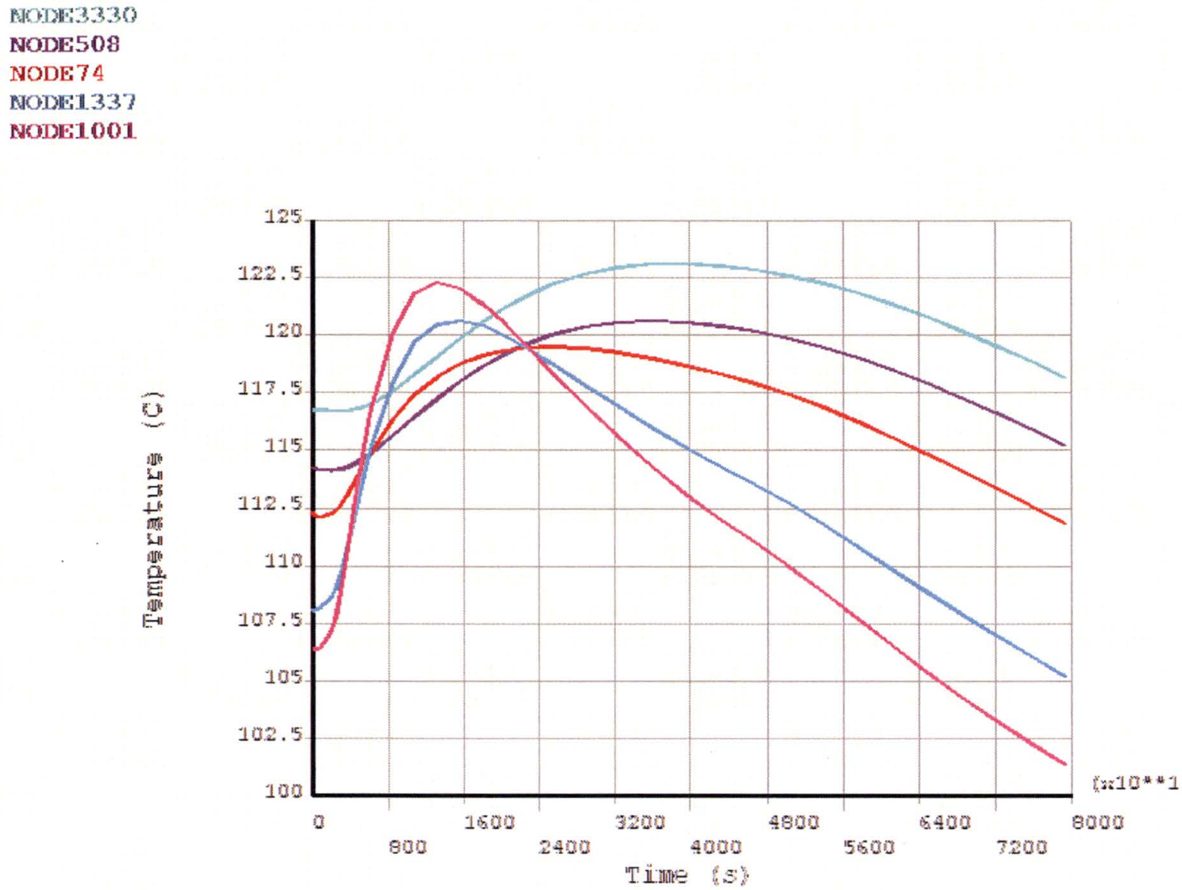


Figure 21: Temperature Transients for Selected Nodes from Figure 10

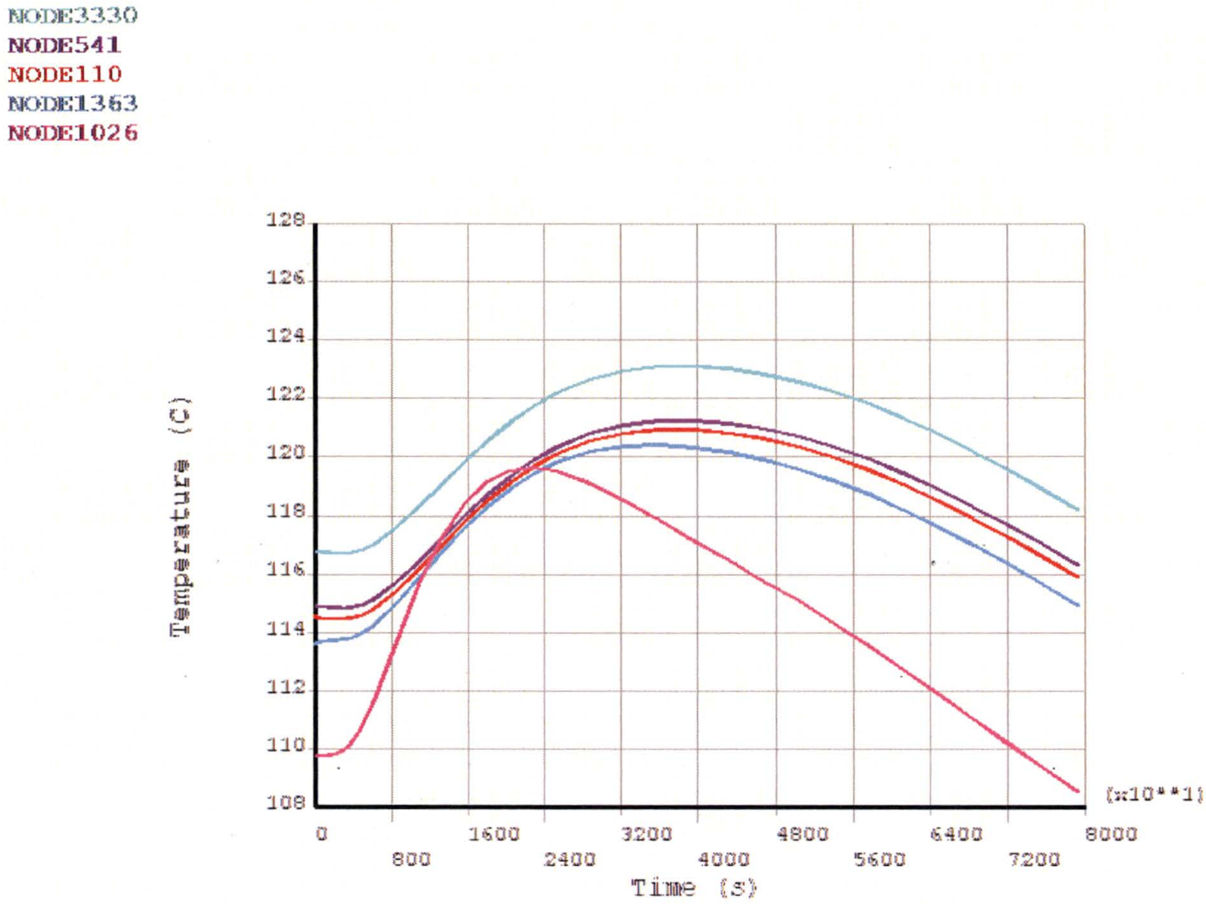


Figure 22: Temperature Transients for Selected Nodes from Figure 10

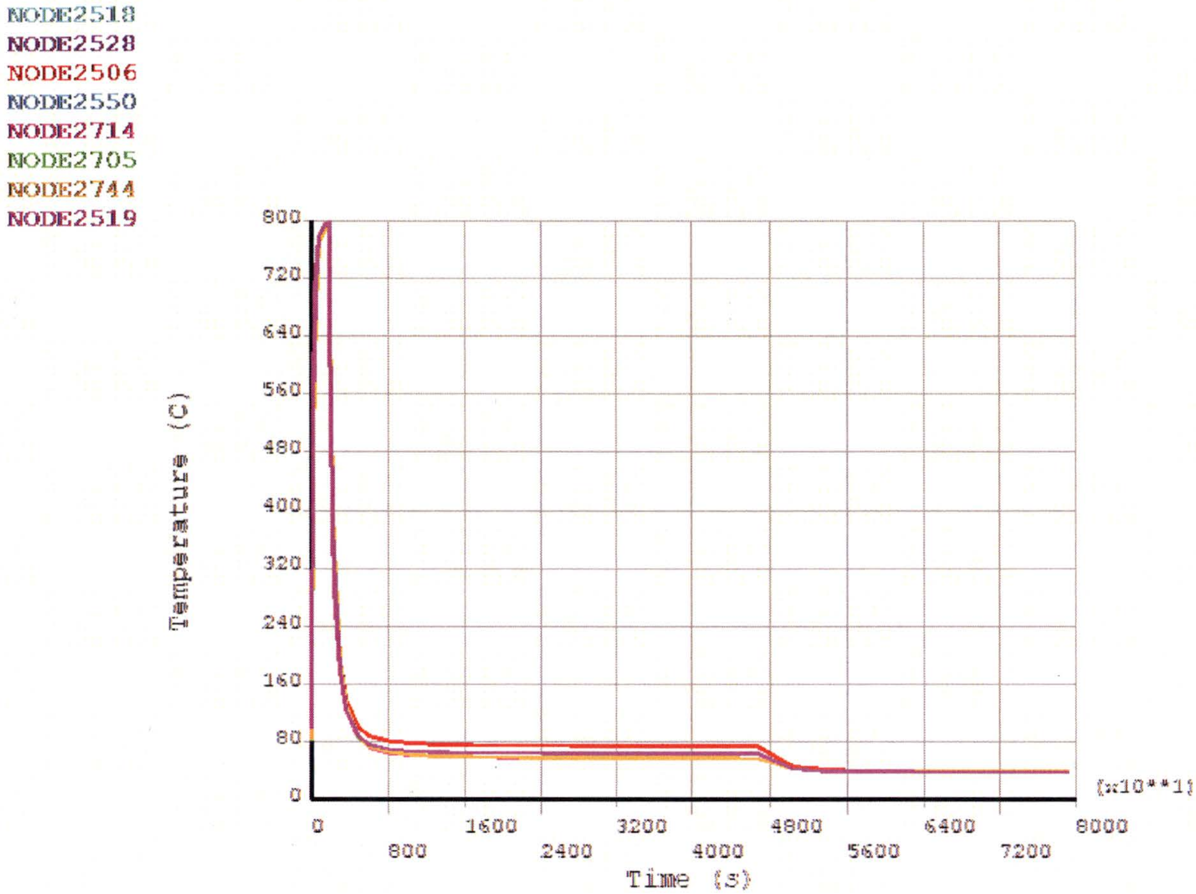


Figure 23: Temperature Transients for Selected Nodes from Figure 10

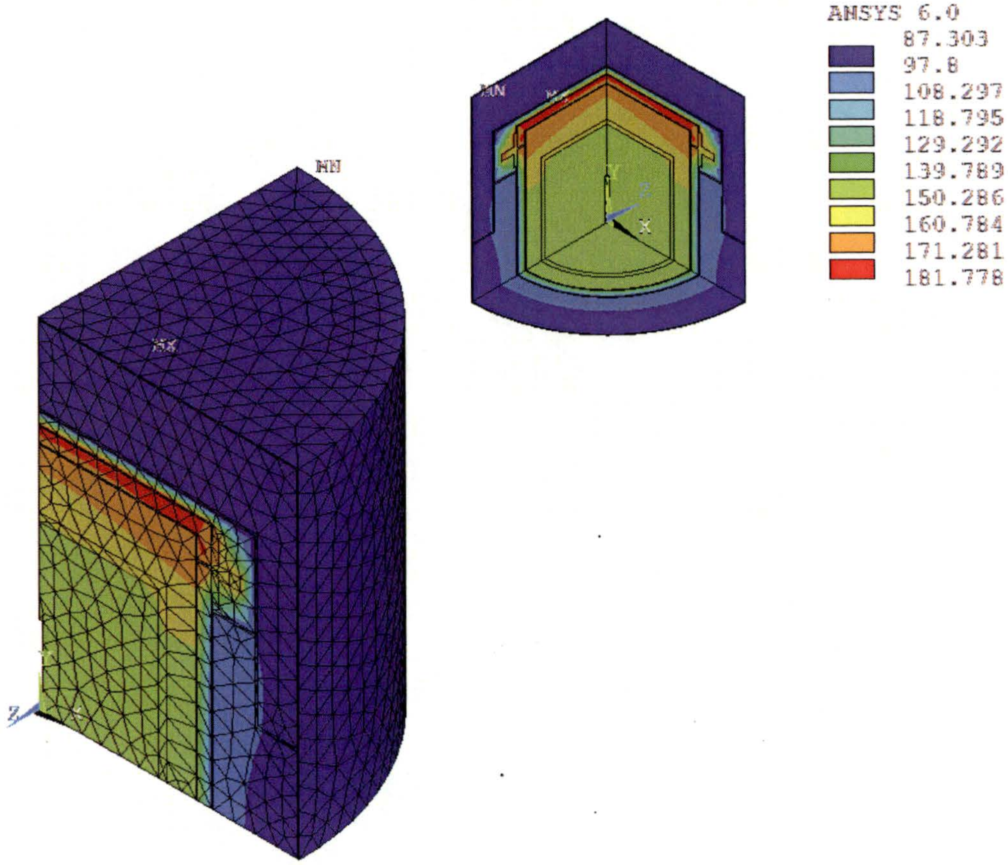


Figure 24: Calculated Temperature Distribution in the Overpack at Time of Maximum Lead Temperature (10,800 s, 3 hrs)

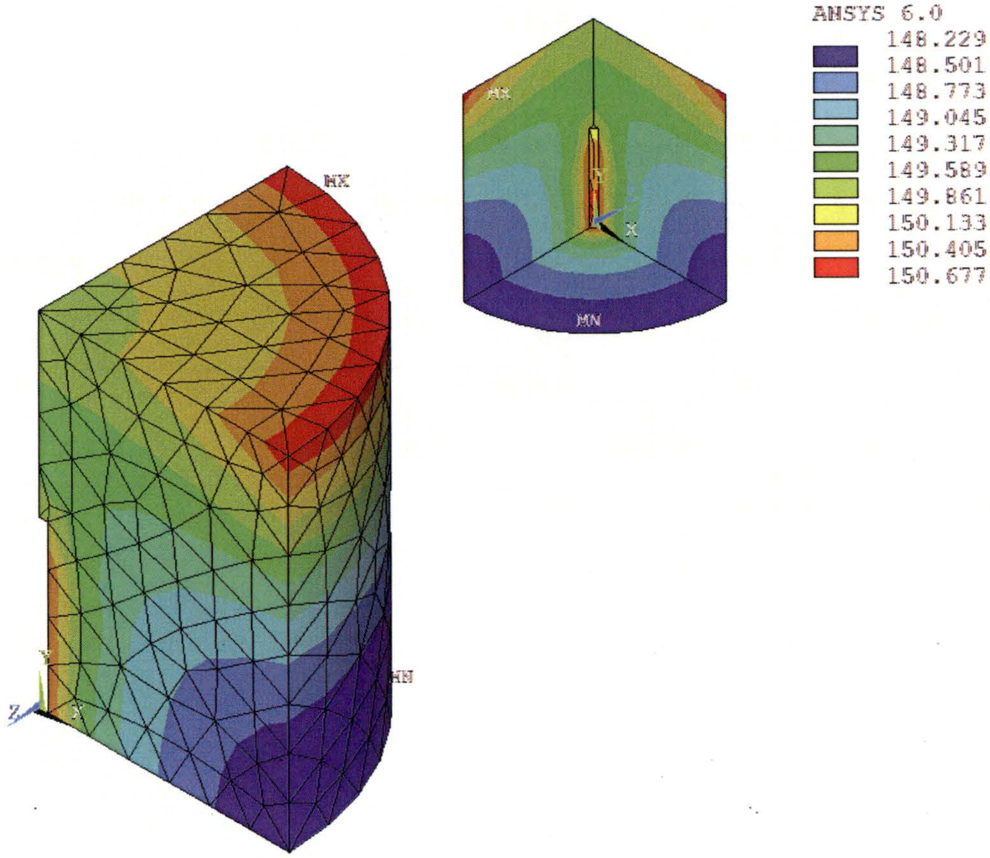


Figure 25: Calculated Temperature Distribution in the Lead Elements Only, at Time of Maximum Lead Temperature (10,800 s, 3 hrs)

APPENDIX A:
Excerpt From Transnucleaire Report on Package Analysis [4]

REPORT ON THE IMPLICATIONS OF THE TESTS REQUIREMENTS FOR TYPE B PACKAGINGS AND A STUDY OF PRACTICAL SOLUTIONS

EURATOM CONTRACT N° 024 - 65 - E.C.I.C.

TRANSNUCLEAIRE

11 & 11 bis Rue Christophe Colomb
Paris 8e
Tel. 225 14 77
225 08 86
Telex 28 992

7 West 57th Street
New York, NY 10019
355 7320

170.-

3 - LEAD-STEEL JUNCTION -

a) No bond -

When fabrication is made without trying to obtain bonding between lead and outer shell, shrinkage occurs during cooling after casting due to the difference of dilatation coefficients of lead and steel.

The importance of shrinkage depends on casting methods and outer shell dimensions and materials.

With a stainless steel outer shell and adequate casting method, shrinkage is on the order of 4°/oo, i.e. for instance 2 mm at the radius for a packaging of 1 m diameter.

With a mild steel outer shell, whose dilatation coefficient is lower than for stainless steel, shrinkage may be greater.

b) Lead bonded -

Bonding can be obtained by various processes, which we will not explain here.

Let us say only that bonding can be easily achieve on an open steel wall ; it is much more difficult inside a steel vessel practically closed. It is also more difficult with stainless steel than with mild steel.

If bonding is perfect, which can be checked by ultra-sonic inspection, thermal bond should also be perfect.

This is actually obtained for instance with a plane steel wall and a certain thickness of lead bonded, the outer surface of the lead being bare.

On the other hand, our experience shows us that in the case of packagings and in spite of a perfect bonding to the outer shell, ultra-sonic checked, there is always some discrepancy between thermal test and calculations for the heat transmission through the inner shell/lead/outer shell assembly.

Compared with calculations based on a perfect thermal bonding, tests show that in fact there is a certain extra resistance to the passage of heat.

Thus, on a series of six identical cylindrical 20 ton packagings (constructed by the Société Lyonnaise de Plomberie Industrielle), an extra resistance to the passage of heat compared with calculations is found equivalent to an air gap of 0.5mm varying slightly around this value according to the packaging. Ultrasonic inspection, however, showed perfect outer shell/lead bonding.

There are a number of possible explanations :

- The calculation cannot be very accurate particularly when there is a great difference between the outer shell surface area and the inner cavity surface area. This was the case for the six packagings mentionned above.

  If the heat flux introduced in the calculation is the flux on the inner cavity, there is then good agreement between tests and calculation.

- Bonding to the outer shell has a tendency to work against hooping on the inner shell.

- Lack of homogeneity in the lead mass which is being drawn both towards the outer shell and towards the inner shell.

- Traces of oxide over a varying surface area at the outside shell/lead interface (which does not shown up with ultra-sonic controls).

We have no knowledge of the results obtained by other constructors.

c) <u>Behavior in the thermal test</u> -

In the case of not bonded lead, an air gap of say, 2 mm, corresponds to a temperature drop of several hundred degrees, for the initial heat fluxes involved in the thermal test.

172.-

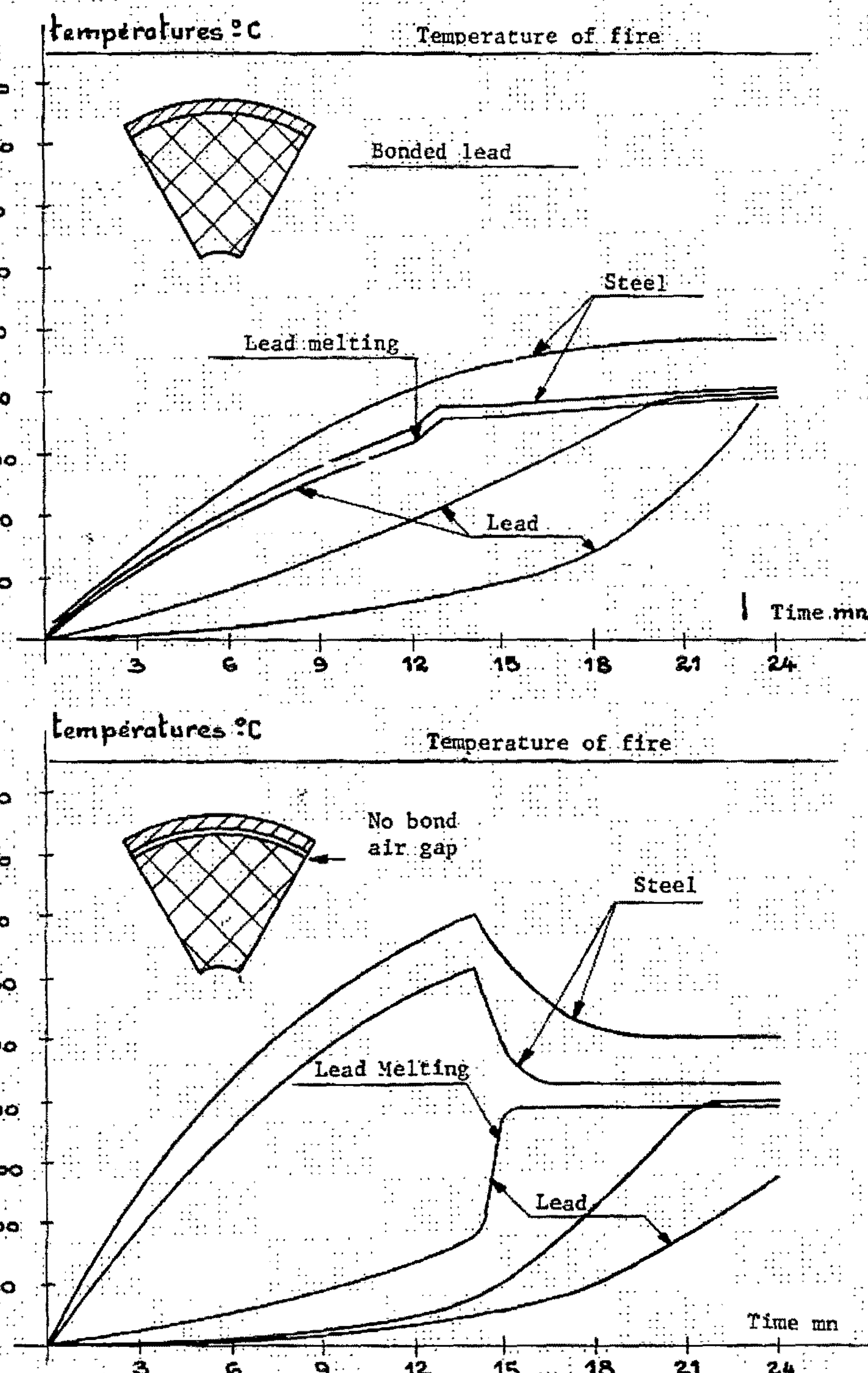

temperatures °C
Temperature of fire
900
800
700
600
500
400
300
200
100
Bonded lead
Steel
Lead melting
Lead
Time mn
3
6
9
12
15
18
21
24
temperatures °C
Temperature of fire
No bond
air gap
Steel
Lead Melting
Lead
Time mn

FIG. A.2

APPENDIX B:
ANSYS Finite Element Descriptions [2]

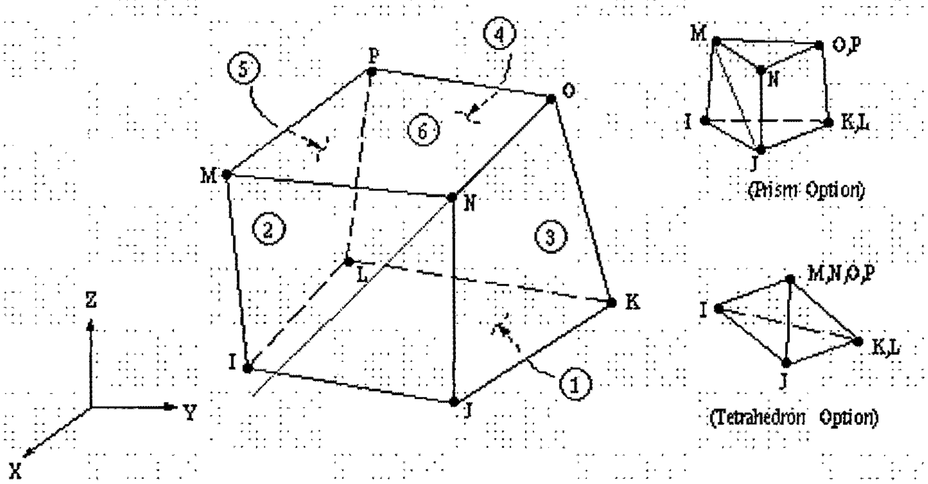
4.70 SOLID70 3-D Thermal Solid

Multiphysics	✓
Mechanical	✓
Structural	
LS-DYNA	
LinearPlus	
Thermal	✓
Emag 3-D	
Emag 2-D	
FLOTRAN	
PrepPost	✓
ED	✓

SOLID70 has a three-dimensional thermal conduction capability. The element has eight nodes with a single degree of freedom, temperature, at each node. The element is applicable to a three-dimensional, steady-state or transient thermal analysis. The element also can compensate for mass transport heat flow from a constant velocity field. If the model containing the conducting solid element is also to be analyzed structurally, the element should be replaced by an equivalent structural element (such as SOLID45). A similar thermal element, with mid-edge node capability, is described in Section 4.90 (SOLID90).

An option exists that allows the element to model nonlinear steady-state fluid flow through a porous medium. With this option, the thermal parameters are interpreted as analogous fluid flow parameters. For example, the temperature degree of freedom becomes equivalent to a pressure degree of freedom. See Section 14.70 of the *ANSYS Theory Reference* for more details about this element.

Figure 4.70-1 SOLID70 3-D Thermal Solid



4.70.1 Input Data

The geometry, node locations, and the coordinate system for this element are shown in Figure 4.70-1. The element is defined by eight nodes and the orthotropic material properties. Orthotropic material directions correspond to the element coordinate directions. The element coordinate system orientation is as described in Section 2.3. Specific heat and density are ignored for steady-state solutions. Properties not input default as described in Section 2.4.

Element loads are described in Section 2.7. Convections or heat fluxes (but not both) may be input as surface loads at the element faces as shown by the circled numbers on Figure 4.70-1.

Heat generation rates may be input as element body loads at the nodes. If the node I heat generation rate HG(I) is input, and all others are unspecified, they default to HG(I).

The nonlinear porous flow option is selected with KEYOPT(7)=1. For this option, temperature is interpreted as pressure and the absolute permeabilities of the medium are input as material properties KXX, KYY, and KZZ. Properties DENS and VISC are used for the mass density and viscosity of the fluid. Properties C and MU are used in calculating the coefficients of permeability as described in Section 14.70 of the *ANSYS Theory Reference*. Temperature boundary conditions input with the **D** command are interpreted as pressure boundary conditions, and heat flow boundary conditions input with the **F** command are interpreted as mass flow rate (mass/time).

A mass transport option is available with KEYOPT(8). With this option the velocities VX, VY, and VZ must be input as real constants (in the element coordinate system). Also, temperatures should be specified along the entire inlet boundary to assure a stable solution. With mass transport, you should use specific heat (C) and density (DENS) material properties instead of enthalpy (ENTH).

A summary of the element input is given in Table 4.70-1. A general description of element input is given in Section 2.1.

Table 4.70-1 SOLID70 Input Summary

Element Name	SOLID70
Nodes	I, J, K, L, M, N, O, P
Degrees of Freedom	TEMP
Real Constants	VX, VY, VZ IF KEYOPT (8) > 0
Material Properties	KXX, KYY, KZZ, DENS, C, ENTH, VISC, MU (VISC and MU used only if KEYOPT (7) = 1. Do not use ENTH with KEYOPT(8)=1).
Surface Loads	Convections: face 1 (J-I-L-K), face 2 (I-J-N-M), face 3 (J-K-O-N), face 4 (K-L-P-O), face 5 (L-I-M-P), face 6 (M-N-O-P) Heat Fluxes: face 1 (J-I-L-K), face 2 (I-J-N-M), face 3 (J-K-O-N), face 4 (K-L-P-O), face 5 (L-I-M-P), face 6 (M-N-O-P)
Body Loads	Heat Generations:HG (I), HG (J), HG (K), HG (L), HG (M), HG (N), HG (O), HG (P)
Special Features	Birth and death.
KEYOPT(2)	0 - Evaluate film coefficient (if any) at average film temperature, (TS + TB)/2 1 - Evaluate at element surface temperature, TS 2 - Evaluate at fluid bulk temperature, TB 3 - Evaluate at differential temperature | TS-TB |
KEYOPT(4)	0 - Evaluate film coefficient (if any) at average film temperature, (TS + TB)/2 1 - Evaluate at element surface temperature, TS
KEYOPT(7)	0 - Standard heat transfer element 1 - Nonlinear steady-state fluid flow analogy element (temperature degree of freedom interpreted as pressure)
KEYOPT(8)	0 - No mass transport effects 1 - Mass transport with VX, VY, VZ

4.70.2 Output Data

The solution output associated with the element is in two forms:

- nodal temperatures included in the overall nodal solution
- additional element output as shown in Table 4.70-2

Heat flowing out of the element is considered to be positive. If KEYOPT(7)=1, the standard thermal output should be interpreted as the analogous fluid flow output. The element output directions are parallel to the element coordinate system. A general description of solution output is given in Section 2.2. See the *ANSYS Basic Analysis Procedures Guide* for ways to view results.

The following notation is used in Table 4.70-2:

A colon (:) in the **Name** column indicates the item can be accessed by the Component Name method [**ETABLE**, **ESOL**] (see Section 2.2.2). The **O** and **R** columns indicate the availability of the items in the file *Jobname*.OUT (**O**) or in the results file (**R**), a **Y** indicates that the item is *always* available, a number refers to a table footnote which describes when the item is *conditionally* available, and a - indicates that the item is *not* available.

Table 4.70-2 SOLID70 Element Output Definitions

Name	Definition	O	R
EL	Element number	Y	Y
NODES	Nodes - I, J, K, L, M, N, O, P	Y	Y
MAT	Material number	Y	Y
VOLU:	Volume	Y	Y
CENT: X, Y, Z	Center location XC, YC, ZC	-	Y
HGEN	Heat generations HG(I), HG(J), HG(K), HG(L), HG(M), HG(N), HG(O), HG(P)	Y	-
TG: X, Y, Z, SUM	Thermal gradient components and vector sum at centroid	Y	Y
TF: X, Y, Z, SUM	Thermal flux (heat flow rate/cross-sectional area) components and vector sum at centroid	Y	Y
FACE	Face label	1	-
AREA	Face area	1	1
NODES	Face nodes	1	-
HFILM	Film coefficient at each node of face	1	-
TBULK	Bulk temperature at each node of face	1	-
TAVG	Average face temperature	1	1
HEAT RATE	Heat flow rate across face by convection	1	1
HEAT RATE/AREA	Heat flow rate per unit area across face by convection	1	-
HFAVG	Average film coefficient of the face	-	1
TBAVG	Average face bulk temperature	-	1
HFLXAVG	Heat flow rate per unit area across face caused by input heat flux	-	1
HFLUX	Heat flux at each node of face	1	-
PRESSURE GRAD	Total pressure gradient and its X, Y, and Z components	2	-
MASS FLUX	Mass flow rate per unit cross-sectional area	2	-
FLUID VELOCITY	Total fluid velocity and its X, Y, and Z components	2	-

1. Output if a surface load is input
2. Output if KEYOPT(7)=1

Table 4.70-3 lists output available through the **ETABLE** command using the Sequence Number method. See Chapter 5 of the *ANSYS Basic Analysis Procedures Guide* and Section 2.2.2.2 of this manual for more information. The following notation is used in Table 4.70-3:

Name - output quantity as defined in the Table 4.70-2
Item - predetermined *Item* label for **ETABLE** command
FC*n* - sequence number for solution items for element Face *n*

Table 4.70-3 SOLID70 Item and Sequence Numbers for the ETABLE and ESOL Commands

Name	Item	FC1	FC2	FC3	FC4	FC5	FC6
AREA	NMISC	1	7	13	19	25	31
HFAVG	NMISC	2	8	14	20	26	32
TAVG	NMISC	3	9	15	21	27	33
TBAVG	NMISC	4	10	16	22	28	34
HEAT RATE	NMISC	5	11	17	23	29	35
HFLXAVG	NMISC	6	12	18	24	30	36

4.70.3 Assumptions and Restrictions

The element must not have a zero volume. This occurs most frequently when the element is not numbered properly. Elements may be numbered either as shown in Figure 4.70-1 or may have the planes IJKL and MNOP interchanged. A prism or tetrahedron shaped element may be formed by defining duplicate node numbers as described in Section 2.8.

The specific heat and enthalpy are evaluated at each integration point to allow for abrupt changes (such as for melting) within a coarse grid. If the thermal element is to be replaced by a SOLID45 structural element with surface stresses requested, the thermal element should be oriented such that face IJNM and/or face KLPO is a free surface.

A free surface of the element (*i.e.*, not adjacent to another element and not subjected to a boundary constraint) is assumed to be adiabatic. Thermal transients having a fine integration time step and a severe thermal gradient at the surface will also require a fine mesh at the surface.
If KEYOPT(8)>0, unsymmetric matrices are produced.

4.70.4 Product Restrictions

When used in the product(s) listed below, the stated product-specific restrictions apply to this element in addition to the general assumptions and restrictions given in the previous section.

ANSYS/Thermal

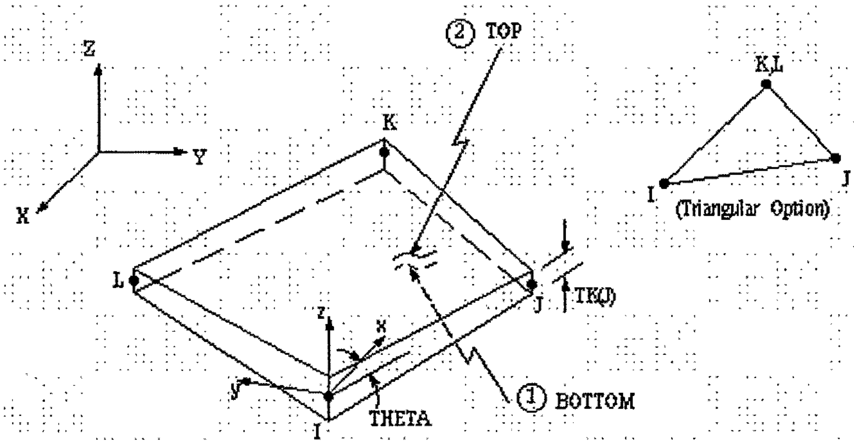
- This element does not have the mass transport or fluid flow options. KEYOPT(7) and KEYOPT(8) can only be set to 0 (default).
- The VX, VY, and VZ real constants are not applicable.
- The VISC and MU material properties are not applicable.
- The element does not have the birth and death feature.

4.57 SHELL57 Thermal Shell

Multiphysics	✓
Mechanical	✓
Structural	
LS-DYNA	
LinearPlus	
Thermal	✓
Emag 3-D	
Emag 2-D	
FLOTRAN	
PrepPost	✓
ED	✓

SHELL57 is a three-dimensional element having in-plane thermal conduction capability. The element has four nodes with a single degree of freedom, temperature, at each node. The conducting shell element is applicable to a three-dimensional, steady-state or transient thermal analysis. See Section 14.57 of the *ANSYS Theory Reference* for more details about this element.
If the model containing the conducting shell element is to be analyzed structurally, the element should be replaced by an equivalent structural element (such as SHELL63). If both in-plane and transverse conduction are needed, a thermal solid element (such as SOLID70 or SOLID90) should be used.

Figure 4.57-1 SHELL57 Thermal Shell



Note—x and y are in the plane of the element

4.57.1 Input Data

The geometry, node locations, and coordinate systems for this element are shown in Figure 4.57-1. The element is defined by four nodes, four thicknesses, a material direction angle, and the material properties.
The element may have variable thickness. The thickness is assumed to vary smoothly over the area of the element, with the thickness input at the four nodes. If the element has a constant thickness, only TK(I) need be input. If the thickness is not constant, all four thicknesses must be input.
Orthotropic material directions correspond to the element coordinate directions. The element coordinate system orientation is as described in Section 2.3. Properties not input default as described in Section 2.4. The element x-axis may be rotated by an angle THETA (in degrees).
Element loads are described in Section 2.7. Convections may be input as surface loads at the element faces as shown by the circled numbers on Figure 4.57-1.
Heat generation rates may be input as element body loads at the nodes. If the node I heat generation rate HG(I) is input, and all others are unspecified, they default to HG(I).
A summary of the element input is given in Table 4.57-1. A general description of element input is given in Section 2.1.

Table 4.57-1 SHELL 57 Summary Input

Element Name	SHELL57
Nodes	I, J, K, L
Degrees of Freedom	TEMP
Real Constants	TK (I), TK (J), TK (K), TK (L), THETA (TK (J), TK (K), TK (L) default to TK (I))
Material Properties	KXX, KYY, DENS, C, ENTH
Surface Loads	Convections: face 1 (I-J-K-L) (bottom, -Z side), face 2 (I-J-K-L) (top, +Z side) Heat Fluxes: face 1 (I-J-K-L) (bottom, -Z side) face 2 (I-J-K-L) (top, +Z side)
Body Loads	Heat Generations: HG (I), HG (J), HG (K), HG (L)
Special Features	Birth and death
KEYOPT(2)	0 - Evaluate film coefficient (if any) at average film temperature, (TS + TB)/2 1 - Evaluate at element surface temperature, TS 2 - Evaluate at fluid bulk temperature, TB 3 - Evaluate at differential temperature, |TS - TB|

4.57.2 Output Data

The solution output associated with the element is in two forms:

- nodal temperatures included in the overall nodal solution
- additional element output as shown in Table 4.57-2

Heat flowing out of the element is considered to be positive. The element output directions are parallel to the element coordinate system. A general description of solution output is given in Section 2.2. See the *ANSYS Basic Analysis Procedures Guide* for ways to view results.
The following notation is used in Table 4.57-2:
A colon (:) in the **Name** column indicates the item can be accessed by the Component Name method [**ETABLE**, **ESOL**] (see Section 2.2.2). The **O** and **R** columns indicate the availability of the items in the file *Jobname*.OUT (**O**) or in the results file (**R**), a **Y** indicates that the item is *always* available, a number refers to a table footnote which describes when the item is *conditionally* available, and a - indicates that the item is *not* available.

Table 4.57-2 SHELL 57 Element Output Definitions

Name	Definition	O	R
EL	Element number	Y	Y
NODES	Nodes - I, J, K, L	Y	Y
MAT	Material number	Y	Y
AREA	Convection face area	Y	Y
CENT: X, Y, Z	Center location XC, YC, ZC	-	Y
HGEN	Heat generations HG(I), HG(J), HG(K), HG(L)	Y	-
TG: X, Y, SUM	Thermal gradient components and vector sum at centroid	Y	Y
TF: X, Y, SUM	Thermal flux (heat flow rate/cross-sectional area) components and vector sum at centroid	Y	Y
FACE	Face label	1	1
AREA	Face area	1	1
NODES	Face nodes	1	1
HFILM	Film coefficient	1	1
TAVG	Average face temperature	1	1
TBULK	Fluid bulk temperature	1	-
HEAT RATE	Heat flow rate across face by convection	1	1
HFAVG	Average film coefficient of the face	-	1
TBAVG	Average face bulk temperature	-	1
HFLXAVG	Heat flow rate per unit area across face caused by input heat flux	-	1
HEAT RATE/AREA	Heat flow rate per unit area across face by convection	1	-
HEAT FLUX	Heat flux at each node of face	1	-

1. If a surface load is input

Table 4.57-3 lists output available through the **ETABLE** command using the Sequence Number method. See Chapter 5 of the *ANSYS Basic Analysis Procedures Guide* and Section 2.2.2.2 of this manual for more information. The following notation is used in Table 4.57-3:

Name - output quantity as defined in the Table 4.57-2

Item - predetermined *Item* label for **ETABLE** command

Table 4.57-3 SHELL57 Item and Sequence Numbers for the ETABLE and ESOL Commands

Name	Item	BOT	TOP
AREA	NMISC	1	7
HFAVG	NMISC	2	8
TAVG	NMISC	3	9
TBAVG	NMISC	4	10
HEAT RATE	NMISC	5	11
HFLXAVG	NMISC	6	12

4.57.3 Assumptions and Restrictions

Zero area elements are not allowed. This occurs most frequently when the elements are not numbered properly. The element must not taper down to a zero thickness at any corner. The four nodes defining the element should lie in an exact flat plane; however, a small out-of-plane tolerance is permitted so that the element may have a slightly warped shape. A warning message will be produced if an element is more than slightly warped (i.e., if any of the three global Cartesian components of any corner normal differs from the corresponding component of the element normal by more than .00001). A triangular element may be formed by defining duplicate K and L node numbers as described in Section 2.8.

4.57.4 Product Restrictions

When used in the product(s) listed below, the stated product-specific restrictions apply to this element in addition to the general assumptions and restrictions given in the previous section.

ANSYS/Thermal

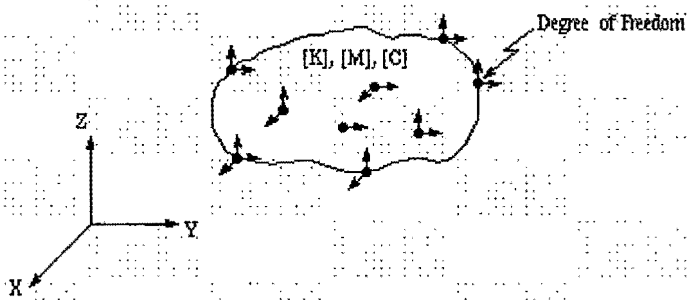
The birth and death special feature is not allowed.

4.50 MATRIX50 Superelement

Multiphysics	✓
Mechanical	✓
Structural	✓
LS-DYNA	
LinearPlus	
Thermal	✓
Emag 3-D	
Emag 2-D	
FLOTRAN	
PrepPost	✓
ED	✓

MATRIX50 is a group of previously assembled ANSYS elements that is treated as a single element. The superelement, once generated, may be included in any ANSYS model and used in any analysis type for which it is applicable. The superelement can greatly decrease the cost of many analyses. Once the superelement matrices have been formed, they are stored on a file and can be used in other analyses as any other ANSYS element. Multiple load vectors may also be stored with the superelement matrices, thereby allowing various loading options. See Section 14.50 of the *ANSYS Theory Reference* for more details about this element.

Figure 4.50-1 MATRIX50 Superelement



4.50.1 Input Data

The superelement, which is a mathematical matrix representation of an arbitrary structure, has no fixed geometrical identity and is conceptually shown in Figure 4.50-1. Any analysis using a superelement as one of its element types is called a superelement use pass (or run). The degrees of freedom are the master degrees of freedom specified during the generation pass.
The element name is MATRIX50 (the number 50 or the name MATRIX50 should be input for the variable *ENAME* on the **ET** command). The **SE** command is used to define a superelement. **SE** reads the superelement from *Jobname*.SUB (defaults to file.SUB) in the working directory. The material number [**MAT**] is only used when material dependent damping [**MP**,DAMP] is present. The real constant table number [**REAL**] is not used. The appropriate element type number [**TYPE**], however, must be entered.
An element load vector is generated along with the element at each load step of the superelement generation pass. Up to 31 load vectors may be generated. Load vectors may be proportionately scaled in the use pass. The scale factor is input on the element surface load command [**SFE**]. The load label is input as SELV, the load key is the load vector number, and the load value is the scale factor. The load vector number is determined from the load step number associated with the superelement generation. If a superelement load vector has a zero scale factor (or is not scaled at all), this load vector is not included in the analysis. Any number of load vector-scale factor combinations may be used in the use pass.
The KEYOPT(1) option is for the special case where the superelement is to be used with a T^4 nonlinearity, such as for radiation. The File.SUB for this case may be constructed directly by the user or may be generated by AUX12, the radiation matrix generator. A summary of the element input is given in Table 4.50-1. A general description of element input is given in Section 2.1.

Table 4.50-1 MATRIX50 Input Summary

Element Name	MATRIX50
Nodes	None input (supplied by element)
Degrees of Freedom	As determined from the included element types (a mixture of multi-field degrees of freedom is not allowed)
Real Constants	None
Material Properties	DAMP
Surface Loads	Surface load effects may be applied through a generated load vector and scale factors. Use the SFE command to supply scale factors with *LAB* = SELV, *LKEY* = load vector number (31 maximum), and *VAL1* = scale factor.
Body Loads	Body loads may be applied through a generated load vector and scale factors as described for surface loads.
Special Features	Radiation (if KEYOPT(1) = 1), Large rotation
KEYOPT(1)	0 - Normal substructure 1 - Special radiation substructure
KEYOPT(6)	0 - Do not print nodal forces 1 - Print nodal forces

4.50.2 Output Data

Displacements and forces may be printed for each (master) degree of freedom in a structural superelement in the "use" pass. The nodal forces may be output if KEYOPT(6)=1. The stress distribution within the superelement and the expanded nodal displacements can be obtained from a subsequent stress pass. In addition to the database and substructure files from the generation run, File.DSUB must be saved from the superelement "use" pass and input to the expansion pass (if an expansion pass is desired). A general description of solution output is given in Section 2.2.

4.50.3 Assumptions and Restrictions

A superelement may contain elements of any type. See the **D** command for degree of freedom field groups. Superelements of different field types may be mixed within the use run. The nonlinear portion of any element included in a superelement will be ignored and any bilinear element will maintain its initial status throughout the analysis. Superelements may contain other superelements.

The PCG solver does not support MATRIX50 elements.

The relative locations of the superelement attachment points in the nonsuperelement portion of the model (if any) should match the initial superelement geometry.

If the superelement contains a mass matrix, acceleration [**ACEL**] defined in the use run will be applied to the superelement. If a load vector containing acceleration effects is also applied in the use run, *both* accelerations (the **ACEL** command and the load vector) will be applied to the superelement. Similarly, if the superelement contains a damping matrix (as specified in the generation run) and α and β damping multipliers [**ALPHA** and **BETA**] are defined in the use run, additional damping effects will be applied to the superelement. Care should be taken to avoid duplication of acceleration and damping effects.

Pressure and thermal effects may be included in a superelement only through its load vectors.

The dimensionality of the superelement correspond to the maximum dimensionality of any element used in its generation. Two-dimensional superelements should only be used in two-dimensional analyses, and three-dimensional superelements in three-dimensional analyses.

See Section 17.6 of the *ANSYS Theory Reference* for a discussion of the substructure matrix assembly procedure.

4.50.4 Product Restrictions

When used in the product(s) listed below, the stated product-specific restrictions apply to this element in addition to the general assumptions and restrictions given in the previous section.

ANSYS/Structural

KEYOPT(1)=0

ANSYS/Thermal

- This element may be used as a radiation substructure only. KEYOPT(1) defaults to 1 instead of 0 and cannot be changed.
- The DAMP material property, surface loads, and body loads are not applicable.
- The large rotation special feature is not applicable.

Chapter 4: Radiation

4.1 What Is Radiation?

Radiation is the transfer of energy via electromagnetic waves. The waves travel at the speed of light, and energy transfer requires no medium. Thermal radiation is just a small band on the electromagnetic spectrum. Because the heat flow that radiation causes varies with the fourth power of the body's absolute temperature, radiation analyses are highly nonlinear.

4.2 Analyzing Radiation Problems

The ANSYS program provides three methods for radiation analysis, each meant for a different situation:

- You can use LINK31, the radiation link element, for simple problems involving radiation between two points or several pairs of points.
- You can use the surface effect elements, SURF19, SURF22, SURF151, and SURF152 for radiation between a surface and a point.
- Use the AUX12 radiation matrix generator for more generalized radiation problems involving two or more surfaces. (Only the ANSYS/Multiphysics, ANSYS/Mechanical, and ANSYS/Thermal programs offer AUX12.)

You can use the three radiation analysis methods for either transient or steady-state thermal analyses. Radiation is a nonlinear phenomenon, so you will need an iterative solution to reach a converged solution.

The unit of temperature also plays an important role in radiation analysis; you perform radiation calculations in absolute temperature units. Therefore, if you define your model data in terms of degrees Fahrenheit or degrees Celsius, you must specify a temperature offset: 460° for the Fahrenheit system and 273° for the Centigrade system.

To specify a temperature offset, use either of the following:

Command(s):
TOFFST

GUI:
Main Menu>Preprocessor>Loads>Analysis Options
Main Menu>Solution>Analysis Options

4.3 Using LINK31, the Radiation Link Element

LINK31 is a two-node, nonlinear line element that calculates the heat flow caused by radiation between two points. The element requires you to specify, in the form of real constants:

- An effective radiating surface area
- Form factor
- Emissivity
- The Stefan-Boltzmann constant.

Limit your use of the LINK31 analysis method to simple cases where you know, or can calculate easily by hand, the radiation form factors.

4.4 Using the Surface Effect Elements

A convenient way to model radiation between a surface and a point is to use surface effect elements superimposed on surfaces that emit or receive radiation. ANSYS provides such elements: SURF19 and SURF151 for two-dimensional models, and SURF22 and SURF152 for three-dimensional models. The element option KEYOPT(9) activates radiation for these elements. The form factor can be specified as a real constant (defaults to 1) using KEYOPT(9)=1, or you can calculate a cosine effect (using KEYOPT(9)=2 or 3) from the basic element orientation and the extra node location.

4.5 Using AUX12, the Radiation Matrix Generator

Offered in the ANSYS/Multiphysics, ANSYS/Mechanical, and ANSYS/Thermal programs only, this method works for generalized radiation problems involving several surfaces receiving and emitting radiation. The method involves generating a matrix of form factors (view factors) between radiating surfaces and using the matrix as a superelement in the thermal analysis. You also can include hidden or partially hidden surfaces, as well as a "space node" that can absorb radiation energy.

The AUX12 analysis method consists of three steps:

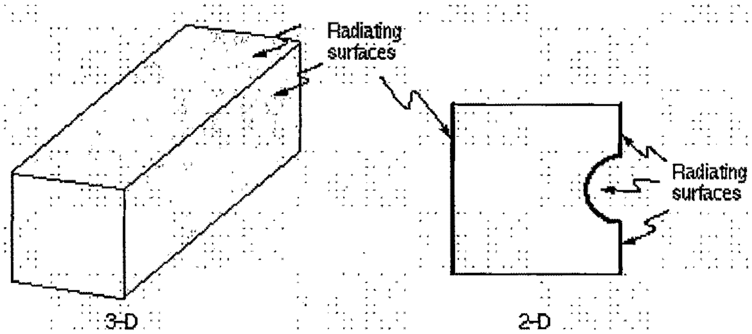
1. Define the radiating surfaces.
2. Generate the radiation matrix.
3. Use the radiation matrix in the thermal analysis.

4.5.1 Defining the Radiating Surfaces

To define the radiating surfaces, you create a superimposed mesh of LINK32 elements in 2-D models and SHELL57 elements in 3-D models. To do so, perform the following tasks:

1. Build the thermal model in the preprocessor (PREP7). Radiating surfaces do not support symmetry conditions, therefore models involving radiating surfaces can not take advantage of geometric symmetry and must therefore be modeled completely. The radiating surfaces usually are *faces* of a 3-D model and *edges* of a 2-D model, as shown below:

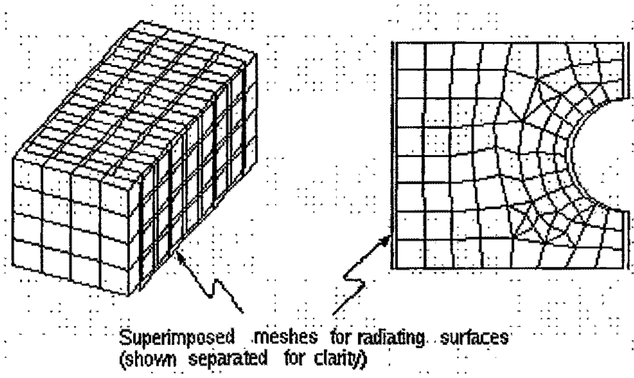
Figure 4-1 Radiating surfaces for 3-D and 2-D models



2. Superimpose the radiating surfaces with a mesh of SHELL57 elements in 3-D models or LINK32 elements in 2-D models, as shown in the graphic below. The best way to do this is to first create a subset of the surface nodes, and then generate the surface elements using one of the following:

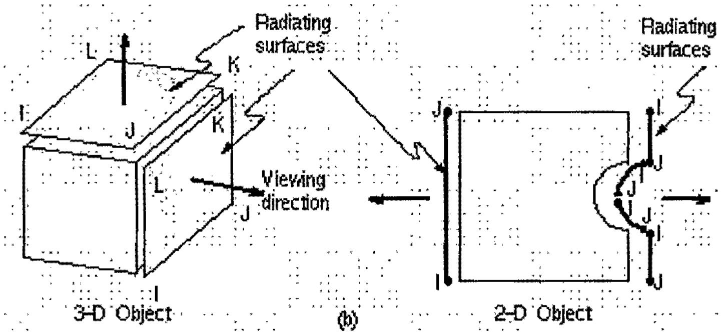
Command(s):
ESURF
GUI:
Main Menu>Preprocessor>Create>Elements>Surf Effect>Extra Node
Main Menu>Preprocessor>Create>Elements>Surf Effect>No extra Node
Make sure to first activate the proper element type for the surface elements. Also, if the surfaces are to have different emissivities, assign different material reference numbers before creating the elements.

Figure 4-2 Superimposing elements on radiating surfaces



Caution: *Radiating surface mesh of* SHELL57 *or* LINK32 *elements must match (node for node) the underlying solid element mesh. If it does not match, the resulting thermal solution will be incorrect.*
The orientation of the superimposed elements is important. AUX12 assumes that the "viewing" direction (that is, the direction of radiation) is along $+Z_e$ for SHELL57 elements and along $+Y_e$ for LINK32 elements (where e denotes the outward normal direction of the element coordinate system). Therefore, you must mesh the superimposed elements so that the radiation occurs from (or to) the proper face. The order in which the element's nodes are defined controls the element orientation, as shown below:

Figure 4-3 Orienting the superimposed elements



3. Define a space node, which simply is a node that absorbs radiant energy not received by other surfaces in the model. Location of this node is not important. An open system usually requires a space node. However, *you should not specify a space node for a closed system.*

4.5.2 Generating the AUX12 Radiation Matrix

Calculating the radiation matrix requires the following inputs:

- Nodes and elements that make up the radiating surfaces
- Model dimensionality (2-D or 3-D)
- Emissivity and Stefan-Boltzmann constant
- The method used to calculate the form factors (hidden or visible)
- A space node, if desired.

To generate the matrix, perform these steps:

1. Enter AUX12 using one of these methods:

Command(s):
/AUX12

GUI:
Main Menu>Radiation Matrix

2. Select the nodes and elements that make up the radiation surfaces. An easy way to do this is to select elements by type and then select all attached nodes. To perform these tasks, use the GUI path **Utility Menu> Select>Entities** or the commands **ESEL**,*S,TYPE* and **NSLE**. If you have defined a space node, remember to select it.

3. Specify whether this is a 2-D model or a 3-D model, using either of the following:

Command(s):
GEOM

GUI:
Main Menu>Radiation Matrix>Other Settings

AUX12 uses different algorithms to calculate the form factors for 2-D and 3-D models respectively. AUX12 assumes a 3-D model by default. Two-dimensional models may be either planar (NDIV value =0), or axisymmetric (NDIV value > 0), with planar as the default. Axisymmetric models are expanded internally to a 3-D model, with NDIV representing the number of axisymmetric sections. For example, setting NDIV to 10 indicates 10 sections, each spanning 36 degrees.

4. Define the emissivity using either method shown below. Emissivity defaults to unity (1.0).

Command(s):
EMIS

GUI:
Main Menu>Radiation Matrix>Emissivities

5. Define the Stefan-Boltzmann constant using either method shown below. The Stefan-Boltzmann constant defaults to 0.119E-10 Btu/hr-in^2-R^4. (In S.I. Units, the constant has the value 5.67E-8 W/m^2-K^4.)

Command(s):
STEF

GUI:
Main Menu>Radiation Matrix>Other Settings

6. Specify how to calculate form factors, using either of the following:

Command(s):
VTYPE

GUI:
Main Menu>Radiation Matrix>Write Matrix

You can choose between the hidden and non-hidden methods:

- The non-hidden method calculates the form factors from every element to every other element regardless of any blocking elements.
- The hidden method (default) first uses a hidden-line algorithm to determine which elements are "visible" to every other element. (A "target" element is visible to a "viewing" element if their normals point toward each other and there are no blocking elements.) Then, form factors are calculated as follows:
- Each radiating or "viewing" element is enclosed with a unit hemisphere (or a semicircle in 2-D).
- All target or "receiving" elements are projected onto the hemisphere or semicircle.
- To calculate the form factor, a predetermined number of rays are projected from the viewing element to the hemisphere or semicircle. Thus, the form factor is the ratio of the number of rays incident on the projected surface to the number of rays emitted by the viewing element. In general, accuracy of the form factors increases with the number of rays. You can increase the number of rays via the NZONE field on the **VTYPE** command or the **Write Matrix** menu option; both indicate the number of radial sampling zones.

7. If necessary, designate the space node using either of the methods shown below:

Command(s):
SPACE

GUI:
Main Menu>Radiation Matrix>Other Settings

8. Use either the **WRITE** command or the **Write Matrix** menu option to write the radiation matrix to the file *Jobname*.SUB. If you want to write more than one radiation matrix, use a separate filename for each matrix. To print your matrices, issue the command **MPRINT**,1 before issuing the **WRITE** command.

9. Reselect all nodes and elements using either of the following:

Command(s):
ALLSEL

GUI:
Utility Menu>Select>Everything

You now have the radiation matrix written as a superelement on a file.

4.5.3 Using the Radiation Matrix in the Thermal Analysis

After writing the radiation matrix, re-enter the ANSYS preprocessor (PREP7) and read the matrix in as a superelement. To do so, perform these steps:

1. Re-enter the preprocessor using one of these methods:
Command(s):
/PREP7
GUI:
Main Menu>Preprocessor
Specify MATRIX50 (the superelement) as one of the element types.

2. Switch the element type pointer to the superelement using either of the following:
Command(s):
TYPE
GUI:
Main Menu>Preprocessor>-Modeling-Create>Elements>Elem Attributes

3. Read in the superelement matrix using one of these methods:
Command(s):
SE
GUI:
Main Menu>Preprocessor>-Modeling-Create>Elements>-Superelements-From .SUB File

4. Either unselect or delete the superimposed mesh of SHELL57 or LINK32 elements, using either of the following:
Command(s):
EDELE
GUI:
Main Menu>Preprocessor>-Modeling-Delete>Elements
(The thermal analysis does not require these elements.)

5. Exit from the preprocessor and enter the SOLUTION processor.

6. Assign the known boundary condition to the space node using either of the following:
Command(s):
D, F
GUI:
Main Menu>Solution>-Loads-Apply...(etc.)
This boundary typically is a temperature (such as ambient temperature), but also may be a heat flow. The boundary condition value should reflect the actual environmental conditions being modeled.

7. Proceed with the thermal analysis as explained in the other chapters of this manual.

4.6 Recommendations for Using Space Nodes

Although modeling radiation does not always require a space node, the decision to or not to use one can affect the accuracy of your thermal analysis results. Keep the following recommendations about space node usage in mind as you build your model.

4.6.1 Considerations for the Non-hidden Method

The non-hidden method of form factor calculation usually is accurate enough for any system without requiring special attention to space nodes. Generally, you *should not* specify a space node for a closed system, but you *should* specify one for an open system. Only one situation requires special attention: when modeling an open system which includes gray body radiation (emissivity is less than 1), you *must* use a space node to ensure accurate results.

4.6.2 Considerations for the Hidden Method

For the hidden method of form factor calculation, the accuracy of the form factor calculations within AUX12 can affect the accuracy of the radiation calculated to the space node. Because inaccuracies in the calculations accumulate at the space node, the relative error in the space node form factor can be exaggerated in a closed or nearly closed system.
When using the hidden method, you may need to increase the number of rays used in the form factor calculation and to refine the mesh in order to make the form factors more accurate. If this is not possible, consider the following tips when defining the space node:

- For a closed system in which all radiating surfaces form an enclosure and do not radiate to space, do not use a space node.
- If the nature of the problem makes it acceptable to simulate radiation between the radiating surfaces only (ignoring radiation to space), then do not specify a space node. This approach is valid only when modeling black body radiation (where emissivity = 1).
- For a nearly closed system, if you must account for radiation to space, then mesh the opening and constrain the temperature of the nodes in the opening to the temperature of space. The form factor to space will then be calculated explicitly and more accurately.
- For an open system where there are significant losses to space, you can use a space node (with a specified boundary condition) to capture the lost radiation with acceptable accuracy using moderate mesh refinement and a moderate number of rays.

4.7 General Guidelines for AUX12

Below are some general guidelines for using the AUX12 approach to radiation analysis:

- The non-hidden method should be used if and only if all the radiating surfaces see each other fully. If the non-hidden method is used for cases where *any* blocking effect exists, there will be significant inaccuracies in view factor calculations, and the subsequent thermal analysis results can be physically inaccurate, or the problem might not even converge.
- The hidden method requires significantly longer computer time than the non-hidden method. Therefore, use it only if blocking surfaces are present or if surfaces cannot be grouped.
- In some cases, you may be able to group radiating surfaces so that each group is isolated completely from the other groups in terms of radiation heat transfer. In such cases, you can save significant time by creating a separate radiation matrix for each group using the non-hidden method. (This is true so long as no blocking effects exist within a group.) You can do this by selecting the desired group of radiating surfaces before writing the matrix.
- For the hidden method, increasing the number of rays usually produces more accurate form factors.
- For both hidden and non-hidden methods, the finer the mesh of the radiating surface elements, the more accurate are the form factors. However, when hidden method is used, it is particularly important to have a fairly refined mesh in order to obtain the same level of accuracy in view factor computation as the non-hidden method. Event though increasing the number of rays used (controlled by NZONE argument of the VTYPE command) helps in accuracy, for a coarse mesh, increasing NZONE to even its maximum limit might not yield an accurate solution for the hidden method.
- For axisymmetric models, about 20 axisymmetric sectors provide reasonably accurate form factors. Elements should have reasonable aspect ratios whey they are expanded to a 3-D model.
- LINK32 elements, which are used as superimposed radiation surface elements in 2-D planar or axisymmetric models, do not directly support the axisymmetric option. In axisymmetric models, therefore, be sure to delete (or unselect) them before doing the thermal analysis.

Theoretically, the summation of view factor from any radiating surface to all other radiating surfaces should be 1.0 for a closed system. This is printed as `***** FORM FACTORS ***** TOTAL=` *Value* for each radiating surface if the view factors for radiating surfaces are printed using the **MPRINT**,1 command. For open systems, the summation should always be less than 1.0. One way of checking whether the view factor calculations are correct or not is to use the MPRINT,1 command, and check if the summation of view factors for any radiating surface exceeds 1.0. This can happen if the non-hidden method is inadvertently used for calculating view factors between radiating surfaces with blocking effects.

APPENDIX C:
Internal Air Space Heat Transfer Calculations

Effective K to Account for Convection Across Air Space

Free convection heat transfer across the air space between the Gammacell and the inner wall of the overpack can be represented by an effective thermal conductivity, k_{eff}, which is the thermal conductivity that a stationary fluid should have to transfer the same amount of heat as the moving fluid [5]. The air space is approximated as the annular space between long concentric cylinders or concentric spheres. The correlation for k_{eff} is then of the form:

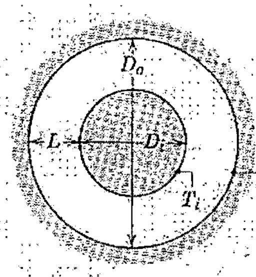
$$\frac{k_{eff}}{k} = 0.386\left(\frac{\Pr}{0.861+\Pr}\right)^{1/4}\left(Ra_c^*\right)^{1/4}$$

where, k is the thermal conductivity of the fluid at the film temperature,

Pr is the Prandtl number for the fluid at the film temperature, and

$$Ra_c^* = \frac{\left[\ln\left(Do/Di\right)\right]^4}{L^3\left(Di^{-3/5}+Do^{-3/5}\right)^5} Ra_L \text{ and } 10^2 < Ra_c^* < 10^7.$$

where Di, Do and L are defined in the following figure,



and,

$$Ra_L = \frac{g\beta(Ti-To)L^3}{\nu\alpha}$$

where, g is the acceleration due to gravity = 9.8 m/s^2,
β is the inverse of the film temperature in degrees Kelvin,
ν is the kinematic viscosity of the fluid at the film temperature,
α is the thermal diffusivity of the fluid at the film temperature,
Ti and To are the temperature of the surfaces as defined in the figure above, and
the film temperature, T = (Ti + To)/2.

Effective k Under Steady State Conditions

Under steady state conditions for Load Cases 1 and 2 (Sections 5.1 and 5.2, respectively), Ti is the temperature measured on the outside of the Gammacell, while To is the temperature measured on the inside wall of the overpack. From the experimental measurements of the Gammacell in the F-430 overpack [3], Ti ≅ 27°C and To ≅ 26°C.

Therefore, the film temperature, T = (27+26)/2 = 26.5°C, and the required air properties are [5],

$\beta = 1/(26.5+273) = 0.0033\ K^{-1}$, $k = 0.026\ W/m°C$, $\nu = 15.9x10^{-6}\ m^2/s$, $\alpha = 26.3x10^{-6}\ m^2/s$, and Pr = 0.707.

The outer diameter of the Gammacell lead casing in the F-431 overpack is, Di = 18 in = 0.46 m.

The diameter to the inside wall of the overpack, Do, is the distance from the center of the Gammacell to the inner F-431 overpack wall multiplied by two.

This yields, Do = 22 in. = 0.56 m.

The distance L is then, (Do – Di)/2 = (0.56-0.46)/2 = 0.05 m.

From the equations in the previous section,

$$Ra_L = \frac{9.81*0.0033*(27-26)(0.05)^3}{15.9x10^{-6}*26.3x10^{-6}} = 9.68x10^3$$

$$Ra_c^* = \frac{[\ln(0.56/0.46)]^4}{(0.05)^3\left((0.46)^{-3/5}+(0.56)^{-3/5}\right)^5}*9.68x10^3 = 3.85x10^4$$

$$\frac{k_{eff}}{k} = 0.386\left(\frac{0.707}{0.861+0.707}\right)^{1/4}\left(3.85x10^4\right)^{1/4} = 4.4$$

k_{eff} is then: $$k_{eff} = 4.4*0.026 = 0.1\ W/m°C$$

Effective K Under Regulatory Fire Conditions

Under regulatory fire conditions for Load Case 3 (Section 5.3), Ti is the temperature on the outside of the Gammacell, while To is the temperature on the inside wall of the overpack. These temperatures are conservatively estimated as, Ti = 27°C (steady state temperature) and To = 800°C (fire temperature).

Therefore, the film temperature, T = (27+800)/2 = 414°C, and the required air properties are [5],

$\beta = 1/(414+273) = 0.0015\ K^{-1}$, $k = 0.052\ W/m°C$, $\nu = 68.0x10^{-6}\ m^2/s$, $\alpha = 98.0x10^{-6}\ m^2/s$, and Pr = 0.7.

The dimensions Do, Di and L are as in the previous section.

From the previous equations,

$$Ra_L = \frac{9.81*0.0015*(800-27)(0.05)^3}{68.0x10^{-6}*98.0x10^{-6}} = 2.13x10^5$$

$$Ra_c^* = \frac{[\ln(0.56/0.46)]^4}{(0.05)^3\left((0.46)^{-3/5}+(0.56)^{-3/5}\right)^5}*2.13x10^5 = 8.48x10^5$$

$$\frac{k_{eff}}{k} = 0.386\left(\frac{0.7}{0.861+0.7}\right)^{1/4}\left(8.48x10^5\right)^{1/4} = 9.6$$

k_{eff} is then: $k_{eff} = 9.6*0.052 = 0.5 \quad W/m°C$

Contribution of Heat Transfer Through Steel Across Air Space

Heat transfer by conduction occurs through the air and through the support structure of the Gammacell. The Gammacell is supported mainly by wood inserts on its top and bottom. The surface area supported by the wood inserts is about 30% of the total area of the Gammacell.

The total thermal conductivity of the air space is calculated by combining the effective thermal conductivity (calculated above) to account for convection and the contribution of conduction through the wood inserts.

For all temperatures, the combined thermal conductivity, k, is calculated as follows;

$k = k_{eff}*0.7 + k_w*0.3$

where, k_{eff} is the effective thermal conductivity to account for convection, and
k_w is the thermal conductivity of plywood = 0.12 W/m°C [5].

So, for example, under the regulatory fire conditions,
$k = 0.5*0.7 + 0.12*0.3 = 0.4$ W/m°C

The thermal analysis for the F-430 [3] considered a steel brace where the surface area supported by the steel brace was about 2% of the total area of the Gammacell. Therefore, the following equation for k was used,

$k = k_{eff}*0.98 + k_{st}*0.02$

where, k_{st} is the thermal conductivity of steel.

So, for example, under the regulatory fire conditions, $k_{st} \cong 16.6$ W/m°C (from Table 1), and therefore,
$k = 0.5*0.98 + 16.6*0.02 = 0.8$ W/m°C

To allow for future changes to the bracing geometry in the F-431, (for example, an all-steel or a combination wood and steel brace), the equation for k used in the F-430 model is also used in the F-431 model. This is a reasonable assumption since the value for k across the air space has little impact on the final results as the polyurethane foam is the dominant thermal shield. For example, during the regulatory fire test, the temperature gradient across the polyurethane foam is approximately 600°C, whereas the gradient across the air space is approximately 20°C (refer to Figure 14).

APPENDIX D: Derivation of Heat Transfer Coefficients

The heat transfer coefficients used in the F-431 analysis were chosen to match empirical results for the F-430 overpack [3]. This appendix demonstrates that the values used are reasonable in comparison with approximate relations for air. It also calculates bounding values for the heat transfer coefficient for a cylinder in a fire environment. For all steady state calculations, the temperatures of the applicable surfaces are taken from the steady state analysis of the F-430 overpack [3].

Heat Transfer Coefficient for Steady State and Solar Load Analyses

The F-431 overpack can be approximated as a cylinder in the cross flow of the air with a diameter, D, of 36.72 in. = 0.93 m. The flow of gas over the outside of the overpack is estimated to take place at a low velocity of 1.0 m/s (3.3 ft./s).

From Incropera and Dewitt [5], the heat transfer coefficient takes the form:

$$h = k/D * C(uD/v)^{n} Pr^{0.333}$$

where: D is the average width of cross section of the overpack = 0.93 m
C,n are constants that depend on the Reynolds number (uD/v)
k = thermal conductivity of the fluid
v = kinematic viscosity of the fluid
Pr = Prandtl number for the fluid
u = free stream velocity

The property values of k,v and Pr are evaluated at the film temperature, which is defined as the mean of the wall and free stream fluid temperatures.

The wall temperature was measured as 21°C on the outside of the F-430 overpack, while the ambient temperature was 21°C. The film temperature is, therefore, 21 °C and, from Incropera and Dewitt [5], the property values are k = 0.026 W/m °C, v = 1.6E-5 m^2/s and Pr = 0.707. This yields a Reynolds number of about 80,000. At this value of Re, the constants C and n are 0.027 and 0.805, respectively [5]. Substituting in the appropriate values in the above equation yields a heat transfer coefficient of :

$$h = \frac{0.026(0.027)(1.0*0.93/1.6E\text{-}5)^{0.805}.707^{0.333}}{0.93} = 4.6\ W/m^2\,°C$$

A value of 5.0 W/m^2 °C was used in the analysis.

Heat Transfer Coefficient During the Fire Test

At the start of the fire, the wall temperature is 21°C on the outside of the overpack. The film temperature is, therefore, 411°C and, from Incropera and Dewitt [5], the property values are k = 0.052 W/m°C, ν = 6.6E-5 m^2/s and Pr =0.693. This yields a Reynolds number of about 200,000. At this value of Re, the constants C and n are 0.027 and 0.805, respectively [5]. The flow of hot gases over the outside of the overpack is assumed to take place at a high velocity of 10.0 m/s
(32.8 ft/s) [11].

Substituting in the appropriate values in the equation from the previous section yields a heat transfer coefficient of :

$$h = \frac{0.052(0.027)(10.0*0.93/6.6E\text{-}5)^{0.805}.693^{0.333}}{0.93} = 18.7\ W/m^2\,°C$$

A value of 19.0 W/m^2 °C was conservatively used in the analysis of the regulatory fire.

APPENDIX E:
ANSYS Input Files for Load Cases

This appendix includes all of the input files used in the analyses of the F-431 overpack. Each of the input files (*.inp) perform different tasks as described below. See Section 5 of the main body of this report for descriptions of the Load Cases.

Input File	Description
Modela.inp	Model of F-431 overpack for Load Cases 1 and 2
Loada.inp	Load input for steady state Load Cases 1 and 2
Loadsolara.inp	Load input for transient solar loading (12 hour insolation) for Load Case 2
Fmodela.inp	Model of F-431 overpack for regulatory fire transient Load Case 3
Modfirea.inp	Model of modified F-431 overpack for regulatory fire transient Load Case 4
Loadfirea.inp	Load input for regulatory fire transient Load Cases 3 and 4

The file bff431.inp listed in the transient load input files (loadsolara.inp and loadfirea.inp) is a file containing the initial steady state temperature condition of the model from Load Case 2.

```
! modela.inp
!
/prep7
cv=39.37
cdread,solid,model
! material properties
! mild steel
mptemp,1,-73,127,327,527,727,927
mp,dens,1,8131
mpdata,kxx,1,1,41.0,42.2,39.7,35.0,27.6,27
.6
mpdata,c,1,1,434,487,559,685,1090,1090
! foam 1 - 40 lb
mptemp
mptemp,1,0,260,400,540,800
mpdata,dens,2,1,641,641,321,256,26
mptemp
mptemp,1,0,260,400,465,800
mpdata,kxx,2,1,0.087,0.087,0.087,0.054,0.
07
mp,c,2,1959
! air
mptemp
mptemp,1,-73,127,327,527,727,927
mpdata,dens,3,1,1.7458,0.8711,0.5804,0.4
354,0.3482,0.2902
mpdata,kxx,3,1,0.0181,0.0338,0.0469,0.05
73,0.0667,0.0763
mpdata,c,3,1,1007,1014,1051,1099,1141,1
175
! radiation surfaces
mp,emis,4,0.5
! stainless steel
mptemp
mptemp,1,-73,127,327,527,727,927
mp,dens,5,7900
mpdata,kxx,5,1,12.6,16.6,19.8,22.6,25.4,28
.0
mpdata,c,5,1,402,515,557,582,611,640
!
! air including conduction and convection
across cavity
mpdata,dens,6,1,1.7458,0.8711,0.5804,0.4
354,0.3482,0.2902
kxx1=41.0*0.02+0.98*0.1
kxx2=42.2*0.02+0.98*0.1
kxx3=39.7*0.02+0.98*0.1
kxx4=35.0*0.02+0.98*0.1
kxx5=27.6*0.02+0.98*0.1
kxx6=27.6*0.02+0.98*0.1
mpdata,kxx,6,1,kxx1,kxx2,kxx3,kxx4,kxx5,kx
x6
mpdata,c,6,1,1007,1014,1051,1099,1141,1
175
!
! lead
mptemp
mptemp,1,20,327,330,800
mpdata,dens,7,1,11340,11005,10686,1068
6
mptemp
mptemp,1,-23,27,127,227,327,328
mptemp,7,331,332,1000
mpdata,c,7,1,127,129,132,136,142,6188
mpdata,c,7,7,6188,159,159
mptemp
mptemp,1,-273,-27,123,227,327,527
mptemp,7,727,927
mpdata,kxx,7,1,35,35,34,33,31,19
mpdata,kxx,7,7,22,24
! foam 2 - 8 lb
mptemp
mptemp,1,0,260,400,540,800
mpdata,dens,8,1,128,128,64,51,5
mptemp
mptemp,1,0,260,400,465,800
mpdata,kxx,8,1,0.038,0.038,0.038,0.054,0.
07
mp,c,8,1959
!
! radiation emissivities
mp,emis,9,0.01
mp,emis,10,0.8
mp,emis,11,0.5
!
! mild steel with contact resistance
mptemp
mptemp,1,-73,127,327,527,727,927
mp,dens,12,8131
mpdata,kxx,12,1,0.53,0.99,1.35,1.63,1.86,2
.11
mpdata,c,12,1,434,487,559,685,1090,1090
!
vdel,1,3
!
csys,5
!
ksel,s,loc,x,0.457
kmodif,all,0.280
ksel,s,loc,x,0.460
kmodif,all,0.283
ksel,s,loc,x,0.485
kmodif,all,0.308
ksel,s,loc,x,0.488
kmodif,all,0.311
ksel,s,loc,x,0.498
kmodif,all,0.321
ksel,s,loc,x,0.538
kmodif,all,0.361
ksel,s,loc,x,0.559
kmodif,all,0.387
ksel,s,loc,x,0.564
kmodif,all,0.392

ksel,s,loc,x,0.6345,0.6355
kmodif,all,0.463
ksel,s,loc,x,0.6375,0.6385
kmodif,all,0.466
allsel
!
ksel,s,loc,z,0.356
kmodif,all,,,0.321
ksel,s,loc,z,0.396
kmodif,all,,,0.361
ksel,s,loc,z,0.4035,0.4045
kmodif,all,,,0.369
ksel,s,loc,z,0.4085,0.4095
kmodif,all,,,0.374
ksel,s,loc,z,0.417
kmodif,all,,,0.382
ksel,s,loc,z,0.4445,0.4455
kmodif,all,,,0.409
ksel,s,loc,z,0.4465,0.4475
kmodif,all,,,0.412
ksel,s,loc,z,0.457
kmodif,all,,,0.422
ksel,s,loc,z,0.472
kmodif,all,,,0.437
ksel,s,loc,z,0.475
kmodif,all,,,0.440
ksel,s,loc,z,0.495
kmodif,all,,,0.460
ksel,s,loc,z,0.500
kmodif,all,,,0.465
ksel,s,loc,z,0.6345,0.6355
kmodif,all,,,0.600
ksel,s,loc,z,0.6375,0.6385
kmodif,all,,,0.603
allsel,below,volu
ksel,inve
lsel,inve
asel,inve
vsel,inve
vdel,all
adel,all
ldel,all
kdel,all
!
allsel
k,1,0,0,0
v,14,26,56,56,10,1,44,44
!
csys,0
vlscale,1,1,1,(0.228/0.28),(0.305/0.409),(0.
228/0.28)
vsbv,1,2,,delete,keep
vlscale,2,2,1,(0.213/0.228),(0.290/0.305),(0
.213/0.228)
vsbv,2,1,,delete,keep
vlscale,1,1,1,(0.00762/0.213),(0.1397/0.290
),(0.00762/0.213)
vsbv,1,2,,delete,delete
allsel
!
! add stainless steel shell volumes
vadd,4,7,9
nummrg,kp
!
! meshing properties
/uis,msgpop,3
mshkey,0
mshape,1,3d
!
! mesh air space around pig
et,1,70
type,1
esize,1.5/cv
mat,6
vmesh,3
mat,12
vmesh,12
mat,5
vmesh,1
!
! create inner radiation enclosure
et,3,57
type,3
!
mat,9
asel,s,area,,9,11
amesh,all

mat,10
asel,s,area,,4
asel,a,area,,7
amesh,all
```

```
mat,11
asel,s,area,,33,34
amesh,all

asel,s,area,,9,11
asel,a,area,,33,34
esla,s
nelem
ensym,0,,0,all
allsel
!
et,1,70
type,1
mat,7
vmesh,13
mat,2
vmesh,5
mat,2
vmesh,6
mat,3
vmesh,8
mat,8
vmesh,10
mat,8
vmesh,11
!
! create outer surface
asel,s,area,,41
asel,a,area,,52
nsla,s,1
cm,outsurf,node
asel,s,area,,41
nsla,s,1
cm,ssurf,node
asel,s,area,,52
nsla,s,1
cm,tsurf,node
allsel
cmsel,s,outsurf
!
! create outer radiation elements
eall
et,2,57
r,4,1.0
type,2
mat,4
real,4
esurf
n,999999,0.75,0.75,-0.75
allsel
esel,s,type,,2
nelem
nsel,r,loc,y,0.601,0.603
esln,s,1
esel,r,type,,2
cm,toprad,elem
esel,s,type,,2
cmsel,u,toprad
cm,siderad,elem
allsel
!
!create outer shell divisions for solar load
application
cmsel,s,tsurf
esln,s,0
nelem
nsel,r,loc,y,0.599,0.604
esln,s,1
esel,r,type,,1
cm,topshell,elem
cmsel,s,ssurf
esln,s,0
nelem
nsel,u,node,,683
nsel,u,node,,2209
esln,s,1
esel,r,type,,1
cmsel,u,topshell
nelem
cm,sideshell,elem
allsel
!calculate volume of side outer shell
elements
cmsel,s,sideshell
*get,totel,elem,,count
*get,minel,elem,,num,min
*get,maxel,elem,,num,max
tvol = 0
*do,i,1,totel,1
 *get,evol,elem,minel,volu
 tvol = tvol + evol
 *get,minel,elem,minel,nxth
*enddo
qside = (400*0.44139)/tvol
!calculate volume of bottom outer shell
elements
cmsel,s,topshell
*get,totel,elem,,count
*get,minel,elem,,num,min
*get,maxel,elem,,num,max
tvol = 0
*do,i,1,totel,1
 *get,evol,elem,minel,volu
 tvol = tvol + evol
 *get,minel,elem,minel,nxth
*enddo
qtop = (800*0.17055)/tvol
allsel
!
fini
/aux12
vtype,0,20
stef,5.7e-8
emis,4,0.5
emis,9,0.01
emis,10,0.8
emis,11,0.5
esel,s,type,,3
write,radmat1
allsel
space,999999
cmsel,s,toprad
nelem
nsel,a,node,,999999
write,radmat2

allsel
cmsel,s,siderad
nelem
nsel,a,node,,999999
write,radmat3
allsel
fini
/prep7
et,4,50,1
type,4
se,radmat1
et,5,50,1
type,5
se,radmat2
se,radmat3
!
/view,1,-1,1,1
/vup,1,y
/facet,norm
! end of file
! loada.inp
!
! apply internal heat generation
sfa,19,1,hflux,((15/8)/0.0017177)*(0.00167
21/0.0017177)
sfa,5,1,hflux,((15/8)/0.0017177)*(0.000045
604/0.0017177)
!
! apply external convection and set initial
ambient temp
cmsel,s,outsurf
sf,all,conv,5.0,21
allsel
d,999999,temp,21
toffst,273
!
! run analysis
fini
/solve
timint,off
esel,u,type,,2,3
solve

! run analysis with 50 W of heat, or 12.5 W
on 1/8 section
! apply internal heat generation
sfa,19,1,hflux,((50/8)/0.0017177)*(0.00167
21/0.0017177)
sfa,5,1,hflux,((50/8)/0.0017177)*(0.000045
604/0.0017177)
solve

! run analysis with 38 C ambient
cmsel,s,outsurf
sf,all,conv,5.0,38
allsel
d,999999,temp,38
esel,u,type,,2,3
solve

! run analysis with solar load
cmsel,s,topshell
nelem
bfe,all,hgen,1,qtop
cmsel,s,sideshell
nelem
bfe,all,hgen,1,qside
allsel
esel,u,type,,2,3
solve
! end of file
```

```
! loadsolara.inp
!
! apply internal heat generation
sfa,19,1,hflux,((50/8)/0.0017177)*(0.00167
21/0.0017177)
sfa,5,1,hflux,((50/8)/0.0017177)*(0.000045
604/0.0017177)
fini
/solve
! apply external convection and set initial
ambient temp
cmsel,s,outsurf
sf,all,conv,5.0,38.0
allsel
toffst,273
!
antype,trans,new
time,1e-6
esel,u,type,,2,3
! input initial temperatures from 38 C steady
state with no solar load
/inp,bff431,inp
timint,off
outres,all,none
outres,nsol
solve

time,1
ddel,all
timint,on
lnsrch,on
kbc,1
! set ambient temp
d,999999,temp,38
! apply solar load
cmsel,s,sideshell
nelem
bfe,all,hgen,1,qside
cmsel,s,topshell
nelem
bfe,all,hgen,1,qtop
allsel
esel,u,type,,2,3
solve

time,200
solve

time,400
solve

time,800
solve

time,1200
solve

time,1600
solve

time,2000
solve

time,2400
solve

time,3600
solve

time,4800
solve
```

```
time,19200
solve

time,43200
solve

time,46800
kbc,1
bfedel,all,hgen
solve

time,50400
solve

time,54000
solve

time,57600
solve

time,61200
solve

time,64800
solve

time,68400
solve

time,72000
solve

time,75600
solve

time,79200
solve

! end of file
```

```
! fmodela.inp
!
/prep7
cv=39.37
cdread,solid,model
! material properties
! mild steel
mptemp,1,-73,127,327,527,727,927
mp,dens,1,8131
mpdata,kxx,1,1,41.0,42.2,39.7,35.0,27.6,27
.6
mpdata,c,1,1,434,487,559,685,1090,1090
! foam 1 - 40 lb
mptemp
mptemp,1,0,260,400,540,800
mpdata,dens,2,1,641,641,321,256,26
mptemp
mptemp,1,0,260,400,465,800
mpdata,kxx,2,1,0.087,0.087,0.087,0.054,0.
07
mp,c,2,1959
! air
mptemp
mptemp,1,-73,127,327,527,727,927
mpdata,dens,3,1,1.7458,0.8711,0.5804,0.4
354,0.3482,0.2902
mpdata,kxx,3,1,0.0181,0.0338,0.0469,0.05
73,0.0667,0.0763
mpdata,c,3,1,1007,1014,1051,1099,1141,1
175
! radiation surfaces
mp,emis,4,0.5
! stainless steel
mptemp
mptemp,1,-73,127,327,527,727,927
mp,dens,5,7900
mpdata,kxx,5,1,12.6,16.6,19.8,22.6,25.4,28
.0
mpdata,c,5,1,402,515,557,582,611,640
!
! air including conduction and convection
across cavity
mpdata,dens,6,1,1.7458,0.8711,0.5804,0.4
354,0.3482,0.2902
kxx1=41.0*0.02+0.98*0.5
kxx2=42.2*0.02+0.98*0.5
kxx3=39.7*0.02+0.98*0.5
kxx4=35.0*0.02+0.98*0.5
kxx5=27.6*0.02+0.98*0.5
kxx6=27.6*0.02+0.98*0.5
mpdata,kxx,6,1,kxx1,kxx2,kxx3,kxx4,kxx5,kx
x6
mpdata,c,6,1,1007,1014,1051,1099,1141,1
175
!
! lead
mptemp
mptemp,1,20,327,330,800
mpdata,dens,7,1,11340,11005,10686,1068
6
mptemp
mptemp,1,-23,27,127,227,327,328
mptemp,7,331,332,1000
mpdata,c,7,1,127,129,132,136,142,6188
mpdata,c,7,7,6188,159,159
mptemp
mptemp,1,-273,-27,123,227,327,527
mptemp,7,727,927
mpdata,kxx,7,1,35,35,34,33,31,19
mpdata,kxx,7,7,22,24
! foam 2 - 8 lb
```

```
mptemp
mptemp,1,0,260,400,540,800
mpdata,dens,8,1,128,128,64,51,5
mptemp
mptemp,1,0,260,400,465,800
mpdata,kxx,8,1,0.038,0.038,0.038,0.054,0.
07
mp,c,8,1959
!
! radiation emissivities
mp,emis,9,0.01
mp,emis,10,0.8
mp,emis,11,0.5
!
! mild steel with contact resistance
mptemp
mptemp,1,-73,127,327,527,727,927
mp,dens,12,8131
mpdata,kxx,12,1,0.53,0.99,1.35,1.63,1.86,2
.11
mpdata,c,12,1,434,487,559,685,1090,1090
!
vdel,1,3
!
csys,5
!
ksel,s,loc,x,0.457
kmodif,all,0.280
ksel,s,loc,x,0.460
kmodif,all,0.283
ksel,s,loc,x,0.485
kmodif,all,0.308
ksel,s,loc,x,0.488
kmodif,all,0.311
ksel,s,loc,x,0.498
kmodif,all,0.321
ksel,s,loc,x,0.538
kmodif,all,0.361
ksel,s,loc,x,0.559
kmodif,all,0.387
ksel,s,loc,x,0.564
kmodif,all,0.392

ksel,s,loc,x,0.6345,0.6355
kmodif,all,0.463
ksel,s,loc,x,0.6375,0.6385
kmodif,all,0.466
allsel
!
ksel,s,loc,z,0.356
kmodif,all,,0.321
ksel,s,loc,z,0.396
kmodif,all,,0.361
ksel,s,loc,z,0.4035,0.4045
kmodif,all,,0.369
ksel,s,loc,z,0.4085,0.4095
kmodif,all,,0.374
ksel,s,loc,z,0.417
kmodif,all,,0.382
ksel,s,loc,z,0.4445,0.4455
kmodif,all,,0.409
ksel,s,loc,z,0.4465,0.4475
kmodif,all,,0.412
ksel,s,loc,z,0.457
kmodif,all,,0.422
ksel,s,loc,z,0.472
kmodif,all,,0.437
ksel,s,loc,z,0.475
kmodif,all,,0.440
ksel,s,loc,z,0.495
kmodif,all,,0.460
ksel,s,loc,z,0.500
kmodif,all,,0.465
ksel,s,loc,z,0.6345,0.6355
kmodif,all,,0.600
ksel,s,loc,z,0.6375,0.6385
kmodif,all,,0.603
allsel,below,volu
ksel,inve
lsel,inve
asel,inve
vsel,inve
vdel,all
adel,all
ldel,all
kdel,all
!
allsel
k,1,0,0,0
v,14,26,56,56,10,1,44,44
!
csys,0
vlscale,1,1,1,(0.228/0.28),(0.305/0.409),(0.
228/0.28)
vsbv,1,2,,delete,keep
vlscale,2,2,1,(0.213/0.228),(0.290/0.305),(0
.213/0.228)
vsbv,2,1,,delete,keep
vlscale,1,1,1,(0.00762/0.213),(0.1397/0.290
),(0.00762/0.213)
vsbv,1,2,,delete,delete
allsel
!
! add stainless steel shell volumes
vadd,4,7,9
nummrg,kp
!
! meshing properties
/uis,msgpop,3
mshkey,0
mshape,1,3d
!
! mesh air space around pig
et,1,70
type,1
esize,1.5/cv
mat,6
vmesh,3
mat,12
vmesh,12
mat,5
vmesh,1
!
! create inner radiation enclosure
et,3,57
type,3
!
mat,9
asel,s,area,,9,11
amesh,all

mat,10
asel,s,area,,4
asel,a,area,,7
amesh,all

mat,11
asel,s,area,,33,34
amesh,all

asel,s,area,,9,11
asel,a,area,,33,34
esla,s
nelem
ensym,0,,0,all
allsel
!
et,1,70
type,1
mat,7
vmesh,13
mat,2
vmesh,5
mat,2
vmesh,6
mat,3
vmesh,8
mat,8
vmesh,10
mat,8
vmesh,11
!
! create outer surface
asel,s,area,,41
asel,a,area,,52
nsla,s,1
cm,outsurf,node
asel,s,area,,41
nsla,s,1
cm,ssurf,node
asel,s,area,,52
nsla,s,1
cm,tsurf,node
allsel
cmsel,s,outsurf
!
! create outer radiation elements
eall
et,2,57
r,4,1.0
type,2
mat,4
real,4
esurf
n,999999,0.75,0.75,-0.75
allsel
esel,s,type,,2
nelem
nsel,r,loc,y,0.601,0.603
esln,s,1
esel,r,type,,2
cm,toprad,elem
esel,s,type,,2
cmsel,u,toprad
cm,siderad,elem
allsel
!
!create outer shell divisions for solar load
application
cmsel,s,tsurf
esln,s,0
nelem
nsel,r,loc,y,0.599,0.604
esln,s,1
esel,r,type,,1
cm,topshell,elem
cmsel,s,ssurf
esln,s,0
nelem
nsel,u,node,,683
nsel,u,node,,2209
esln,s,1
esel,r,type,,1
```

```
cmsel,u,topshell
nelem
cm,sideshell,elem
allsel
!calculate volume of side outer shell
elements
cmsel,s,sideshell
*get,totel,elem,,count
*get,minel,elem,,num,min
*get,maxel,elem,,num,max
tvol = 0
*do,i,1,totel,1
 *get,evol,elem,minel,volu
 tvol = tvol + evol
 *get,minel,elem,minel,nxth
*enddo
qside = (400*0.44139)/tvol
!calculate volume of bottom outer shell
elements
cmsel,s,topshell
*get,totel,elem,,count
*get,minel,elem,,num,min
*get,maxel,elem,,num,max
tvol = 0
*do,i,1,totel,1
 *get,evol,elem,minel,volu
 tvol = tvol + evol
 *get,minel,elem,minel,nxth
*enddo
qtop = (800*0.17055)/tvol
allsel
!
fini
/aux12
vtype,0,20
stef,5.7e-8
emis,4,0.5
emis,9,0.01
emis,10,0.8
emis,11,0.5
esel,s,type,,3
write,radmat1
allsel
space,999999
cmsel,s,toprad
nelem
nsel,a,node,,999999
write,radmat2

allsel
cmsel,s,siderad
nelem
nsel,a,node,,999999
write,radmat3
allsel
fini
/prep7
et,4,50,1
type,4
se,radmat1
et,5,50,1
type,5
se,radmat2
se,radmat3
!
/view,1,-1,1,1
/vup,1,y
/facet,norm
!
! end of file
```

```
! modfirea.inp
!
/prep7
cv=39.37
cdread,solid,model
! material properties
! mild steel
mptemp,1,-73,127,327,527,727,927
mp,dens,1,8131
mpdata,kxx,1,1,41.0,42.2,39.7,35.0,27.6,27
.6
mpdata,c,1,1,434,487,559,685,1090,1090
! foam 1 - 40 lb
mptemp
mptemp,1,0,260,400,540,800
mpdata,dens,2,1,641,641,321,256,26
mptemp
mptemp,1,0,260,400,465,800
mpdata,kxx,2,1,0.087,0.087,0.087,0.054,0.
07
mp,c,2,1959
! air
mptemp
mptemp,1,-73,127,327,527,727,927
mpdata,dens,3,1,1.7458,0.8711,0.5804,0.4
354,0.3482,0.2902
mpdata,kxx,3,1,0.0181,0.0338,0.0469,0.05
73,0.0667,0.0763
mpdata,c,3,1,1007,1014,1051,1099,1141,1
175
! radiation surfaces
mp,emis,4,0.5
! stainless steel
mptemp
mptemp,1,-73,127,327,527,727,927
mp,dens,5,7900
mpdata,kxx,5,1,12.6,16.6,19.8,22.6,25.4,28
.0
mpdata,c,5,1,402,515,557,582,611,640
!
! air including conduction and convection
across cavity
mpdata,dens,6,1,1.7458,0.8711,0.5804,0.4
354,0.3482,0.2902
kxx1=41.0*0.02+0.98*0.5
kxx2=42.2*0.02+0.98*0.5
kxx3=39.7*0.02+0.98*0.5
kxx4=35.0*0.02+0.98*0.5
kxx5=27.6*0.02+0.98*0.5
kxx6=27.6*0.02+0.98*0.5
mpdata,kxx,6,1,kxx1,kxx2,kxx3,kxx4,kxx5,kx
x6
mpdata,c,6,1,1007,1014,1051,1099,1141,1
175
!
! lead
mptemp
mptemp,1,20,327,330,800
mpdata,dens,7,1,11340,11005,10686,1068
6
mptemp
mptemp,1,-23,27,127,227,327,328
mptemp,7,331,332,1000
mpdata,c,7,1,127,129,132,136,142,6188
mpdata,c,7,7,6188,159,159
mptemp
mptemp,1,-273,-27,123,227,327,527
mptemp,7,727,927
mpdata,kxx,7,1,35,35,34,33,31,19
mpdata,kxx,7,7,22,24
! foam 2 - 8 lb
```

```
mptemp
mptemp,1,0,260,400,540,800
mpdata,dens,8,1,128,128,64,51,5
mptemp
mptemp,1,0,260,400,465,800
mpdata,kxx,8,1,35,35,35,35,35
mp,c,8,1959
!
! radiation emissivities
mp,emis,9,0.01
mp,emis,10,0.8
mp,emis,11,0.5
!
! mild steel with contact resistance
mptemp
mptemp,1,-73,127,327,527,727,927
mp,dens,12,8131
mpdata,kxx,12,1,0.53,0.99,1.35,1.63,1.86,2
.11
mpdata,c,12,1,434,487,559,685,1090,1090
!
vdel,1,3
!
csys,5
!
ksel,s,loc,x,0.457
kmodif,all,0.280
ksel,s,loc,x,0.460
kmodif,all,0.283
ksel,s,loc,x,0.485
kmodif,all,0.308
ksel,s,loc,x,0.488
kmodif,all,0.311
ksel,s,loc,x,0.498
kmodif,all,0.321
ksel,s,loc,x,0.538
kmodif,all,0.361
ksel,s,loc,x,0.559
kmodif,all,0.387
ksel,s,loc,x,0.564
kmodif,all,0.392
ksel,s,loc,x,0.6345,0.6355
kmodif,all,0.463
ksel,s,loc,x,0.6375,0.6385
kmodif,all,0.466
allsel
!
ksel,s,loc,z,0.356
kmodif,all,,0.321
ksel,s,loc,z,0.396
kmodif,all,,0.361
ksel,s,loc,z,0.4035,0.4045
kmodif,all,,0.369
ksel,s,loc,z,0.4085,0.4095
kmodif,all,,0.374
ksel,s,loc,z,0.417
kmodif,all,,0.382
ksel,s,loc,z,0.4445,0.4455
kmodif,all,,0.409
ksel,s,loc,z,0.4465,0.4475
kmodif,all,,0.412
ksel,s,loc,z,0.457
kmodif,all,,0.422
ksel,s,loc,z,0.472
kmodif,all,,0.437
ksel,s,loc,z,0.475
kmodif,all,,0.440
ksel,s,loc,z,0.495
kmodif,all,,0.460
ksel,s,loc,z,0.500
kmodif,all,,0.465
```

```
ksel,s,loc,z,0.6345,0.6355
kmodif,all,,,0.600
ksel,s,loc,z,0.6375,0.6385
kmodif,all,,,0.603
allsel,below,volu
ksel,inve
lsel,inve
asel,inve
vsel,inve
vdel,all
adel,all
ldel,all
kdel,all
!
allsel
k,1,0,0,0
v,14,26,56,56,10,1,44,44
!
csys,0
vlscale,1,1,1,(0.228/0.28),(0.305/0.409),(0.
228/0.28)
vsbv,1,2,,delete,keep
vlscale,2,2,1,(0.213/0.228),(0.290/0.305),(0
.213/0.228)
vsbv,2,1,,delete,keep
vlscale,1,1,1,(0.00762/0.213),(0.1397/0.290
),(0.00762/0.213)
vsbv,1,2,,delete,delete
allsel
!
! add stainless steel shell volumes
vadd,4,7,9
nummrg,kp
!
! meshing properties
/uis,msgpop,3
mshkey,0
mshape,1,3d
!
! mesh air space around pig
et,1,70

type,1
esize,1.5/cv
mat,6
vmesh,3
mat,12
vmesh,12
mat,5
vmesh,1
!
! create inner radiation enclosure
et,3,57
type,3
!
mat,9
asel,s,area,,9,11
amesh,all

mat,10
asel,s,area,,4
asel,a,area,,7
amesh,all

mat,11
asel,s,area,,33,34
amesh,all

asel,s,area,,9,11
asel,a,area,,33,34
esla,s
nelem
ensym,0,,0,all
allsel
!
et,1,70
type,1
mat,7
vmesh,13
mat,2
vmesh,5
mat,2
vmesh,6
mat,3
vmesh,8
mat,8
vmesh,10
mat,8
vmesh,11
!
! create outer surface
asel,s,area,,41
asel,a,area,,52
nsla,s,1
cm,outsurf,node
asel,s,area,,41
nsla,s,1
cm,ssurf,node
asel,s,area,,52
nsla,s,1
cm,tsurf,node
allsel
cmsel,s,outsurf
!
! create outer radiation elements
eall
et,2,57
r,4,1.0
type,2
mat,4
real,4
esurf
n,999999,0.75,0.75,-0.75
allsel
esel,s,type,,2
nelem
nsel,r,loc,y,0.601,0.603
esln,s,1
esel,r,type,,2
cm,toprad,elem
esel,s,type,,2
cmsel,u,toprad
cm,siderad,elem
allsel
!
!create outer shell divisions for solar load
application
cmsel,s,tsurf
esln,s,0
nelem
nsel,r,loc,y,0.599,0.604
esln,s,1
esel,r,type,,1
cm,topshell,elem
cmsel,s,ssurf
esln,s,0
nelem
nsel,u,node,,683
nsel,u,node,,2209
esln,s,1
esel,r,type,,1
cmsel,u,topshell
nelem
cm,sideshell,elem
allsel
!calculate volume of side outer shell
elements
cmsel,s,sideshell
*get,totel,elem,,count
*get,minel,elem,,num,min
*get,maxel,elem,,num,max
tvol = 0
*do,i,1,totel,1
 *get,evol,elem,minel,volu
 tvol = tvol + evol
 *get,minel,elem,minel,nxth
*enddo
qside = (400*0.44139)/tvol
!calculate volume of top outer shell
elements
cmsel,s,topshell
*get,totel,elem,,count
*get,minel,elem,,num,min
*get,maxel,elem,,num,max
tvol = 0
*do,i,1,totel,1
 *get,evol,elem,minel,volu
 tvol = tvol + evol
 *get,minel,elem,minel,nxth
*enddo

qtop = (800*0.17055)/tvol
allsel
!
fini
/aux12
vtype,0,20
stef,5.7e-8
emis,4,0.5
emis,9,0.01
emis,10,0.8
emis,11,0.5
esel,s,type,,3
write,radmat1
allsel
space,999999
cmsel,s,toprad
nelem
nsel,a,node,,999999
write,radmat2
allsel
cmsel,s,siderad
nelem
nsel,a,node,,999999
write,radmat3
allsel
fini
/prep7
et,4,50,1
type,4
se,radmat1
et,5,50,1
type,5
se,radmat2
se,radmat3
!
/view,1,-1,1,1
/vup,1,y
/facet,norm
!
! end of file
```

```
! loadfirea.inp
!
! apply internal heat generation
sfa,19,1,hflux,((50/8)/0.0017177)*(0.00167
21/0.0017177)
sfa,5,1,hflux,((50/8)/0.0017177)*(0.000045
604/0.0017177)
!
fini
/solve
! apply external convection and set initial
ambient temp
cmsel,s,outsurf
sf,all,conv,19.0,800.0
allsel
toffst,273
!
antype,trans,new
time,1e-6
esel,u,type,,2,3
! input initial temperatures from 38 C steady
state with no solar load
/inp,bff431,inp
timint,off
outres,all,none
outres,nsol
solve

time,1
ddel,all
timint,on
lnsrch,on
kbc,1
! apply external convection and set ambient
fire temp
cmsel,s,outsurf
sf,all,conv,19.0,800
allsel
d,999999,temp,800
esel,u,type,,2,3
solve

time,200
solve
time,400
solve
time,800
solve
time,1600
solve
time,1860

solve

time,1920
kbc,0
! apply external convection and set ambient
temp back to 38 C
cmsel,s,outsurf
sf,all,conv,19.0,38
allsel
d,999999,temp,38
! apply solar load
cmsel,s,sideshell
nelem
bfe,all,hgen,1,qside
cmsel,s,topshell
nelem
bfe,all,hgen,1,qtop
allsel
esel,u,type,,2,3
solve

time,2000
solve

time,2200
solve

time,2400
solve

time,3000
solve

time,3600
solve

time,4800
solve

time,6000
solve

time,8400
solve

time,10800
solve

time,13200
solve

time,15600
solve

time,18000
solve

time,20400
solve
time,22800
solve

time,25200
solve

time,28800
solve

time,32400
solve

time,36000
solve

time,39600
solve

time,43200
solve

time,46800
solve

time,50400
kbc,1
bfedel,all,hgen
solve

time,54000
solve

time,57600
solve

time,61200
solve

time,64800
solve

time,68400
solve

time,72000
solve

time,75600
solve

time,79200
solve

! end of file
```

APPENDIX F:

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

APPENDIX 3.7.2:
Thermal Analysis of F-430 Overpack

IN/TR 1645 F-430 (2)

Thermal Analysis of F-430 Overpack

Signatures

Prepared by: [redacted] Date: 01.10.12

Reviewed by: Date: 01/10/12

Approved by: Date: 01 OCT 16

Document History

Date	Version	Comments	Prepared by	Reviewed by	Approved by
May 00	1	CCF A1297-C-00A	[redacted]		
Oct 01	2	DCN A1297-D-10A Added sections 5.6 & 6.6 and Fig's 25 & 26. Minor editorial & fomatting changes.			

[redacted] writing. **NOTE:** The portion of this text affected by the changes is indicated by a vertical line in the margin.

TABLE OF CONTENTS

1. INTRODUCTION

This report is a summary of the analysis performed to determine the thermal behaviour of the F-430 overpack loaded with a Gammacell-40 before, during and after the IAEA regulatory fire test [1]. A three-dimensional eighth-section model was constructed, using the ANSYS finite element code Version 5.5.3 [2], to simulate the fire test. The solid model, finite element mesh, material properties, boundary conditions and load cases used in the ANSYS simulations are discussed. Results of physical testing performed on the package and the finite element simulations are presented and compared to verify the thermal model.

The results of the analysis show there is no lead melt in the Gammacell-40 contained in the F-430 overpack when it is subjected to the regulatory fire.

2. SOLID MODEL GEOMETRY

The F-430 overpack loaded with the Gammacell-40 is shown in Figure 1. A three-dimensional, eighth-section solid model of the main components of the F-430 overpack and Gammacell-40 was constructed, as shown in Figures 2 and 3. This model was generated from boolean solids and boolean operations (subtractions, unions) created within ANSYS. These solids were then assigned material properties, meshed, and boundary conditions and loading applied as described in the following sections. A one-eighth section was modelled to take advantage of the symmetry of the package and reduce the size and complexity of the model.

3. MATERIAL PROPERTIES

Material properties were required for mild steel, stainless steel, lead, air and foam insulation as shown in Tables 1 and 2. The properties required included density, thermal conductivity and specific heat. The specific heat of lead incorporated the latent heat of fusion (24,750 J/g) to simulate the phase change when the material melts (note that lead melt was not encountered in any of the load case scenarios).

Convection coefficients and surface emissivities required to define the heat transfer by convection and radiation on the outside of the overpack are discussed in Section 4.3. The conduction, convection and radiation heat transfer across the air space between the Gammacell-40 and the overpack, and the required material properties, are discussed in Section 4.2.

The lead-to-steel contact resistance at the Gammacell-40 outer shell was modelled by modifying the conduction coefficient of the steel outer shell to include an equivalent air gap of 0.02" [3 and Appendix A]. The contact resistance was removed for the fire simulation to allow the maximum amount of heat to penetrate into the centre of the package.

Above 465°C, [redacted] [11]. To account for this, the foam was assumed to take on the conduction properties of air at temperatures above 465 °C.

4. FINITE ELEMENT MESH, BOUNDARY AND LOAD CONDITIONS

4.1 THREE-DIMENSIONAL EIGTH-SECTION MODEL MESH

The solid model was meshed using thermal three-dimensional tetragonal elements [2 and Appendix B], as shown in Figure 4. The optimal mesh density shown in the figures was achieved by refining the mesh to the point where the temperature results were not dependent on the mesh density. The mesh used for the simulations presented in this report contained 47,018 elements and 8,389 nodes. The integrity of the elements (connectivity, aspect ratios and internal angles) is automatically checked by ANSYS prior to the run.

4.2 HEAT TRANSFER ACROSS THE INTERNAL AIR SPACE

The heat transfer across the air space between the Gammacell-40 and the overpack inner frame is comprised of conduction, convection and radiation.

Heat transfer by conduction occurs through the air and through the steel support structure of the Gammacell-40. The total conduction area of the steel components is calculated in Appendix C to be about 2 percent of the overall conduction area. The remaining 98 percent of the conduction occurs through the air.

Convection heat transfer through the air is accounted for by an effective thermal conductivity [4], as calculated in Appendix C. The air inside the package will tend to circulate due to the temperature gradients across the air space transferring additional heat by free convection. The effective thermal conductivity is the thermal conductivity that a stationary fluid should have to transfer the same amount of heat as the moving fluid.

A total thermal conductivity for the air space is calculated (Appendix C) to combine the contribution of the conduction and convection across the air space.

Radiation across the air space is modelled by a radiation enclosure [2 and Appendix B], as shown in Figure 5. The Gammacell-40 surface, painted grey, was given an emissivity of 0.8, while the stainless steel surfaces of the inner frame and floor of the overpack were assigned an emissivity of 0.5 [7]. The symmetry surfaces of the radiation enclosure are given a very low emissivity of 0.01, such that they behave as mirrored surfaces, reflecting heat back into the enclosure.

The actual radiation heat transfer across the air space will be less than that modelled, since the blocking effects of the Gammacell-40 support structure are neglected. The radiation heat transfer is, therefore, conservatively modelled.

4.3 CONVECTION AND RADIATION BOUNDARY CONDITIONS

Convection and radiation boundary conditions used in the model are shown in Figure 6.

Convection was applied on the outer surface of the overpack by selecting the external nodes and applying a convection coefficient (calculated in Appendix D) and ambient temperature as a surface load.

To model the radiation on the outer surface of the overpack, surface elements [2 and Appendix B] were used to define a radiation matrix with view factors conservatively set to 1.0. A space node external to the model was used to define the ambient temperature for the radiating surface elements. For the steady state condition, an emissivity of 0.5 was used for the stainless steel surface elements [7]. For the fire condition an emissivity of 1.0 was conservatively used for the surface elements.

4.4 INTERNAL HEAT GENERATION

The decay of the Cs-137 carried inside the F-430 overpack generates 4.84 W of heat per kCi, based on 566 keV of photon energy, 62 keV of atomic electron energy and 188 keV of continuous radiation [6], as calculated below:

1000 Ci/kCi * 3.7e+10 dis/s/Ci * 816 keV/dis * 1.602e-16 J/keV * 1 W/J/s = 4.84 W/kCi

The overpack in the physical test used to verify the model [6] was loaded with 1.72 kCi of Cs-137 for a total heat output of 8.3 W (4.84*1.72). The maximum expected heat load to be transported in the F-430 overpack is about 50 W. Twice this heat load, or 100 W, was applied for all other load cases, including the simulation of the regulatory fire, as a worst-case internal heat load.

The internal heat generated in the Gammacell-40 was applied as a uniform heat generation on the inside of the Gammacell-40 source cavity. The heated elements and the applied heat generation rates are shown in Figure 7. Self-attenuation of the capsules generally results in lower radiation fields in the axial dimension and higher radial fields. This effect was ignored in the model due to the small size of the cavity and the low heat generation of the source.

4.5 SOLAR HEAT LOAD

Figure 7 shows the elements that were subjected to the solar heat flux required by the regulations [1]. A heat flux of 400 W/m^2 was applied to the side of the overpack and a heat flux of 800 W/m^2 was applied to the top of the overpack as per the regulations. This heat flux was applied both as a steady state load, and as a transient load over 12 hours as specified in the regulations for the Normal Conditions of Transport, to determine the response of the overpack to both conditions.

4.6 FIRE TEST TRANSIENT LOAD

The IAEA fire test [1] was applied by defining a transient temperature curve for the ambient temperature as shown in Figure 8. This curve was applied to the convection boundary conditions and the node representing the ambient temperature for the external radiation matrix (Section 4.3). The 30 minute, 800°C fire was followed by a one minute ramp-down to pre-fire ambient temperatures, followed by a 19.5 hour (1170 minute) cool-down period. This 1170 minutes of cooling was sufficient to allow all temperatures to reach their maximum values.

The solar heat flux discussed in Section 4.5 was applied for 12 of the 19.5 hour cool down period as required by the regulations [1].

To simulate the effects of increased convection to the environment, the convection heat transfer coefficient on the outside of the overpack was set to 18 W/m^2°C, as calculated in Appendix D.

To maximise the radiation heat transfer during the fire, a conservative emissivity of 1.0 was used for the outside stainless steel surface of the overpack.

Also to simulate a worst-case fire condition, the lead-to-steel contact resistance at the Gammacell-40 outer shell was removed.

5. LOAD CASES

The ANSYS input files for all of the following load case scenarios considered are listed in Appendix E.

5.1 LOAD CASE 1 (VALIDATION): STEADY STATE, 8.3 W Cs-137, NO SOLAR LOAD, 21°C AMBIENT

This load case was used to verify the steady state behaviour of the model. Steady state conditions were used with 1.72 kCi or 8.3 W (Section 4.4) of cobalt-60 loaded into the Gammacell-40. This was a simulation of a physical thermal test performed on the F-430 overpack containing a Gammacell-40 loaded with C-198's [6]. No solar load was applied as the physical test was conducted indoors.

The ambient temperature at the side and bottom of the overpack was taken from the physical test data to be 21°C.

5.2 LOAD CASE 2: STEADY STATE, 100 W Cs-137, NO SOLAR LOAD, 21°C AMBIENT

This load case is identical to Load Case 1 (Section 5.1), except the internal heat generation in the Gammacell-40 cavity was increased to 100 W from 8.3 W. An internal heat generation of 100 W was used as a worst-case condition and is twice the maximum expected heat load to be transported in the F-430 overpack (Section 4.4).

This load case shows the effect of the increased internal heat generation between the test and worst-case internal heat load conditions.

5.3 LOAD CASE 3: STEADY STATE, 100 W Cs-137, NO SOLAR LOAD, 38°C AMBIENT

This load case is identical to Load Case 2 (Section 5.3), except with the ambient temperature at the side and bottom of the overpack assumed to be 38°C as per the regulations [1].

This load case shows the effect of the increased ambient temperature between the test and regulatory ambient conditions.

5.4 LOAD CASE 4: STEADY STATE/TRANSIENT, 100 W Cs-137, SOLAR LOAD, 38°C AMBIENT

This load case is identical to Load Case 3 (Section 5.3), except that the solar heat load discussed in Section 4.5 was applied.

This load case shows the effect of the solar load with a 38°C ambient temperature under steady state conditions and applied as a 12 hour transient as required by the regulations [1].

5.5 LOAD CASE 5: FIRE TRANSIENT, 100 W Cs-137, SOLAR LOAD, 38°C AMBIENT

This load case shows the response of the F-430 overpack and Gammacell-40 to the IAEA regulatory fire test [1].

Transient conditions were used with initial temperatures from the steady state analysis in Load Case 3 (Section 5.3) above, with the ambient temperature at the side and bottom of the overpack assumed to be 38°C as per the regulations [1].

The transient loading consisted of the IAEA regulatory fire loading [1], as discussed in Section 4.6. The model was loaded with 100 W of cobalt-60 (Section 4.4) and had the solar load (Section 4.5) applied after the fire, during the cool-down of the overpack, as required by the regulations.

5.6 LOAD CASE 6: SIMULATION OF DAMAGED OUTER FOAM UNDER FIRE TRANSIENT

This load case is identical to Load Case 5, except that the thermal conductivity of the outer foam was increased to a value of 35 W/m°C, similar to lead. This change simulates a very conservative worst-case scenario where all of the outer foam is crushed so as to provide no thermal insulation to the fire. The remainder of the material properties and loading are identical to Load Case 5 in that the inner foam and air spaces remain to provide resistance to the fire and solar load.

6. RESULTS AND DISCUSSION

6.1 LOAD CASE 1 (VALIDATION): STEADY STATE, 8.3 W Cs-137, NO SOLAR LOAD, 21°C AMBIENT

The calculated steady state temperature distribution in the overpack is shown in Figure 9. Table 3 lists the temperatures from the experiment and the analysis at the key locations shown in Figure 10, where thermocouple temperature readings were taken in the experiment. The correlation is good indicating the approximations used in the analysis are appropriate.

The largest differential between measured and calculated temperatures was for the Gammacell-40 cavity. The calculated Gammacell-40 cavity temperature was about 3°C lower than the experimental value. This difference was expected since the air space between the Gammacell-40 and the inner frame of the overpack was modelled as an open air space and none of the Gammacell-40 support structure was included to reduce the size and complexity of the model. Similarly, the steel lining of the internal cavity, and the subsequent lead-steel interface and air resistance, were not modelled. The heat flow out of the package was, therefore, slightly overestimated due to the approximation. This was considered an acceptable trade-off, however, in that the heat flow into the overpack during the fire transient would also be higher than in reality and, therefore, a worst-case condition is modelled.

6.2 LOAD CASE 2: STEADY STATE, 100 W Cs-137, NO SOLAR LOAD, 21°C AMBIENT

The calculated steady state temperature distribution in the overpack for this load case is shown in Figure 11. Temperature results at various points within the model are compared to those of Load Case 1 (Section 6.1), which is the same model with 8.3 W of Cs 137, in Table 4. The results show a 27-40°C temperature increase in the overpack and an approximately 50°C temperature increase in the Gammacell-40, whereas the temperatures on the outside of the overpack are similar. Therefore, the increase in internal heat generation from 8.3 to 100 W causes a significant increase in the internal temperatures of the overpack and Gammacell-40, which was expected due to the magnitude of the increase.

6.3 LOAD CASE 3: STEADY STATE, 100 W Cs-137, NO SOLAR LOAD, 38°C AMBIENT

The calculated steady state temperature distribution in the overpack for this load case is shown in Figure 12. Temperature results at various points within the model are compared to those of Load Case 2 (Section 6.2), which is the same model with a 21°C ambient temperature, in Table 4. The results show a 15-17°C increase in all of the model temperatures for an increase in ambient temperature of 17°C. Therefore, the model temperatures increase approximately in proportion with the ambient temperature in the steady state condition. This linear extrapolation was expected since heat transfer at these temperatures is primarily due to conduction and convection, which are linear relations.

6.4 LOAD CASE 4: STEADY STATE/TRANSIENT, 100 W Cs-137, SOLAR LOAD, 38°C AMBIENT

The calculated steady state temperature distribution in the overpack for this load case is shown in Figure 13. Temperature results at various points in the model are compared to those of Load Case 3 (Section 6.3), which is the same model without the solar load. The results show an approximately 50°C increase in the internal temperatures, an 87°C increase on the top and a 49°C increase on the side of the overpack when the solar load is applied. Therefore, the solar heat flux applied as a steady state load has a significant effect on the internal temperatures of the overpack. Note, however, that even for this worst-case condition, the maximum temperature in the lead shielding, 142°C, is still well below the melting point of lead, 327°C.

The regulations only require the solar load to be applied over a 12 hour period, or during daylight hours. So the solar heat flux was also applied as a transient load (Section 4.5) to determine how the maximum temperature reached in 12 hours compares to the steady state temperatures calculated.

Figure 14 shows the temperature distribution in the overpack at the end of the 12 hour transient. The maximum temperature reached in the lead shielding is 95°C, much lower than for the steady state case (142°C). The maximum surface temperature reached, 124°C, is virtually the same as that for the steady state case (126°C), however.

Therefore, the steady state model of the solar heat flux overestimates the internal overpack temperatures that would be reached in a 12 hour insolation period. The temperatures for the steady state model, however, are still all well below lead melt (maximum temperature of 142°C as compared to 327°C for lead melt), and therefore, show unequivocally that the overpack meets the requirements of the regulations under solar load.

6.5 LOAD CASE 5: FIRE TRANSIENT, 100 W Cs-137, SOLAR LOAD, 38°C AMBIENT

The calculated temperature distribution in the overpack 30 minutes into the transient (as the fire is turned off) is shown in Figure 15. The calculated temperature distribution in the overpack at the time of maximum lead temperature (64,800 s, 18 hrs) is shown in Figure 16. The calculated temperature distribution in the lead elements only, at the time of maximum lead temperature (64,800 s, 18 hrs), is shown in Figure 17.

The transient temperature results at the key locations shown in Figure 10 are shown in Figures 18 through 24. All of the temperature transients show temperatures below the melting temperature of lead, 327°C. The maximum temperature reached in the lead, 102°C at 64,800 s (18 hrs), was at the Gammacell-40 cavity.

6.6 LOAD CASE 6: SIMULATION OF DAMAGED OUTER FOAM UNDER FIRE TRANSIENT

The calculated temperature distribution in the overpack at the time of maximum lead temperature (15,600 s, 4 hrs 20 min.) is shown in Figure 25. The calculated temperature distribution in the lead elements only, at the time of maximum lead temperature (15,600 s, 4 hrs 20 min.) is shown in Figure 26.

As expected, the maximum lead temperature was higher and peaked earlier than in Load Case 5, since the outer foam provided no resistance to the heat of the fire. The maximum temperature reached in the lead was 128°C, which is 26°C higher than in Load Case 5, but still well below the melting temperature of lead, 327°C, even in such a worst-case scenario.

7. CONCLUSIONS

Good agreement between the experimental measurements of the transport package steady state temperatures and the ANSYS simulated results was obtained.

The results of the IAEA fire test showed no lead melt in the Gammacell-40 modelled inside the F-430 overpack. The maximum lead temperature reached was 128°C, well below 327°C, the melting point of lead. In reality, the maximum lead temperature expected during such a regulatory fire would be much lower than this, considering the extremely conservative assumptions used in the model.

The F-430 overpack and Gammacell-40 analysed in this report passed the IAEA regulatory fire test.

8. REFERENCES

1. IAEA Safety Standard, Safety Series No. 6, "Regulations for the Safe Transport of Radioactive Material", 1985 Revised Edition (As Amended 1990).

2. ANSYS User's Manual, Revision 5.5, ANSYS Inc., Houston, PA, 1998.

3. E7515, Euratom Contract No. 024-65-ECIC, Transnucleaire, "Report on the Implications of the Test Requirements for Type B Packagings and a Study of Practical Solutions", Transnucleaire, Paris, France, Part II.

4. Incropera, F.P. and Dewitt, D.P., "Fundamentals of Heat and Mass Transfer", John Wiley and Sons, Inc., New York, 1985

5. Browne, E., Firestone, R.B., "Tables of Radioactive Isotopes", John Wiley and Sons, Inc., New York, 1986.

6. Krupka, J., "F-430 Test Report", MDS Nordion Inc. Report IN/TR 1604 F430/GC40.

7. Holman, J.P., "Heat Transfer", McGraw-Hill Book Company, 5th Edition, New York, 1981.

8. Lead Industries Association, "Lead in Modern Industry", New York City, New York, 1952.

9. Perry, R.H., Green, P.W. and Maloney, J.O., "Perry's Chemical Engineer's Handbook", McGraw-Hill Book Company, 6th Edition, New York, 1984.

10. Baumeister, T., Avallone, A., Baumeister III, T., Ed., "Mark's Standard Handbook for Mechanical Engineers", McGraw-Hill Book Company, 8th Edition, New York, 1978.

11. General Plastics Manufacturing Company, "General Plastics Last-A-Foam FR-3700 for Crash and Fire Protection of Nuclear Material Shipping Containers", June, 1997.

TABLE 1: Material Properties of Mild Steel, [redacted] Air and [redacted]

#	Material Description	Density ρ (kg/m^3)				Thermal Conductivity k (W/m°C)				Specific Heat c (J/kg°C)			
1	Mild Steel [4]	8131				°C	k	°C	k	°C	c	°C	c
						-73	41.0	127	42.2	-73	434	127	487
						327	39.7	527	35.0	327	559	527	685
						727	27.6	927	27.6	727	1090	927	1090
[redacted]	[redacted]	°C	ρ	°C	ρ	°C	k	°C	k	[redacted]			
		[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]				
		[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]				
		[redacted]	[redacted]			[redacted]	[redacted]						
[redacted]	[redacted]	°C	ρ	°C	ρ	°C	k	°C	k	[redacted]			
		[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]				
		[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]				
		[redacted]	[redacted]			[redacted]	[redacted]						
3	Air [4]	°C	ρ	°C	ρ	°C	k	°C	k	°C	c	°C	c
		-73	1.75	127	0.87	-73	0.018	127	0.034	-73	1007	127	1014
		327	0.58	527	0.44	327	0.047	527	0.057	327	1051	527	1099
		727	0.35	927	0.29	727	0.067	927	0.076	727	1141	927	1175
[redacted]	[redacted]	[redacted]				°C	k	°C	k	°C	c	°C	c
						[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
						[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
						[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]

TABLE 2: Material Properties of Air Including Conduction and Convection, Lead, and Mild Steel Including Contact Resistance

#	Material Description	Density ρ (kg/m³)				Thermal Conductivity k (W/m°C)				Specific Heat c (J/kg°C)			
6	Air With Conduction and Convection Steady State [App. C]	°C	ρ	°C	ρ	°C	k	°C	k	°C	c	°C	c
		-73	1.75	127	0.87	-73	1.02	127	1.04	-73	1007	127	1014
		327	0.58	527	0.44	327	0.99	527	0.90	327	1051	527	1099
		727	0.35	927	0.29	727	0.75	927	0.75	727	1141	927	1175
6	Air With Conduction and Convection Transient [App. C]	°C	ρ	°C	ρ	°C	k	°C	k	°C	c	°C	c
		-73	1.75	127	0.87	-73	1.51	127	1.53	-73	1007	127	1014
		327	0.58	527	0.44	327	1.48	527	1.39	327	1051	527	1099
		727	0.35	927	0.29	727	1.24	927	1.24	727	1141	927	1175
7	Lead [8]	°C	ρ	°C	ρ	°C	k	°C	k	°C	c	°C	c
		20	11340	327	11005	-273	35	-27	35	-23	127	27	129
		330	10686	800	10686	123	34	227	33	127	132	227	136
						327	31	527	19	327	142	328	6188
						727	22	927	24	331	6188	332	159
12	Mild Steel Including Lead-Steel Contact Resistance [3, 4 and App. F]	8131				°C	k	°C	k	°C	c	°C	c
						-73	0.53	127	0.99	-73	434	127	487
						327	1.35	527	1.63	327	559	527	685
						727	1.86	927	2.11	727	1090	927	1090

TABLE 3: Comparison of Load Case 1 Steady State Experimental and ANSYS Results

Description	ANSYS Node (see Figure 10)	Experiment (°C)	ANSYS (°C)
Inside Gammacell-40 cavity	6359/6423	29	26/26
Outside Gammacell-40 on cylindrical surface	26	27	25
Outside Gammacell-40 on end surface	178	26	25
Inside inner frame - top	14	26	25
Inside inner frame - side	1	26	25
Inside outer frame	2274	24	23
Outside overpack - top	5128	21	21
Outside overpack - side	5141/5444	21	21/21

TABLE 4: Comparison of Load Cases 1 Through 6

Description	ANSYS Node (Fig. 10)	Load Case 1 Steady State, 8.3 W Cs-137, No Solar Load, 21°C Ambient	Load Case 2 Steady State, 100 W Cs-137, No Solar Load, 21°C Ambient	Load Case 3 Steady State, 100 W Cs-137, No Solar Load, 38°C Ambient	Load Case 4A Steady State, 100 W Cs-137, Solar Load, 38°C Ambient	Load Case 4B Transient, 100 W Cs-137, Solar Load*, 38°C Ambient	Load Case 5 Fire Transient, 100 W Cs-137, Fire/Solar Load**, 38°C Ambient	Load Case 6 Simulation of Damaged Outer Foam Under Fire Transient**
Inside Gammacell-40 cavity	6359/ 6423	26/26	75/75	91/90	143/142	96/95	102/101 (64,800 s)	128/127 (15,600 s)
Outside Gammacell-40 on cylindrical surface	26	25	70	86	138	91	98 (64,800 s)	125 (15,600 s)
Outside Gammacell-40 on end surface	178	25	69	84	136	89	97 (64,800 s)	123 (15,600 s)
Inside inner frame - top	14	25	64	80	133	86	94 (57,600 s)	138 (8,400 s)
Inside inner frame - side	1	25	63	80	132	86	94 (57,600 s)	191 (3,000 s)
Inside outer frame	2274	23	50	66	125	80	89 (32,400)	779 (1,860 s)
Outside overpack - top	5128	21	22	39	126	124	797 (1,860 s)	790 (1,860 s)
Outside overpack - side	5141/ 5444	21/21	23/23	40/40	89/89	86/86	798/797 (1,860 s)	783/783 (1,860 s)

* Temperatures are taken at end of 12 hour transient.
** Temperatures are maximum values during the fire transient at the given time in parentheses.

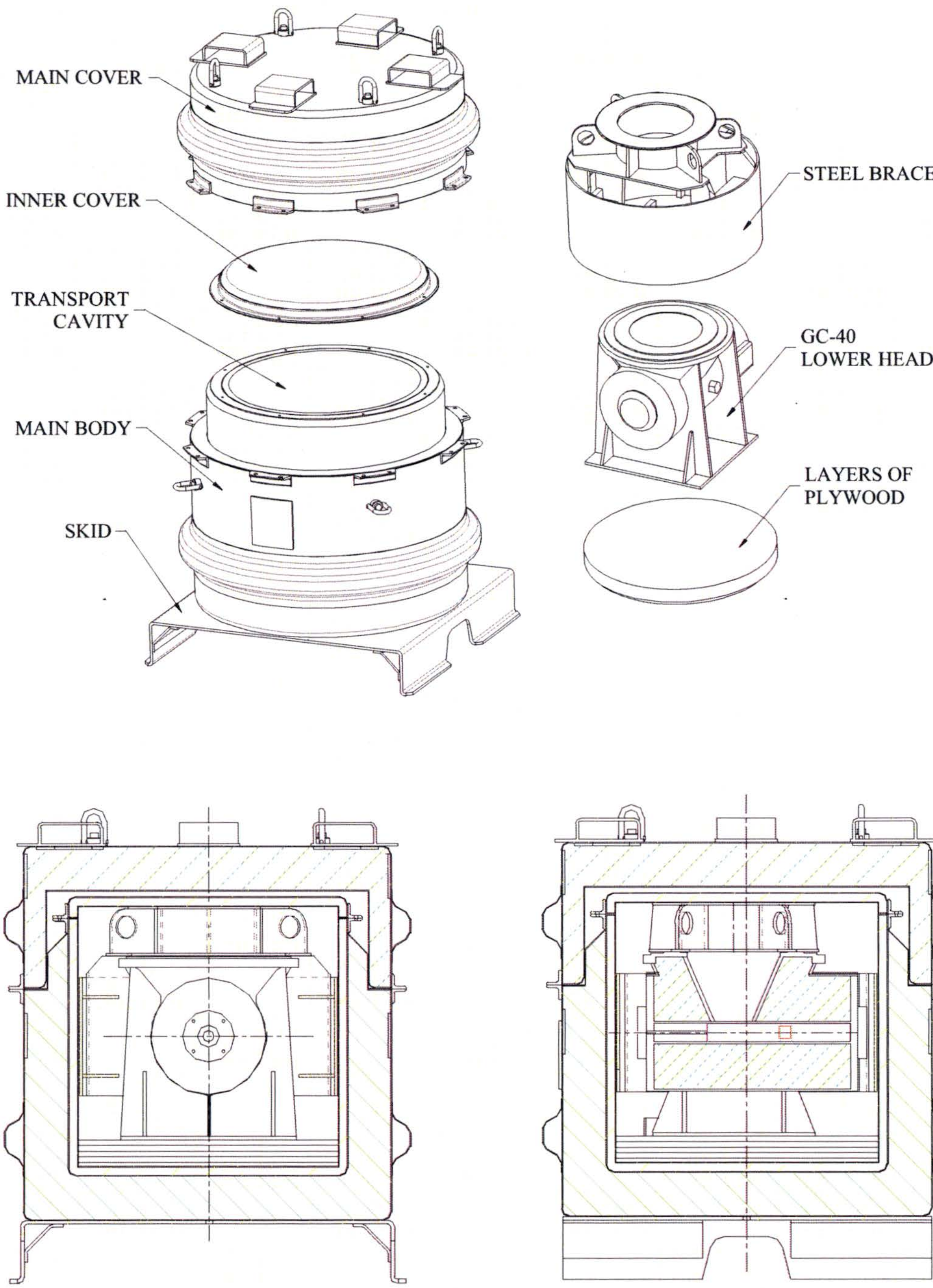


FIGURE 1: F-430/GAMMACELL-40 TRANSPORT PACKAGE (TEST SPECIMEN)

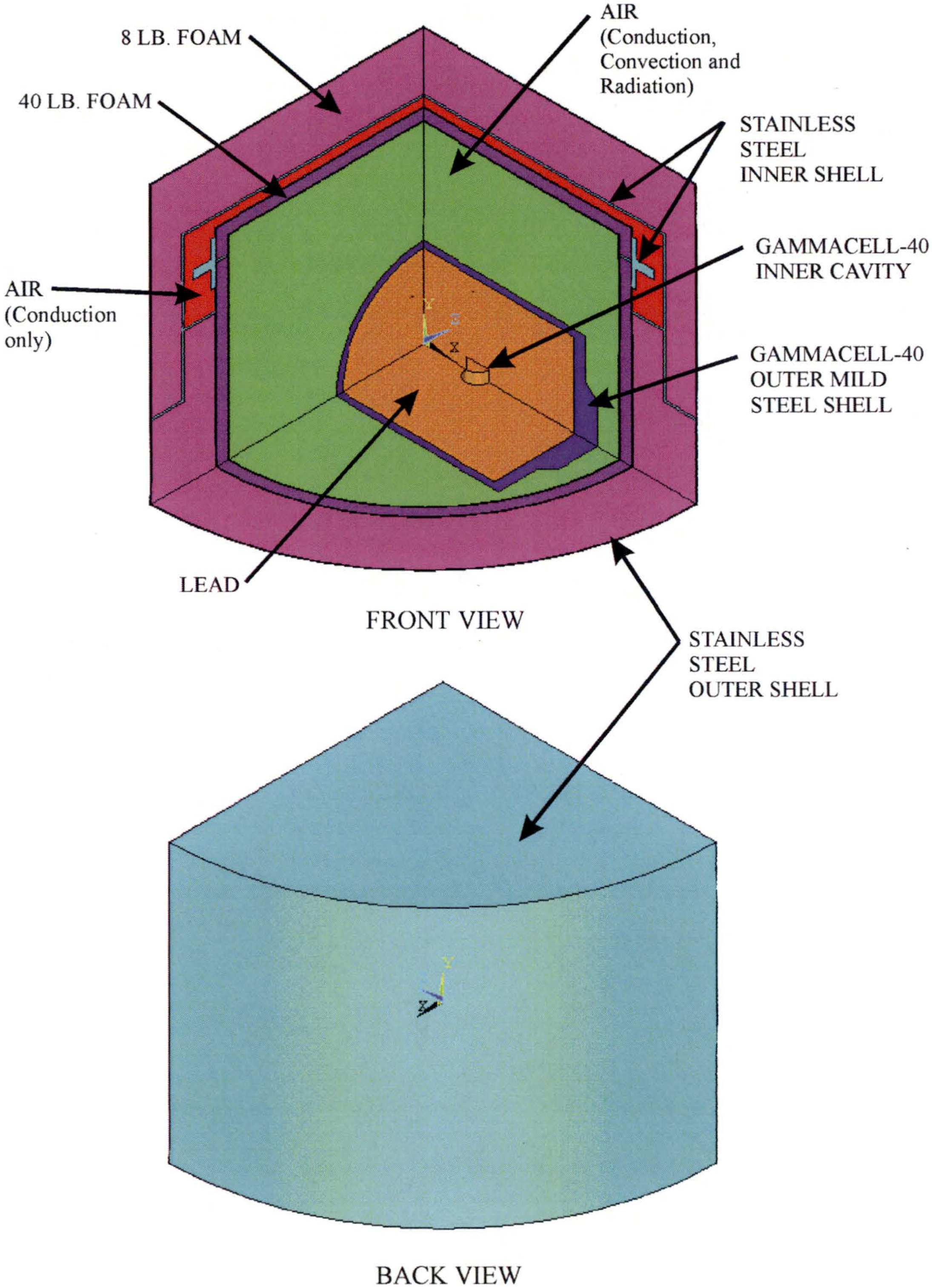


FIGURE 2: F-430 OVERPACK SOLID MODEL

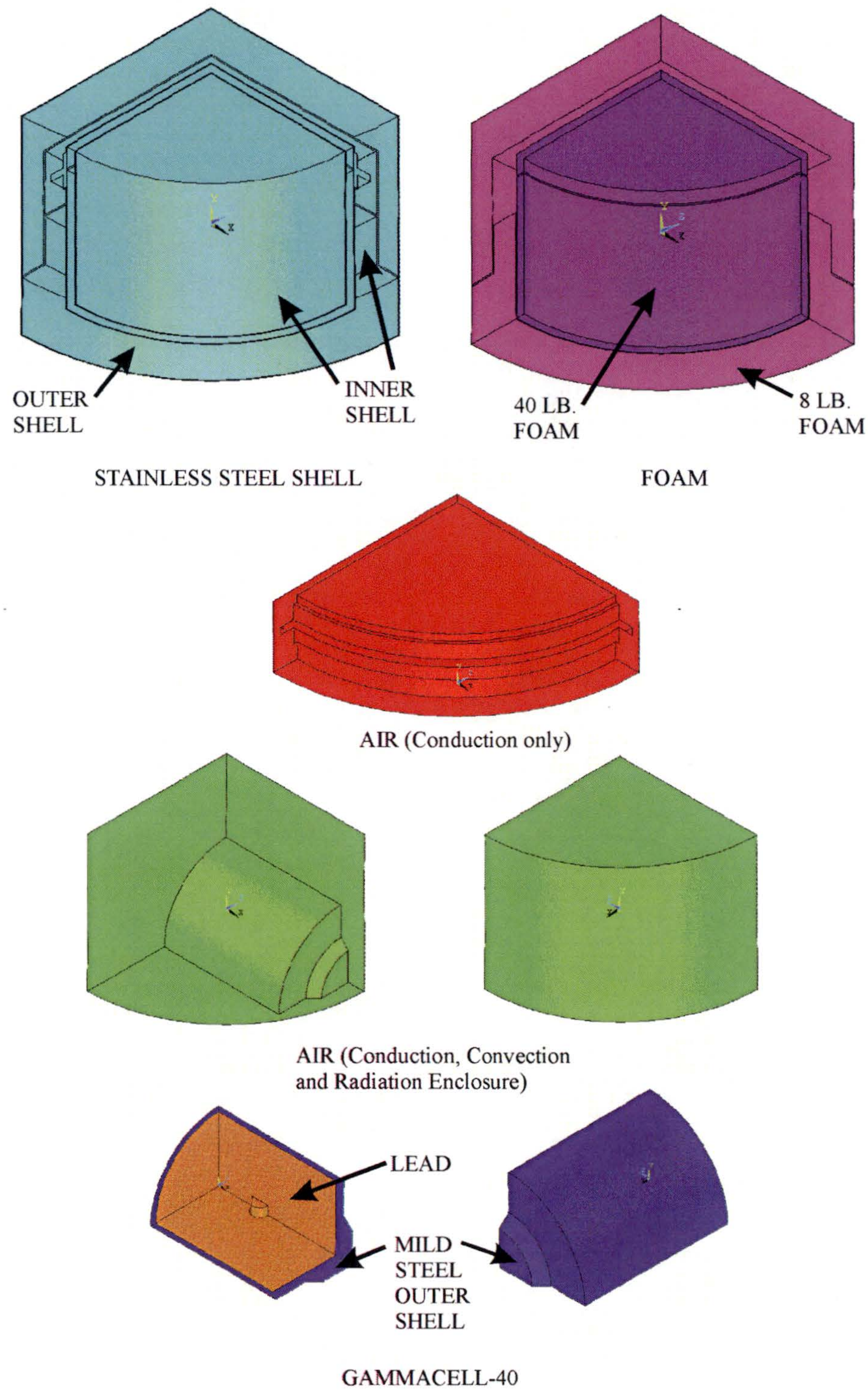


FIGURE 3: F-430 OVERPACK SOLID MODEL COMPONENTS

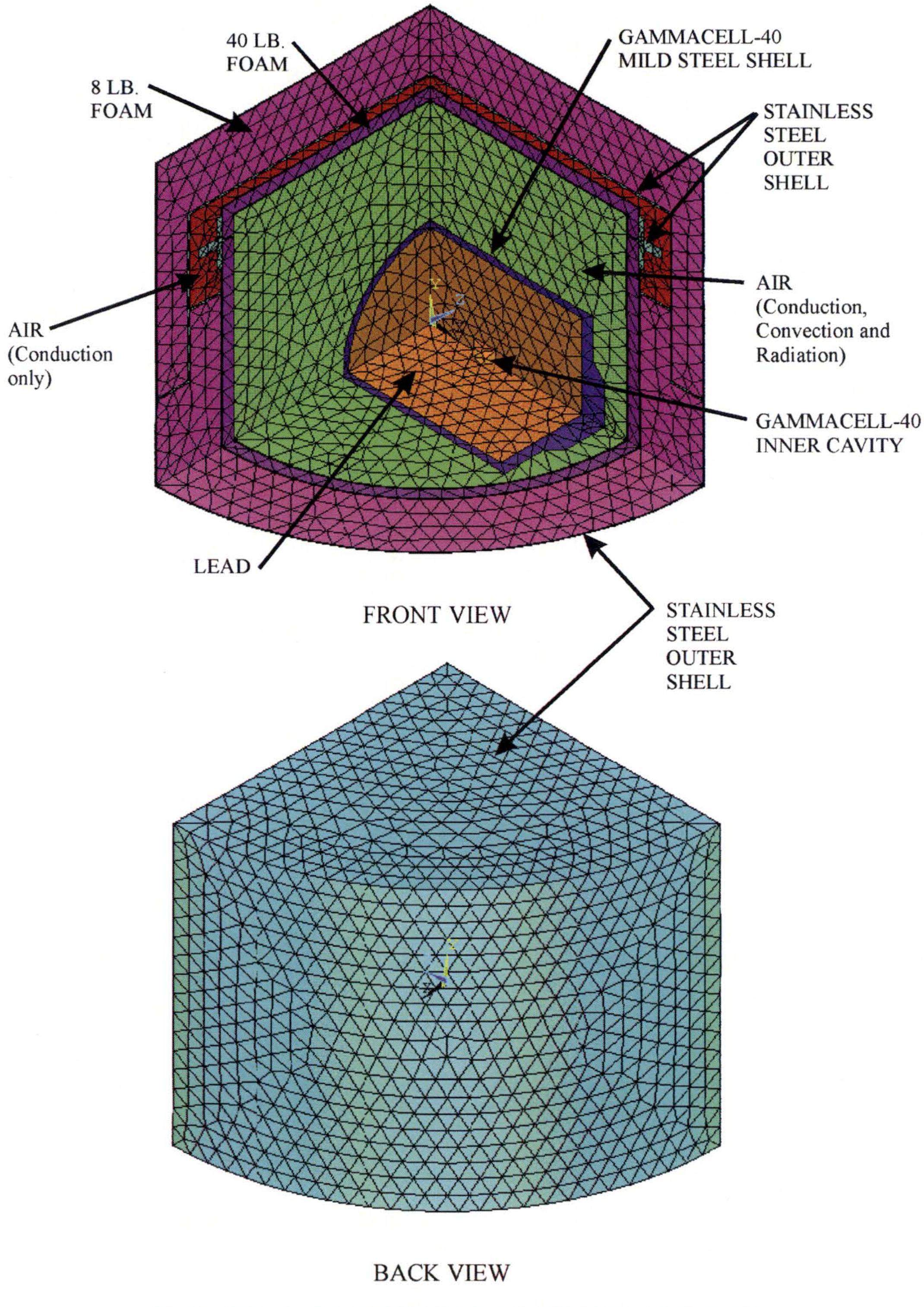
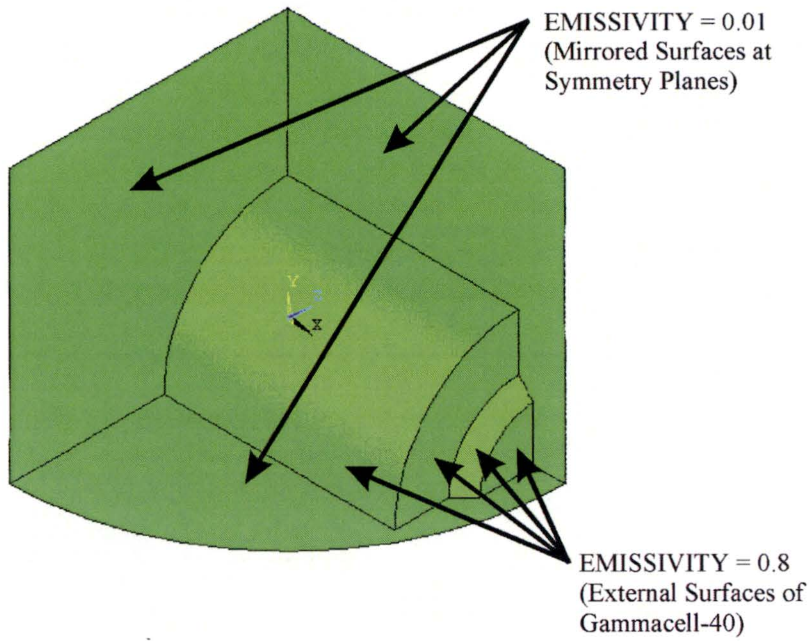
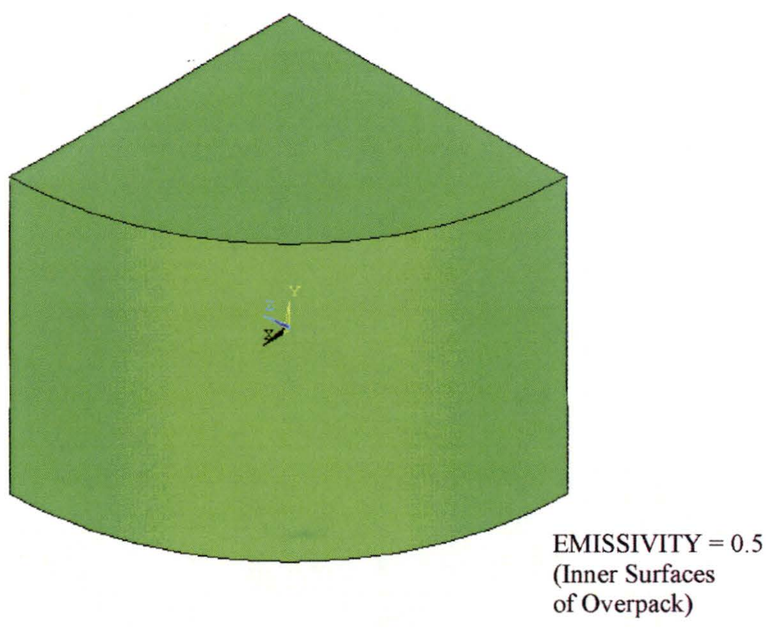


FIGURE 4: F-430 OVERPACK FINITE ELEMENT MESH



FRONT VIEW OF ENCLOSURE



BACK VIEW OF ENCLOSURE

FIGURE 5: RADIATION ENCLOSURE FOR INTERNAL AIR SPACE

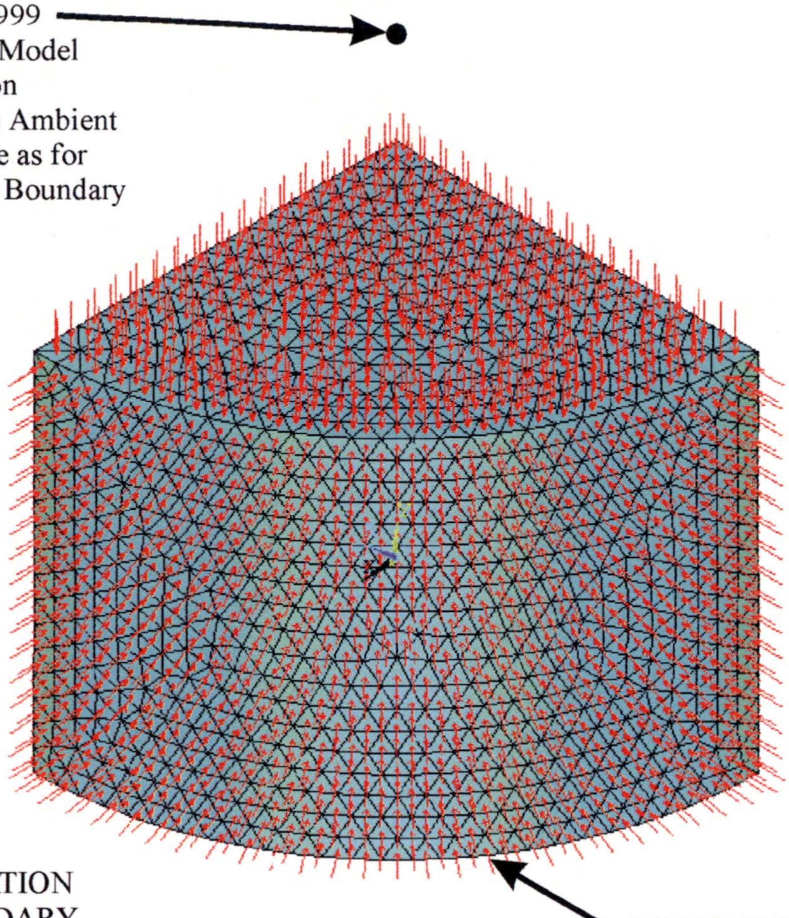


FIGURE 6: RADIATION AND CONVECTION BOUNDARY CONDITIONS

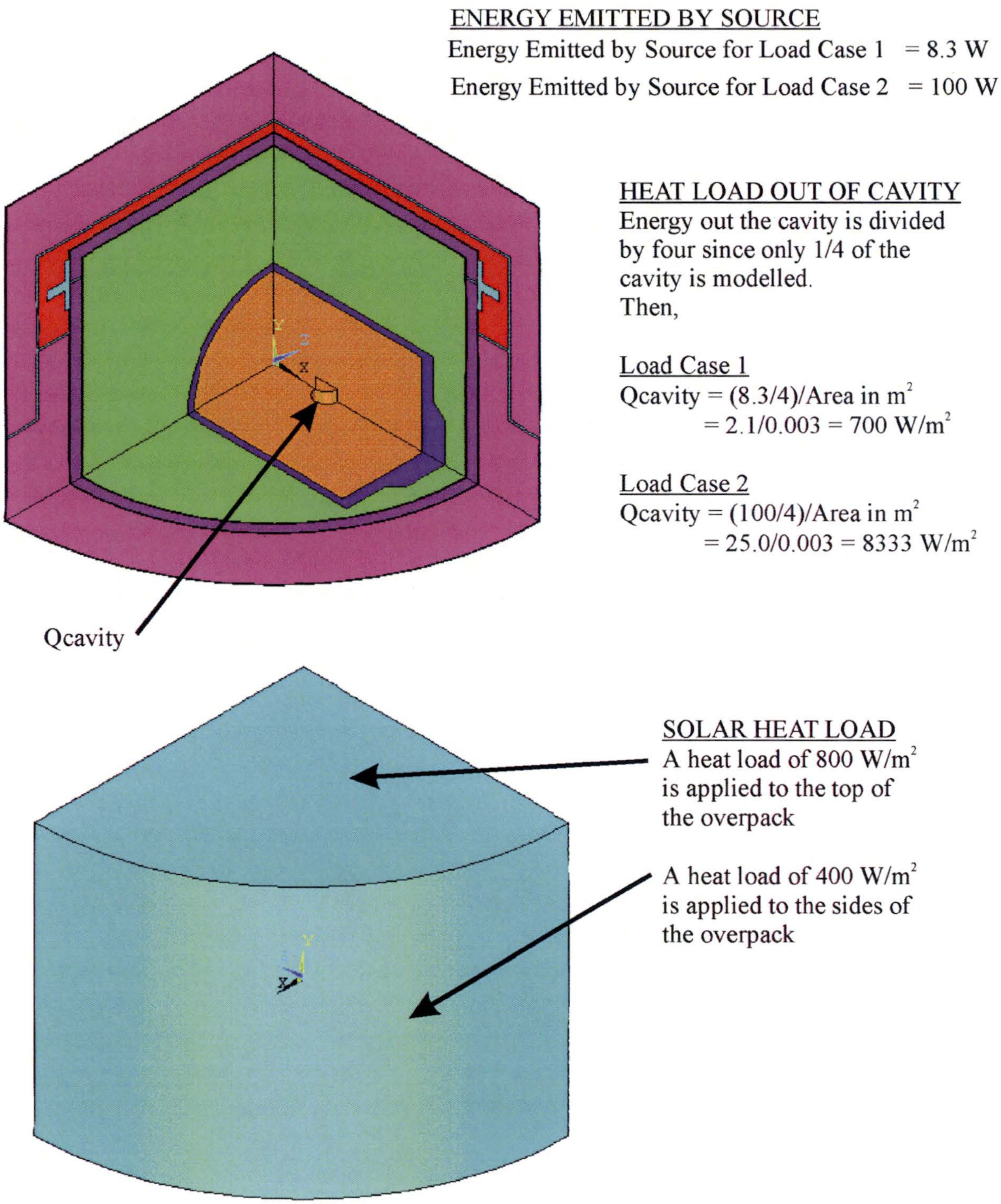


FIGURE 7: INTERNAL HEAT GENERATION AND SOLAR HEAT LOAD

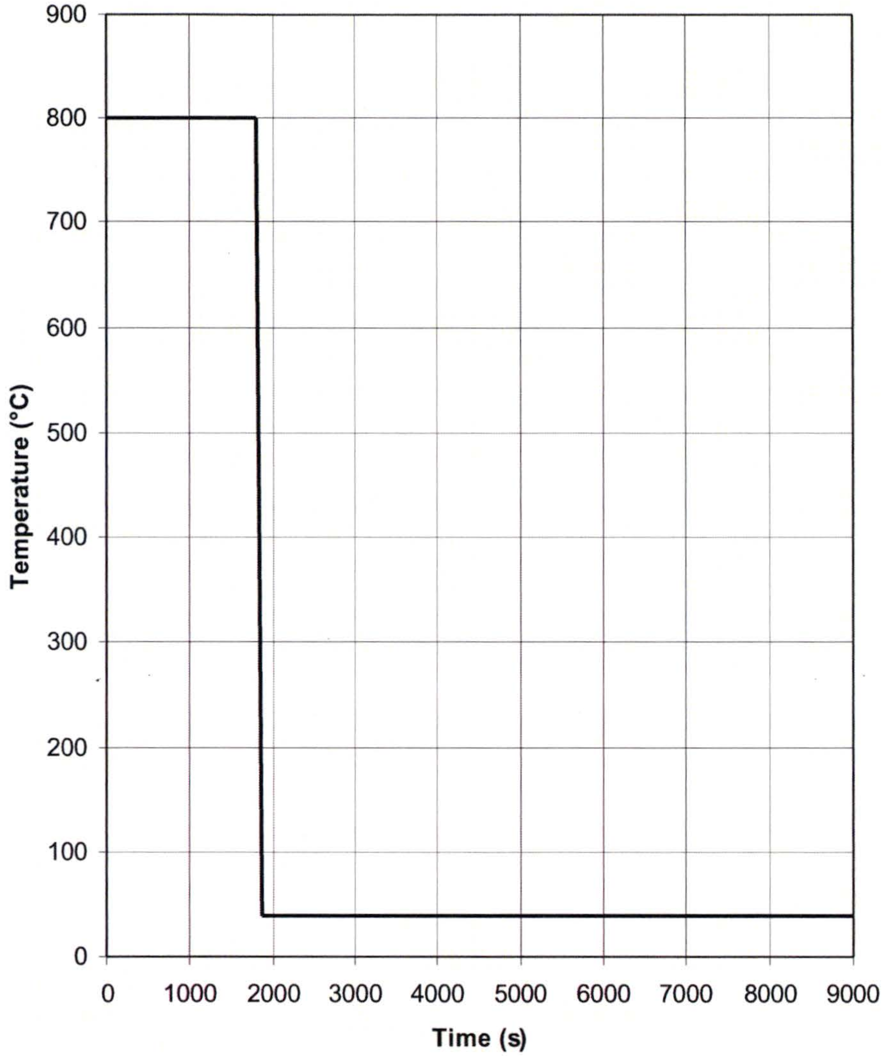


FIGURE 8: IAEA REGULATORY FIRE CURVE

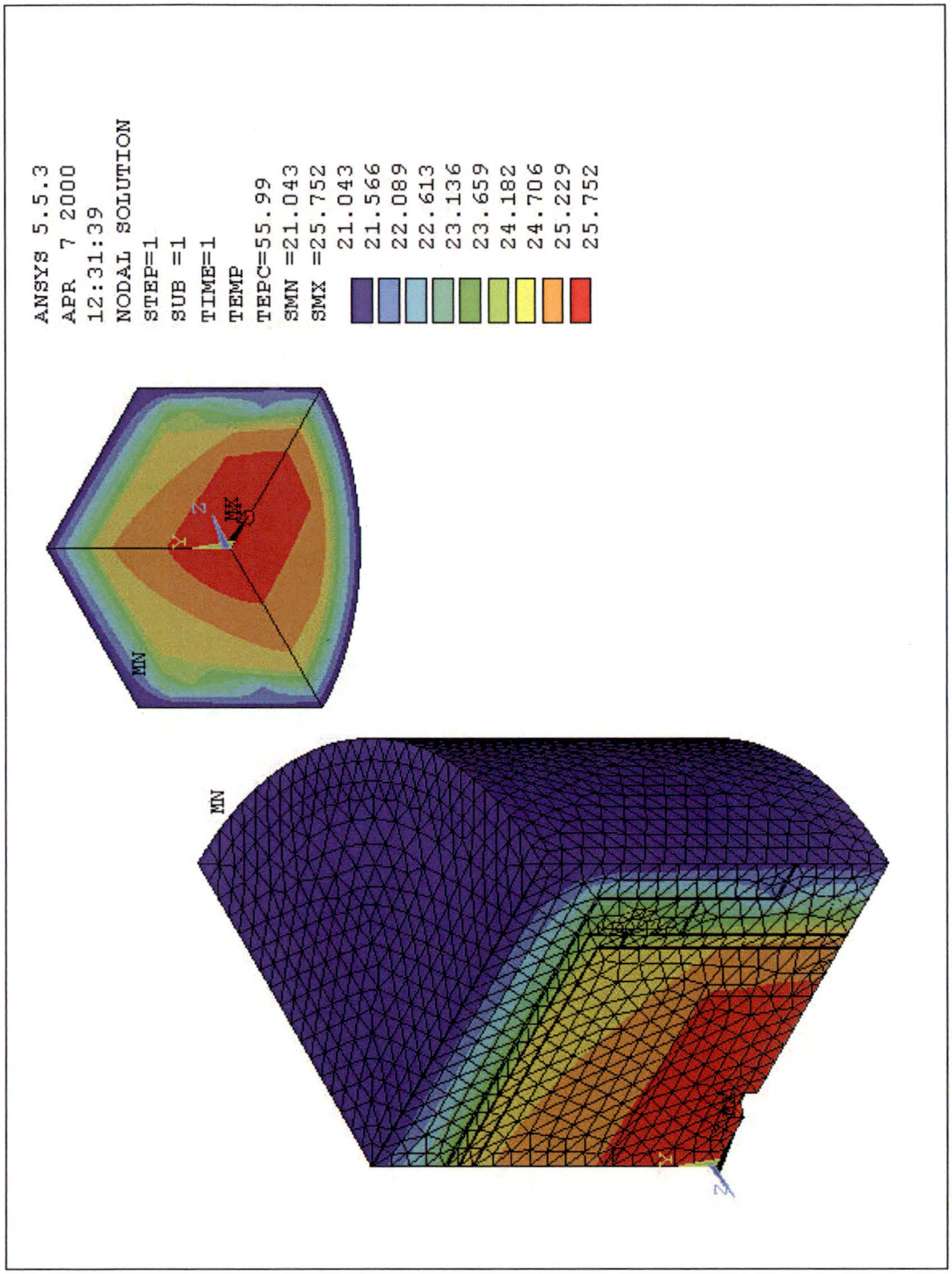


FIGURE 9: STEADY STATE TEMPERATURE DISTRIBUTION FOR F-430 MODEL WITH 8.3 W CS-137, NO SOLAR LOAD AND 21°C AMBIENT: LOAD CASE 1

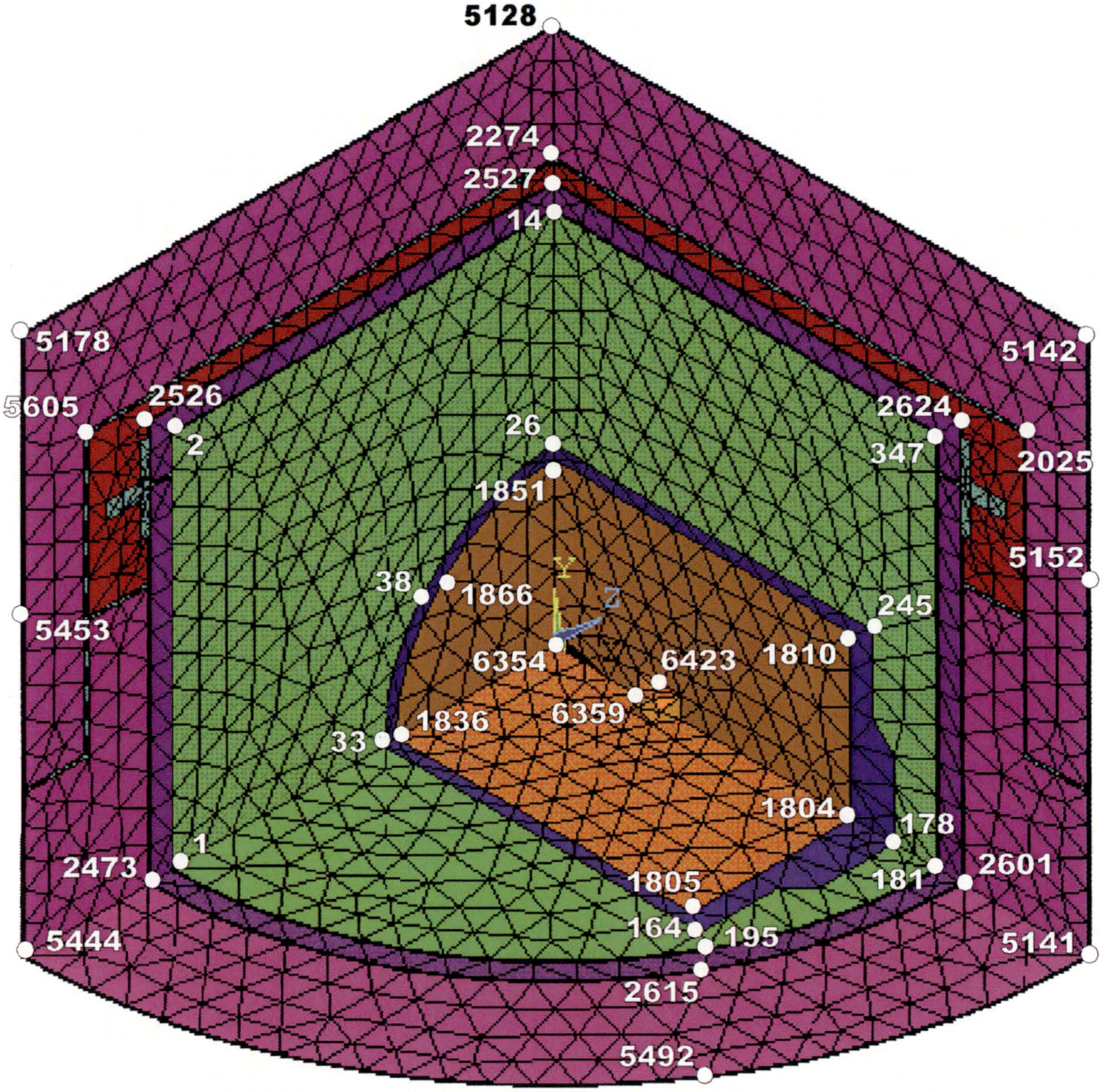


FIGURE 10: KEY NODAL TEMPERATURE LOCATIONS

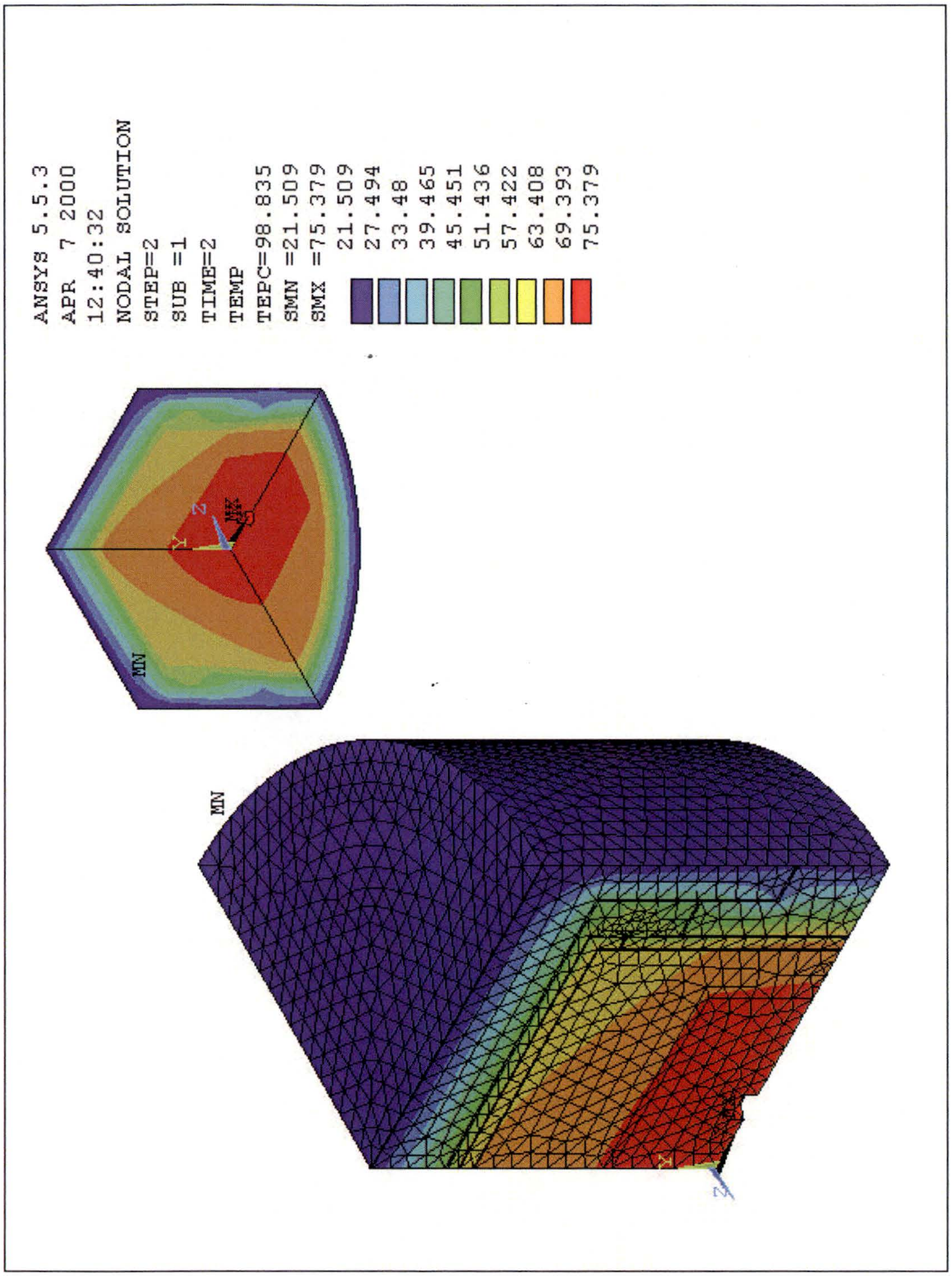


FIGURE 11: STEADY STATE TEMPERATURE DISTRIBUTION FOR F-430 MODEL WITH 100 W CS-137, NO SOLAR LOAD AND 21°C AMBIENT: LOAD CASE 2

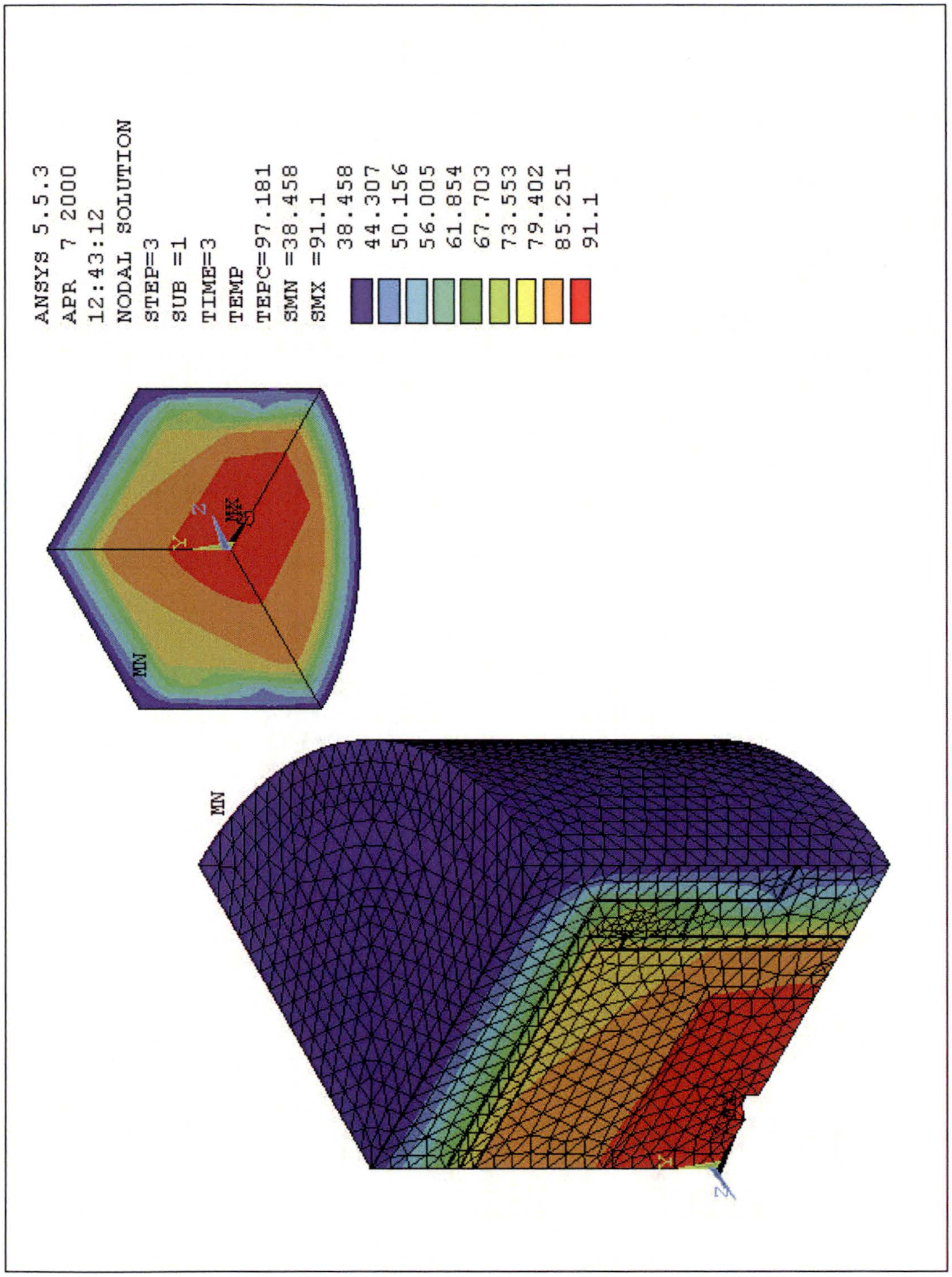


FIGURE 12: STEADY STATE TEMPERATURE DISTRIBUTION FOR F-430 MODEL WITH 100 W CS-137, NO SOLAR LOAD AND 38°C AMBIENT: LOAD CASE 3

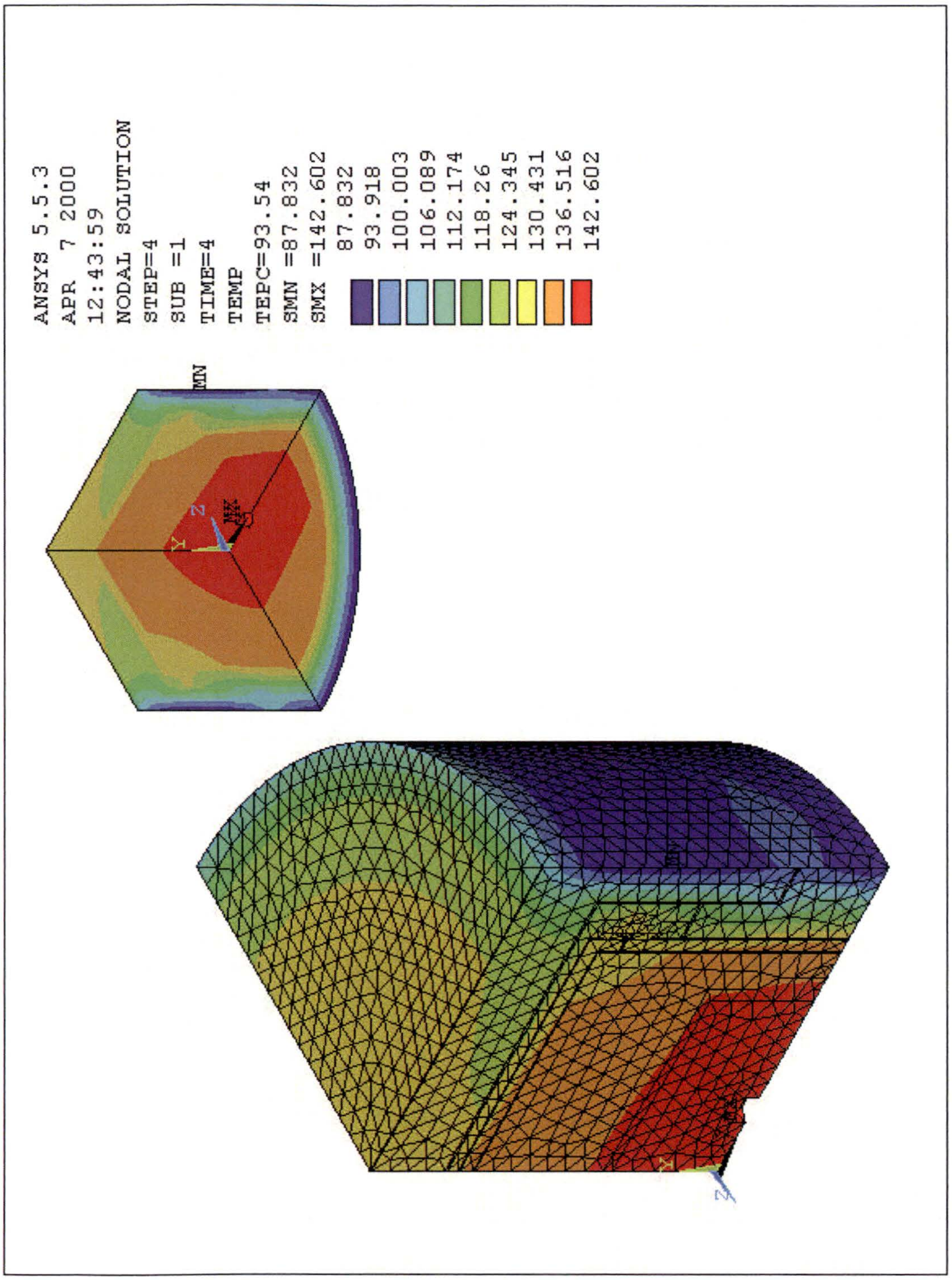


FIGURE 13: STEADY STATE TEMPERATURE DISTRIBUTION FOR F-430 MODEL WITH 100 W CS-137, SOLAR LOAD AND 38°C AMBIENT: LOAD CASE 4

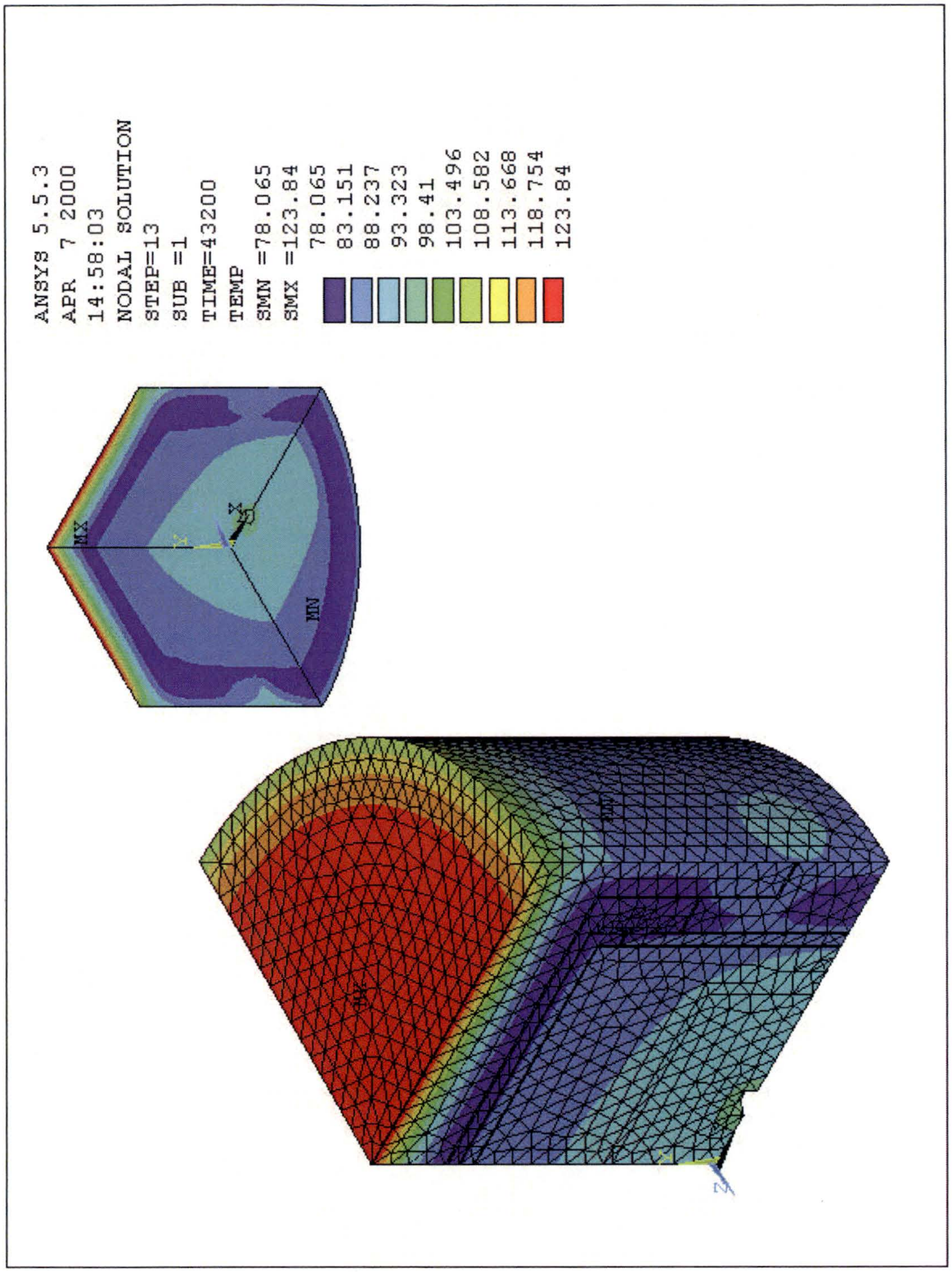


FIGURE 14: TEMPERATURE DISTRIBUTION FOR F-430 MODEL WITH 100 W CS-137, SOLAR LOAD AND 38°C AMBIENT AFTER 12 HOUR TRANSIENT: LOAD CASE 4

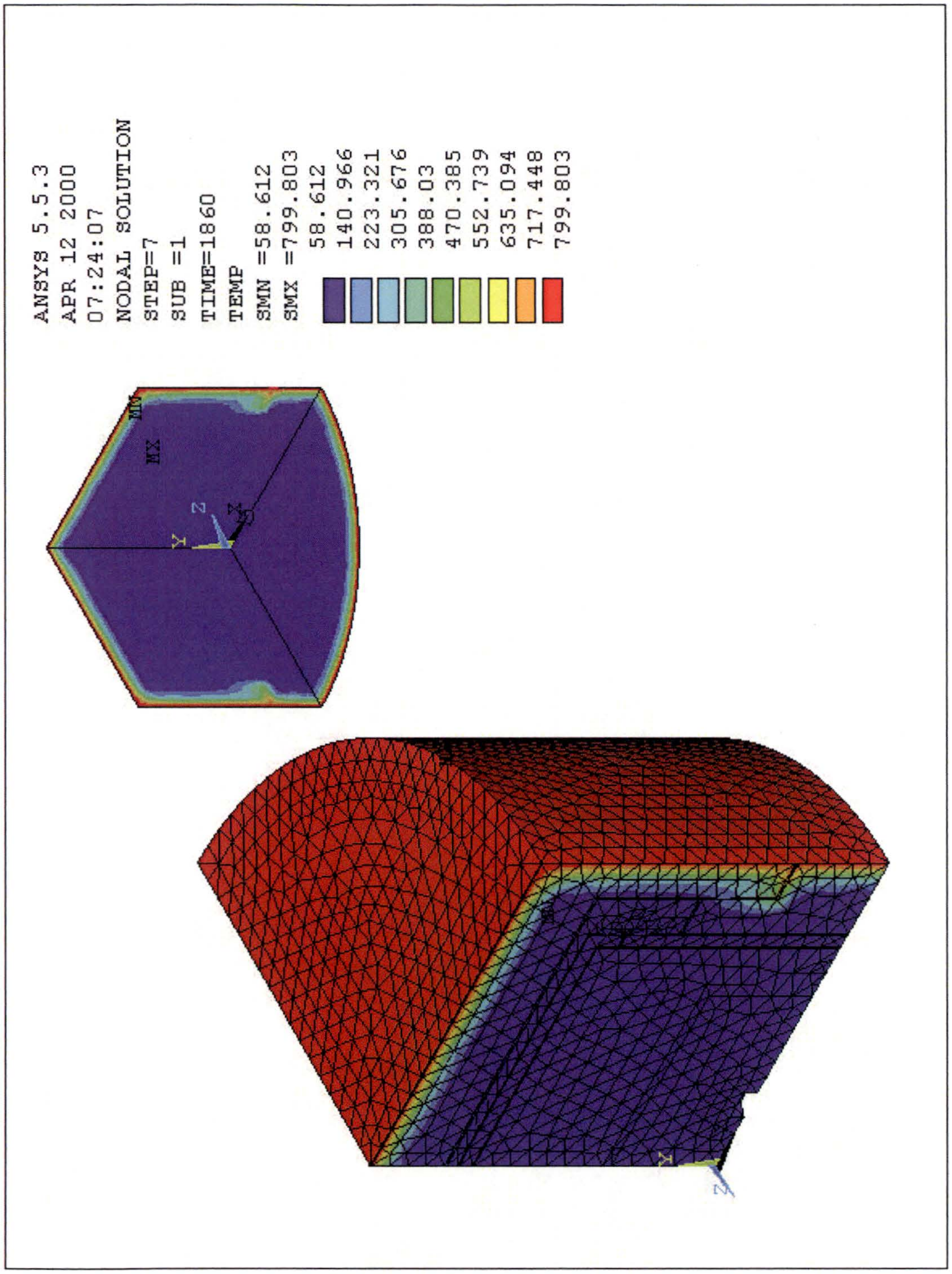


FIGURE 15: TEMPERATURE DISTRIBUTION AT END OF FIRE (1860 S) FOR F-430 MODEL: LOAD CASE 5

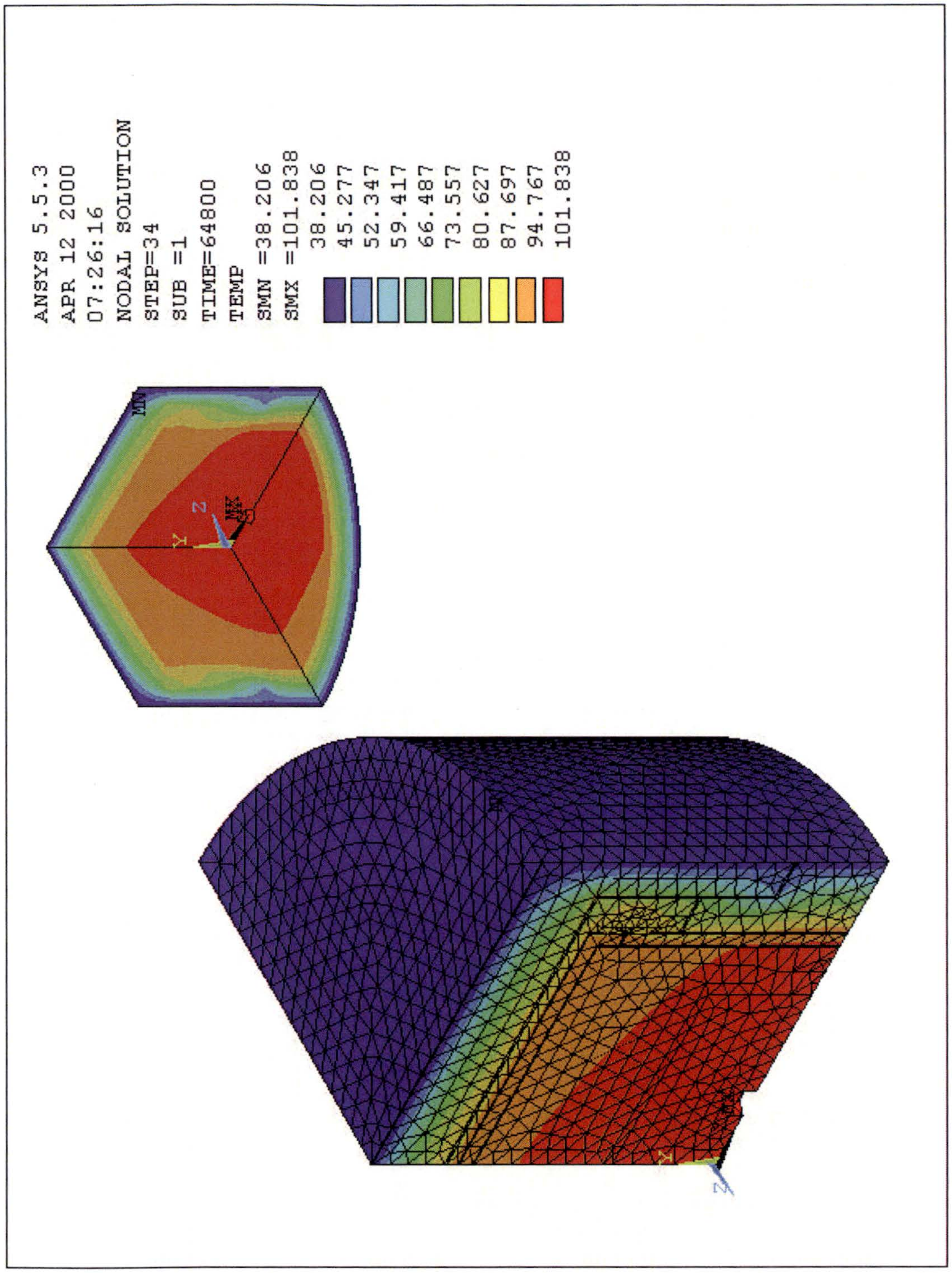


FIGURE 16: TEMPERATURE DISTRIBUTION AT MAXIMUM LEAD TEMPERATURE (64,800 S, 18 HRS) FOR F-430 MODEL: LOAD CASE 5

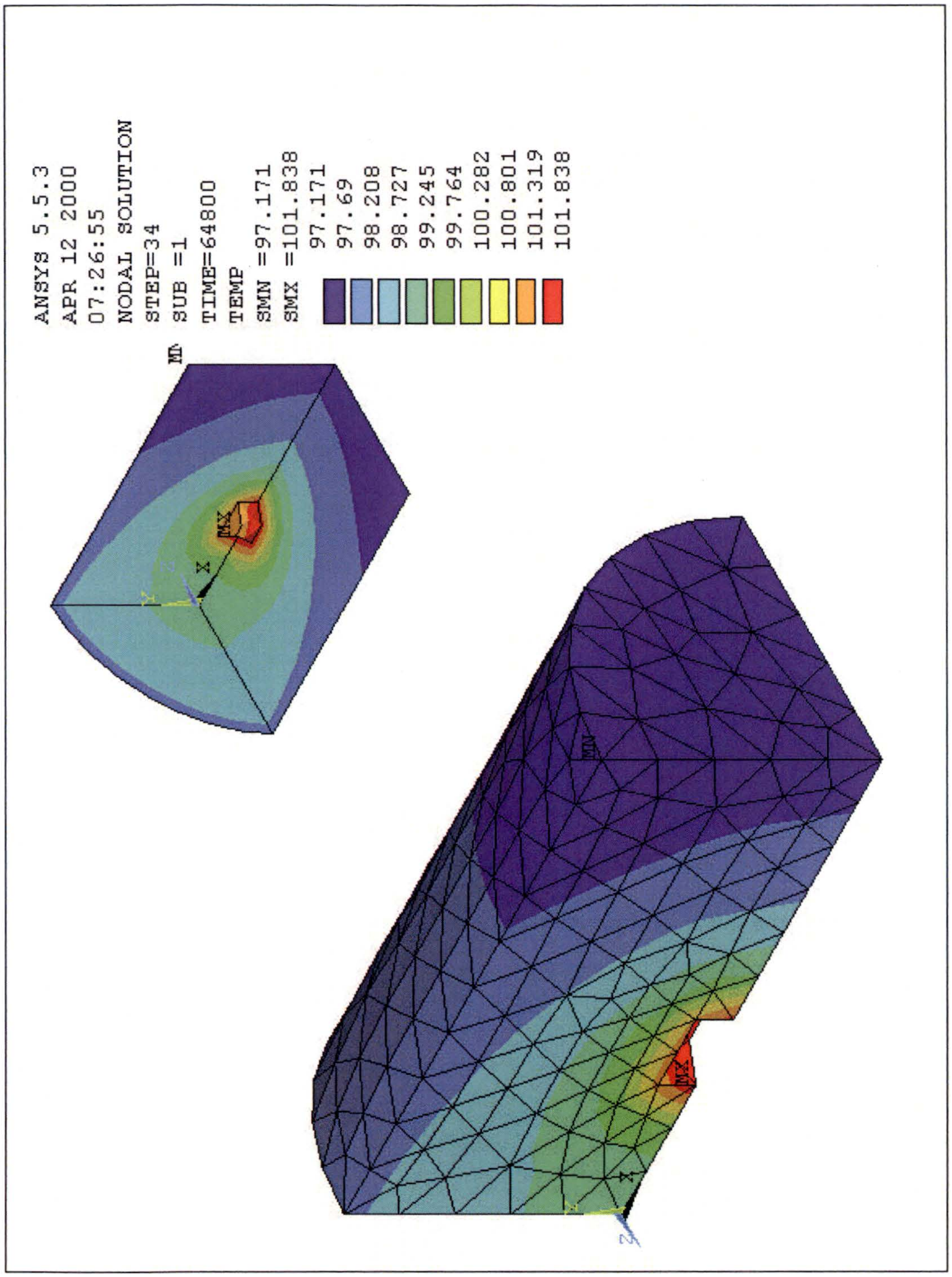


FIGURE 17: TEMPERATURE DISTRIBUTION IN LEAD ELEMENTS AT MAXIMUM LEAD TEMPERATURE (64,800 S, 18 HRS) FOR F-430 MODEL: LOAD CASE 5

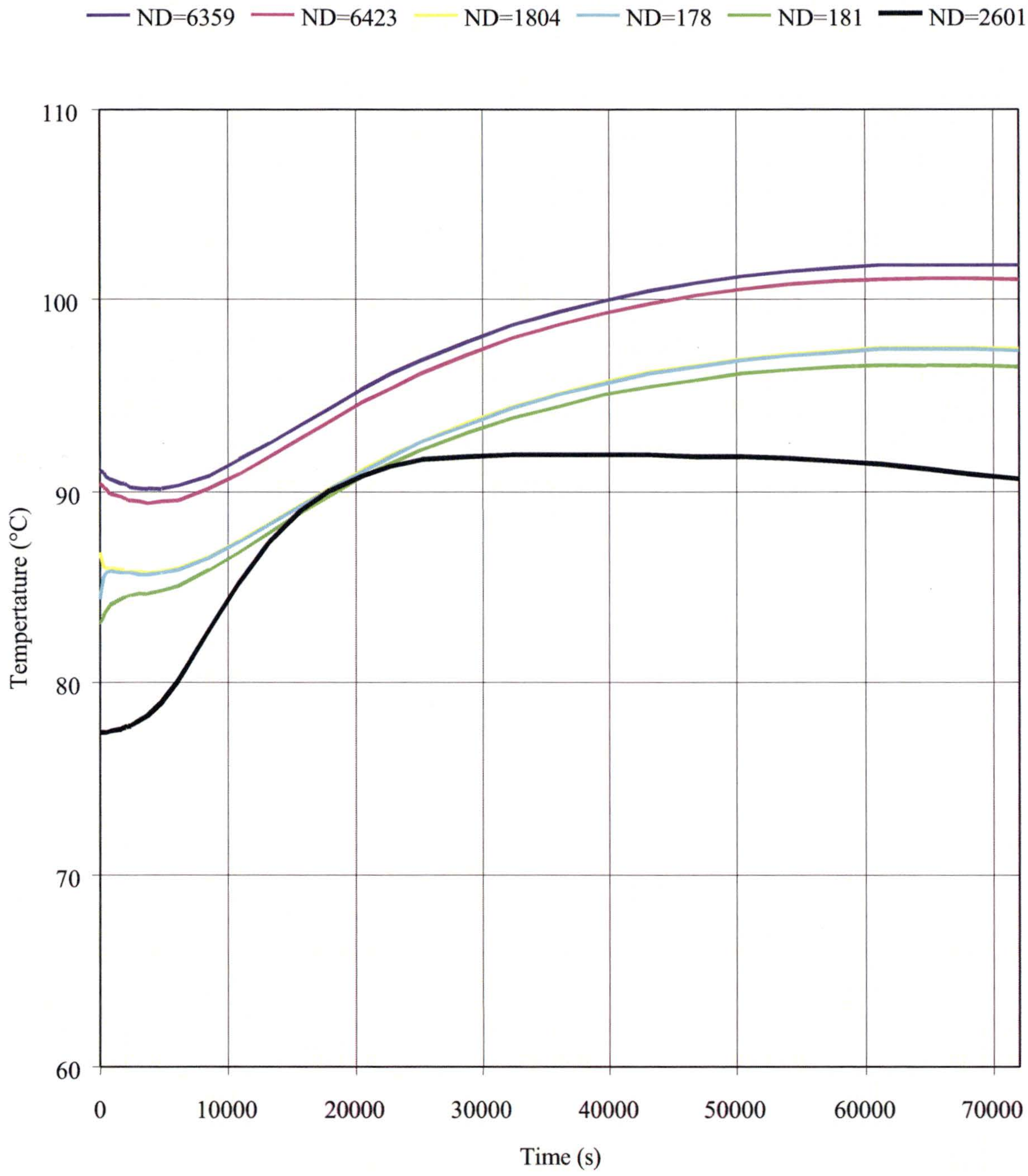


FIGURE 18: TEMPERATURE TRANSIENTS FOR SELECTED NODES FROM FIGURE 10

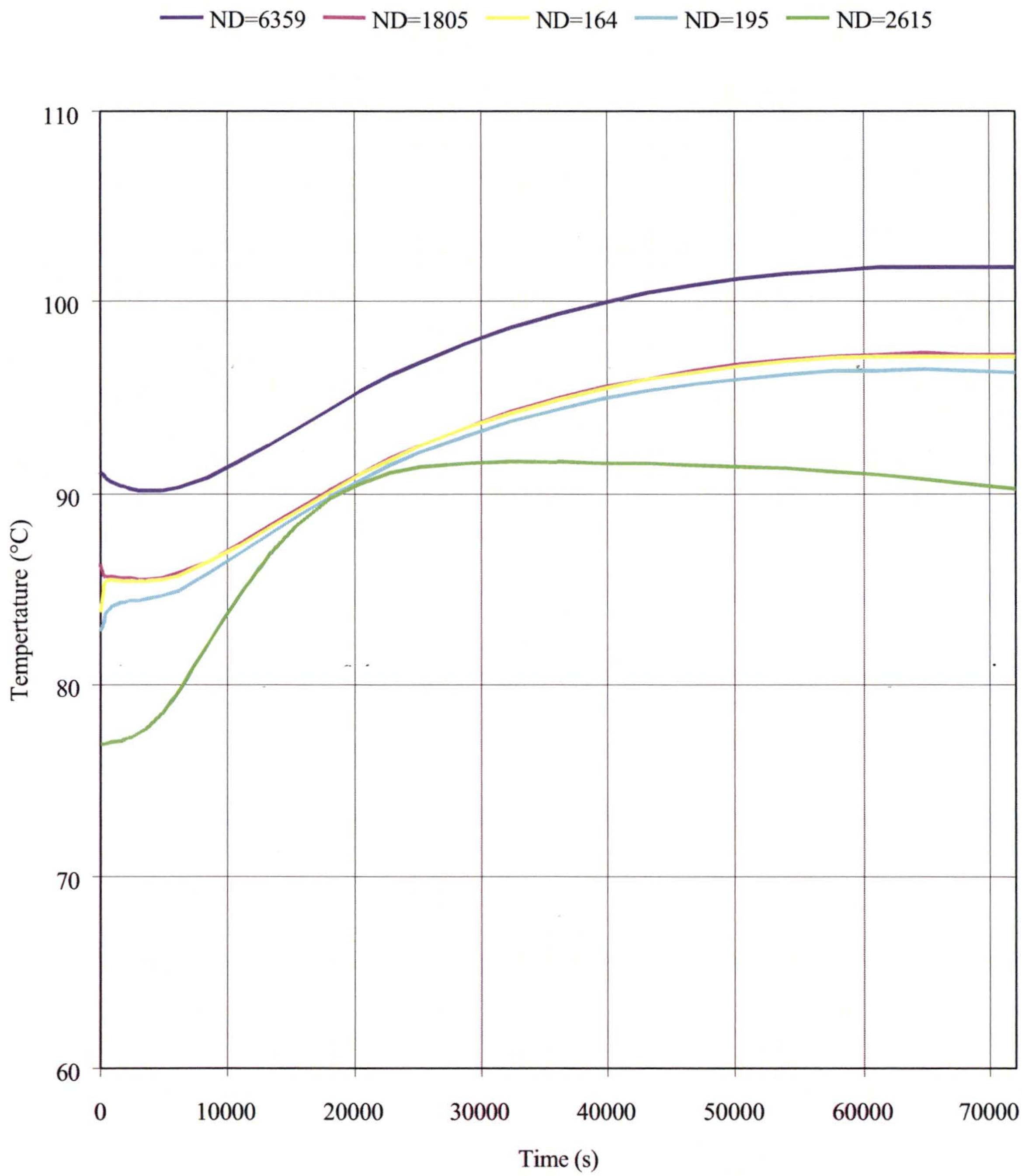


FIGURE 19: TEMPERATURE TRANSIENTS FOR SELECTED NODES FROM FIGURE 10

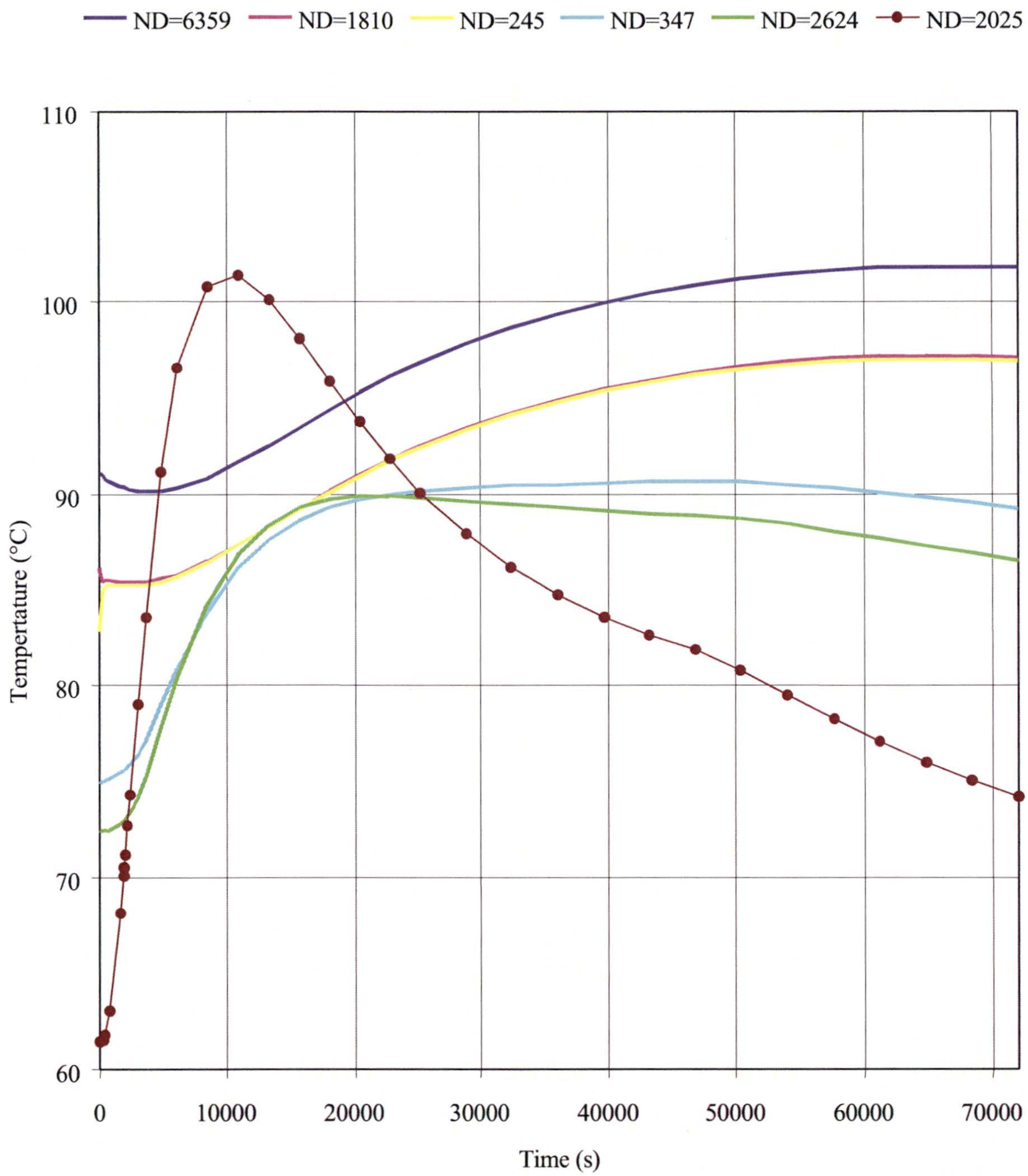


FIGURE 20: TEMPERATURE TRANSIENTS FOR SELECTED NODES FROM FIGURE 10

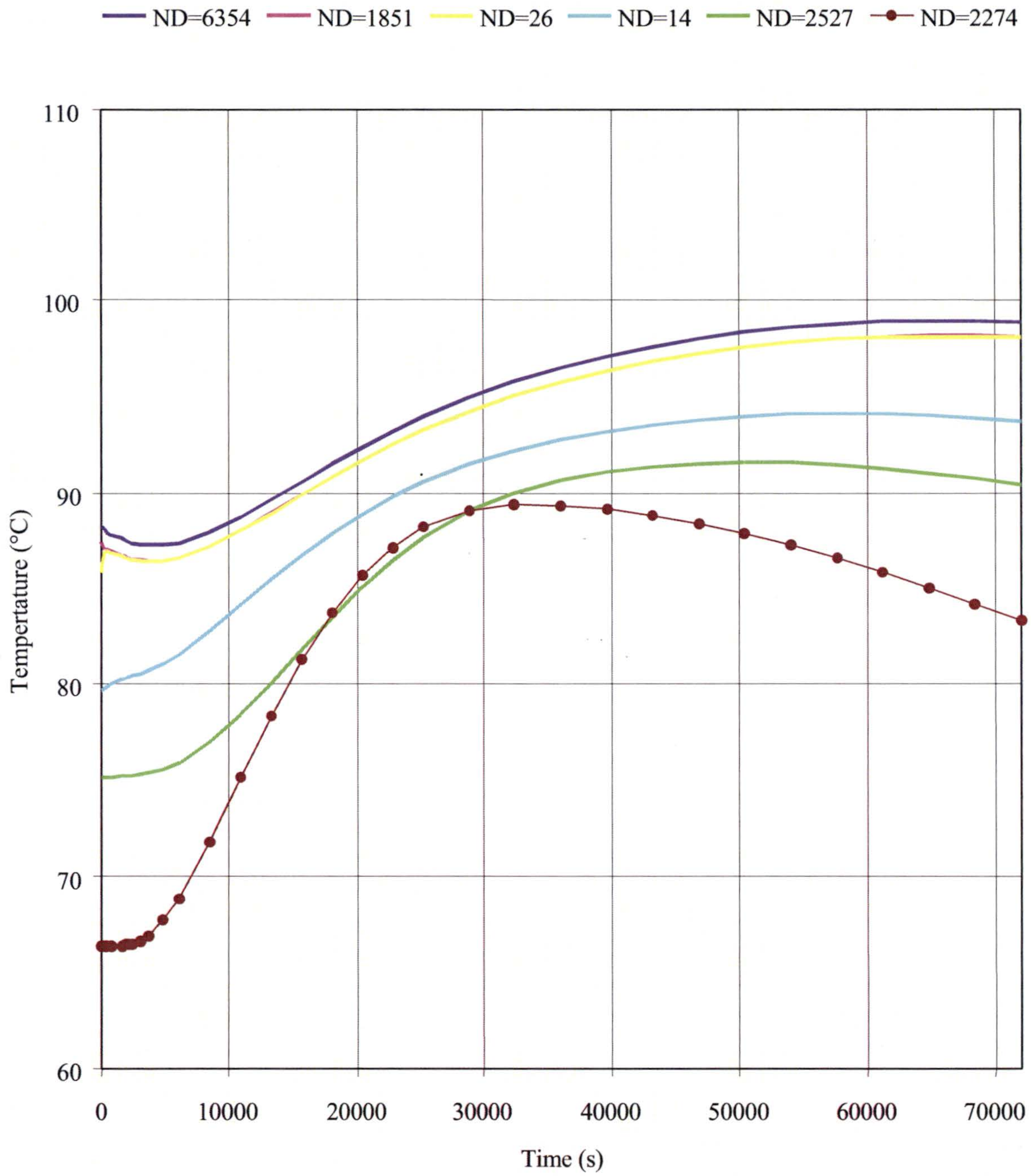


FIGURE 21: TEMPERATURE TRANSIENTS FOR SELECTED NODES FROM FIGURE 10

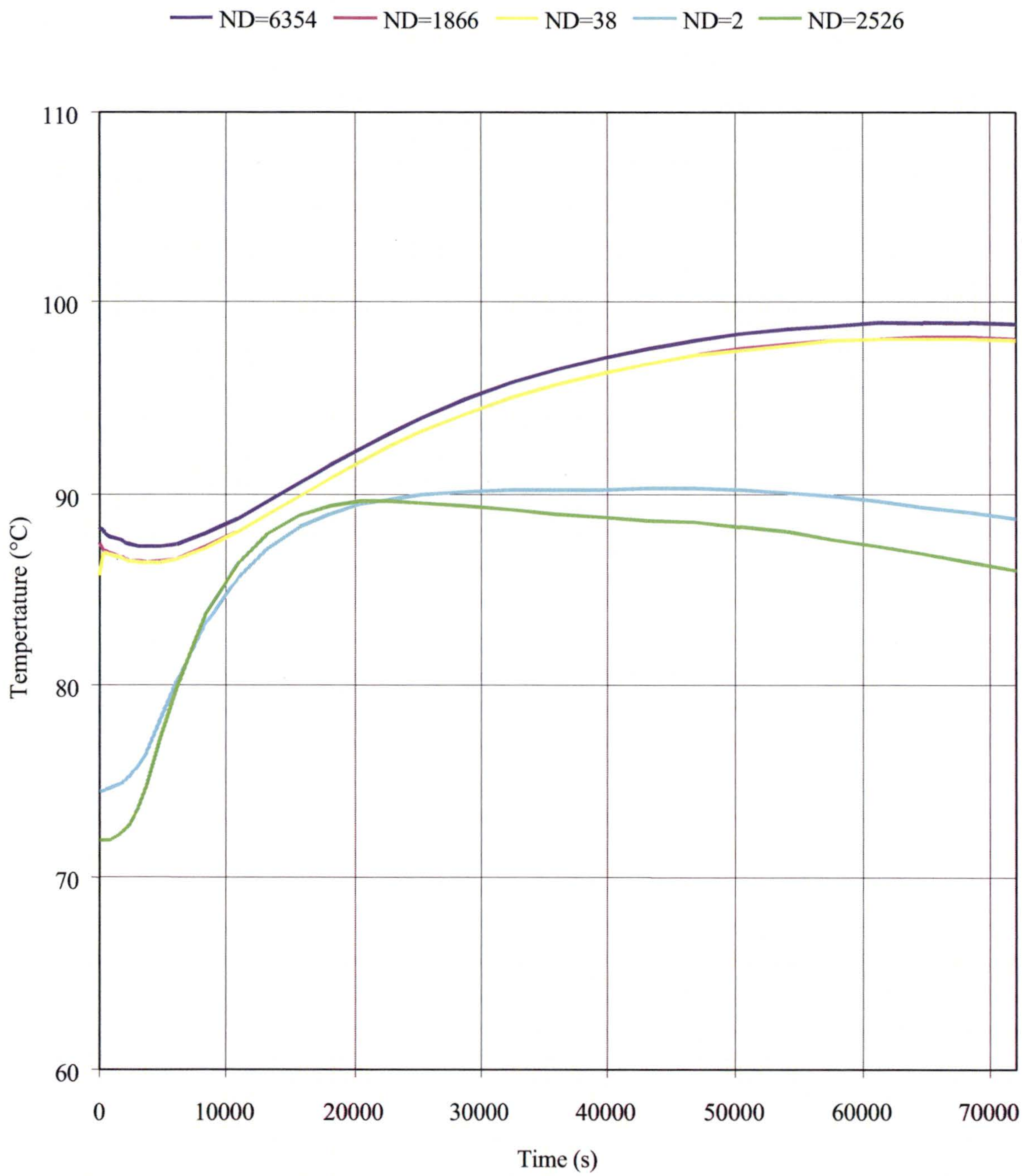


FIGURE 22: TEMPERATURE TRANSIENTS FOR SELECTED NODES FROM FIGURE 10

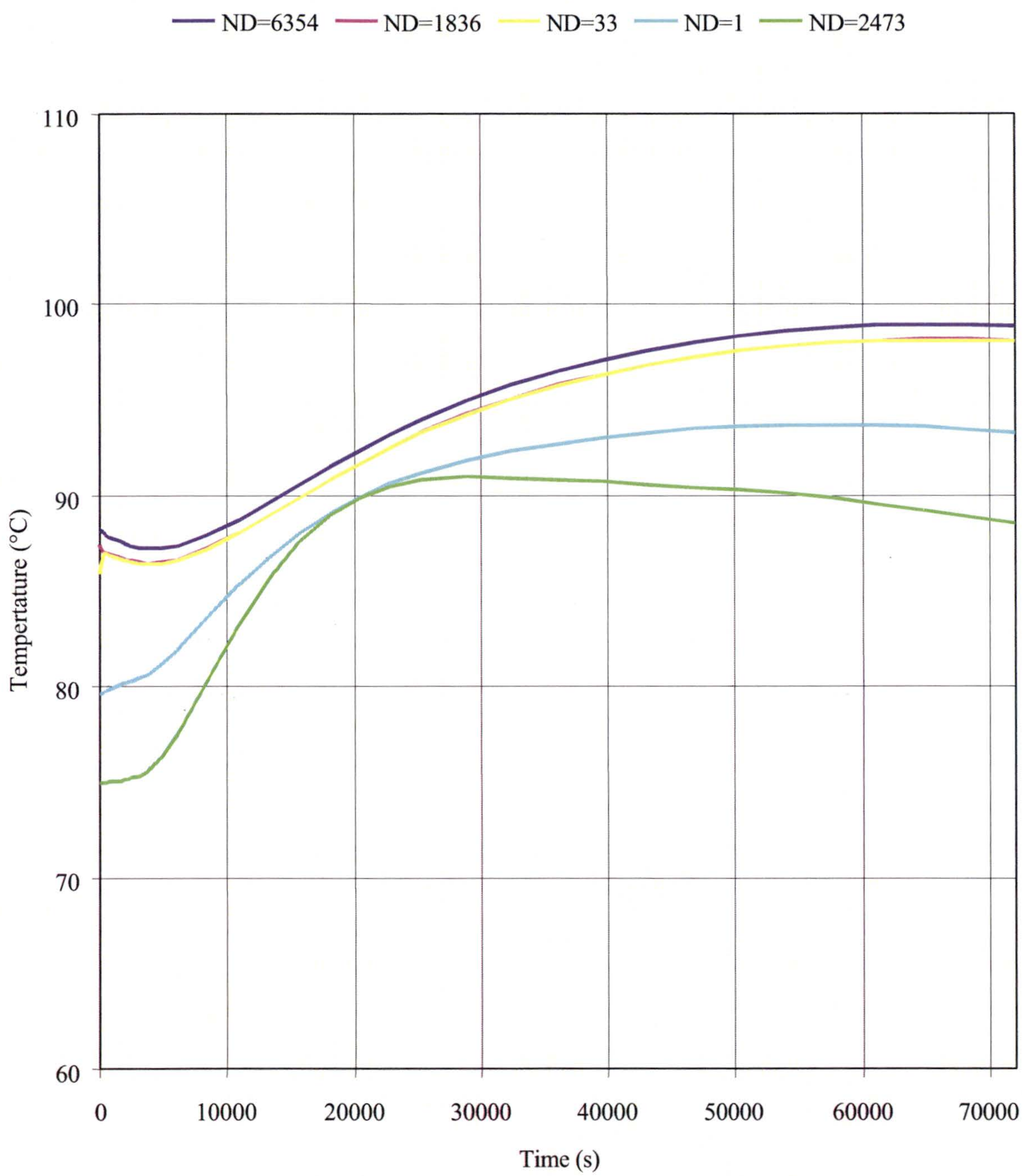


FIGURE 23: TEMPERATURE TRANSIENTS FOR SELECTED NODES FROM FIGURE 10

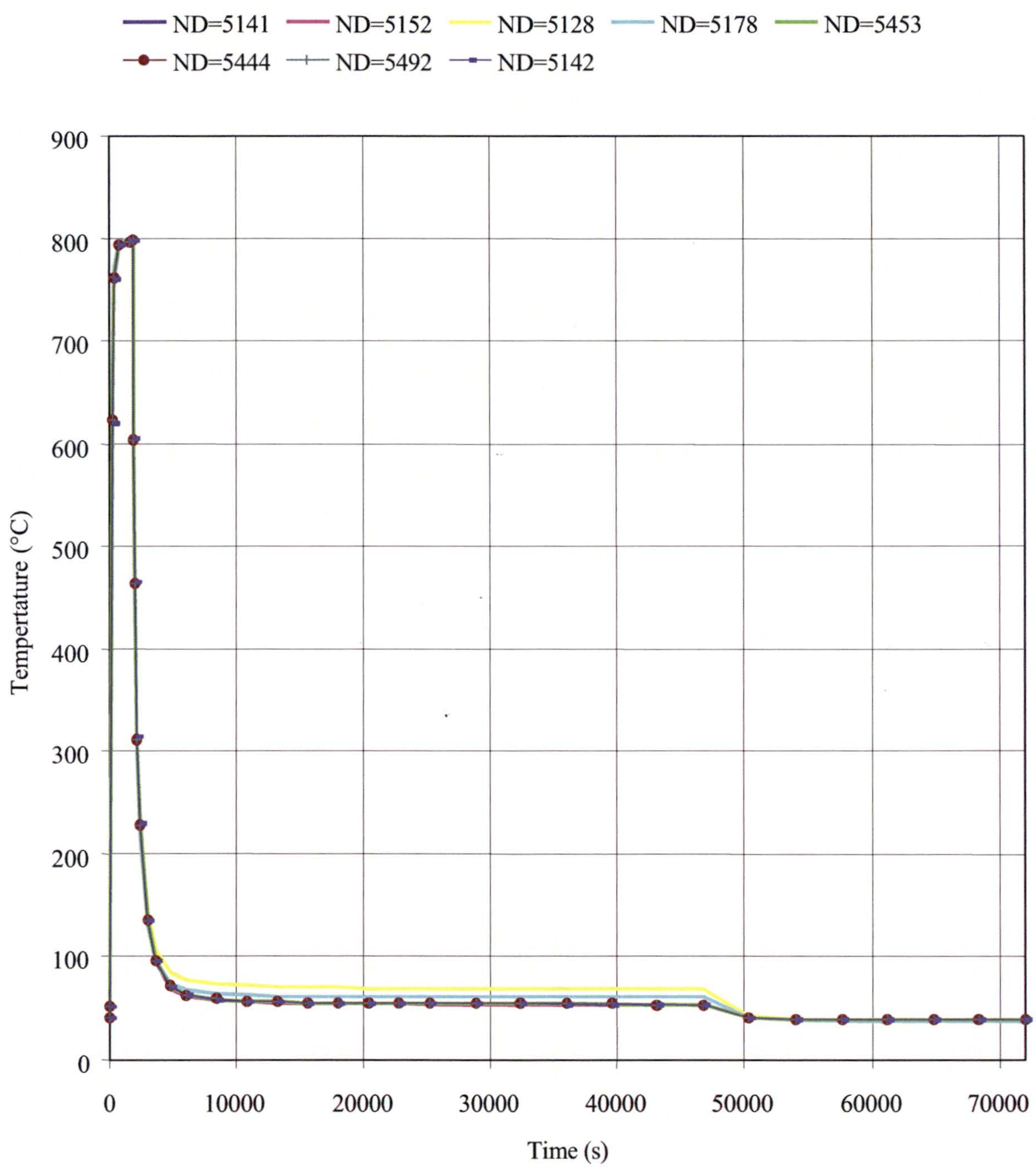


FIGURE 24: TEMPERATURE TRANSIENTS FOR SELECTED NODES FROM FIGURE 10

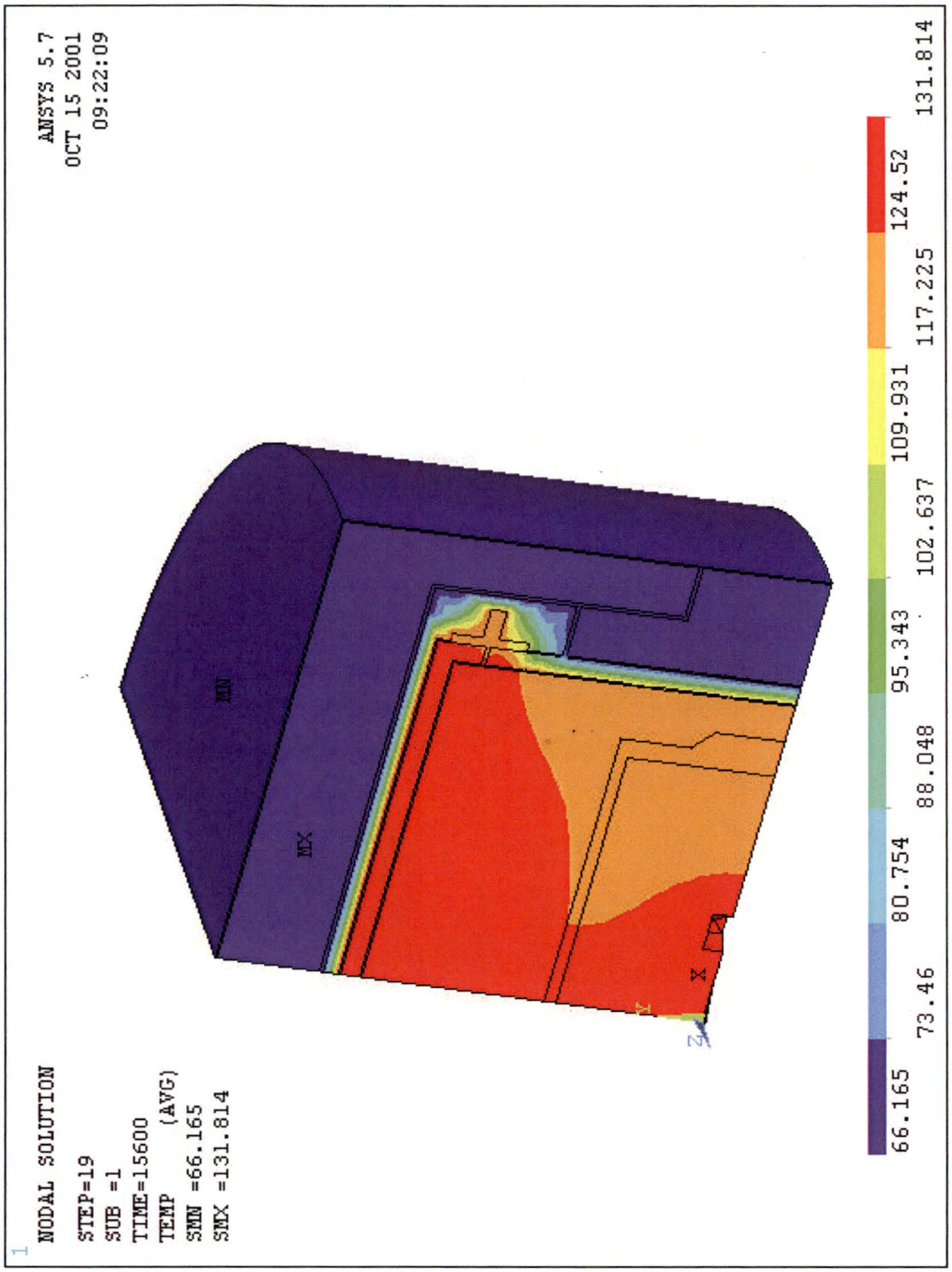


FIGURE 25: CALCULATED TEMPERATURE DISTRIBUTION IN THE OVERPACK AT TIME OF MAXIMUM LEAD TEMPERATURE (15,600 S, 4 HRS 20 MIN.)

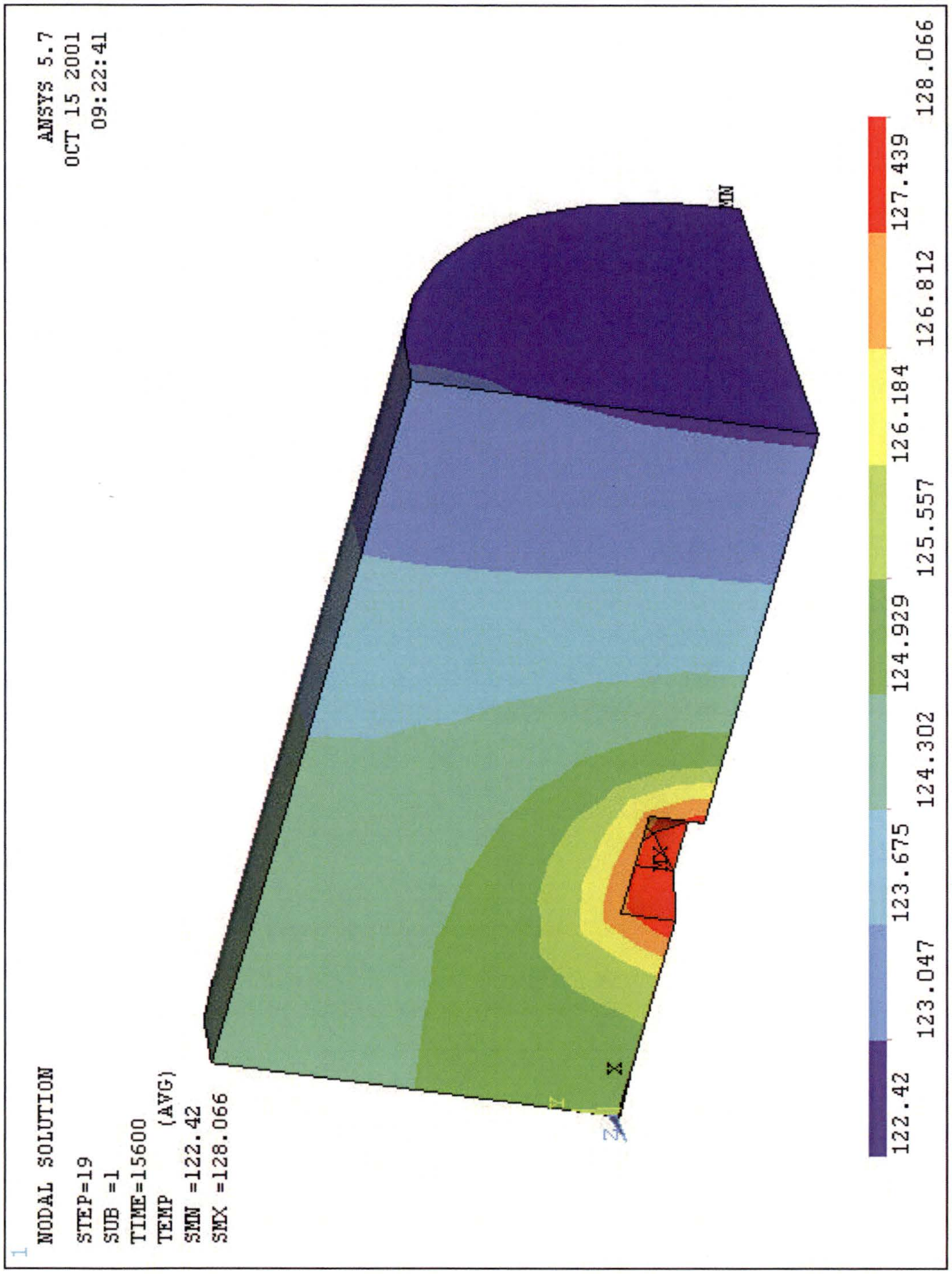


FIGURE 26: CALCULATED TEMPERATURE DISTRIBUTION IN THE LEAD ELEMENTS ONLY, AT TIME OF MAXIMUM LEAD TEMPERATURE (15,600 S, 4 HRS 20 MIN.)

Appendix A
Excerpt From Transnucleaire Report on Package Analysis [3]

E 7510

REPORT ON THE IMPLICATIONS OF THE TESTS REQUIREMENTS FOR TYPE B PACKAGINGS AND A STUDY OF PRACTICAL SOLUTIONS

EURATOM CONTRACT N° 024 - 65 - E.C.I.C.

TRANSNUCLEAIRE

11 & 11 bis Rue Christophe Colomb
Paris 8e
Tel. 225 14 77
225 08 86
Telex 28 992

7 West 57th Street
New York, NY 10019
355 7320

170.-

3 - LEAD-STEEL JUNCTION -

a) No bond -

When fabrication is made without trying to obtain bonding between lead and outer shell, shrinkage occurs during cooling after casting due to the difference of dilatation coefficients of lead and steel.

The importance of shrinkage depends on casting methods and outer shell dimensions and materials.

With a stainless steel outer shell and adequate casting method, shrinkage is on the order of 4°/oo, i.e. for instance 2 mm at the radius for a packaging of 1 m diameter.

With a mild steel outer shell, whose dilatation coefficient is lower than for stainless steel, shrinkage may be greater.

b) Lead bonded -

Bonding can be obtained by various processes, which we will not explain here.

Let us say only that bonding can be easily achieve on an open steel wall ; it is much more difficult inside a steel vessel practically closed. It is also more difficult with stainless steel than with mild steel.

If bonding is perfect, which can be checked by ultra-sonic inspection, thermal bond should also be perfect.

This is actually obtained for instance with a plane steel wall and a certain thickness of lead bonded, the outer surface of the lead being bare.

On the other hand, our experience shows us that in the case of packagings and in spite of a perfect bonding to the outer shell, ultra-sonic checked, there is always some discrepancy between thermal test and calculations for the heat transmission through the inner shell/lead/outer shell assembly.

Compared with calculations based on a perfect thermal bonding, tests show that in fact there is a certain extra resistance to the passage of heat.

Thus, on a series of six identical cylindrical 20 ton packagings (constructed by the Société Lyonnaise de Plomberie Industrielle), an extra resistance to the passage of heat compared with calculations is found equivalent to an air gap of 0.5mm varying slightly around this value according to the packaging. Ultrasonic inspection, however, showed perfect outer shell/lead bonding.

There are a number of possible explanations :

- The calculation cannot be very accurate particularly when there is a great difference between the outer shell surface area and the inner cavity surface area. This was the case for the six packagings mentionned above.

  If the heat flux introduced in the calculation is the flux on the inner cavity, there is then good agreement between tests and calculation.

- Bonding to the outer shell has a tendency to work against hooping on the inner shell.

- Lack of homogeneity in the lead mass which is being drawn both towards the outer shell and towards the inner shell.

- Traces of oxide over a varying surface area at the outside shell/lead interface (which does not shown up with ultra-sonic controls).

We have no knowledge of the results obtained by other constructors.

c) Behavior in the thermal test -

In the case of not bonded lead, an air gap of say, 2 mm, corresponds to a temperature drop of several hundred degrees, for the initial heat fluxes involved in the thermal test.

172.-

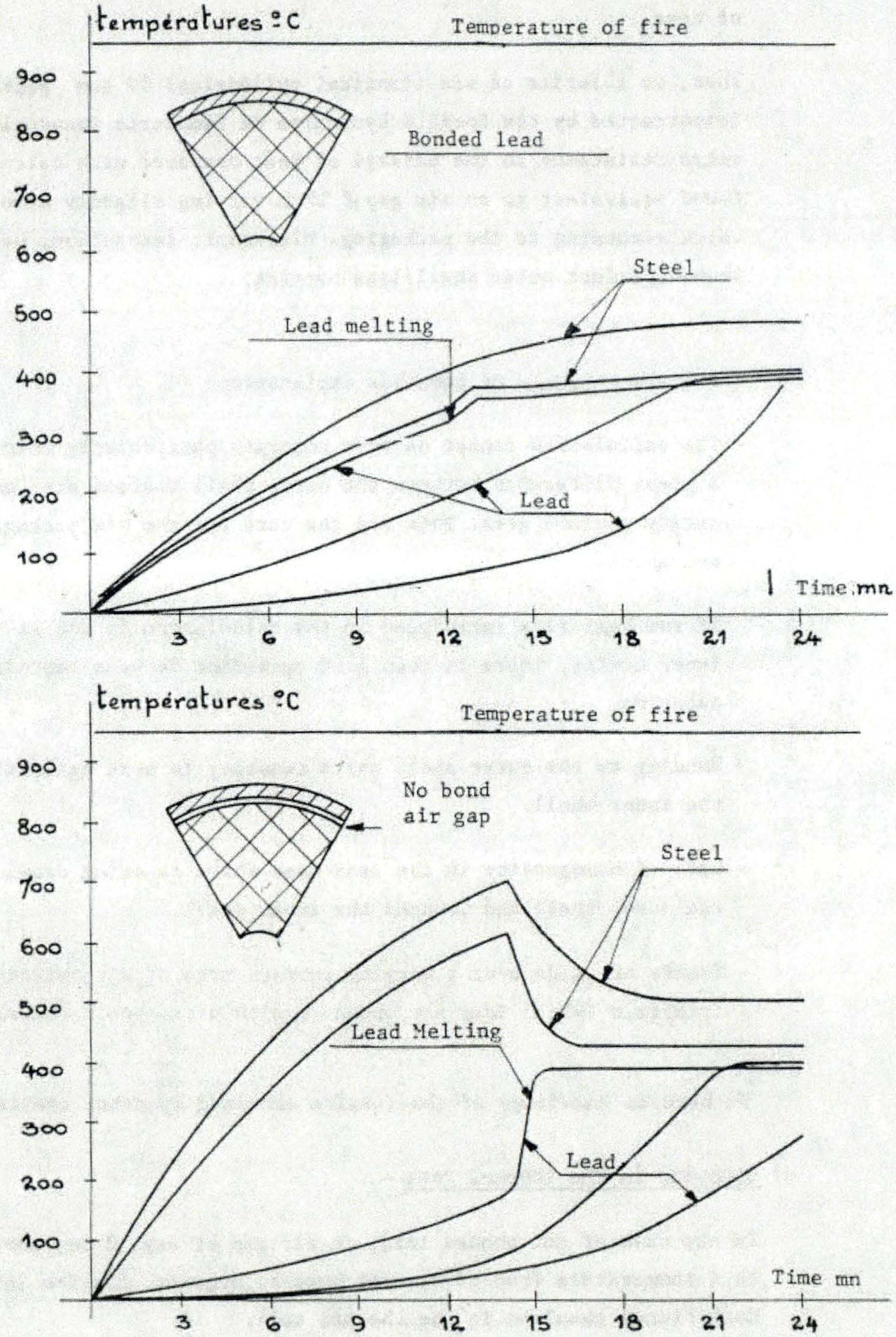

températures °C
Temperature of fire
900
800
700
600
500
400
300
200
100
Bonded lead
Steel
Lead melting
Lead
Time mn
3
6
9
12
15
18
21
24
températures °C
Temperature of fire
No bond
air gap
Steel
Lead Melting
Lead
Time mn

FIG. A.2

Appendix B
Ansys Finite Element Descriptions [2]

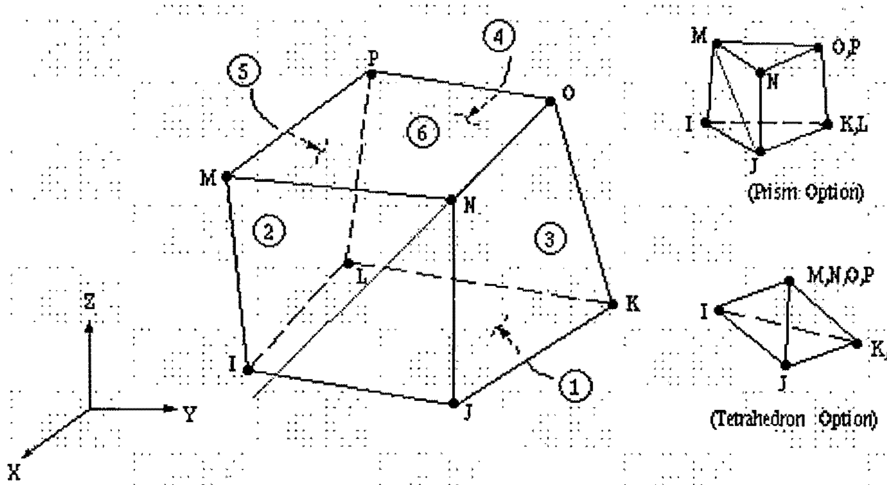
4.70 SOLID70 3-D Thermal Solid

Multiphysics	✓
Mechanical	✓
Structural	
LS-DYNA	
LinearPlus	
Thermal	✓
Emag 3-D	
Emag 2-D	
FLOTRAN	
PrepPost	✓
ED	✓

SOLID70 has a three-dimensional thermal conduction capability. The element has eight nodes with a single degree of freedom, temperature, at each node. The element is applicable to a three-dimensional, steady-state or transient thermal analysis. The element also can compensate for mass transport heat flow from a constant velocity field. If the model containing the conducting solid element is also to be analyzed structurally, the element should be replaced by an equivalent structural element (such as SOLID45). A similar thermal element, with mid-edge node capability, is described in Section 4.90 (SOLID90).

An option exists that allows the element to model nonlinear steady-state fluid flow through a porous medium. With this option, the thermal parameters are interpreted as analogous fluid flow parameters. For example, the temperature degree of freedom becomes equivalent to a pressure degree of freedom. See Section 14.70 of the *ANSYS Theory Reference* for more details about this element.

Figure 4.70-1 SOLID70 3-D Thermal Solid



4.70.1 Input Data

The geometry, node locations, and the coordinate system for this element are shown in Figure 4.70-1. The element is defined by eight nodes and the orthotropic material properties. Orthotropic material directions correspond to the element coordinate directions. The element coordinate system orientation is as described in Section 2.3. Specific heat and density are ignored for steady-state solutions. Properties not input default as described in Section 2.4.

Element loads are described in Section 2.7. Convections or heat fluxes (but not both) may be input as surface loads at the element faces as shown by the circled numbers on Figure 4.70-1.

Heat generation rates may be input as element body loads at the nodes. If the node I heat generation rate HG(I) is input, and all others are unspecified, they default to HG(I).

The nonlinear porous flow option is selected with KEYOPT(7)=1. For this option, temperature is interpreted as pressure and the absolute permeabilities of the medium are input as material properties KXX, KYY, and KZZ. Properties DENS and VISC are used for the mass density and viscosity of the fluid. Properties C and MU are used in calculating the coefficients of permeability as described in Section 14.70 of the *ANSYS Theory Reference*. Temperature boundary conditions input with the D command are interpreted as pressure boundary conditions, and heat flow boundary conditions input with the F command are interpreted as mass flow rate (mass/time).
A mass transport option is available with KEYOPT(8). With this option the velocities VX, VY, and VZ must be input as real constants (in the element coordinate system). Also, temperatures should be specified along the entire inlet boundary to assure a stable solution. With mass transport, you should use specific heat (C) and density (DENS) material properties instead of enthalpy (ENTH).
A summary of the element input is given in Table 4.70-1. A general description of element input is given in Section 2.1.

Table 4.70-1 SOLID70 Input Summary

Element Name	SOLID70
Nodes	I, J, K, L, M, N, O, P
Degrees of Freedom	TEMP
Real Constants	VX, VY, VZ IF KEYOPT (8) > 0
Material Properties	KXX, KYY, KZZ, DENS, C, ENTH, VISC, MU (VISC and MU used only if KEYOPT (7) = 1. Do not use ENTH with KEYOPT(8)=1).
Surface Loads	Convections: face 1 (J-I-L-K), face 2 (I-J-N-M), face 3 (J-K-O-N), face 4 (K-L-P-O), face 5 (L-I-M-P), face 6 (M-N-O-P) Heat Fluxes: face 1 (J-I-L-K), face 2 (I-J-N-M), face 3 (J-K-O-N), face 4 (K-L-P-O), face 5 (L-I-M-P), face 6 (M-N-O-P)
Body Loads	Heat Generations:HG (I), HG (J), HG (K), HG (L), HG (M), HG (N), HG (O), HG (P)
Special Features	Birth and death.
KEYOPT(2)	0 - Evaluate film coefficient (if any) at average film temperature, (TS + TB)/2 1 - Evaluate at element surface temperature, TS 2 - Evaluate at fluid bulk temperature, TB 3 - Evaluate at differential temperature | TS-TB |
KEYOPT(4)	0 - Evaluate film coefficient (if any) at average film temperature, (TS + TB)/2 1 - Evaluate at element surface temperature, TS
KEYOPT(7)	0 - Standard heat transfer element 1 - Nonlinear steady-state fluid flow analogy element (temperature degree of freedom interpreted as pressure)
KEYOPT(8)	0 - No mass transport effects 1 - Mass transport with VX, VY, VZ

4.70.2 Output Data

The solution output associated with the element is in two forms:

- nodal temperatures included in the overall nodal solution
- additional element output as shown in Table 4.70-2

Heat flowing out of the element is considered to be positive. If KEYOPT(7)=1, the standard thermal output should be interpreted as the analogous fluid flow output. The element output directions are parallel to the element coordinate system. A general description of solution output is given in Section 2.2. See the *ANSYS Basic Analysis Procedures Guide* for ways to view results.
The following notation is used in Table 4.70-2:
A colon (:) in the **Name** column indicates the item can be accessed by the Component Name method [**ETABLE**, **ESOL**] (see Section 2.2.2). The **O** and **R** columns indicate the availability of the items in the file *Jobname*.OUT (**O**) or in the results file (**R**), a **Y** indicates that the item is *always* available, a number refers to a table footnote which describes when the item is *conditionally* available, and a - indicates that the item is *not* available.

Table 4.70-2 SOLID70 Element Output Definitions

Name	Definition	O	R
EL	Element number	Y	Y
NODES	Nodes - I, J, K, L, M, N, O, P	Y	Y
MAT	Material number	Y	Y
VOLU:	Volume	Y	Y
CENT: X, Y, Z	Center location XC, YC, ZC	-	Y
HGEN	Heat generations HG(I), HG(J), HG(K), HG(L), HG(M), HG(N), HG(O), HG(P)	Y	-
TG: X, Y, Z, SUM	Thermal gradient components and vector sum at centroid	Y	Y
TF: X, Y, Z, SUM	Thermal flux (heat flow rate/cross-sectional area) components and vector sum at centroid	Y	Y
FACE	Face label	1	-
AREA	Face area	1	1
NODES	Face nodes	1	-
HFILM	Film coefficient at each node of face	1	-
TBULK	Bulk temperature at each node of face	1	-
TAVG	Average face temperature	1	1
HEAT RATE	Heat flow rate across face by convection	1	1
HEAT RATE/AREA	Heat flow rate per unit area across face by convection	1	-
HFAVG	Average film coefficient of the face	-	1
TBAVG	Average face bulk temperature	-	1
HFLXAVG	Heat flow rate per unit area across face caused by input heat flux	-	1
HFLUX	Heat flux at each node of face	1	-
PRESSURE GRAD	Total pressure gradient and its X, Y, and Z components	2	-
MASS FLUX	Mass flow rate per unit cross-sectional area	2	-
FLUID VELOCITY	Total fluid velocity and its X, Y, and Z components	2	-

1. Output if a surface load is input
2. Output if KEYOPT(7)=1

Table 4.70-3 lists output available through the **ETABLE** command using the Sequence Number method. See Chapter 5 of the *ANSYS Basic Analysis Procedures Guide* and Section 2.2.2.2 of this manual for more information. The following notation is used in Table 4.70-3:

Name - output quantity as defined in the Table 4.70-2
Item - predetermined *Item* label for **ETABLE** command
FC*n* - sequence number for solution items for element Face *n*

Table 4.70-3 SOLID70 Item and Sequence Numbers for the ETABLE and ESOL Commands

Name	Item	FC1	FC2	FC3	FC4	FC5	FC6
AREA	NMISC	1	7	13	19	25	31
HFAVG	NMISC	2	8	14	20	26	32
TAVG	NMISC	3	9	15	21	27	33
TBAVG	NMISC	4	10	16	22	28	34
HEAT RATE	NMISC	5	11	17	23	29	35
HFLXAVG	NMISC	6	12	18	24	30	36

4.70.3 Assumptions and Restrictions

The element must not have a zero volume. This occurs most frequently when the element is not numbered properly. Elements may be numbered either as shown in Figure 4.70-1 or may have the planes IJKL and MNOP interchanged. A prism or tetrahedron shaped element may be formed by defining duplicate node numbers as described in Section 2.8.
The specific heat and enthalpy are evaluated at each integration point to allow for abrupt changes (such as for melting) within a coarse grid. If the thermal element is to be replaced by a SOLID45 structural element with surface stresses requested, the thermal element should be oriented such that face IJNM and/or face KLPO is a free surface.

A free surface of the element (*i.e.*, not adjacent to another element and not subjected to a boundary constraint) is assumed to be adiabatic. Thermal transients having a fine integration time step and a severe thermal gradient at the surface will also require a fine mesh at the surface.
If KEYOPT(8)>0, unsymmetric matrices are produced.

4.70.4 Product Restrictions

When used in the product(s) listed below, the stated product-specific restrictions apply to this element in addition to the general assumptions and restrictions given in the previous section.

ANSYS/Thermal

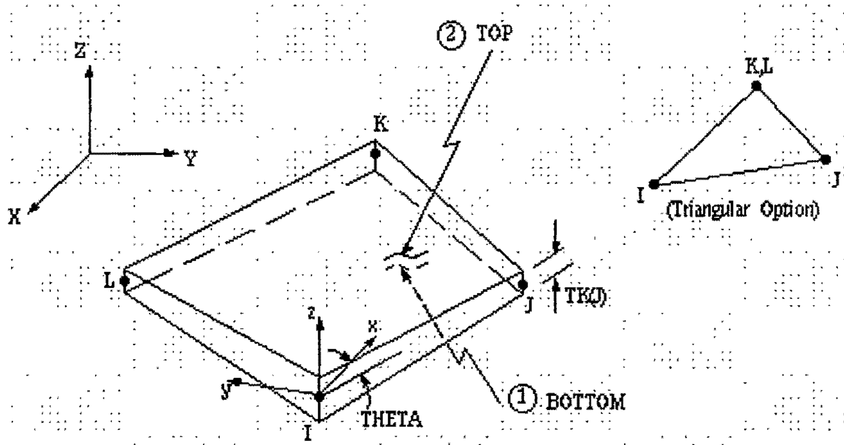
- This element does not have the mass transport or fluid flow options. KEYOPT(7) and KEYOPT(8) can only be set to 0 (default).
- The VX, VY, and VZ real constants are not applicable.
- The VISC and MU material properties are not applicable.
- The element does not have the birth and death feature.

4.57 SHELL57 Thermal Shell

Multiphysics	✓
Mechanical	✓
Structural	
LS-DYNA	
LinearPlus	
Thermal	✓
Emag 3-D	
Emag 2-D	
FLOTRAN	
PrepPost	✓
ED	✓

SHELL57 is a three-dimensional element having in-plane thermal conduction capability. The element has four nodes with a single degree of freedom, temperature, at each node. The conducting shell element is applicable to a three-dimensional, steady-state or transient thermal analysis. See Section 14.57 of the *ANSYS Theory Reference* for more details about this element.
If the model containing the conducting shell element is to be analyzed structurally, the element should be replaced by an equivalent structural element (such as SHELL63). If both in-plane and transverse conduction are needed, a thermal solid element (such as SOLID70 or SOLID90) should be used.

Figure 4.57-1 SHELL57 Thermal Shell



Note—x and y are in the plane of the element

4.57.1 Input Data

The geometry, node locations, and coordinate systems for this element are shown in Figure 4.57-1. The element is defined by four nodes, four thicknesses, a material direction angle, and the material properties.
The element may have variable thickness. The thickness is assumed to vary smoothly over the area of the element, with the thickness input at the four nodes. If the element has a constant thickness, only TK(I) need be input. If the thickness is not constant, all four thicknesses must be input.
Orthotropic material directions correspond to the element coordinate directions. The element coordinate system orientation is as described in Section 2.3. Properties not input default as described in Section 2.4. The element x-axis may be rotated by an angle THETA (in degrees).
Element loads are described in Section 2.7. Convections may be input as surface loads at the element faces as shown by the circled numbers on Figure 4.57-1.
Heat generation rates may be input as element body loads at the nodes. If the node I heat generation rate HG(I) is input, and all others are unspecified, they default to HG(I).
A summary of the element input is given in Table 4.57-1. A general description of element input is given in Section 2.1.

Table 4.57-1 SHELL 57 Summary Input

Element Name	SHELL57
Nodes	I, J, K, L
Degrees of Freedom	TEMP
Real Constants	TK (I), TK (J), TK (K), TK (L), THETA (TK (J), TK (K), TK (L) default to TK (I))
Material Properties	KXX, KYY, DENS, C, ENTH
Surface Loads	Convections: face 1 (I-J-K-L) (bottom, -Z side), face 2 (I-J-K-L) (top, +Z side) Heat Fluxes: face 1 (I-J-K-L) (bottom, -Z side) face 2 (I-J-K-L) (top, +Z side)
Body Loads	Heat Generations: HG (I), HG (J), HG (K), HG (L)
Special Features	Birth and death
KEYOPT(2)	0 - Evaluate film coefficient (if any) at average film temperature, (TS + TB)/2 1 - Evaluate at element surface temperature, TS 2 - Evaluate at fluid bulk temperature, TB 3 - Evaluate at differential temperature, |TS - TB|

4.57.2 Output Data

The solution output associated with the element is in two forms:

- nodal temperatures included in the overall nodal solution
- additional element output as shown in Table 4.57-2

Heat flowing out of the element is considered to be positive. The element output directions are parallel to the element coordinate system. A general description of solution output is given in Section 2.2. See the *ANSYS Basic Analysis Procedures Guide* for ways to view results. The following notation is used in Table 4.57-2:
A colon (:) in the **Name** column indicates the item can be accessed by the Component Name method [**ETABLE**, **ESOL**] (see Section 2.2.2). The **O** and **R** columns indicate the availability of the items in the file *Jobname*.OUT (**O**) or in the results file (**R**), a **Y** indicates that the item is *always* available, a number refers to a table footnote which describes when the item is *conditionally* available, and a - indicates that the item is *not* available.

Table 4.57-2 SHELL 57 Element Output Definitions

Name	Definition	O	R
EL	Element number	Y	Y
NODES	Nodes - I, J, K, L	Y	Y
MAT	Material number	Y	Y
AREA	Convection face area	Y	Y
CENT: X, Y, Z	Center location XC, YC, ZC	-	Y
HGEN	Heat generations HG(I), HG(J), HG(K), HG(L)	Y	-
TG: X, Y, SUM	Thermal gradient components and vector sum at centroid	Y	Y
TF: X, Y, SUM	Thermal flux (heat flow rate/cross-sectional area) components and vector sum at centroid	Y	Y
FACE	Face label	1	1
AREA	Face area	1	1
NODES	Face nodes	1	1
HFILM	Film coefficient	1	1
TAVG	Average face temperature	1	1
TBULK	Fluid bulk temperature	1	-
HEAT RATE	Heat flow rate across face by convection	1	1
HFAVG	Average film coefficient of the face	-	1
TBAVG	Average face bulk temperature	-	1
HFLXAVG	Heat flow rate per unit area across face caused by input heat flux	-	1
HEAT RATE/AREA	Heat flow rate per unit area across face by convection	1	-
HEAT FLUX	Heat flux at each node of face	1	-

1. If a surface load is input

Table 4.57-3 lists output available through the **ETABLE** command using the Sequence Number method. See Chapter 5 of the *ANSYS Basic Analysis Procedures Guide* and Section 2.2.2.2 of this manual for more information. The following notation is used in Table 4.57-3:

Name - output quantity as defined in the Table 4.57-2

Item - predetermined *Item* label for **ETABLE** command

Table 4.57-3 SHELL57 Item and Sequence Numbers for the ETABLE and ESOL Commands

Name	Item	BOT	TOP
AREA	NMISC	1	7
HFAVG	NMISC	2	8
TAVG	NMISC	3	9
TBAVG	NMISC	4	10
HEAT RATE	NMISC	5	11
HFLXAVG	NMISC	6	12

4.57.3 Assumptions and Restrictions

Zero area elements are not allowed. This occurs most frequently when the elements are not numbered properly. The element must not taper down to a zero thickness at any corner. The four nodes defining the element should lie in an exact flat plane; however, a small out-of-plane tolerance is permitted so that the element may have a slightly warped shape. A warning message will be produced if an element is more than slightly warped (i.e., if any of the three global Cartesian components of any corner normal differs from the corresponding component of the element normal by more than .00001). A triangular element may be formed by defining duplicate K and L node numbers as described in Section 2.8.

4.57.4 Product Restrictions

When used in the product(s) listed below, the stated product-specific restrictions apply to this element in addition to the general assumptions and restrictions given in the previous section.

ANSYS/Thermal

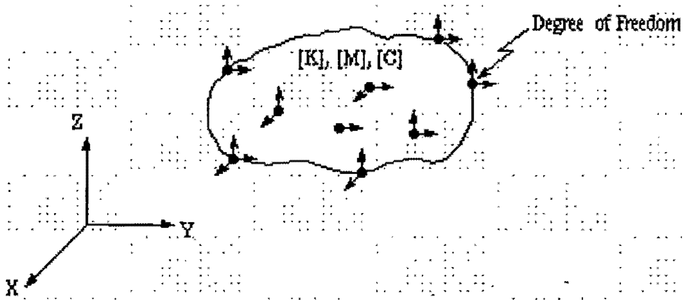
The birth and death special feature is not allowed.

4.50 MATRIX50 Superelement

Multiphysics	✓
Mechanical	✓
Structural	✓
LS-DYNA	
LinearPlus	
Thermal	✓
Emag 3-D	
Emag 2-D	
FLOTRAN	
PrepPost	✓
ED	✓

MATRIX50 is a group of previously assembled ANSYS elements that is treated as a single element. The superelement, once generated, may be included in any ANSYS model and used in any analysis type for which it is applicable. The superelement can greatly decrease the cost of many analyses. Once the superelement matrices have been formed, they are stored on a file and can be used in other analyses as any other ANSYS element. Multiple load vectors may also be stored with the superelement matrices, thereby allowing various loading options. See Section 14.50 of the *ANSYS Theory Reference* for more details about this element.

Figure 4.50-1 MATRIX50 Superelement



4.50.1 Input Data

The superelement, which is a mathematical matrix representation of an arbitrary structure, has no fixed geometrical identity and is conceptually shown in Figure 4.50-1. Any analysis using a superelement as one of its element types is called a superelement use pass (or run). The degrees of freedom are the master degrees of freedom specified during the generation pass.

The element name is MATRIX50 (the number 50 or the name MATRIX50 should be input for the variable *ENAME* on the **ET** command). The **SE** command is used to define a superelement. **SE** reads the superelement from *Jobname*.SUB (defaults to file.SUB) in the working directory. The material number [**MAT**] is only used when material dependent damping [**MP**,DAMP] is present. The real constant table number [**REAL**] is not used. The appropriate element type number [**TYPE**], however, must be entered.

An element load vector is generated along with the element at each load step of the superelement generation pass. Up to 31 load vectors may be generated. Load vectors may be proportionately scaled in the use pass. The scale factor is input on the element surface load command [**SFE**]. The load label is input as SELV, the load key is the load vector number, and the load value is the scale factor. The load vector number is determined from the load step number associated with the superelement generation. If a superelement load vector has a zero scale factor (or is not scaled at all), this load vector is not included in the analysis. Any number of load vector-scale factor combinations may be used in the use pass.

The KEYOPT(1) option is for the special case where the superelement is to be used with a T^4 nonlinearity, such as for radiation. The File.SUB for this case may be constructed directly by the user or may be generated by AUX12, the radiation matrix generator.

A summary of the element input is given in Table 4.50-1. A general description of element input is given in Section 2.1.

Table 4.50-1 MATRIX50 Input Summary

Element Name	MATRIX50
Nodes	None input (supplied by element)
Degrees of Freedom	As determined from the included element types (a mixture of multi-field degrees of freedom is not allowed)
Real Constants	None
Material Properties	DAMP
Surface Loads	Surface load effects may be applied through a generated load vector and scale factors. Use the SFE command to supply scale factors with *LAB* = SELV, *LKEY* = load vector number (31 maximum), and *VAL1* = scale factor.
Body Loads	Body loads may be applied through a generated load vector and scale factors as described for surface loads.
Special Features	Radiation (if KEYOPT(1) = 1), Large rotation
KEYOPT(1)	0 - Normal substructure 1 - Special radiation substructure
KEYOPT(6)	0 - Do not print nodal forces 1 - Print nodal forces

4.50.2 Output Data

Displacements and forces may be printed for each (master) degree of freedom in a structural superelement in the "use" pass. The nodal forces may be output if KEYOPT(6)=1. The stress distribution within the superelement and the expanded nodal displacements can be obtained from a subsequent stress pass. In addition to the database and substructure files from the generation run, File.DSUB must be saved from the superelement "use" pass and input to the expansion pass (if an expansion pass is desired). A general description of solution output is given in Section 2.2.

4.50.3 Assumptions and Restrictions

A superelement may contain elements of any type. See the **D** command for degree of freedom field groups. Superelements of different field types may be mixed within the use run. The nonlinear portion of any element included in a superelement will be ignored and any bilinear element will maintain its initial status throughout the analysis. Superelements may contain other superelements.
The PCG solver does not support MATRIX50 elements.
The relative locations of the superelement attachment points in the nonsuperelement portion of the model (if any) should match the initial superelement geometry.
If the superelement contains a mass matrix, acceleration [ACEL] defined in the use run will be applied to the superelement. If a load vector containing acceleration effects is also applied in the use run, *both* accelerations (the ACEL command and the load vector) will be applied to the superelement. Similarly, if the superelement contains a damping matrix (as specified in the generation run) and α and β damping multipliers [**ALPHA** and **BETA**] are defined in the use run, additional damping effects will be applied to the superelement. Care should be taken to avoid duplication of acceleration and damping effects.
Pressure and thermal effects may be included in a superelement only through its load vectors.
The dimensionality of the superelement correspond to the maximum dimensionality of any element used in its generation. Two-dimensional superelements should only be used in two-dimensional analyses, and three-dimensional superelements in three-dimensional analyses.
See Section 17.6 of the *ANSYS Theory Reference* for a discussion of the substructure matrix assembly procedure.

4.50.4 Product Restrictions

When used in the product(s) listed below, the stated product-specific restrictions apply to this element in addition to the general assumptions and restrictions given in the previous section.

ANSYS/Structural

KEYOPT(1)=0

ANSYS/Thermal

- This element may be used as a radiation substructure only. KEYOPT(1) defaults to 1 instead of 0 and cannot be changed.
- The DAMP material property, surface loads, and body loads are not applicable.
- The large rotation special feature is not applicable.

Chapter 4: Radiation

4.1 What Is Radiation?

Radiation is the transfer of energy via electromagnetic waves. The waves travel at the speed of light, and energy transfer requires no medium. Thermal radiation is just a small band on the electromagnetic spectrum. Because the heat flow that radiation causes varies with the fourth power of the body's absolute temperature, radiation analyses are highly nonlinear.

4.2 Analyzing Radiation Problems

The ANSYS program provides three methods for radiation analysis, each meant for a different situation:

- You can use LINK31, the radiation link element, for simple problems involving radiation between two points or several pairs of points.
- You can use the surface effect elements, SURF19, SURF22, SURF151, and SURF152 for radiation between a surface and a point.
- Use the AUX12 radiation matrix generator for more generalized radiation problems involving two or more surfaces. (Only the ANSYS/Multiphysics, ANSYS/Mechanical, and ANSYS/Thermal programs offer AUX12.)

You can use the three radiation analysis methods for either transient or steady-state thermal analyses. Radiation is a nonlinear phenomenon, so you will need an iterative solution to reach a converged solution.
The unit of temperature also plays an important role in radiation analysis; you perform radiation calculations in absolute temperature units. Therefore, if you define your model data in terms of degrees Fahrenheit or degrees Celsius, you must specify a temperature offset: 460° for the Fahrenheit system and 273° for the Centigrade system.
To specify a temperature offset, use either of the following:

Command(s):
TOFFST

GUI:
Main Menu>Preprocessor>Loads>Analysis Options
Main Menu>Solution>Analysis Options

4.3 Using LINK31, the Radiation Link Element

LINK31 is a two-node, nonlinear line element that calculates the heat flow caused by radiation between two points. The element requires you to specify, in the form of real constants:

- An effective radiating surface area
- Form factor
- Emissivity
- The Stefan-Boltzmann constant.

Limit your use of the LINK31 analysis method to simple cases where you know, or can calculate easily by hand, the radiation form factors.

4.4 Using the Surface Effect Elements

A convenient way to model radiation between a surface and a point is to use surface effect elements superimposed on surfaces that emit or receive radiation. ANSYS provides such elements: SURF19 and SURF151 for two-dimensional models, and SURF22 and SURF152 for three-dimensional models. The element option KEYOPT(9) activates radiation for these elements. The form factor can be specified as a real constant (defaults to 1) using KEYOPT(9)=1, or you can calculate a cosine effect (using KEYOPT(9)=2 or 3) from the basic element orientation and the extra node location.

4.5 Using AUX12, the Radiation Matrix Generator

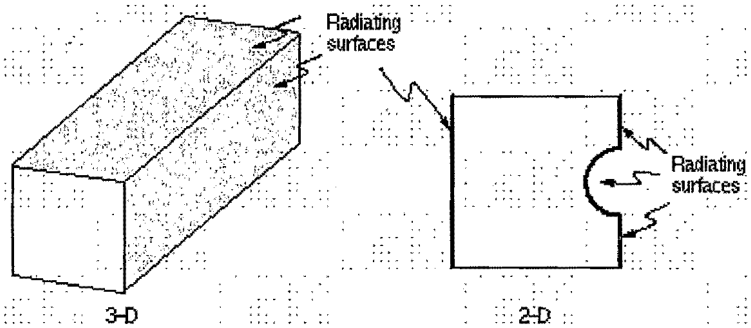
Offered in the ANSYS/Multiphysics, ANSYS/Mechanical, and ANSYS/Thermal programs only, this method works for generalized radiation problems involving several surfaces receiving and emitting radiation. The method involves generating a matrix of form factors (view factors) between radiating surfaces and using the matrix as a superelement in the thermal analysis. You also can include hidden or partially hidden surfaces, as well as a "space node" that can absorb radiation energy.
The AUX12 analysis method consists of three steps:
1. Define the radiating surfaces.
2. Generate the radiation matrix.
3. Use the radiation matrix in the thermal analysis.

4.5.1 Defining the Radiating Surfaces

To define the radiating surfaces, you create a superimposed mesh of LINK32 elements in 2-D models and SHELL57 elements in 3-D models. To do so, perform the following tasks:

1. Build the thermal model in the preprocessor (PREP7). Radiating surfaces do not support symmetry conditions, therefore models involving radiating surfaces can not take advantage of geometric symmetry and must therefore be modeled completely. The radiating surfaces usually are *faces* of a 3-D model and *edges* of a 2-D model, as shown below:

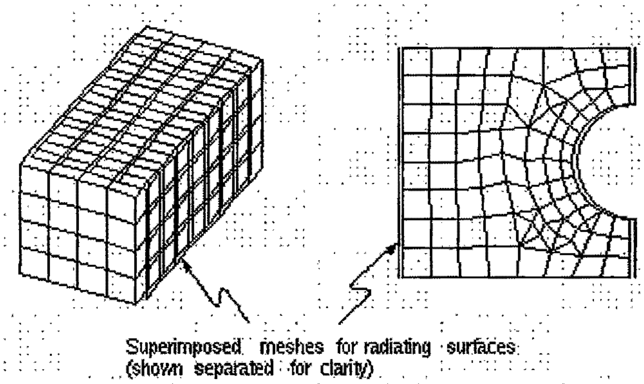
Figure 4-1 Radiating surfaces for 3-D and 2-D models



2. Superimpose the radiating surfaces with a mesh of SHELL57 elements in 3-D models or LINK32 elements in 2-D models, as shown in the graphic below. The best way to do this is to first create a subset of the surface nodes, and then generate the surface elements using one of the following:

Command(s):
ESURF
GUI:
Main Menu>Preprocessor>Create>Elements>Surf Effect>Extra Node
Main Menu>Preprocessor>Create>Elements>Surf Effect>No extra Node
Make sure to first activate the proper element type for the surface elements. Also, if the surfaces are to have different emissivities, assign different material reference numbers before creating the elements.

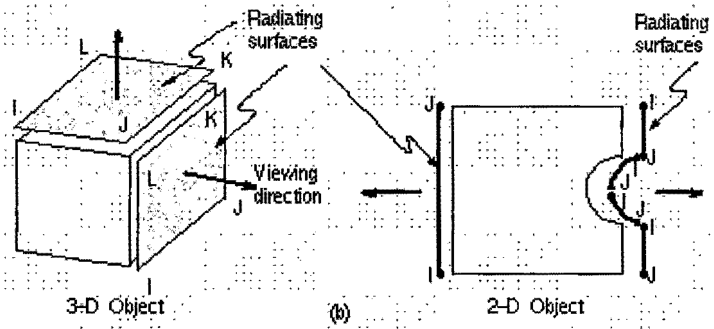
Figure 4-2 Superimposing elements on radiating surfaces



Caution: *Radiating surface mesh of* SHELL57 *or* LINK32 *elements must match (node for node) the underlying solid element mesh. If it does not match, the resulting thermal solution will be incorrect.*

The orientation of the superimposed elements is important. AUX12 assumes that the "viewing" direction (that is, the direction of radiation) is along $+Z_e$ for SHELL57 elements and along $+Y_e$ for LINK32 elements (where *e* denotes the outward normal direction of the element coordinate system). Therefore, you must mesh the superimposed elements so that the radiation occurs from (or to) the proper face. The order in which the element's nodes are defined controls the element orientation, as shown below:

Figure 4-3 Orienting the superimposed elements



3. Define a space node, which simply is a node that absorbs radiant energy not received by other surfaces in the model. Location of this node is not important. An open system usually requires a space node. However, *you should not specify a space node for a closed system.*

4.5.2 Generating the AUX12 Radiation Matrix

Calculating the radiation matrix requires the following inputs:

- Nodes and elements that make up the radiating surfaces
- Model dimensionality (2-D or 3-D)
- Emissivity and Stefan-Boltzmann constant
- The method used to calculate the form factors (hidden or visible)
- A space node, if desired.

To generate the matrix, perform these steps:

1. Enter AUX12 using one of these methods:

Command(s):
/AUX12

GUI:
Main Menu>Radiation Matrix

2. Select the nodes and elements that make up the radiation surfaces. An easy way to do this is to select elements by type and then select all attached nodes. To perform these tasks, use the GUI path **Utility Menu> Select>Entities** or the commands ESEL,S,*TYPE* and NSLE. If you have defined a space node, remember to select it.

3. Specify whether this is a 2-D model or a 3-D model, using either of the following:

Command(s):
GEOM

GUI:
Main Menu>Radiation Matrix>Other Settings

AUX12 uses different algorithms to calculate the form factors for 2-D and 3-D models respectively. AUX12 assumes a 3-D model by default. Two-dimensional models may be either planar (NDIV value =0), or axisymmetric (NDIV value > 0), with planar as the default. Axisymmetric models are expanded internally to a 3-D model, with NDIV representing the number of axisymmetric sections. For example, setting NDIV to 10 indicates 10 sections, each spanning 36 degrees.

4. Define the emissivity using either method shown below. Emissivity defaults to unity (1.0).

Command(s):
EMIS

GUI:
Main Menu>Radiation Matrix>Emissivities

5. Define the Stefan-Boltzmann constant using either method shown below. The Stefan-Boltzmann constant defaults to 0.119E-10 Btu/hr-in^2-R^4. (In S.I. Units, the constant has the value 5.67E-8 W/m^2-K^4.)

Command(s):
STEF

GUI:
Main Menu>Radiation Matrix>Other Settings

6. Specify how to calculate form factors, using either of the following:

Command(s):
VTYPE

GUI:
Main Menu>Radiation Matrix>Write Matrix
You can choose between the hidden and non-hidden methods:

- The non-hidden method calculates the form factors from every element to every other element regardless of any blocking elements.
- The hidden method (default) first uses a hidden-line algorithm to determine which elements are "visible" to every other element. (A "target" element is visible to a "viewing" element if their normals point toward each other and there are no blocking elements.) Then, form factors are calculated as follows:
- Each radiating or "viewing" element is enclosed with a unit hemisphere (or a semicircle in 2-D).
- All target or "receiving" elements are projected onto the hemisphere or semicircle.
- To calculate the form factor, a predetermined number of rays are projected from the viewing element to the hemisphere or semicircle. Thus, the form factor is the ratio of the number of rays incident on the projected surface to the number of rays emitted by the viewing element. In general, accuracy of the form factors increases with the number of rays. You can increase the number of rays via the NZONE field on the VTYPE command or the **Write Matrix** menu option; both indicate the number of radial sampling zones.

7. If necessary, designate the space node using either of the methods shown below:

Command(s):
SPACE

GUI:
Main Menu>Radiation Matrix>Other Settings

8. Use either the WRITE command or the **Write Matrix** menu option to write the radiation matrix to the file *Jobname*.SUB. If you want to write more than one radiation matrix, use a separate filename for each matrix. To print your matrices, issue the command MPRINT,1 before issuing the WRITE command.

9. Reselect all nodes and elements using either of the following:

Command(s):
ALLSEL

GUI:
Utility Menu>Select>Everything
You now have the radiation matrix written as a superelement on a file.

4.5.3 Using the Radiation Matrix in the Thermal Analysis

After writing the radiation matrix, re-enter the ANSYS preprocessor (PREP7) and read the matrix in as a superelement. To do so, perform these steps:

1. Re-enter the preprocessor using one of these methods:
Command(s):
/PREP7
GUI:
Main Menu>Preprocessor
Specify MATRIX50 (the superelement) as one of the element types.

2. Switch the element type pointer to the superelement using either of the following:
Command(s):
TYPE
GUI:
Main Menu>Preprocessor>-Modeling-Create>Elements>Elem Attributes

3. Read in the superelement matrix using one of these methods:
Command(s):
SE
GUI:
Main Menu>Preprocessor>-Modeling-Create>Elements> -Superelements-From .SUB File

4. Either unselect or delete the superimposed mesh of SHELL57 or LINK32 elements, using either of the following:
Command(s):
EDELE
GUI:
Main Menu>Preprocessor>-Modeling-Delete>Elements
(The thermal analysis does not require these elements.)

5. Exit from the preprocessor and enter the SOLUTION processor.

6. Assign the known boundary condition to the space node using either of the following:
Command(s):
D, F
GUI:
Main Menu>Solution >-Loads-Apply...(etc.)
This boundary typically is a temperature (such as ambient temperature), but also may be a heat flow. The boundary condition value should reflect the actual environmental conditions being modeled.

7. Proceed with the thermal analysis as explained in the other chapters of this manual.

4.6 Recommendations for Using Space Nodes

Although modeling radiation does not always require a space node, the decision to or not to use one can affect the accuracy of your thermal analysis results. Keep the following recommendations about space node usage in mind as you build your model.

4.6.1 Considerations for the Non-hidden Method

The non-hidden method of form factor calculation usually is accurate enough for any system without requiring special attention to space nodes. Generally, you *should not* specify a space node for a closed system, but you *should* specify one for an open system. Only one situation requires special attention: when modeling an open system which includes gray body radiation (emissivity is less than 1), you *must* use a space node to ensure accurate results.

4.6.2 Considerations for the Hidden Method

For the hidden method of form factor calculation, the accuracy of the form factor calculations within AUX12 can affect the accuracy of the radiation calculated to the space node. Because inaccuracies in the calculations accumulate at the space node, the relative error in the space node form factor can be exaggerated in a closed or nearly closed system.
When using the hidden method, you may need to increase the number of rays used in the form factor calculation and to refine the mesh in order to make the form factors more accurate. If this is not possible, consider the following tips when defining the space node:

- For a closed system in which all radiating surfaces form an enclosure and do not radiate to space, do not use a space node.
- If the nature of the problem makes it acceptable to simulate radiation between the radiating surfaces only (ignoring radiation to space), then do not specify a space node. This approach is valid only when modeling black body radiation (where emissivity = 1).
- For a nearly closed system, if you must account for radiation to space, then mesh the opening and constrain the temperature of the nodes in the opening to the temperature of space. The form factor to space will then be calculated explicitly and more accurately.
- For an open system where there are significant losses to space, you can use a space node (with a specified boundary condition) to capture the lost radiation with acceptable accuracy using moderate mesh refinement and a moderate number of rays.

4.7 General Guidelines for AUX12

Below are some general guidelines for using the AUX12 approach to radiation analysis:

- The non-hidden method should be used if and only if all the radiating surfaces see each other fully. If the non-hidden method is used for cases where *any* blocking effect exists, there will be significant inaccuracies in view factor calculations, and the subsequent thermal analysis results can be physically inaccurate, or the problem might not even converge.
- The hidden method requires significantly longer computer time than the non-hidden method. Therefore, use it only if blocking surfaces are present or if surfaces cannot be grouped.
- In some cases, you may be able to group radiating surfaces so that each group is isolated completely from the other groups in terms of radiation heat transfer. In such cases, you can save significant time by creating a separate radiation matrix for each group using the non-hidden method. (This is true so long as no blocking effects exist within a group.) You can do this by selecting the desired group of radiating surfaces before writing the matrix.
- For the hidden method, increasing the number of rays usually produces more accurate form factors.
- For both hidden and non-hidden methods, the finer the mesh of the radiating surface elements, the more accurate are the form factors. However, when hidden method is used, it is particularly important to have a fairly refined mesh in order to obtain the same level of accuracy in view factor computation as the non-hidden method. Event though increasing the number of rays used (controlled by NZONE argument of the **VTYPE** command) helps in accuracy, for a coarse mesh, increasing NZONE to even its maximum limit might not yield an accurate solution for the hidden method.
- For axisymmetric models, about 20 axisymmetric sectors provide reasonably accurate form factors. Elements should have reasonable aspect ratios whey they are expanded to a 3-D model.
- LINK32 elements, which are used as superimposed radiation surface elements in 2-D planar or axisymmetric models, do not directly support the axisymmetric option. In axisymmetric models, therefore, be sure to delete (or unselect) them before doing the thermal analysis.

Theoretically, the summation of view factor from any radiating surface to all other radiating surfaces should be 1.0 for a closed system. This is printed as ***** FORM FACTORS ***** TOTAL= *Value* for each radiating surface if the view factors for radiating surfaces are printed using the **MPRINT**,1 command. For open systems, the summation should always be less than 1.0. One way of checking whether the view factor calculations are correct or not is to use the MPRINT,1 command, and check if the summation of view factors for any radiating surface exceeds 1.0. This can happen if the non-hidden method is inadvertently used for calculating view factors between radiating surfaces with blocking effects.

Appendix C
Internal Air Space Heat Transfer Calculations

EFFECTIVE K TO ACCOUNT FOR CONVECTION ACROSS AIR SPACE

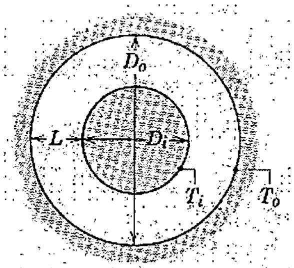
Free convection heat transfer across the air space between the Gammacell-40 and the inner wall of the overpack can be represented by an effective thermal conductivity, k_{eff}, which is the thermal conductivity that a stationary fluid should have to transfer the same amount of heat as the moving fluid [4]. The air space is approximated as the annular space between long concentric cylinders or concentric spheres. The correlation for k_{eff} is then of the form:

$$\frac{k_{eff}}{k} = 0.386\left(\frac{\Pr}{0.861+\Pr}\right)^{1/4}\left(Ra_c^*\right)^{1/4}$$

where, k is the thermal conductivity of the fluid at the film temperature,
Pr is the Prandtl number for the fluid at the film temperature, and

$$Ra_c^* = \frac{\left[\ln(Do/Di)\right]^4}{L^3\left(Di^{-3/5}+Do^{-3/5}\right)^5}Ra_L \text{ and } 10^2 < Ra_c^* < 10^7.$$

where Di, Do and L are defined in the following figure,



and,

$$Ra_L = \frac{g\beta(Ti-To)L^3}{\nu\alpha}$$

where, g is the acceleration due to gravity = 9.8 m/s^2,
β is the inverse of the film temperature in degrees Kelvin,
ν is the kinematic viscosity of the fluid at the film temperature,
α is the thermal diffusivity of the fluid at the film temperature,
Ti and To are the temperature of the surfaces as defined in the figure above, and
the film temperature, T = (Ti + To)/2.

EFFECTIVE K UNDER STEADY STATE CONDITIONS

Under steady state conditions for Load Cases 1 through 5 (Sections 5.1 through 5.5, respectively), Ti is the temperature measured on the outside of the Gammacell-220, while To is the temperature measured on the inside wall of the overpack. From the experimental measurements, Ti ≅ 27°C and To ≅ 26°C.

Therefore, the film temperature, T = (27+26)/2 = 26.5°C, and the required air properties are [4],

$\beta = 1/(26.5+273) = 0.0033\ K^{-1}$, $k = 0.026$ W/m°C, $\nu = 15.9x10\text{-}6\ m^2/s$, $\alpha = 26.3x10\text{-}6\ m^2/s$, and Pr = 0.707.

The outer diameter of the Gammacell-40 lead casing, Di = 16.2 in = 0.41 m.

The diameter to the inside wall of the overpack, Do, is the distance from the center of the Gammacell-40 to the inner overpack wall multiplied by two.
This yields, Do = 17.5*2 = 35 in = 0.89 m.

The distance L is then, (Do – Di)/2 = (0.89-0.41)/2 = 0.24 m.

From the equations in the previous section,

$$Ra_L = \frac{9.81*0.0033*(27-26)(0.24)^3}{15.9x10^{-6}*26.3x10^{-6}} = 1.07x10^6$$

$$Ra_c^* = \frac{[\ln(0.89/0.41)]^4}{(0.24)^3\left((0.41)^{-3/5}+(0.89)^{-3/5}\right)^5}*1.07x10^6 = 1.68x10^5$$

$$\frac{k_{eff}}{k} = 0.386\left(\frac{0.707}{0.861+0.707}\right)^{1/4}\left(1.68x10^5\right)^{1/4} = 6.4$$

k_{eff} is then: $k_{eff} = 6.4*0.026 = 0.2\ \ W/m°C$

EFFECTIVE K UNDER REGULATORY FIRE CONDITIONS

Under regulatory fire conditions for Load Case 5 (Section 5.5), Ti is the temperature on the outside of the Gammacell-40, while To is the temperature on the inside wall of the overpack. These temperatures are conservatively estimated as, Ti = 27°C (steady state temperature) and To = 800°C (fire temperature).

Therefore, the film temperature, T = (27+800)/2 = 414°C, and the required air properties are [4],

$\beta = 1/(414+273) = 0.0015\ K^{-1}$, $k = 0.052$ W/m°C, $\nu = 68.0x10\text{-}6\ m^2/s$, $\alpha = 98.0x10\text{-}6\ m^2/s$, and Pr = 0.7.

The dimensions Do, Di and L are as in the previous section.

From the previous equations,

$$Ra_L = \frac{9.81*0.0015*(800-27)(0.24)^3}{68.0x10^{-6}*98.0x10^{-6}} = 2.36x10^7$$

$$Ra_c^* = \frac{[\ln(0.89/0.41)]^4}{(0.24)^3\left((0.41)^{-3/5}+(0.89)^{-3/5}\right)^5}*2.36x10^7 = 3.71x10^6$$

$$\frac{k_{eff}}{k} = 0.386\left(\frac{0.7}{0.861+0.7}\right)^{1/4}\left(3.71x10^6\right)^{1/4} = 13.9$$

k_{eff} is then: $k_{eff} = 13.9*0.052 = 0.7 \; W/m°C$

CONTRIBUTION OF HEAT TRANSFER THROUGH STEEL ACROSS AIR SPACE

Heat transfer by conduction occurs through the air and through the steel support structure of the Gammacell-40, specifically the top steel brace. The contribution of the conduction through the top steel brace is calculated as follows:

The area of the inside top of the overpack inside the inner frame is π*(18")^2 = 1018 in^2.

The conduction area of the top steel brace is about,

Number of fins around diameter = 6, Width of fins = 0.5", Length of fins = 8"
Conduction area of the steel brace is, therefore, 6 * 0.5 * 8 = 24 in^2.

Percentage of total area is then 100*(24/1018) = 2 %.

TOTAL THERMAL CONDUCTIVITY OF AIR SPACE

The total thermal conductivity of the air space is calculated by combining the effective thermal conductivity to account for convection and the contribution of conduction through the steel support structure of the Gammacell-40.

For all temperatures, the combined thermal conductivity, k, is calculated as follows;

$$k = k_{eff}*0.98 + k_{st}*0.02$$

where, k_{eff} is the effective thermal conductivity to account for convection, and
k_{st} is the thermal conductivity of steel.

Appendix D
Derivation of Heat Transfer Coefficients

The heat transfer coefficients used in the analysis were chosen to match the empirical results. This appendix demonstrates that the values used are reasonable in comparison with approximate relations for air. It also calculates bounding values for the heat transfer coefficient for a cylinder in a fire environment. For all steady state calculations, the temperatures of the applicable surfaces are taken from the steady state analysis of the F-430 overpack, Load Case 1, Sections 5.1 and 6.1.

HEAT TRANSFER COEFFICIENT FOR STEADY STATE AND SOLAR LOAD ANALYSES

The F-430 overpack can be approximated as a cylinder in the cross flow of the air with a diameter, D, of 50.22" = 1.28 m. The flow of gas over the outside of the overpack is estimated to take place at a low velocity of 1.0 m/s (3.3 ft/s).

From Incropera and Dewitt [4], the heat transfer coefficient takes the form:

$$h = k/D * C(uD/v)^n Pr^{0.333}$$

where: D is the average width of cross section of the overpack = 1.28 m
C,n are constants that depend on the Reynolds number (uD/v)
k = thermal conductivity of the fluid
v = kinematic viscosity of the fluid
Pr = Prandtl number for the fluid
u = free stream velocity

The property values of k,v and Pr are evaluated at the film temperature, which is defined as the mean of the wall and free stream fluid temperatures.

The wall temperature was measured as 21 °C on the outside of the overpack, while the ambient temperature was 21°C. The film temperature is, therefore, 21 °C and, from Incropera and Dewitt [4], the property values are k = 0.026 W/m °C, v = 1.6E-5 m^2/s and Pr = 0.707. This yields a Reynolds number of about 80,000. At this value of Re, the constants C and n are 0.027 and 0.805, respectively [4]. Substituting in the appropriate values in the above equation yields a heat transfer coefficient of :

$$h = \frac{0.026(0.027)(1.0*1.28/1.6E\text{-}5)^{0.805}.707^{0.333}}{1.28} = 4.3\ W/m^2\,°C$$

A value of 4.0 W/m^2 °C was used in the analysis.

HEAT TRANSFER COEFFICIENT DURING THE FIRE TEST

At the start of the fire, the wall temperature is 21 °C on the outside of the overpack. The film temperature is, therefore, 411 °C and, from Incropera and Dewitt [4], the property values are k = 0.052 W/m °C, ν = 6.6E-5 m^2/s and Pr = 0.693. This yields a Reynolds number of about 200,000. At this value of Re, the constants C and n are 0.027 and 0.805, respectively [4]. The flow of hot gases over the outside of the overpack is assumed to take place at a high velocity of 10.0 m/s (32.8 ft/s) [12].

Substituting in the appropriate values in the equation from the previous section yields a heat transfer coefficient of :

$$h = \frac{0.052(0.027)(10.0*1.28/6.6E\text{-}5)^{0.805}.693^{0.333}}{1.28} = 17.5\ W/m^2\,°C$$

A value of 18.0 W/m^2 °C was conservatively used in the analysis of the regulatory fire.

Appendix E
ANSYS Input Files for Load Cases

This appendix includes all of the input files used in the analyses of the F-430 overpack. Each of the input files (*.inp) perform different tasks as described below. See Section 5 of the main body of this report for descriptions of the Load Cases.

Input File	Description
Modela.inp	Model of F-430 overpack for Load Cases 1, 2, 3 and 4
Loada.inp	Load input for steady state Load Cases 1, 2, 3 and 4
Loadsolar.inp	Load input for transient solar loading (12 hour insolation) for Load Case 4
Modfire.inp	Model of F-430 overpack for regulatory fire transient Load Case 5
Loadfire.inp	Load input for regulatory fire transient Load Case 5

The file bff430.inp listed in the transient load input files (loadsolar.inp and loadfire.inp) is a file containing the initial steady state temperature condition of the model from Load Case 3.

```
! modela.inp
!
/prep7
/facet,norml
cv=39.37
cdread,solid,model
! material properties
! mild steel
mptemp,1,-73,127,327,527,727,927
mp,dens,1,8131
mpdata,kxx,1,1,41.0,42.2,39.7,35.0,27.6,27.
6
mpdata,c,1,1,434,487,559,685,1090,1090
! foam 1 - 40 lb
mptemp
mptemp,1,0,260,400,540,800
mpdata,dens,2,1,641,641,321,256,26
mptemp
mptemp,1,0,260,400,465,800
mpdata,kxx,2,1,0.087,0.087,0.087,0.054,0.0
7
mp,c,2,1959
! air
mptemp
mptemp,1,-73,127,327,527,727,927
mpdata,dens,3,1,1.7458,0.8711,0.5804,0.43
54,0.3482,0.2902
mpdata,kxx,3,1,0.0181,0.0338,0.0469,0.057
3,0.0667,0.0763
mpdata,c,3,1,1007,1014,1051,1099,1141,11
75
! radiation surfaces
mp,emis,4,0.5
! stainless steel
mptemp
mptemp,1,-73,127,327,527,727,927
mp,dens,5,7900
mpdata,kxx,5,1,12.6,16.6,19.8,22.6,25.4,28.
0
mpdata,c,5,1,402,515,557,582,611,640
!
! air including conduction and convection
across cavity
mpdata,dens,6,1,1.7458,0.8711,0.5804,0.43
54,0.3482,0.2902
kxx1=41.0*0.02+0.98*0.2
kxx2=42.2*0.02+0.98*0.2
kxx3=39.7*0.02+0.98*0.2
kxx4=35.0*0.02+0.98*0.2
kxx5=27.6*0.02+0.98*0.2
kxx6=27.6*0.02+0.98*0.2
mpdata,kxx,6,1,kxx1,kxx2,kxx3,kxx4,kxx5,
kxx6
mpdata,c,6,1,1007,1014,1051,1099,1141,11
75
!
! lead
mptemp
mptemp,1,20,327,330,800
mpdata,dens,7,1,11340,11005,10686,10686
mptemp
mptemp,1,-23,27,127,227,327,328
mptemp,7,331,332,1000
mpdata,c,7,1,127,129,132,136,142,6188
mpdata,c,7,7,6188,159,159
mptemp
mptemp,1,-273,-27,123,227,327,527
mptemp,7,727,927
mpdata,kxx,7,1,35,35,34,33,31,19
mpdata,kxx,7,7,22,24
! foam 2 - 8 lb
mptemp
mptemp,1,0,260,400,540,800
mpdata,dens,8,1,128,128,64,51,5
mptemp
mptemp,1,0,260,400,465,800
mpdata,kxx,8,1,0.038,0.038,0.038,0.054,0.0
7
mp,c,8,1959
!
! radiation emissivities
mp,emis,9,0.01
mp,emis,10,0.8
mp,emis,11,0.5
!
! mild steel with contact resistance
mptemp
mptemp,1,-73,127,327,527,727,927
mp,dens,12,8131
mpdata,kxx,12,1,0.53,0.99,1.35,1.63,1.86,2.
11
mpdata,c,12,1,434,487,559,685,1090,1090
!
! add stainless steel shell volumes
vadd,4,7,9
nummrg,kp
!
! meshing properties
/uis,msgpop,3
mshkey,0
mshape,1,3d
!
! mesh air space around pig
et,1,70
type,1
esize,1.5/cv
mat,6
vmesh,3
mat,12
vmesh,2
mat,5
vmesh,12
!
! create inner radiation enclosure
et,3,57
type,3
!
mat,9
asel,s,area,,26,27
asel,a,area,,29
amesh,all

mat,10
asel,s,area,,22,25
amesh,all

mat,11
asel,s,area,,33,34
amesh,all

asel,s,area,,26,27
asel,a,area,,29
asel,a,area,,33,34
esla,s
nelem
ensym,0,,0,all
allsel
!
et,1,70
type,1
mat,7
vmesh,1
mat,2
vmesh,5
mat,2
vmesh,6
mat,3
vmesh,8
mat,8
vmesh,10
mat,8
vmesh,11
!
! create outer surface
asel,s,area,,41
asel,a,area,,52
nsla,s,1
cm,outsurf,node
asel,s,area,,41
nsla,s,1
cm,ssurf,node
asel,s,area,,52
nsla,s,1
cm,tsurf,node
allsel
cmsel,s,outsurf
!
! create outer radiation elements
eall
et,2,57
r,4,1.0
type,2
mat,4
real,4
esurf
n,999999,0.75,0.75,-0.75
allsel
esel,s,type,,2
nelem
nsel,r,loc,y,0.636,0.638
esln,s,1
esel,r,type,,2
cm,toprad,elem
esel,s,type,,2
cmsel,u,toprad
cm,siderad,elem
allsel
!
!create outer shell divisions for solar load
application
cmsel,s,tsurf
esln,s,0
nelem
nsel,r,loc,y,0.634,0.639
esln,s,1
esel,r,type,,1
cm,topshell,elem
cmsel,s,ssurf
esln,s,0
nelem
esln,s,1
esel,r,type,,1
cmsel,u,topshell
nelem
cm,sideshell,elem
allsel
!calculate volume of side outer shell
elements
cmsel,s,sideshell
*get,totel,elem,,count
```

```
*get,minel,elem,,num,min
*get,maxel,elem,,num,max
tvol = 0
*do,i,1,totel,1
 *get,evol,elem,minel,volu
 tvol = tvol + evol
 *get,minel,elem,minel,nxth
*enddo
qside = (400*0.63846)/tvol
!calculate volume of bottom outer shell
elements
cmsel,s,topshell
*get,totel,elem,,count
*get,minel,elem,,num,min
*get,maxel,elem,,num,max
tvol = 0
*do,i,1,totel,1
 *get,evol,elem,minel,volu
 tvol = tvol + evol
 *get,minel,elem,minel,nxth
*enddo
qtop = (800*0.31923)/tvol
allsel
!
*go,:skip
fini
/aux12
vtype,0,20
stef,5.7e-8
emis,4,0.5
emis,9,0.01
emis,10,0.8
emis,11,0.5
esel,s,type,,3
write,radmat1
allsel
space,999999
cmsel,s,toprad
nelem
nsel,a,node,,999999
write,radmat2
allsel
cmsel,s,siderad
nelem
nsel,a,node,,999999
write,radmat3
allsel
fini
/prep7
:skip
et,4,50,1
type,4
se,radmat1
et,5,50,1
type,5
se,radmat2
se,radmat3
!
! end of file
```

```
!loada.inp
!
! apply internal heat generation
sfa,12,1,hflux,(2.1/0.003)*0.66
sfa,13,1,hflux,(2.1/0.003)*0.33
!
! apply external convection and set initial
ambient temp
cmsel,s,outsurf
sf,all,conv,4.0,21
allsel
d,999999,temp,21
toffst,273
!
! run analysis
fini
/solve
timint,off
esel,u,type,,2,3
solve

! run analysis with 100 W of heat, or 25 W
on 1/4 section
! apply internal heat generation
sfa,12,1,hflux,(25.0/0.003)*0.66
sfa,13,1,hflux,(25.0/0.003)*0.33
solve

! run analysis with 38 C ambient
cmsel,s,outsurf
sf,all,conv,4.0,38
allsel
d,999999,temp,38
esel,u,type,,2,3
solve

! run analysis with solar load
cmsel,s,topshell
nelem
bfe,all,hgen,1,qtop
cmsel,s,sideshell
nelem
bfe,all,hgen,1,qside
allsel
esel,u,type,,2,3
solve
```

```
!loadsolar.inp
!
! apply internal heat generation
sfa,12,1,hflux,(25.0/0.003)*0.66
sfa,13,1,hflux,(25.0/0.003)*0.33
!
fini
/solve
! apply external convection and set initial
ambient temp
cmsel,s,outsurf
sf,all,conv,4.0,38.0
allsel
toffst,273
!
antype,trans,new
time,1e-6
esel,u,type,,2,3
! input initial temperatures from 38 C steady
state with no solar load
/inp,bff430,inp
timint,off
outres,all,none
outres,nsol
solve

time,1
ddel,all
timint,on
lnsrch,on
kbc,1
! set ambient temp
d,999999,temp,38
! apply solar load
cmsel,s,sideshell
nelem
bfe,all,hgen,1,qside
cmsel,s,topshell
nelem
bfe,all,hgen,1,qtop
allsel
esel,u,type,,2,3
solve

time,200
solve

time,400
solve

time,800
solve

time,1200
solve

time,1600
solve

time,2000
solve

time,2400
solve

time,3600
solve

time,4800
solve
```

```
time,19200
solve

time,43200
solve

time,46800
kbc,1
bfedel,all,hgen
solve

time,50400
solve

time,54000
solve
```

```
! modfire.inp
!
/prep7
/facet,norml
cv=39.37
cdread,solid,model
! material properties
! mild steel
mptemp,1,-73,127,327,527,727,927
mp,dens,1,8131
mpdata,kxx,1,1,41.0,42.2,39.7,35.0,27.6,27.
6
mpdata,c,1,1,434,487,559,685,1090,1090
! foam 1 - 40 lb
mptemp
mptemp,1,0,260,400,540,800
mpdata,dens,2,1,641,641,321,256,26
mptemp
mptemp,1,0,260,400,465,800
mpdata,kxx,2,1,0.087,0.087,0.087,0.054,0.0
7
mp,c,2,1959
! air
mptemp
mptemp,1,-73,127,327,527,727,927
mpdata,dens,3,1,1.7458,0.8711,0.5804,0.43
54,0.3482,0.2902
mpdata,kxx,3,1,0.0181,0.0338,0.0469,0.057
3,0.0667,0.0763
mpdata,c,3,1,1007,1014,1051,1099,1141,11
75
! radiation surfaces
mp,emis,4,1.0
! stainless steel
mptemp
mptemp,1,-73,127,327,527,727,927
mp,dens,5,7900
mpdata,kxx,5,1,12.6,16.6,19.8,22.6,25.4,28.
0
mpdata,c,5,1,402,515,557,582,611,640
!
! air including conduction and convection
across cavity
mpdata,dens,6,1,1.7458,0.8711,0.5804,0.43
54,0.3482,0.2902
kxx1=41.0*0.02+0.98*0.7
kxx2=42.2*0.02+0.98*0.7
kxx3=39.7*0.02+0.98*0.7
kxx4=35.0*0.02+0.98*0.7
kxx5=27.6*0.02+0.98*0.7
kxx6=27.6*0.02+0.98*0.7
mpdata,kxx,6,1,kxx1,kxx2,kxx3,kxx4,kxx5,
kxx6
mpdata,c,6,1,1007,1014,1051,1099,1141,11
75
!
! lead
mptemp
mptemp,1,20,327,330,800
mpdata,dens,7,1,11340,11005,10686,10686
mptemp
mptemp,1,-23,27,127,227,327,328
mptemp,7,331,332,1000
mpdata,c,7,1,127,129,132,136,142,6188
mpdata,c,7,7,6188,159,159
mptemp
mptemp,1,-273,-27,123,227,327,527
mptemp,7,727,927
mpdata,kxx,7,1,35,35,34,33,31,19
mpdata,kxx,7,7,22,24
! foam 2 - 8 lb
```

```
mptemp
mptemp,1,0,260,400,540,800
mpdata,dens,8,1,128,128,64,51,5
mptemp
mptemp,1,0,260,400,465,800
mpdata,kxx,8,1,0.038,0.038,0.038,0.054,0.0
7
mp,c,8,1959
!
! radiation emissivities
mp,emis,9,0.01
mp,emis,10,0.8
mp,emis,11,0.5
!
! mild steel with contact resistance
mptemp
mptemp,1,-73,127,327,527,727,927
mp,dens,12,8131
mpdata,kxx,12,1,0.53,0.99,1.35,1.63,1.86,2.
11
mpdata,c,12,1,434,487,559,685,1090,1090
!
! add stainless steel shell volumes
vadd,4,7,9
nummrg,kp
!
! meshing properties
/uis,msgpop,3
mshkey,0
mshape,1,3d
!
! mesh air space around pig
et,1,70
type,1
esize,1.5/cv
mat,6
vmesh,3
mat,1
vmesh,2
mat,5
vmesh,12
!
! create inner radiation enclosure
et,3,57
type,3
!
mat,9
asel,s,area,,26,27
asel,a,area,,29
amesh,all

mat,10
asel,s,area,,22,25
amesh,all

mat,11
asel,s,area,,33,34
amesh,all

asel,s,area,,26,27
asel,a,area,,29
asel,a,area,,33,34
esla,s
nelem
ensym,0,,0,all
allsel
!
et,1,70
type,1
mat,7
vmesh,1
```

```
mat,2
vmesh,5
mat,2
vmesh,6
mat,3
vmesh,8
mat,8
vmesh,10
mat,8
vmesh,11
!
! create outer surface
asel,s,area,,41
asel,a,area,,52
nsla,s,1
cm,outsurf,node
asel,s,area,,41
nsla,s,1
cm,ssurf,node
asel,s,area,,52
nsla,s,1
cm,tsurf,node
allsel
cmsel,s,outsurf
!
! create outer radiation elements
eall
et,2,57
r,4,1.0
type,2
mat,4
real,4
esurf
n,999999,0.75,0.75,-0.75
allsel
esel,s,type,,2
nelem
nsel,r,loc,y,0.636,0.638
esln,s,1
esel,r,type,,2
cm,toprad,elem
esel,s,type,,2
cmsel,u,toprad
cm,siderad,elem
allsel
!
!create outer shell divisions for solar load
application
cmsel,s,tsurf
esln,s,0
nelem
nsel,r,loc,y,0.634,0.639
esln,s,1
esel,r,type,,1
cm,topshell,elem
cmsel,s,ssurf
esln,s,0
nelem
esln,s,1
esel,r,type,,1
cmsel,u,topshell
nelem
cm,sideshell,elem
allsel
!calculate volume of side outer shell
elements
cmsel,s,sideshell
*get,totel,elem,,count
*get,minel,elem,,num,min
*get,maxel,elem,,num,max
tvol = 0
*do,i,1,totel,1
 *get,evol,elem,minel,volu
 tvol = tvol + evol
 *get,minel,elem,minel,nxth
*enddo
qside = (400*0.63846)/tvol
!calculate volume of bottom outer shell
elements
cmsel,s,topshell
*get,totel,elem,,count
*get,minel,elem,,num,min
*get,maxel,elem,,num,max
tvol = 0
*do,i,1,totel,1
 *get,evol,elem,minel,volu
 tvol = tvol + evol
 *get,minel,elem,minel,nxth
*enddo
qtop = (800*0.31923)/tvol
allsel
!
*go,:skip
fini
/aux12
vtype,0,20
stef,5.7e-8
emis,4,1.0
emis,9,0.01
emis,10,0.8
emis,11,0.5
esel,s,type,,3
write,radmat1
allsel
space,999999
cmsel,s,toprad
nelem
nsel,a,node,,999999
write,radmat2
allsel
cmsel,s,siderad
nelem
nsel,a,node,,999999
write,radmat3
allsel
:skip
fini
/prep7
et,4,50,1
type,4
se,radmat1
et,5,50,1
type,5
se,radmat2
se,radmat3
!
! end of file
! loadfire.inp
!
! apply internal heat generation
sfa,12,1,hflux,(25.0/0.003)*0.66
sfa,13,1,hflux,(25.0/0.003)*0.33
!
fini
/solve
! apply external convection and set initial
ambient temp
cmsel,s,outsurf
sf,all,conv,18.0,800.0
allsel
toffst,273
!
antype,trans,new
time,1e-6
esel,u,type,,2,3
! input initial temperatures from 38 C steady
state with no solar load
/inp,bff430,inp
timint,off
outres,all,none
outres,nsol
solve

time,1
ddel,all
timint,on
lnsrch,on
kbc,1
! apply external convection and set ambient
fire temp
cmsel,s,outsurf
sf,all,conv,18.0,800
allsel
d,999999,temp,800
esel,u,type,,2,3
solve

time,200
solve
time,400
solve
time,800
solve
time,1600
solve
time,1860
solve

time,1920
kbc,0
! apply external convection and set ambient
temp back to 38 C
cmsel,s,outsurf
sf,all,conv,18.0,38
allsel
d,999999,temp,38
! apply solar load
cmsel,s,sideshell
nelem
bfe,all,hgen,1,qside
cmsel,s,topshell
nelem
bfe,all,hgen,1,qtop
allsel
esel,u,type,,2,3
solve

time,2000
```

```
solve

time,2200
solve

time,2400
solve

time,3000
solve

time,3600
solve

time,4800
solve

time,6000
solve

time,8400
solve

time,10800
solve

time,13200
solve

time,15600
solve

time,18000
solve

time,20400
solve

time,22800
solve

time,25200
solve

time,28800
solve

time,32400
solve

time,36000
solve

time,39600
solve

time,43200
solve

time,46800
solve

time,50400
kbc,1
bfedel,all,hgen
solve

time,54000
solve

time,57600
solve

time,61200
solve

time,64800
solve

time,68400
solve

time,72000
solve
```

Appendix F

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

APPENDIX 3.7.3: [redacted]

[redacted]

[redacted]

CHAPTER 4 – CONTAINMENT

This chapter identifies and discusses the package containment for the Normal Conditions of Transport (NCOT) and the Accident Conditions of Transport (ACOT).

4.1 CONTAINMENT BOUNDARY

4.1.1 Containment Vessel

The containment vessel for the F-431 is defined as the sealed sources which are located inside the source cavity. The source cavity is a weldment inside the Gammacell shielding head. The opening to the source cavity is blocked with the Shield Plug which is secured either by a continuous weld, double retaining rings, or four screws.

The sources are cradled in the Source Holder, which is a stainless steel assembly and sometimes includes additional tungsten or other shielding metals. The source holder also provides attenuation for the sealed sources. It weighs up to 6 kg, including the sealed sources.

The location of the sealed sources is shown in Figure 4.1. The sealed source models are illustrated in Figures 4.2 through 4.9.

[redacted]

Figure 4.1: Gammacell Shielding Head

Security-Related Information
Figure Withheld Under
10 CFR 2.390

Figure 4.2: Best Theratronics C-378 Sealed Source

Security-Related Information
Figure Withheld Under
10 CFR 2.390

Figure 4.3: Best Theratronics C-1000 Sealed Source

Security-Related Information Figure Withheld Under 10 CFR 2.390

Figure 4.4: Best Theratronics C-1001 Sealed Source

Security-Related Information Figure Withheld Under 10 CFR 2.390

Figure 4.5: C-3000 Sealed Source

Security-Related Information
Figure Withheld Under
10 CFR 2.390

Figure 4.6: Best Theratronics C-3001 Sealed Source

Security-Related Information Figure Withheld Under 10 CFR 2.390

Figure 4.7: Best Theratronics C-3100 Sealed Source

Security-Related Information Figure Withheld Under 10 CFR 2.390

Figure 4.8: ISO-1000 Sealed Source

Security-Related Information Figure Withheld Under 10 CFR 2.390

Figure 4.9: ORNL RAMCO-50 Sealed Source

The different models of sealed sources that are installed inside the source cavity are summarized in Tables 4.1 and 4.2. The maximum total activity of Cs-137 is 113 TBq (3,050 Ci). Except for the RAMCO-50 sources, all of the sources have been certified to meet the Special Form requirements of 10 CFR 71 SS 71.75 [1] or IAEA TS-R-1 [2]. Although the RAMCO-50 sources were never certified as Special Form, it was demonstrated by the manufacturer that they satisfy the requirement of Special Form. Furthermore, this source has been approved for use by the NRC. Refer to the registration certificate in Appendix 4.4.12.

Table 4.1: Details of Cs-137 Sources

Source Model	Maximum Activity of Cs-137	Overall Height	Diameter	Wall Thickness	Special Form Certificate No.
C-378	20.4 TBq (550 Ci)	279.2 mm (10.99 in.)	16.1 mm (0.63 in.)	0.6 mm (0.025 in.)	CDN/0017/S-96
C-1000	26.6 TBq (720 Ci)	271.5 mm (10.69 in.)	12.7 mm (0.50 in.)	0.9 mm (0.035 in.)	CDN/0011/S
C-1001	30 TBq (810 Ci)	271.5 mm (10.69 in.)	12.7 mm (0.50 in.)	1.0 mm (0.039 in.)	GB/372/S-85
C-3000	56 TBq (1,500 Ci)	271.5 mm (10.69 in.)	17.5 mm (0.69 in.)	0.9 mm (0.035 in.)	CDN/0012/S-85
C-3001	60 TBq (1,620 Ci)	271.5 mm (10.69 in.)	17.5 mm (0.69 in.)	1.0 mm (0.039 in.)	GB/373/S-85
C-3100	56.25 TBq (1,520 Ci)	271.5 mm (10.69 in.)	17.58 mm (0.69 in.)	1.0 mm (0.039 in.)	CDN/0035/S-96
ISO-1000	26.6 TBq (720 Ci)	271.3 mm (1068 in.)	12.6 mm (0.50 in.)	0.9 mm (0.035 in.)	USA/0192/S
RAMCO-50	14.8 TBq (400 Ci)	114 mm (early design) 137 mm (late design)	12.7 mm (0.50 in.)	0.5 mm (0.020 in.)	See Note

Note: The RAMCO-50 source was never formally certified as meeting the requirements of Special Form Radioactive Material. However, it was tested by the manufacturer (Oak Ridge National Laboratory) and demonstrated to satisfy the requirements for Special Form.

Table 4.2: Gammacell Models and Corresponding Sources

Gammacell Model	Source Model	Maximum Number of Sources	Maximum Total Activity of Cs-137
GC1000	RAMCO-50	8	121 TBq (3,264 Ci)*
	ISO-1000	4	107 TBq (2,880 Ci)
	C-1000, C-1001	3	80 TBq (2,160 Ci)
	C-3000, C-3001, C-3100	2	113 TBq (3,048 Ci)
GC3000	C-1000, C-1001	3	80 TBq (2,160 Ci)
	C-3000, C-3001, C-3100	2	113 TBq (3,048 Ci)

*The GC1000 was formerly registered to contain a maximum activity of (3,264 Ci) of Cs-137 in RAMCO-50 sources. These sources have not been manufactured for 20 years, and their activity has now decayed significantly below the proposed Cs-137 limit for the F-431 (3,048 Ci).

4.1.2 Containment Penetration

There are no penetrations into the containment system.

4.1.3 Seals and Welds

4.1.3.1 Seals

There are no seals in the containment system.

4.1.3.2 Welds

The sealed sources are double encapsulated. Both encapsulations are sealed with a fusion weld at each end.

4.2 REQUIREMENTS FOR NORMAL CONDITIONS OF TRANSPORT

This section uses the applicable analysis and discussion from Chapter 2 to demonstrate that the integrity of the package containment system is maintained under the normal conditions of transport.

4.2.1 Release of Radioactive Material

The tests for Normal Conditions of Transport were discussed in Chapter 2. The F-431 was compared to the F430 Transport Package and to the GC3000 which was dropped from 9 m without a protective overpack. By comparison, it was demonstrated that there would be no release of radioactive material as a result of the tests for the Normal Conditions of Transport. Specifically, it was demonstrated that the Gammacell would be retained inside the F-431, that there would be no measurable increase in surface radiation for the F-431, and that the sealed sources would be undamaged.

These test results are further supported by the test for Special Form Radioactive Material that was performed on all of the source models. These tests are much more severe than the tests for the Normal Conditions of Transport. The tests for the Normal Conditions of Transport allow a leakage rate of 2 x 10^{-6} TBq (54 μCi) per hour (A2 x 10^{-6}) (Para 71.51 (a)(1) of Ref. [1], while those for Special Form certification allow a leakage of 0.05 x 10^{-6} Ci(0.05 μCi) (Para 71.75 (c)(2)(vi) of Ref. [1]).

Therefore, no radioactive material will be released from the containment system as a result of normal conditions of transport.

4.2.2 Pressurization of Containment System

Under the normal conditions of transport, the only mechanism that would cause an increase in pressure inside the sealed sources is the thermal expansion of the air inside the capsules. The maximum temperature of the outer encapsulation of the sealed sources under the Normal Conditions of Transport is 326°C (see Chapter 3, Section 3.5.6). In Chapter 2, Section 2.6.3 it was shown that the sources can withstand the pressure generated at this temperature. Therefore, the sealed source can withstand the maximum internal temperature resulting from the normal conditions of transport.

4.2.3 Coolant Contamination

This factor is not applicable to the F-431 since it does not contain any coolant.

4.2.4 Coolant Loss

This factor is not applicable to the F-431 since it does not contain any coolant.

4.3 CONTAINMENT REQUIREMENTS FOR HYPOTHETICAL ACCIDENT CONDITIONS

In Chapter 2, section 2.7, it was demonstrated that the F-431 can withstand the accident conditions of transport. Specifically, it was demonstrated that if the F-431 were subjected to a 9 m drop test followed by a 30 minute regulatory fire test, there would be no breach in containment. This was supported by full scale tests on the F-430/GC40 and a GC3000 that was drop tested from 9 m with no protective overpack. After the testing, there was no measurable damage to the simulated sealed sources. Therefore, the F-431 can withstand the Accident Conditions of Transport without an escape of radioactive material.

4.3.1 Fission Gas Products

This requirement is not applicable since the F-431 does not contain any fissile material.

4.3.2 Release of Contents

The analysis in Chapter 2 showed that as a result of the tests for the Hypothetical Accident Conditions of Transport, there would be no significant damage to the contained irradiator and no release of the contents from the shield.

4.4 REFERENCES FOR CHAPTER 4

[1] 10 CFR, Chapter 1, Part 71 - Packaging and Transportation of Radioactive Material, 1-1-99 Edition.

[2] IAEA Safety Standard, No. TS-R-1, Regulations for the Safe Transport of Radioactive Material, 1996 Edition (Revised). Vienna. 2000.

[3] NR-0220-D-102-S, Gammacell 1000/3000 Registration of Radioactive Sealed Sources and Devices Safety Evaluation of Device. 2002.

[4] NR-0880-D-806-S, Gammator Model M., M34, M38 Registration of Radioactive Sealed Sources and Devices Safety Evaluation of Device. 1995.

[5] NR-0880-D-808-S, Gammacell 1000 Registration of Radioactive Sealed Sources and Devices Safety Evaluation of Device. 1995.

4.5 APPENDICES

Appendix 4.4.1: C-378 Special Form Certificate

Appendix 4.4.2: C-1000 Special Form Certificate

Appendix 4.4.3: C-1001 Special Form Certificate

Appendix 4.4.4: C-3000 Special Form Certificate

Appendix 4.4.5: C-3001 Special Form Certificate

Appendix 4.4.6: ISO-1000 Special Form Certificate

Appendix 4.4.7: C-378 Sealed Source Classification Designation and Performance Certificate

Appendix 4.4.8: C-1000 Sealed Source Classification Designation and Performance Certificate

Appendix 4.4.9: C-3000 Sealed Source Classification Designation and Performance Certificate

Appendix 4.4.10: C-1001 Sealed Source Test Certificate

Appendix 4.4.11: C-3001 Sealed Source Test Certificate

Appendix 4.4.12: Registry of Radioactive Sealed Sources and Devices, Safety Evaluation of Sealed Source, Certificate No. NR-0880-S-804-S

Appendix 4.4.13: C-3100 Special Form Certificate

APPENDIX 4.4.1: C-378 Special Form Certificate

Certification

Canadian Nuclear Safety Commission | Commission canadienne de sûreté nucléaire

SPECIAL FORM RADIOACTIVE MATERIAL CERTIFICATE NO. CDN/0017/S-96, (REV. 0)

30-A2-236-0 April 10, 2002

The Canadian Nuclear Safety Commission (CNSC) hereby certifies that the capsule design as described below has been demonstrated to meet the regulatory requirements prescribed for special form radioactive material as defined in the *Canadian Packaging and Transport of Nuclear Substances Regulations*[1] and the IAEA Regulations[2] subject to the following limitations, terms and conditions.

CAPSULE IDENTIFICATION

MDS Nordion C-378 Capsule

CAPSULE DESCRIPTION

The C-378 capsule, as shown on MDS Nordion Drawing No. G120201-140 (Issue C) consists of an ISO-1000 sealed source capsule further encapsulated in a 316L stainless steel capsule 0.64 mm thick. The dimensions of the C-378 capsule are approximately 279.22 mm long by 16.05mm diameter at the end caps. The total mass of the capsule is approximately 300 grams.

An illustration of the capsule is shown on attached Drawing No. C-378 (Issue 3).

AUTHORIZED RADIOACTIVE CONTENTS

This capsule is authorized to contain not more than 20.4 TBq of Cs-137 in the form of pressed or tamped Cs-137 chloride powder encapsulated within an ISO-1000 capsule.

QUALITY ASSURANCE

The quality assurance programme for the C-378 capsule shall be in accordance with the requirements of MDS Nordion Operating Procedure No. IN/QA 0562 A000 (2)[3] and the Technical Specifications Nos. IN/TS 1487 C000 (2) and IN/TS 0474 C000 (5) for design, manufacture, testing, documentation and inspection, as required by paragraph 310 of the IAEA Regulations[2].

EXPIRY DATE

This certificate expires April 30, 2006.

P. Nelson
Designated Officer pursuant to
Subsection 37 (2)a) of the
Nuclear Safety and Control Act

REFERENCES

[1] Canadian Packaging and Transport of Nuclear Substances Regulations, SOR/2000-208, 31 May 2000.

[2] International Atomic Energy Agency Safety Standards Series No. TS-R-1 (ST-1 Revised), Regulations for the Safe Transport of Radioactive Material, 1996 Edition (Revised).

[3] Or latest current revision.

NOTES

1. Revision 0:April 10, 2002. Original issue.

APPENDIX 4.4.2: C-1000 Special Form Certificate

DEC 19'01 11:39 FR NII ENG AND COMM 613 592 9779 TO 5916934 P.01/04

Certification

Atomic Energy Control Board **Commission de contrôle de l'énergie atomique**

SPECIAL FORM RADIOACTIVE MATERIAL CERTIFICATE NO. CDN/0011/S, (REV. 4)

30-A2-228-0 June 25, 1999

The Atomic Energy Control Board hereby certifies that the capsules, as described below, have been demonstrated to meet the regulatory requirements prescribed for special form radioactive material as defined in the Canadian *Transport Packaging of Radioactive Materials Regulations* and in the IAEA Regulations*, subject to the following limitations, terms and conditions.

CAPSULE IDENTIFICATION

MDS Nordion Inc. C-161 Type 8 Capsule and C-1000 Capsule

CAPSULE DESCRIPTION

The C-161 Type 8 Capsule, as shown on Nordion Drawing No. G120201-100 (Issue B), is a cylindrical, welded, 316L stainless steel, double-walled capsule. The dimensions of the capsule are 40 mm diameter by 43 mm long.

The C-1000 Capsule, as shown on Nordion Drawing No. G120201-102, (Issue B), is a cylindrical, welded, 316L stainless steel, double-walled capsule. The dimensions of the capsule are 12.7 mm diameter by 271.5 mm long.

Illustrations of the capsules are shown on attached Drawing Nos. C-161, Type 8 (Rev. 0) and C-1000, (Rev. 0).

AUTHORIZED RADIOACTIVE CONTENTS

The C-161 Type 8 Capsule is authorized to contain not more than 80 TBq (2160 Ci) of cesium-137 in 102g of cesium chloride. The C-1000 capsule is authorized to contain not more than 26.6 TBq (720 Ci) of cesium-137 in 34g of cesium chloride.

Page 1 of/de 2

Canada

EXPIRY DATE

This certificate expires June 30, 2003.

R. Thomas
Director
Materials Regulation Division

REFERENCE

* International Atomic Energy Agency Safety Series No. 6, Regulations for the Safe Transport of Radioactive Materials, 1973 Revised Edition (as amended).

NOTES

1. Revision 0: July 5, 1990. Original certificate.
2. Revision 1: June 4, 1991. C-1000 capsule added.
3. Revision 2: November 20, 1991. Capsule Description and Authorized Contents revised.
4. Revision 3: April 28, 1995. Certificate renewed.
5. Revision 4: June 25, 1999. Certificate renewed.

APPENDIX 4.4.3:
C-1001 Special Form Certificate

[redacted]

[redacted]

APPENDIX 4.4.4: C-3000 Special Form Certificate

DEC 19'01 11:41 FR NII ENG AND COMM 613 592 9779 TO 5916934 P.01/03

Certification

Canadian Nuclear Safety Commission | Commission canadienne de sûreté nucléaire

SPECIAL FORM RADIOACTIVE MATERIAL CERTIFICATE NO. CDN/0012/S-85, (REV. 2)

30-A2-228-0 November 9, 2000

The Canadian Nuclear Safety Commission hereby certifies that the capsule, as described below, has been demonstrated to meet the regulatory requirements prescribed for special form radioactive material as defined in the Canadian *Packaging and Transport of Nuclear Substances Regulations*[1] and in the IAEA Regulations[2], subject to the following limitations, terms and conditions.

CAPSULE IDENTIFICATION

MDS Nordion Inc. C-3000 Capsule

CAPSULE DESCRIPTION

The C-3000 Capsule, as shown on MDS Nordion Drawing No. G120201-104 (Issue A), is a cylindrical, welded, 316L stainless steel, double-walled capsule. The dimensions of the capsule are 17.5 mm diameter by 271.5 mm long. The approximate total mass is 280 g.

An illustration of the capsule is shown on attached Drawing No. C-3000, (Rev. 0).

AUTHORIZED RADIOACTIVE CONTENTS

The C-3000 capsule is authorized to contain not more than 56 TBq (1500 Ci) of cesium-137 in 74 g of cesium chloride pellets.

QUALITY ASSURANCE

The Quality Assurance Program for the C-3000 source assembly design shall be in accordance with MDS Nordion's Document No. QSF 00 (8)[3] "Industrial Irradiation Quality Manual" which meets the applicable requirements of Paragraph 209 of the IAEA Regulations[2]. Users and consignors of these sources shall satisfy the transport and in-transit storage quality assurance requirements of Paragraph 209 of the IAEA Regulations[2].

Page 1 of/de 2

Canada

DEC 19'01 11:41 FR NII ENG AND COMM   613 592 8779 TO 5916934   P.02/03

CDN/0012/S-85, (REV. 2)   Page 2 of/de 2   Canada

EXPIRY DATE

This certificate expires November 30, 2004.

P. Eyre
Designated officer pursuant to
subsection 37(2)(a) of the
Nuclear Safety and Control Act

REFERENCES

[1] Canadian Packaging and Transport of Nuclear Substances Regulations, SOR/2000-208, 31 May 2000.

[2] International Atomic Energy Agency Safety Series No. 6, Regulations for the Safe Transport of Radioactive Material, 1985 Edition (As Amended 1990).

[3] Or subsequent approved revision.

NOTES

1. Revision 0: December 16, 1991. Original certificate.
2. Revision 1: November 22, 1996. Certificate renewed.
3. Revision 2: November 9, 2000. Certificate renewed.

APPENDIX 4.4.5:
C-3001 Special Form Certificate

[redacted]

[redacted]

APPENDIX 4.4.6: ISO-1000 Special Form Certificate

DEC 19'01 11:36 FR NII ENG AND COMM 613 592 9779 TO 5916934 P.01/03

U.S. Department of Transportation
Research and Special Programs Administration

400 Seventh Street, S.W.
Washington, D.C. 20590

IAEA CERTIFICATE OF COMPETENT AUTHORITY
SPECIAL FORM RADIOACTIVE MATERIALS
CERTIFICATE NUMBER USA/0192/S, REVISION 4

This certifies that the source described has been demonstrated to meet the regulatory requirements for special form radioactive material as prescribed in the regulations of the International Atomic Energy Agency[1] and the United States of America[2] for the transport of radioactive materials.

1. Source Identification - Isomedix Model ISO-1000 manufactured prior to June 30, 1998.

2. Source Description - As shown in the attached drawing, the source is a welded double encapsulation constructed of Type 304L stainless steel. Outer dimensions are 1.263 cm (0.497") in diameter and 27.127 cm (10.68") in length.

3. Radioactive Contents - Not more than 26.64 TBq (720 Ci) of Cesium-137 as cesium chloride powder, per capsule.

4. Expiration Date - This certificate expires July 31, 2003.

This certificate is issued in accordance with paragraph 803 of the IAEA Regulations and Section 173.476 of Title 49 of the Code of Federal Regulations, in response to the petition and information dated June 9, 1998 submitted by MDS Nordion, Kanata, Ontario, Canada, and in consideration of other information on file in this Office.

Certified by:

[signature]

JUL 20 1998
(DATE)

for Alan I. Roberts
Associate Administrator for Hazardous Materials Safety

Revision 4 - Issued to extend the expiration date.

---

1 "Safety Series No. 6, Regulations for the Safe Transport of Radioactive Materials, 1973 Revised Edition, as amended," published by the International Atomic Energy Agency (IAEA), Vienna, Austria.

2 Title 49, Code of Federal Regulations, Parts 100 - 199, United States of America.

JUL 20 '98 16:10 202 366 3753 PAGE.002

APPENDIX 4.4.7:
C-378 Sealed Source Classification Designation and Performance Certificate

MDS Nordion

CERTIFICATE

SEALED SOURCE
CLASSIFICATION DESIGNATION AND PERFORMANCE

Sealed sources are classified in accord with standards established by
THE AMERICAN NATIONAL STANDARDS INSTITUTE (ANSI) and
THE INTERNATIONAL ORGANIZATION FOR STANDARDIZATION (ISO)

CERTIFICATE NO: 103A

DATE: 02-09-04

CAPSULE MODEL: C-378 Sealed source assembly

CONTENTS: Cesium-137

DRAWING. G1200201-140

CAPSULE MATERIAL: 316L Stainless Steel

OVERALL DIAMETER: 0.632"

ENCAPSULATION: Triple

OVERALL LENGTH: 10.993"

ANSI CLASSIFICATION AND PERFORMANCE STANDARD(1) ANSI 97E64334(5) ISO/99/E64334(5)

CLASSIFIED PERFORMANCE STANDARD(2)

TEST	CLASS	METHOD	REMARKS
TEMPERATURE	6	TEST	PASS
EXTERNAL PRESSURE	4	TEST	PASS
IMPACT	3	TEST	PASS
VIBRATION	3	TEST	PASS
PUNCTURE	4	TEST	PASS
BENDING TEST	5	TEST	PASS

(1) See definition on reverse side
(2) See Table 1. Performance Standards on reverse side
(3) This certificate was revised to reflect a typographical change on the impact worksheet (50 g was changed to 200g in the Test paragraph).

COMMENTS: Capsule integrity evaluated by Helium leak test (ANSI/HPS N43.6 – 1997, Annex A, paragraph A2.2.5 or A2.2.6)

It is hereby certified that the described sealed source meets the requirements and classification specified in American National Standard N43.6-1997 "Sealed Radioactive sources, Classification" and in International Standard, ISO 2919-1999(E), "Radiation Protection – Sealed Radioisotope Sources – General Requirements and Classification.

Tested by Helen Sheehan
Title Materials Technologist
Date 4 Sept 2002

Approved Blaine Merriman
Title Manager, Package Engineering
Date 02 Sept 05

REFERENCES

(1)DEFINITION - CLASSIFICATION DESIGNATION:

The classification of a sealed source shall be designated by the code ANSI followed by two digits to indicate the year of approval of the American National Standard used to determine the classification followed by a letter and five digits.

The letter shall be either a C or an E. The letter C designates that the contained activity does not exceed the maximum levels established by ANSI. The letter E designates that the contained activity exceeds the maximum levels established by ANSI.

The first digit shall be the class number which describes the performance standards for temperature.

The second digit shall be the class number which describes the performance standards for external pressure.

The third digit shall be the class number which describes the performance standards for impact.

The fourth digit shall be the class number which describes the performance standards for vibration.

The fifth digit shall be the class number which describes the performance standards for puncture.

(2) TABLE 1 - PERFORMANCE STANDARDS:

TEST	CLASS						
	1	2	3	4	5	6	X
Temperature	No Test	-40°C (20 min) +80°C (1h)	-40°C (20 min) +180°C (1h)	-40°C (20 min) +400°C (1h) and thermal shock 400°C to 20°C	-40°C (20 min) +600°C (1h) and thermal shock 600°C to 20°C	-40°C (20 min) +800°C (1h) and thermal shock 800°C to 20°C	Special Test
External Pressure	No Test	25 kN/m² abs. (3.6 lbf/in²) to atmosphere	25 kN/m² abs. to 2 MN/m² (290 lbf/in²) abs.	25 kN/m² abs. to 7 MN/m² (1015 lbf/in²) abs.	25 kN/m² abs. to 70 MN/m² (10153 lbf/in²) abs.	25 kN/m² abs. to 170 MN/m² (24 656 lbf/in²) abs.	Special Test
Impact	No Test	50 g (1.8oz) from 1 m (3.28 ft) and free drop ten times to a steel surface from 1.5 m (4.92 ft)	200 g (7 oz) from 1 m	2 kg (4.4 lb) from 1 m	5 kg (11 lb) from 1 m	20 kg (44 lb) from 1 m	Special Test
Vibration	No Test	30 min 25 to 500 Hz at 5 g peak amp.	30 min 25 to 50 Hz at 5 g peak amp. and 50 to 90 Hz at 0.635 mm amp. peak to peak and 90 to 500 Hz at 10 g	90 min 25 to 80 Hz at 1.5 mm amp. peak to peak and 80 to 2000 Hz at 20g	Not Used	Not Used	Special Test
Puncture	No Test	1 g (15.4 gr) from 1 m (3.28 ft)	10 g (154 gr) from 1 m	50 g (1.76 oz) from 1 m	300 g (10.6 oz) from 1 m	1 kg (2.2 lb) from 1 m	Special Test

APPENDIX 4.4.8:
C-1000 Sealed Source Classification Designation and Performance Certificate

CERTIFICATE

SEALED SOURCE
CLASSIFICATION DESIGNATION AND PERFORMANCE

Sealed sources are classified in accord with standards established by
THE AMERICAN NATIONAL STANDARDS INSTITUTE (ANSI) and
THE INTERNATIONAL ORGANIZATION FOR STANDARDIZATION (ISO)

CERTIFICATE NO: 70 — **DATE:** April 10, 1991

CAPSULE MODEL: C1000 — **CONTENTS:** Cs Cl pressed pellets

DRWG. NO: G120201-102

CAPSULE MATERIAL: 316L Stainless Steel — **OVERALL DIAMETER:** 0.5"

ENCAPSULATION: Double — **OVERALL LENGTH:** 10.690"

ANSI CLASSIFICATION AND PERFORMANCE STANDARD (1) — ANSI 77 E65546

CLASSIFIED PERFORMANCE STANDARD (2)

TEST	CLASS	METHOD	REMARKS
TEMPERATURE	6	Test	Pass
EXTERNAL PRESSURE	5	Test	Pass
IMPACT	5	Test	Pass
VIBRATION	4	Test	Pass
PUNCTURE	6	Test	Pass

(1) See definition on reverse side
(2) See Table 1, Performance Standards on reverse side
(3) American National Standard N542-1977 is a revision of ANSI N5.10-1968

COMMENTS:

All capsules were integrity tested (Helium leak test) following each individual performance test. No leakage occurred in any capsule.

The capsule has also passed Class 6 of the ANSI N433.1-1977 Special Bend test for Category 1 dry storage gamma irradiators.

It is hereby certified that the described sealed source meets the specified standard as prescribed in (3) American National Standard N542-1977 "Sealed Radioactive Sources, Classification". This standard complies with the classification and performance requirements of ISO 2919-1980(E).

Tested by J. Culbertson [signature] — *Authorized* G.A. Burbidge [signature]

Title Sr. Met. Technician — *Title* Manager, Package Eng.

Date 91/04/26 — *Date* 91/04/10

NORDION INTERNATIONAL INC.

REFERENCES

(1) DEFINITION - CLASSIFICATION DESIGNATION:

The classification of a sealed source shall be designated by the code ANSI followed by two digits to indicate the year of approval of the American National Standard used to determine the classification followed by a letter and five digits.

The letter shall be either a C or an E. The letter C designates that the contained activity does not exceed the maximum levels established by ANSI. The letter E designates that the contained activity exceeds the maximum levels established by ANSI.

The first digit shall be the class number which describes the performance standards for temperature.

The second digit shall be the class number which describes the performance standards for external pressure.

The third digit shall be the class number which describes the performance standards for impact.

The fourth digit shall be the class number which describes the performance standards for vibration.

The fifth digit shall be the class number which describes the performance standards for puncture.

(2) TABLE 1 - PERFORMANCE STANDARDS:

TEST	CLASS						
	1	2	3	4	5	6	X
Temperature	No Test	-40°C (20 min) +80°C (1h)	-40°C (20 min) +180°C (1h)	-40°C (20 min) +400°C (1h) and thermal shock 400°C to 20°C	-40°C (20 min) +600°C (1h) and thermal shock 600°C to 20°C	-40°C (20 min) +800°C (1h) and thermal shock 800°C to 20°C	Special Test
External Pressure	No Test	25 kN/m² abs. (3.6 lbf/in²) to atmosphere	25 kN/m² abs. to 2 MN/m² (290 lbf/in²) abs.	25 kN/m² abs. to 7 MN/m² (1015 lbf/in²) abs.	25 kN/m² abs. to 70 MN/m² (10 153 lbf/in²) abs.	25 kN/m² abs. to 170 MN/m² (24 656 lbf/in²) abs.	Special Test
Impact	No Test	50 g (1.8 oz) from 1 m (3.28 ft) and free drop ten times to a steel surface from 1.5 m (4.92 ft)	200 g (7 oz) from 1 m	2 kg (4.4 lb) from 1 m	5 kg (11 lb) from 1 m	20 kg (44 lb) from 1 m	Special Test
Vibration	No Test	30 min 25 to 500 Hz at 5 g peak amp.	30 min 25 to 50 Hz at 5 g peak amp. and 50 to 90 Hz at 0.635 mm amp. peak to peak and 90 to 500 Hz at 10 g	90 min 25 to 80 Hz at 1.5 mm amp. peak to peak and 80 to 2000 Hz at 20g	Not Used	Not Used	Special Test
Puncture	No Test	1 g (15.4 gr) from 1 m (3.28 ft)	10 g (154 gr) from 1 m	50 g (1.76 oz) from 1 m	300 g (10.6 oz) from 1 m	1 kg (2.2 lb) from 1 m	Special Test

NORDION INTERNATIONAL INC.

447 March Road, P.O. Box 13500, Kanata, Ontario, Canada K2K 1X8 Tel.: (613) 592-2790 Telex: (053) 4162 Fax: (613) 592-6937
447 chemin March, C.P. 13500, Kanata, Ontario, Canada K2K 1X8 Tél.: (613) 592-2790 Télex: (053) 4162 Fax: (613) 592-6937

APPENDIX 4.4.9: C-3000 Sealed Source Classification Designation and Performance Certificate

CERTIFICATE

SEALED SOURCE CLASSIFICATION DESIGNATION AND PERFORMANCE

Sealed sources are classified in accord with standards established by THE AMERICAN NATIONAL STANDARDS INSTITUTE (ANSI) and THE INTERNATIONAL ORGANIZATION FOR STANDARDIZATION (ISO)

CERTIFICATE NO: 74 **DATE:** November 22, 1991

CAPSULE MODEL: C-3000 **CONTENTS:** Cs Cl pressed pellets

DRWG. NO: G120201-104

CAPSULE MATERIAL: 316L Stainless Steel **OVERALL DIAMETER:** 0.687"

ENCAPSULATION: Double **OVERALL LENGTH:** 10.690"

ANSI CLASSIFICATION AND PERFORMANCE STANDARD (1) **ANSI 77 E65546**

CLASSIFIED PERFORMANCE STANDARD (2)

TEST	CLASS	METHOD	REMARKS
TEMPERATURE	6	Comparison	Compared with C-1000
EXTERNAL PRESSURE	5	Comparison	Compared with C-1000
IMPACT	5	Comparison	Compared with C-1000
VIBRATION	4	Comparison	Compared with C-1000
PUNCTURE	6	Comparison	Compared with C-1000

(1) See definition on reverse side
(2) See Table 1: Performance Standards on reverse side
(3) American National Standard N542-1977 is a revision of ANSI N5.10-1968

COMMENTS:

The C-3000 capsule has been compared to the C-1000 capsule (ANSI Certificate No.70). By comparison to C-1000, the C-3000 capsule also meets Class 6 of the ANSI N433.1-1977 Special Bend Test for Category 1 Dry Storage Gamma Irradiators.

It is hereby certified that the described sealed source meets the specified standard as prescribed in (3) American National Standard N542-1977 "Sealed Radioactive Sources, Classification". This standard complies with the classification and performance requirements of ISO 2919-1980(E).

Tested by	J. Culbertson	*Authorized*	G.A. Burbidge
Title	Sr. Met. Tech.	*Title*	Manager, Package Eng.
Date	Nov. 22, 1991	*Date*	Nov. 22, 1991

NORDION INTERNATIONAL INC.

REFERENCES

(1) DEFINITION - CLASSIFICATION DESIGNATION:

The classification of a sealed source shall be designated by the code ANSI followed by two digits to indicate the year of approval of the American National Standard used to determine the classification followed by a letter and five digits.

The letter shall be either a C or an E. The letter C designates that the contained activity does not exceed the maximum levels established by ANSI. The letter E designates that the contained activity exceeds the maximum levels established by ANSI.

The first digit shall be the class number which describes the performance standards for temperature.

The second digit shall be the class number which describes the performance standards for external pressure.

The third digit shall be the class number which describes the performance standards for impact.

The fourth digit shall be the class number which describes the performance standards for vibration.

The fifth digit shall be the class number which describes the performance standards for puncture.

(2) TABLE 1 - PERFORMANCE STANDARDS:

TEST	CLASS						
	1	2	3	4	5	6	X
Temperature	No Test	-40°C (20 min) +80°C (1h)	-40°C (20 min) +180°C (1h)	-40°C (20 min) +400°C (1h) and thermal shock 400°C to 20°C	-40°C (20 min) +600°C (1h) and thermal shock 600°C to 20°C	-40°C (20 min) +800°C (1h) and thermal shock 800°C to 20°C	Special Test
External Pressure	No Test	25 kN/m² abs. (3.6 lbf/in²) to atmosphere	25 kN/m² abs. to 2 MN/m² (290 lbf/in²) abs.	25 kN/m² abs. to 7 MN/m² (1015 lbf/in²) abs.	25 kN/m² abs. to 70 MN/m² (10 153 lbf/in²) abs.	25 kN/m² abs. to 170 MN/m² (24 656 lbf/in²) abs.	Special Test
Impact	No Test	50 g (1.8 oz) from 1 m (3.28 ft) and free drop ten times to a steel surface from 1.5 m (4.92 ft)	200 g (7 oz) from 1 m	2 kg (4.4 lb) from 1 m	5 kg (11 lb) from 1 m	20 kg (44 lb) from 1 m	Special Test
Vibration	No Test	30 min 25 to 500 Hz at 5 g peak amp.	30 min 25 to 50 Hz at 5 g peak amp. and 50 to 90 Hz at 0.635 mm amp. peak to peak and 90 to 500 Hz at 10 g	90 min 25 to 80 Hz at 1.5 mm amp. peak to peak and 80 to 2000 Hz at 20g	Not Used	Not Used	Special Test
Puncture	No Test	1 g (15.4 gr) from 1 m (3.28 ft)	10 g (154 gr) from 1 m	50 g (1.76 oz) from 1 m	300 g (10.6 oz) from 1 m	1 kg (2.2 lb) from 1 m	Special Test

NORDION INTERNATIONAL INC.
447 March Road, P.O. Box 13500, Kanata, Ontario, Canada K2K 1X8 Tel.: (613) 592-2790 Telex: (053) 4162 Fax: (613) 592-6937
447 chemin March, C.P. 13500, Kanata, Ontario, Canada K2K 1X8 Tél.: (613) 592-2790 Télex: (053) 4162 Fax: (613) 592-6937

APPENDIX 4.4.10:
C-1001 Sealed Source Test Certificate

[redacted]

[redacted]

APPENDIX 4.4.11:
C-3001 Sealed Source Test Certificate

[redacted]

[redacted]

APPENDIX 4.4.12: Registry of Radioactive Sealed Sources and Devices, Safety Evaluation of Sealed Source, Certificate No. NR-0880-S-804-S

JSD 6/1/95
NJH 6/12/95

REGISTRY OF RADIOACTIVE SEALED SOURCES AND DEVICES
SAFETY EVALUATION OF SEALED SOURCE

NO.: NR-0880-S-804-S DATE: May 11, 1995 **PAGE 1 OF 5**

SEALED SOURCE TYPE: Irradiator Source

MODEL: RAMCO-50-ORNL

DISTRIBUTOR:
Isomedix Inc.
(formerly Radiation Machinery Corp.)
11 Apollo Drive
Whippany, NJ 07981

MANUFACTURER:
Oak Ridge National Lab
P.O. Box 2008
Oak Ridge, TN 37831

ISOTOPE:	**MAXIMUM ACTIVITY:**
Cesium-137	420 Ci (15.5 TBq)

LEAK TEST FREQUENCY: 6 months

PRINCIPAL USE: (J) Gamma Irradiator, Category I

CUSTOM DEVICE: ________ YES ____X____ NO

REGISTRY OF RADIOACTIVE SEALED SOURCES AND DEVICES
SAFETY EVALUATION OF SEALED SOURCE

NO.: NR-0880-S-804-S DATE: May 11, 1995 PAGE 2 OF 5

SEALED SOURCE TYPE: Irradiator Source

DESCRIPTION:

The RAMCO-50-ORNL source is designed for use primarily in self-contained Gammator irradiators manufactured and distributed by Isomedix, Inc. (formerly Radiation Machinery Corp.). The source were produced in three variations.

In all cases, the cesium-137 material of the source consists of pellets of cesium chloride which are placed between spacers into the inner capsule tube of the double wall encapsulation. The inner capsule is made of type 316L stainless steel tubing 0.450" (1.14 cm) diameter with 0.020" (0.051 cm) walls. This is plugged on both ends and placed inside the outer capsule, which is made of type 316L stainless steel tubing 1/2" (1.27 cm) diameter with 0.020" (0.051 cm) walls. Both the inner and outer capsules are plugged and sealed by welding.

For the first design, the active length of the capsule is 3.2" (8.1 cm) and the overall length of the capsule is 4.5" (11.4 cm). The cesium density in the source pellets is 3.3 gm/cc (0.206 lbm/ft^3), and the lineal activity along the 3.2-inch active length is approximately 120 Ci/inch (1.75 TBq/cm) using 4 pellets. The nominal source strength is 380 Ci (14 TBQ) ±5%, or a maximum of 399 curies (14.8 TBq).

In the second design, the dimensions remained unchanged, but the total nominal source strength was increased to 400 curies (14.8 TBq).

The third design of this source is similar to the second RAMCO-50 model, except that the active length is increased to 4 inches (10.2 cm) from the original 3.2 inches (8.1 cm) length. The curie content remained the same. The cesium density in the source pellets was decreased from 3.3 to 2.6 gm/cc (from 0.206 to 0.162 lbm/ft^3), and the lineal activity along the 4-inch length was decreased from approximately 120 to 100 Ci/inch (from 1.75 to 1.46 TBq/cm) by using 5 pellets instead of 4 pellets. This increased the overall length of the source (including its double encapsulation) from the original 4.5 inches (11.4 cm) to 5.375 inches (13.7 cm). The outer diameter remained unchanged at 0.5 inch (1.27 cm).

REGISTRY OF RADIOACTIVE SEALED SOURCES AND DEVICES
SAFETY EVALUATION OF SEALED SOURCE

NO.: NR-0880-S-804-S **DATE:** May 11, 1995 **PAGE 3 OF 5**

SEALED SOURCE TYPE: Irradiator Source

LABELING:

Isomedix reports there were no labels on these sources. However, the sources were shipped with devices, and the devices were labeled.

DIAGRAM:

See attachment 1.

CONDITIONS OF NORMAL USE:

These sealed sources are designed for use in Isomedix Inc. Gammator irradiators under laboratory conditions with ambient temperatures and normal atmospheric pressure.

PROTOTYPE TESTING:

The RAMCO-50-ORNL sources have been in use since approximately 1969.

EXTERNAL RADIATION LEVELS:

The calculated radiation levels from this 400-curie source of cesium-137 are as follows:

Distance	R/hr	Sv/hr
5 cm	52,800	528
30 cm	1,467	14.7
100 cm	132	1.32

QUALITY ASSURANCE AND CONTROL:

The manufacturer (ORNL) states that both the inner and outer capsules are tested for leaks by (a) a visual inspection and (b) an ethylene glycol partial vacuum bubble test. The outer capsule of the fabricated source is retested a second time by method (b) after the source has been subjected to 200°C for one hour.

REGISTRY OF RADIOACTIVE SEALED SOURCES AND DEVICES
SAFETY EVALUATION OF SEALED SOURCE

NO.: NR-0880-S-804-S DATE: May 11, 1995 PAGE 4 OF 5

SEALED SOURCE TYPE: Irradiator Source

LIMITATIONS AND/OR OTHER CONSIDERATIONS OF USE:

- The sources may be distributed to persons specifically licensed by the NRC or an Agreement State.
- Handling, storage, use, transfer, and disposal are to be determined by the licensing authority.
- These sources are required to be leak tested at intervals not to exceed 6 months using techniques approved by the licensing authority and capable of detecting 0.005 microcuries (185 Bq) of removable contamination.
- This registration sheet and the information contained within the references shall not be changed without the written consent of the NRC.

SAFETY ANALYSIS SUMMARY:

The Model RAMCO-50-ORNL sources are not current products manufactured by Oak Ridge National Laboratory for use in Isomedix Inc. devices. The devices in which they were used were discontinued and the company no longer provides service or support to these devices.

Based on review of the Model RAMCO-50-ORNL sources, and the information and test data cited below, we continue to conclude that these sources are acceptable for licensing purposes.

Furthermore, we continue to conclude that these sources would be expected to maintain their containment integrity for normal conditions of use and the accidental conditions which might occur during uses specified in this certificate.

REGISTRY OF RADIOACTIVE SEALED SOURCES AND DEVICES
SAFETY EVALUATION OF SEALED SOURCE

NO.: NR-0880-S-804-S **DATE:** May 11, 1995 **PAGE 5 OF 5**

SEALED SOURCE TYPE: Irradiator Source

REFERENCES:

The following supporting documents for the Model RAMCO-50-ORNL are hereby incorporated by reference and are made a part of this registry document.

- Isomedix Inc. letter dated September 22, 1993, noting that the entire irradiator business was sold to AECL in 1983, and that it is now owned by Nordion International
- Isomedix Inc. letter dated August 13, 1991, requesting termination of the registry for the Model RAMCO-50-ORNL sources.
- Oak Ridge National Laboratory letter of June 18, 1980 enclosing test procedures for their sources
- Isomedix Inc. letter dated February 20, 1980, describing sources for their devices
- Oak Ridge National Laboratory report dated June 18, 1980, describing source testing procedures
- Enclosure for Radiation Machinery Corp. letter dated May 28, 1968, describing changes in RAMCO-50-ORNL source design
- Enclosure for Radiation Machinery Corp. letter dated December 19, 1967, drawing of RAMCO-50-ORNL source

ISSUING AGENCY:

U.S. Nuclear Regulatory Commission

Date: May 11, 1995 Reviewer: Thomas W. Rich (signature)
Thomas W. Rich

Date: May 11, 1995 Concurrence: Steven L. Baggett (signature)
Steven L. Baggett

Security-Related Information Figure Withheld Under 10 CFR 2.390

APPENDIX 4.4.13:
CNSC Canadian Certificate No. CDN/0035/S-96 (Rev. 0)

Canada's Nuclear Regulator
Organisme de réglementation nucléaire du Canada

Canadian Certificate No.: CDN/0035/ S -96 (Rev. 0)
Issue Date: Nov-19-2014
Expiry Date: Nov-30-2019
CNSC File: 30-B5-1-2

Certificate

CDN/0035/ S -96 (Rev. 0)

Special Form

The special form radioactive material identified below is certified by the Canadian Nuclear Safety Commission pursuant to paragraph 21(1)(h) of the *Nuclear Safety and Control Act* and Section 7 of the *Packaging and Transport of Nuclear Substances Regulations*, and to the 1996 Edition (Revised) of the IAEA *Regulations for the Safe Transport of Radioactive Material*.

CAPSULE IDENTIFICATION

Designer: **Best Theratronics**
Make/Model: **C3100**

CAPSULE DESCRIPTION

The C3100 capsule, as shown on Best Theratronics Drawing No. G143101-001 (Issue 5), consists of two sealed stainless steel inner capsules further encapsulated in a stainless steel capsule.

An illustration of the capsule is shown on attached Drawing No. C3100 (Issue A).

The configuration of the capsule is as follows:

Shape:	**Cylinder**	Shielding:	**n/a**
Mass:	**0.3 kg**	Outer Casing:	**Stainless Steel**
Length:	**271.5 mm**	Height:	**n/a**
Width:	**n/a**	Diameter:	**17.58 mm**

AUTHORIZED RADIOACTIVE CONTENTS

This capsule is authorized to contain not more than 56.25 TBq of Cs-137 in the form of pressed or tamped Cs-137 chloride powder within two inner encapsulations.

Page 1 of 2

Canadian Nuclear Safety Commission | Commission canadienne de sûreté nucléaire

Canada

Canada's Nuclear Regulator
L'organisme de réglementation nucléaire du Canada

Canadian Certificate No.: CDN/0035/ S -96 (Rev. 0)
Issue Date: Nov-19-2014
Expiry Date: Nov-30-2019
CNSC File: 30-B5-1-2

QUALITY ASSURANCE

Quality assurance for the design, manufacture, testing, documentation, use, maintenance and inspection of the capsule shall be in accordance with:

- Best Theratronics Document No. 5.05-QA-02 (2)*, "Sealed Source Quality Plan"
- Best Theratronics Document No. IN/TS 2578 C000 (C), "Technical Specification for Sealed Sources"
- Best Theratronics Document No. IN/TS 2714 C000 (C), "Technical Specification for Sealed Sources Containing Cs-137"
- Packaging and Transport of Nuclear Substances Regulations
- IAEA Regulations
- * or latest current revision

S. Faille
Designated Officer pursuant to paragraph 37(2)(a) of the Nuclear Safety and Control Act

CHAPTER 5 – SHIELDING EVALUATION

5.1 INTRODUCTION

The F-431 overpack has been designed to transport self-contained irradiators with a maximum weight of 1,230 kg (2,700 lb.) including internal frames and braces. The maximum permissible activity is 113 TBq (3,050 Ci) of Cs-137.

Shielding is provided by the self-contained irradiators (e.g. GC1000 or GC3000). The GC1000 and GC3000 are very similar in design and construction. They are lead-filled welded steel constructions. Their basic features as they relate to shielding are listed in Table 5.1. The GC1000 and GC3000 are illustrated in Appendix 1.3.2. Their laboratory configurations are described in the Radioactive Sealed Source and Device Registration NR-0220-D-102-S (refer to Appendix 5.5.1).

Table 5.1: Features of the GC1000 and GC3000

Gammacell Model	Rated Capacity	Nominal Pb Thickness	Steel Shell Thickness
GC1000	113 TBq (3,050 Ci)	140 mm (5.5 in.)	9.5 mm (0.375 in)
GC3000	113 TBq (3,050 Ci)	105 mm (4.1 in.)	9.5 mm (0.375 in)

Each gammacell has specific acceptance criteria for radiation shielding. When loaded with the Cs-137 source(s).at the time of manufacture, the radiation levels do not exceed the following:

GC1000:

- 125 mR/h maximum at the surface of the shield
- 3 mR/h at 1 m from the surface of the shield

GC3000:

- 135 mR/h maximum at the surface of the shield
- 6 mR/h at 1 m from the source centerline

5.2 SOURCE SPECIFICATION

The self-contained irradiator contains radioactive material in double encapsulated sealed sources. These typically have been certified to meet the requirements of Special Form sealed sources.

The F-431 is authorized to contain not more than 113 TBq (3,050 Ci) of Cesium-137.

5.3 MODEL SPECIFICATION

No models were used. Shielding evaluation was based on test results.

5.4 SHIELDING EVALUATION

When the gammacell is installed inside the F-431, typically the radiation levels are less than 30 mR/h on the surface of the F-431 and less than 1 mR/h at one meter from the surface. Under no circumstances will the F-431 be shipped if the radiation fields exceed 200 mR/h on the surface of the F-431 or 10 mR/h at one meter from the surface (refer to Chapter 7).

In order to demonstrate the effects of the accident conditions of transport on the shielding, a full-scale GC3000 irradiator was subjected to a 9 m drop test, without the F-431 overpack. The test specimen (without the F-431 overpack) was subjected to a radiation survey before and after the drop tests. The results are presented in Appendix 2.10.4 and are summarized in Table 5.2.

Table 5.2: Maximum Radiation Levels for GC3000 Test Specimen				
	Surface Radiation*		Radiation Field at 1 m from Surface*	
Location	Pre-drop (with 2,897 Ci)	Post-drop (with 2,812 Ci)	Pre-drop (with 2,897 Ci)	Post-drop (with 2,812 Ci)
Top Surface	30	30	0.65	1.1
Left Surface	1.5	0.5	0.5	0
Right Side	2.0	0.6	0.45	0
Back Side	100 mR/h	90 mR/h	3.0 mR/h	3.5 mR/h

* The radiation measurements were performed on the GC3000 shield without the F-431 overpack.

The results show no significant increase in radiation levels after the drop tests. The gammacells are extremely robust structures and their shielding performance is not compromised even by a 9 m drop test without a protective overpack. In Chapter 3, it was demonstrated that the F-431 sufficiently protects its payload from the effects of the regulatory fire test. Therefore, when installed inside the F-431, the only increase in radiation fields would result from a shift in the position of the self-contained irradiator inside the F-431. This would result in a reduction in source-to-dose distance.

Since there was no dose points that remotely approached 1 R/h at 1 m from the surface of the GC3000 when surveyed without the F-431, then there would be none when the irradiator is packaged in the F-431, regardless of its position inside. This satisfies 10 CFR Part 71, Paragraph 71.51(a)(2) and IAEA TS-R-1 paragraph 656.

Furthermore, since the GC1000 is virtually identical to the GC3000 (same manufacturing process, same overall dimensions, same steel shell thickness, same weld sizes, and slightly greater lead shielding thickness), the GC1000 also satisfies the requirements of the Regulations.

5.5 APPENDICES

Appendix 5.5.1 Registry of Radioactive Sealed Sources and Devices, Safety Evaluation of a Device Certificate No. NR-1307-D-102-S.

APPENDIX 5.5.1:
Registry of Radioactive Sealed Sources and Devices, Safety Evaluation of a Device

Certificate No. NR-1307-D-102-S

(22 pages to follow)

REGISTRY OF RADIOACTIVE SEALED SOURCES AND DEVICES
SAFETY EVALUATION OF A DEVICE
(AMENDED IN ITS ENTIRETY)

DEVICE TYPE: Gamma Irradiator

MODEL: Gammacell 1000-A, B, C, or D and
Gammacell 1000 Elite-A, B, C, D, Type I or Type II and
Gammacell 3000 Elan-A, B, C, Type I or Type II

DISTRIBUTOR: Best Theratronics Ltd.
7643 Fullerton Road
Springfield, VA 22153

MANUFACTURER: Best Theratronics Ltd.
413 March Road
Ottawa, Ontario
Canada K2K 0E4

SEALED SOURCE MODEL DESIGNATION: Isomedix RAMCO-50 or ISO-1000
MDS Nordion C-1000, C-3000
Best Theratronics C-1001, C-3001,
Best Theratronics C-378
Best Theratronics C3100

ISOTOPE:	MAXIMUM ACTIVITY:
Cesium-137	3,264 curies (120.8 TBq)

LEAK TEST FREQUENCY: 6 months

PRINCIPAL USE: (J) Gamma Irradiator, Category I

CUSTOM DEVICE: ______ YES ___X___ NO

DEVICE TYPE: Gamma Irradiator

DESCRIPTION:

The Gammacell 1000, 1000 Elite, and 3000 Elan are fully self-contained irradiators. The weight range for the Gammacell 1000 and 1000 Elite is 2500 to 2800 lbs (1134 to 1270.1 kg). The weight range for the Gammacell 3000 Elan is 3000 to 3300 lbs (1360.8 to 1496.9 kg). Each unit contains a sample chamber with a built-in turntable which provides dose uniformity for the sample when rotating. The A, B, C, D, Type I, and Type II designations refer to the various configurations of sources which can be provided with each unit. Doubly encapsulated sources are fixed in a source holder designed specifically according to the unit and source selected. The source holder, with sources installed, is inserted into the source cavity of the unit and a cover is either bolted or fully welded in place to prevent access. The various source configurations allowed are described later in this document.

The Gammacell 1000 measures 24 inches wide by 24 inches in length by 65 inches in height (60.96 cm wide by 60.96 cm length and 165.1 cm in height). The sample chamber accepts beakers up to 8 inches (20.3 cm) in height and 3 inches (7.6 cm) in diameter (0.25 gallon (0.96 liter) capacity). The sample chamber is introduced into the radiation field by manually turning the rotor 1800 by means of a lever. Irradiation of the sample will continue until the sample chamber is returned to the 'load'-'unload' position.

In October of 1988, AECL divided a portion of its source and device production between two separate entities (Theratronics International Limited and Nordion International, Inc.). At that time only the Gammacell 1000 was being manufactured. AECL ceased all manufacture, distribution and servicing of the Gammacell 1000 irradiators and Nordion International, Inc., took over the manufacturing and servicing responsibilities-for these devices. The Gammacell 1000 is no longer supplied as a new unit.

The Gammacell 1000 Elite is an updated version of the Gammacell 1000. Operation of the unit has been mechanized in order to simplify operation and provide more precise irradiation. The

DESCRIPTION (Cont.):

unit is housed in a fire resistant cabinet which measures 30 inches to 33 inches wide by 26 inches to 32 inches length by 56 inches to 63 inches in height (76.2 to 83.82 cm wide by 66 cm to 81.3 cm in length and 142.2 to 160 cm in height). Access to the sample chamber is gained by opening a door in the cabinet. An interlock system prevents operation of the unit when the door is open. The manual lever which was used to introduce the sample chamber to and from the radiation field has been replaced by a DC motor. This motor is controlled by digital DC components which are programmed from a control panel on the cabinet face. From this control panel the unit can be programmed to rotate a sample into the radiation field for a prescribed time and automatically return it to the 'load'-'unload' position. A DC battery backup has been added which, when input power is lost, will complete the current programmed cycle; however no additional cycles will be initiated until power is restored. The backup battery is continuously recharged while input power is available.

The Gammacell 3000 Elan is essentially similar to the Gammacell 1000 Elite. Only differences between the two will be discussed. The sample chamber of the Gammacell 3000 Elan has been enlarged to accommodate sample beakers of up to 0.69 gallon (2.6 liter) capacity. As a consequence of this, radiation shielding was slightly reduced. In order to compensate for the reduced shielding, secondary shielding constructed of lead is bolted onto the rear and side of the existing radiation shield at the time of installation.

The C-1000 and C-3000 sources are manufactured by Westinghouse Hanford Co., USA for the exclusive use in the Gammacell 1000 Elite and Gammacell 3000 Elan research irradiators. The sources are not registered by the NRC under any other name or manufacturer. These sources are similar in design and construction. Both are doubly encapsulated using 316L stainless steel capsules with fusion welded end caps and contain cesium-137 pellets in the form of pressed cesium chloride powder.

DESCRIPTION (Cont.):

Nominal activity for the C-1000 is 600 Ci (22.2 TBq) +20%, -10%, and for the C-3000 is 1,270 Ci (47.0 TBq) +20%, -10%. Nominal capsule wall thickness for both sources is 0.035 inches (0.89 mm).

The C-1001 and C-3001 sources are manufactured by Reviss Services Ltd. (formerly AEA Technology QSA, Inc., Amersham Corporation) for the exclusive use in the Gammacell 1000 Elite and Gammacell 3000 Elan research irradiators. The sources are not registered by the NRC under any other name or manufacturer. These sources are similar in design and construction to the C-1000 and C-3000. The only significant differences between the C-1001 and the C-1000 sources and the C-3001 and C-3000 sources is that the C-1001 and C-3001 contain cesium-137 encapsulated in three inner capsules instead of a single capsule and the nominal wall thickness of the C-1001 and C-3001 sources is 0.039 inches (1.0 mm) as compared to 0.035 inches (0.89 mm). All sources are doubly encapsulated using 316L stainless steel with fusion welded end caps and contain cesium-137 in the form of cesium chloride powder. Nominal activity for the C-1001 is 590 Ci (21.9 TBq) with a maximum activity of 810 Ci (30.0 TBq) and for the C-3001 nominal activity is 1,270 Ci (47.0 TBq) with a maximum activity of 1,620 Ci (60.0 TBq).

The inner capsule of the Model C-1000 measures 9.840 inches in length by 0.375 inches in diameter (25.0 cm by 0.953 cm) and is sealed by fusion weld at each end by 0.250 inches thick by 0.317 inches in diameter (0.635 cm by 0.805 cm) end caps. The outer capsule measures 10.690 inches in length by 0.500 inches in diameter (27.15 cm by 1.27 cm) and is sealed by fusion weld at each end by 0.375 inches thick by 0.442 inches in diameter (0.953 cm by 1.12 cm) end caps.

Each of the inner capsules of the Model C-1001 measures maximum 3.47 inches in length by 0.406 inches in diameter (8.805 cm by 1.03 cm) and is sealed by fusion weld at each end by 0.075 inches thick by 0.328 inches in diameter (0.19 cm by 0.834 cm) end caps. The outer capsule measures 10.690 inches in length by

DESCRIPTION (Cont.):

0.50 inches in diameter (27.15 cm by 1.28 cm) and is sealed by fusion weld at each end by 0.114 inches thick by 0.427 inches in diameter (0.290 cm by 1.084 cm) end caps.

The inner capsule of the Model C-3000 measures 9.840 inches in length by 0.562 inches in diameter (24.9 cm by 1.43 cm) and is sealed by fusion weld at each end by 0.250 inches thick by 0.50 inches in diameter end caps (0.64 cm by 1.28 cm). The outer capsule measures 10.690 inches in length by 0.687 inches in diameter (27.15 cm by 1.75 cm) and is sealed by fusion weld at each end by 0.375 inches thick by 0.630 inches in diameter end caps (0.95 cm by 1.60 cm).

Each of the inner capsules of the Model C-3001 measures maximum 3.467 inches in length by 0.593 inches in diameter (8.8065 cm by 1.5065 cm) and is sealed by fusion weld at each end by 0.075 inches thick by 0.513 inches in diameter end caps (0.19 cm by 1.31 cm). The outer capsule measures 10.690 inches in length by 0.687 inches in diameter (27.15 cm by 1.74 cm) and is sealed by fusion weld at each end by 0.114 inches thick by 0.618 inches in diameter end caps (0.29 cm by 1.56 cm).

RAMCO-50 source is constructed of 316L stainless steel and contains cesium-137. ISO-1000 source is constructed of 304L stainless steel and contains cesium-137. The ISO-1000 or the RAMCO-50 sealed sources for GC-1000 or GC-3000 models are no longer manufactured.

The Model C-378 sealed source is manufactured for exclusive use in the Gammacell 1000 Elite and Gammacell 3000 Elan research irradiators. The sources are not registered by the NRC under any other name or manufacture. The Model C-378 sealed source is an over-encapsulation of the ISO-1000 approved sealed source with an additional outer shell of 316L stainless steel. The maximum activity for each Model C-378 cesium-137, source is 550 curies (20.4 TBq).

DESCRIPTION (Cont.):

The outer capsule has a maximum length of 10.993 inches (279.22 mm), a maximum diameter of 0.632 inches (16.05 mm) with a 0.025 inches (0.64 mm) wall thickness. The C-378 is produced by inserting an active used leak tested ISO-1000 capsule into the C-378 body with one end cap already welded into place. The final end cap is then inserted and fusion welded. The manufacturer provides a one year warranty for the C-378 source. However, the manufacturer expects the physical and working life of the source to be unlimited.

The Model C3100 sealed source is manufactured for exclusive use in the Gammacell 1000 Elite and Gammacell 3000 Elan research irradiators. Sealed source model C3100 is a direct replacement for the C3001 source model. Model C3100 sources contain cesium-137 in the form of cesium chloride. The maximum activity for each C3001 source capsule is 1520.3 Ci (56.25 TBq) of cesium-137.

The C3100 source capsule consists of two sealed 316L stainless steel inner capsules further encapsulated in a 316L outer stainless steel capsule. Each inner capsule has a length of 4.667 inches (118.55 mm) and a diameter of 0.506 inches (12.85 mm), with an inner wall thickness of 0.041 inches (1.05 mm). The outer capsule has a maximum length of 10.689 inches (271.5 mm), a maximum diameter of 0.692 inches (17.58 mm), with a wall thickness of 0.039 inches (1 mm). The thickness of the end caps is 0.375 inches (9.525 mm). Caps are press fit into position and fusion welded. Model C3100 sealed sources have a recommended working life of 15 years. However, the recommended working life may be extended by Best Theratronics based on inspection and technical assessment.

The sources are installed into source holders designed specifically for each source type. The source holder, with sources installed, is then inserted into the source cavity of the unit and a cover plate is welded over the cavity to prevent access to the sources. The sources are installed according to the activity requested by the customer. Table 1 shows the

DESCRIPTION (Cont.):

allowable configurations for the sources loaded with maximum activity for each model.

Table 1

Gammacell	Number of sources	Max. Activity (Ci)
1000	2, 4, 6, or 8 RAMCO-50 sources	3264.0
	1, 2, 3, or 4 ISO-1000 sources	2880.0
1000 Elite	1, 2, 3, or 4 ISO-1000 sources	2880.0
	Any combination of C1000/C1001, C3000/C3001/**C3100**, or C378 sources, up to 3 sources	3048.0
3000 Elan	Any combination of C1000/C1001, C3000/C3001/**C3100**, or C378 sources, up to 3 sources	3048.0

LABELING:

The devices are labeled in accordance with the requirements of Section 20.1901, 10 CFR Part 20 and with the requirements of ANSI N433.1-1977, "Safe Design and Use of Self Contained, Dry Source Storage Gamma Irradiators (Category I)." The labels are affixed to the exterior of the unit by screws and contain the radiation symbol, isotope, activity, model number, serial number, name of manufacturer, and the words "CAUTION-RADIOACTIVE MATERIAL".

The following information is engraved on the C-1000, C-3000, C-1001, and C-3001 sources:

For the C-1000
NII
Cs137B
XXXX (Serial Number)
Radiation Symbol
or
Radioactive

For the C-3000
NII
Cs137C
XXXX (Serial Number)
Radiation Symbol
or
Radioactive

For the C-1001
NII or MDSN or BTL
Cs137E
C1001
XXXX (Serial Number)
Radioactive

For the C-3001
NII or MDSN or BTL
Cs137F
C3001
XXXX (Serial Number)
Radioactive

For the C3100
BTL
C3100
XXXX (Serial Number)
Cs137
Radiation Symbol
or
Radioactive

LABELING (Cont.):

The following is engraved on the outer surface of the C-378 sources:

MDSN or BTL
Cs137G
C378
XXXX (Serial Number)
RADIOACTIVE

DIAGRAMS:

Attachments 1 through 6.

CONDITIONS OF NORMAL USE:

The Gammacell 1000, Gammacell 1000 Elite, and the Gammacell 3000 Elan are low dose rate irradiators designed to irradiate biological or other samples requiring low dose rate, (e.g., blood and blood components to eliminate small lymphocytes, sprout stimulation of seeds and tubers, non-sporulating bacteria and molds -- pasteurization and sterilizations, viruses, polymerization, etc.). The irradiators would be located in laboratory environments and will be used only by personnel trained in radiation safety.

PROTOTYPE TESTING:

The manufacturer claims that the devices comply with ANSI N433.1-1977. The Gammacell 1000 has been in use for over 15 years without any reported problems. The Gammacell 1000 Elite and 3000 Elan are essentially similar to the Gammacell 1000 and for this reason the manufacturer claims they are expected to perform with comparable reliability.

The RAMCO-50 and ISO-1000 sealed sources have passed special form tests conducted by the manufacturer, Oak Ridge National Laboratory. The C-1000 and C-3000 sealed sources have passed special form tests conducted by the manufacturer and have been tested to and received a rating of 77E65546 as per ANSI N542-

DEVICE TYPE: Gamma Irradiator

PROTOTYPE TESTING (Cont.):

1977. The C-1001 and C-3001 sealed sources have passed special form tests conducted by Amersham Corporation.

The C-378 sealed sources have passed special form tests performed by MDS Nordion and have achieved a rating of 96E64334(5)as per ANSI N43.6-1997. MDS Nordion subjected this sealed source model to a bend test to satisfy ISO 2919.1999(E) requirements.

The Model C3100 sealed sources were tested to IAEA special form requirements by Best Theratronics and have achieved an ISO 2919:2012 E65646 classification.

EXTERNAL RADIATION LEVELS:

MDS Nordion reported that the Gammacell 1000 has an average dose rate less than 0.5 mrem/hr (5 μSv/hr) at 1.97 inches (5 cm) from its surface when loaded with maximum activity.

The Gammacell 1000 Elite is self-shielded and can be safely operated in an existing lab environment. The manufacturer claims that with the secondary shielding installed the Gammacell 3000 Elan can be safely operated in an existing lab environment as well. When loaded with maximum activity the external radiation levels for these devices in the transient condition have been calculated by Nordion to be no greater than 5.0 mrem/hr (50 μSv/hr) at 1.97 inches (5.0 cm) from the accessible surface of the unit and 0.5 mrem/hr (5 μSv/hr) at 39.4 inches (100 cm) from the accessible surface of the unit.

With the devices in the "in use" or "not in use" condition the external radiation levels have been calculated by Nordion to be no greater than 1.0 mrem/hr (10 μSv/hr) at 1.97 inches (5 cm) from the accessible surface of the unit and 0.05 mrem/hr (0.5 μSv/hr) at 39.4 inches (100 cm) from the accessible surface of the unit.

QUALITY ASSURANCE AND CONTROL:

Best Theratronics maintains a quality assurance and control program **(QA/QC)** which has been deemed acceptable for licensing purposes by NRC **and is ISO 9001:2008 certified. The manufacture of Model C3100 sealed source is covered by Best Theratronics' QA/QC program.** A copy of the program is on file with the NRC.

LIMITATIONS AND/OR OTHER CONSIDERATIONS OF USE:

- The irradiators and sources shall be distributed only to persons specifically licensed by the NRC or an Agreement State.

- Handling, Storage, Use, Transfer, and Disposal: To be determined by the licensing authority.

- The irradiators shall be leak tested at intervals not to exceed 6 months using techniques capable of detecting 0.005 microcurie (185 Bq) of removable contamination.

- REVIEWER NOTE: The secondary shielding for the Gammacell 3000 Elan must be installed at the time of delivery to the user's facility and prior to the initial use of the device. This installation must be performed by Best Theratronics or persons specifically licensed by the NRC or an Agreement State to perform service on this device.

- **The Model C-1000, C-1001, C-3000, C-3001, C-378, and C3100 sealed sources are approved by the NRC for use in the Gammacell 1000 and Gammacell 3000 Series irradiators. These sources are not registered on a separate certificate.**

- This registration sheet and the information contained within the references shall not be changed without the written consent of the NRC.

DEVICE TYPE: Gamma Irradiator

SAFETY ANALYSIS SUMMARY:

This certificate supersedes NR-0220-D-102-S. MDS Nordion has transferred the manufacture and distribution of these devices to Best Theratronics. The quality control programs remain the same and the technical capability to administer these programs has not been changed. The transfer is limited to the name change, no changes were made in the design, fabrication, or operating procedures.

The Gammacell 1000 was deemed acceptable for licensing purposes in 1979. At that time, the device was manufactured by Isomedix, Inc. and distributed by AECL.

The Gammacell 1000 Elite was deemed acceptable for licensing purposes in 1990. The unit has a simplified operation from that of the Gammacell 1000. The cavity door has been equipped with an interlock to prevent the sample chamber from rotating when the door is open. This reduces the risk of hand injuries and radiation exposure. The unit is more stable due to a lower center of gravity and larger base. No significant changes were made to the source housing as compared to the Gammacell 1000.

The Gammacell 3000 Elan is identical to the Gammacell 1000 Elite in operation and essentially similar in design. Slight changes in the sample chamber, source cavity, rotor and exterior appearance were made for the Gammacell 3000 Elan. These changes do not affect the safety of the device and do not significantly change the radiation profile of the unit. Since the Gammacell 1000 and Gammacell 1000 Elite were deemed acceptable for licensing and that the changes made do not affect the safety of the device, the Gammacell 3000 Elan is deemed acceptable for specific licensing purposes.

The C-1000 source is essentially similar to the ISO-1000 source. The C-3000 source is identical in construction to the C-1000 source, but with a slightly larger diameter and a higher activity. The C-1000 source has been subjected to tests sufficient to receive an ANSI N542-1977 rating of 77E65546 and by comparison the C-3000 source has received the same rating.

DEVICE TYPE: Gamma Irradiator

SAFETY ANALYSIS SUMMARY(Cont.):

For these reasons the C-1000 and C-3000 sources are deemed acceptable for use in the Gammacell 1000 Elite and Gammacell 3000 Elan.

The C-1001 source is essentially similar to the C-1000 source and the C-3001 source is essentially similar to the C-1001 source. The C-1001 and C-3001 sources are expected to be able to withstand similar conditions to the C-1000 and C-3000 sources.

The C-378 has an additional encapsulation of ISO-1000 approved source with a leak tested single outer shell. The C-378 sealed source has passed special form tests performed by MDS Nordion and have been tested to and achieved a rating of 96E64334(5) as per ANSI N43.6-1997.

The Model C3100 sealed source is a direct replacement of the Model C-3001 sealed source. The C3100 sealed source has passed special forms test performed by Best Theratronics and has been tested to and achieved an ISO 2919 classification of E65646. Based on our review of the information and test results provided by Best Theratronics we conclude that the Model C3100 sealed source is acceptable for licensing purposes when used in the Gammacell 1000 and Gammacell 3000 Series irradiators. Furthermore, we conclude that the Model C3100 source would be expected to maintain its integrity for normal and accidental conditions of use which might occur during uses specified in this certificate.

We **continue to** conclude that these devices and sources would be expected to maintain their containment integrity for normal conditions of use specified in this certificate.

REFERENCES:

The following supporting documents for the Gammacell 1000 research irradiator are hereby incorporated by reference and are made a part of this registry document.

- Isomedix, Inc. letters dated May 9, 1980 and June 11, 1980 with enclosures thereto.
- ORNL letter dated June 18, 1980. Atomic Energy of Canada, Ltd. letter dated June 2, 1983 with enclosures thereto.

The following supporting documents for the Gammacell 1000 Elite research irradiator are hereby incorporated by reference and are made a part of this registry document.

- Atomic Energy of Canada, Ltd. letter dated August 20, 1986 with enclosures thereto.
- Nordion International, Inc. letters dated December, 8, 1988 and April 11, 1990 with enclosures thereto.

The following supporting documents for the Gammacell 3000 Elan research irradiator, C-1000, and C-3000 sources are hereby incorporated by reference and are made a part of this registry document.

- Nordion International, Inc. letters dated September 5, 1991, September 24, 1991, November 4, 1991, December 17, 1991 and December, 20, 1991 with enclosures thereto.
- Nordion International, Inc. facsimile received November 22, 1991. MDS Nordion, Inc., letters dated September 25, 1997, and January 13, 1998, with enclosures thereto.

REFERENCES (Cont.):

The following supporting documents for the C-1001 and C-3001 sources are hereby incorporated by reference and are made a part of this registry document.

- Nordion International, Inc. letters dated June 4, 1993, and March 18, 1993, with enclosures thereto.
- Amersham Corporation's letter, in support of Nordion's application, dated December 16, 1992, with enclosures thereto.
- MDS Nordion, Inc., letters dated September 25, 1997, and January 13, 1998, with enclosures thereto.
- MDS Nordion letter dated December 14, 2001, requesting name and address change.MDS Nordion letter dated September 18, 2003, and electronic mail dated November 24, 2003, with enclosures thereto.

The following supporting documents for the C-378 sources are hereby incorporated by reference and are made a part of this registry document.

- MDS Nordion letters dated May 23, 2002, and September 16, 2002, with enclosures thereto.
- Best Theratronics letter dated March 20, 2008, with enclosures thereto.
- Best Theratronics letter and e-mail dated September 9, 2010, with enclosures thereto.
- Best Theratronics letters dated June 28, 2011, with enclosures thereto.

REFERENCES (Cont.):

- Best Theratronics letters dated November 17, 2011, and April 27, 2012, with enclosures thereto.
- Best Theratonics emails dated April 27, 2012, with enclosures thereto.

The following supporting documents for the C3100 sources are hereby incorporated by reference and are made a part of this registry document.

- **Best Theratonics letters dated December 3, 2014 (ML15005A339), March 26, 2015 (ML15090A673), April 24, 2015 (ML15117A055), and May 1, 2015 (ML15124A003), with enclosures thereto.**

ISSUING AGENCY:

U.S. Nuclear Regulatory Commission

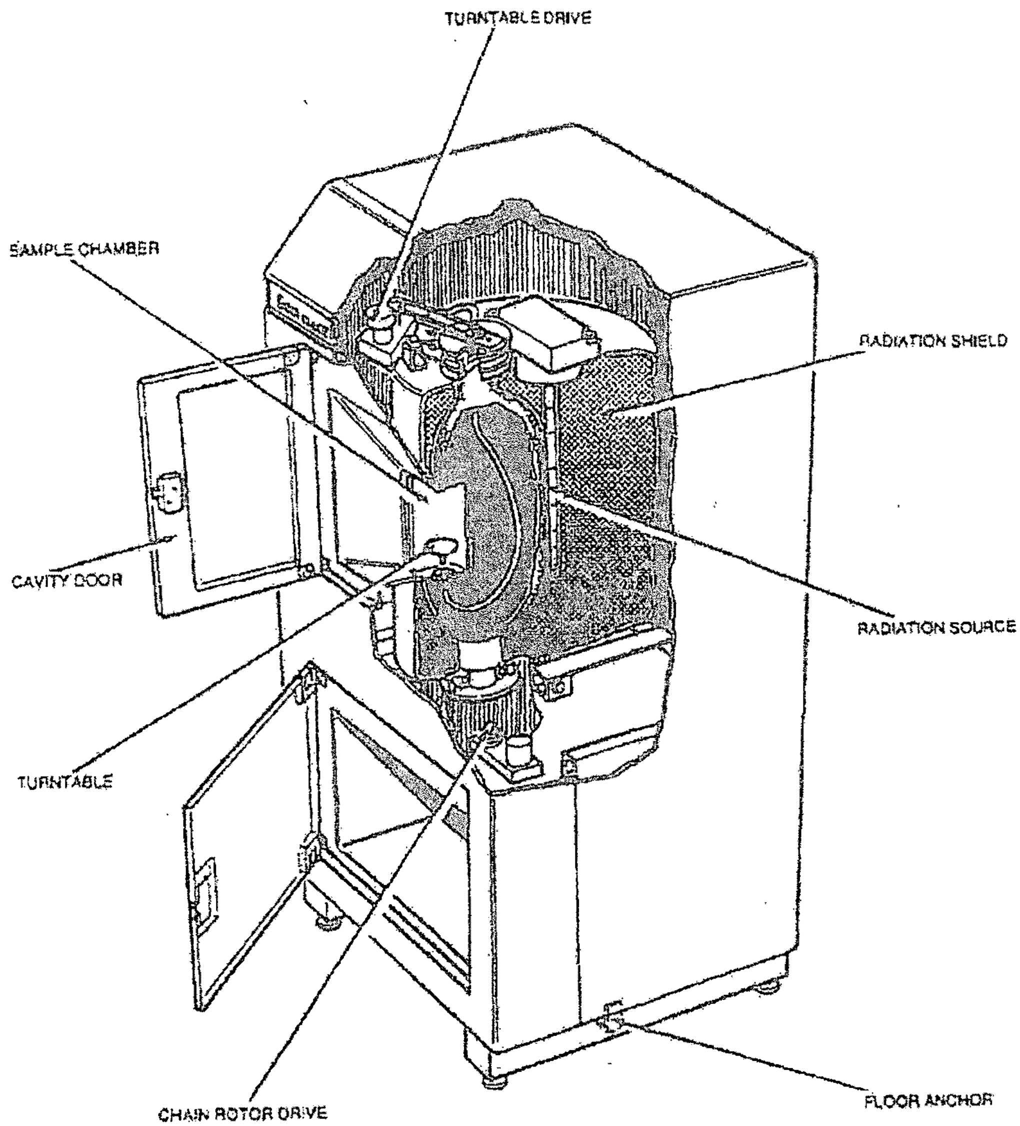
Date: May 15, 2015 Reviewer: Tomas Herrera

Date: May 15, 2015 Concurrence: Lymari Sepulveda

REGISTRY OF RADIOACTIVE SEALED SOURCES AND DEVICES
SAFETY EVALUATION OF A DEVICE
(AMENDED IN ITS ENTIRETY)

NO.: NR-1307-D-102-S DATE: May 15, 2015 ATTACHMENT: 1 of 6

DEVICE TYPE: Gamma Irradiator

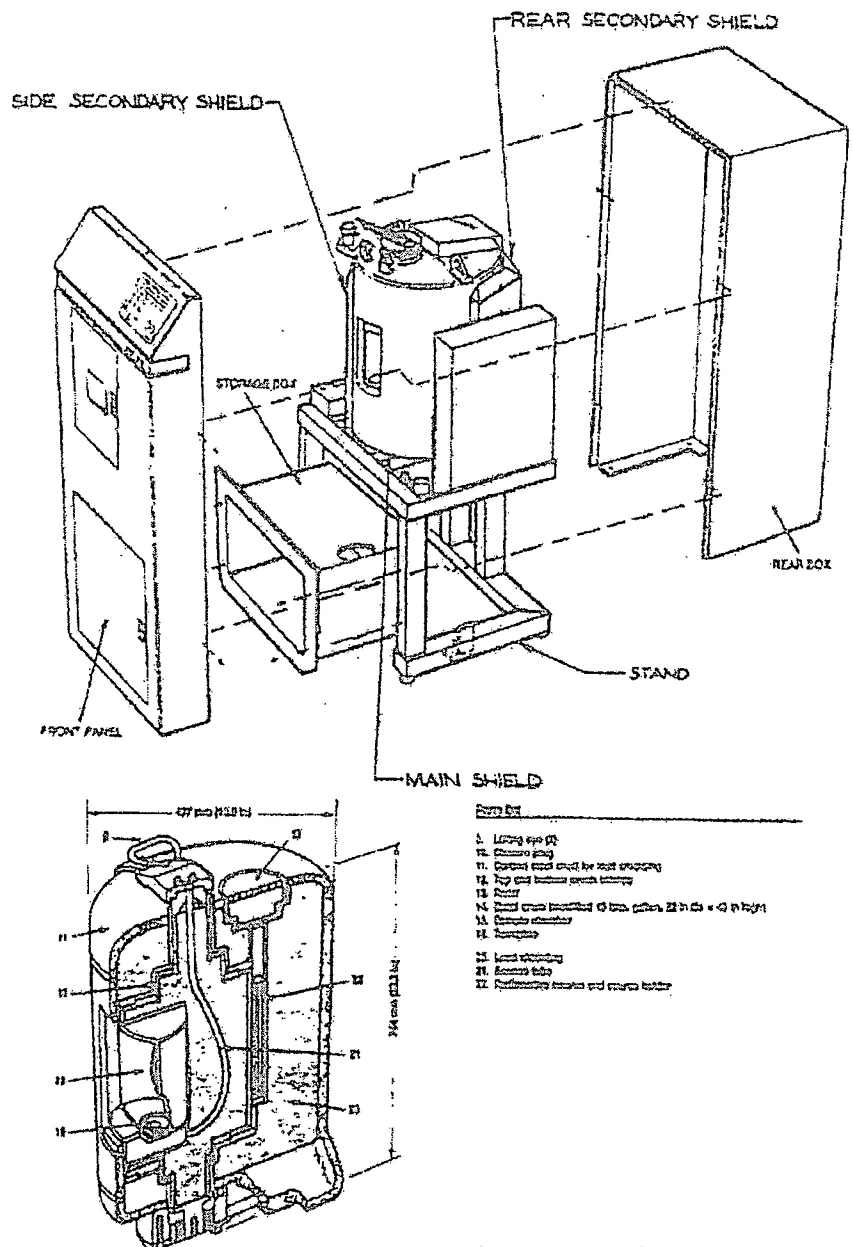


Model Gammacell 1000 Elite

REGISTRY OF RADIOACTIVE SEALED SOURCES AND DEVICES
SAFETY EVALUATION OF A DEVICE
(AMENDED IN ITS ENTIRETY)

NO.: NR-1307-D-102-S   DATE: May 15, 2015   ATTACHMENT: 2 of 6

DEVICE TYPE: Gamma Irradiator



Model Gammacell 3000 Elan

**Security-Related Information
Figure Withheld Under
10 CFR 2.390**

C-3000 Source Capsule C-3001 Source Capsule

Security-Related Information
Figure Withheld Under
10 CFR 2.390

ISO-1000 Source Capsule

**Security-Related Information
Figure Withheld Under
10 CFR 2.390**

C-378 Source Capsule

Security-Related Information
Figure Withheld Under
10 CFR 2.390

C3100 Source Capsule

CHAPTER 6 – CRITICALITY EVALUATION

The requirements of this chapter are not applicable since the F-431 package is not intended to transport fissile materials.

CHAPTER 7 – OPERATING PROCEDURES

This chapter describes the operating procedures for the F-431 package. The following operations are described:

1. Loading the GC1000 or GC3000 into the F-431 Overpack and preparation for shipment,
2. Unloading the F-431, and
3. Preparing an Empty Packaging for Shipment.

7.1 COMPLIANCE AND RESPONSIBILITY

1. It is the responsibility of Best Theratronics to ensure that the radioactive material transport packaging is approved and maintained in compliance with the approval certificates.
2. It is the responsibility of Best Theratronics personnel or its qualified agent to ensure that the operations described by these procedures are followed and that the F-431 transport package is prepared for shipment in compliance with this procedure and any supplementary regulatory requirements.
3. Only trained personnel shall prepare the package for shipment.
4. The package shall contain only isotopes in quantities and form specified on the Transport Package Design Approval Certificate. Only package configurations listed on the Certificate shall be shipped.

7.2 PROCEDURES FOR PREPARING THE GC1000 OR GC3000 FOR SHIPMENT

1. Remove the Gammacell covers.
2. Perform a contamination test. The level of non-fixed radioactive contamination shall be determined by wiping an area of 300 cm^2 of the external surface by hand with a dry filter paper, or a wad of dry cotton wool, or any other material of this nature. The maximum permissible level of contamination is 4 Bq/cm^2 (10^{-4} $\mu Ci/cm^2$).
3. Remove the Gammacell from its stand.
4. Install the rotor lock.
5. Install the chamber cover.

7.3 LOADING AND PREPARING THE F-431 PACKAGE FOR SHIPMENT

1. Ensure that the lower inner brace is in the bottom of the F-431 cavity.
2. Place the Gammacell head into the transport cavity.
3. Install the upper inner brace and the vertical supports around the Gammacell.
4. Close cavity with internal cover and secure cover with [redacted]
5. Close the container with the main cover and secure it with [redacted]
6. Install a tamper evident seal between the main cover and the body of the package.
7. Check the radiation fields on the external surface of the overpack and at 1 m, to determine which of the Radioactive I or II or III Category labels is appropriate (see Table 7.1). The maximum field at the surface of the package must be less than 200 mrem/h. The maximum field 1 m from the surface of the package must be less than 10 mrem/h.

8. Perform a routine wipe test on the unit to check for removable contamination. The level of non-fixed radioactive contamination shall be determined by wiping an area of 300 cm^2 of the external surface by hand with a dry filter paper, or a wad of dry cotton wool, or any other material of this nature. The maximum permissible level of contamination is 4 Bq/cm^2 (10^{-4} $\mu Ci/cm^2$).
9. Ensure that at least one Identification Plate and at least one Radiation Caution Plate are securely affixed to the exterior of the F-431.
10. Affix two appropriate category labels to opposite sides of the package. Complete the required information regarding the contents (i.e. radionuclide, activity, transport index, etc.).

Note: The Radioactive Category label depends on the measured radiation fields. The requirements are summarized in Table 7.1. The TI is the highest reading obtained in mrem/h at 1 metre from any external surface of the package.

Table 7.1: Package Label Requirements

Label	Radiation Level at External Surface of Package	Transport Index (T.I.)[1]	Radiation Level at External Surface of Vehicle
Radioactive I (white)	≤ 5.0 μ Sv/h (0.5 mrem/h)	-	-
Radioactive II (yellow)	>5.0 μ Sv/h (0.5 mrem/h) ≤ 500 μ Sv/h (50 mrem/h)	≤1.0	
Radioactive III (yellow)	>500 μ Sv/h (0.5 mrem/h) ≤ 2,000 μ Sv/h (200 mrem/h)	> 1 and ≤10.0	

[1] T.I. - Radiation level in microsieverts per hour at 1 m from the external surface of the package divided by 10 (mrem/h at 1 m).

1. Affix two UN number labels. These labels must be printed with both the "UN2916" marking and the proper shipping name "Radioactive Material, Type B(U) Package". Note: one label must be affixed next to each of the Radioactive category labels.
2. Affix the "ship to" label and the appropriate shipping documents to the package.
3. Complete the Shipper's Declaration, the Emergency Response Form, and the Waybill.
4. Include the applicable Transport Package Design Approval Certificates with the shipping documents.

[redacted]

Figure 7.1a: [redacted]

[redacted]

Figure 7.1b: [redacted]

7.4 PROCEDURES FOR UNLOADING THE F-431 PACKAGE

7.4.1 Receipt of F-431 Transport Package

1. Visually inspect the F-431 transport package for damage and deterioration. Immediately contact Best Theratronics regarding any damage or deterioration that may affect the integrity of the package.
2. Check and verify that the tamper-proof seal is intact. If the tamper-proof seal is not intact, contact the RSO at the customer's site or Best Theratronics for further disposition.
3. Check all external surfaces on the package for contamination.
4. Perform a radiation survey of the assembled package. If the radiation fields are higher than anticipated (e.g. if the TI exceeds the value on the category label), contact the RSO at the customer's site or Best Theratronics for further disposition.

7.4.2 Unloading the Gammacell from the F-431

1. Move the F-431 Overpack to a location accessible by overhead crane, using a 4-legged lifting sling rated to at least 2270 kg (5000 lb.). Note: that the maximum weight of the transport package is 2270 kg or 5000 lb.
2. Perform a routine wipe test on the exterior of the F-431 to check for removable contamination. The level of removable contamination shall be less than 4 Bq/cm^2.
3. Remove [redacted] and, using the same lifting slings as in step 1, remove the F-431 lid and set it in a safe place.
4. Remove [redacted] remove the cover and set it in a safe place.
5. Remove the inner top brace from the Gammacell. Lift the Gammacell shielding head from the F-431 cavity.
6. Perform a radiation survey of the Gammacell. Radiation levels should not exceed 2 mSv/h (200 mrem/h) on accessible surfaces of the Gammacell or 0.1 mSv/h (10 mrem/h) at any point one meter from the surface. If the radiation fields exceed these limits, contact Best Theratronics immediately.
7. Put the internal fixing brace inside the F-431, close both covers and move the F-431 to storage.

7.5 PREPARATION OF AN EMPTY PACKAGE FOR TRANSPORT

1. After the overpack is empty and on the trailer truck or in the designated staging area, monitor around the overpack to confirm that it is empty.
2. Check all external surfaces on the overpack for contamination.
3. [redacted]
4. If the shipment originates in the USA, cover the "Radiation Caution" with "EMPTY" labels. For shipments originating from other countries, cover the "Radiation Caution" but do not attach "EMPTY" labels.
5. Remove the Category labels.
6. Affix address label to the container.

CHAPTER 8 – ACCEPTANCE TESTS AND MAINTENANCE PROGRAM

This chapter discusses the acceptance tests and maintenance program used on the F-431 transport package, in compliance with the applicable subsections of 10 CFR Part 71. Best Theratronics has a quality assurance program in place governing all aspects of the F-431 overpack (design, manufacturing, testing, use, inspection and maintenance etc.).

8.1 ACCEPTANCE TESTS

All inspections and tests of the GC1000, GC3000 and the F-431 overpack prior to the first shipment are an integral part of the manufacturing process. The manufacturing process and its quality assurance requirements are established in a technical specification that is maintained by Best Theratronics in accordance with its Radioactive Material Transport Package Quality Plan (refer to Appendix 9.3.2).

8.1.1 Inspection

The F-431 package and the GC1000 or GC3000 are visually and dimensionally inspected for any non-conformance in materials or fabrication using applicable codes, standards and drawings. In particular it is ensured that:

1. The dimensions are in accordance with the engineering drawings,
2. The components fit together properly,
3. All fasteners are in place and properly installed, and
4. Welding is in accordance with the engineering drawings.

8.1.2 Structural and Pressure Tests

Inspections and tests to ensure the structural integrity of the package are an integral part of the manufacturing process. All critical materials, components, welding supplies, fasteners etc. are subject to the quality program. All critical components and subassemblies are inspected to engineering drawings and/or specifications at key points in the manufacturing process.

Should an inspection or test fail to meet the prescribed criteria, corrective action shall be in accordance with the Radioactive Material Transport Package Quality Plan.

No pressure testing is required for the GC1000, GC3000 or F-431 overpack.

8.1.3 Leak Tests

Containment is provided by Sealed Sources. The Sealed Sources are subjected to the following tests during manufacturing:

1. Leakage testing by hot-liquid bubble test per ISO 9978 or a test of equivalent or better sensitivity.
2. Dry wipe contamination testing per ISO 9978 or a test of equivalent or better sensitivity.

There are no leak tests specified for the F-431..

8.1.4 Component Tests

8.1.4.1 Valves, Rupture Discs, and Fluid Transfer Devices

This section is not applicable since there are no valves, rupture discs or fluid transfer devices on the F-431 package.

8.1.4.2 Gaskets

The F-431 overpack and its components undergo inspection prior to each shipment from Best Theratronics, Kanata, Ontario, Canada. The gaskets are visually examined for defects. The seal surfaces are visually examined for nicks or damage.

New gaskets may be installed on the F-431 during the regular or annual inspection and maintenance.

8.1.4.3 Miscellaneous

[redacted]

8.1.5 Tests for Shielding Integrity

Shielding is provided by the GC1000 or GC3000. The GC1000 and GC3000 are subjected to a thorough radiation survey as part of manufacturing. The acceptance criteria are as follows:

When installed in the laboratory configuration,

1. the maximum radiation fields on the external surface of the GC1000 shall not exceed 125 mrem/h.
2. the maximum radiation fields on the external surface of the GC3000 shall not exceed 135 mrem/h.
3. the maximum radiation fields at 1 m from any accessible external surface of the GC1000 shall not exceed 3 mrem/h.
4. the maximum radiation fields at 1 m from any accessible external surface of the GC3000 shall not exceed 6 mrem/h.

There are no neutron sources in the F-431 package.

8.1.6 Thermal Acceptance Tests

Thermal acceptance testing is not required for each F-431, since the internal heat generation in the GC1000 or GC3000 is low (15 Watts) and the thermal gradients are low. [redacted]

8.2 MAINTENANCE PROGRAM

This section describes the maintenance program used to ensure the continued performance of the F-431 overpack. The F-431 package is inspected prior to each loading. The inspection and maintenance is carried out as per the Best Theratronics Radioactive Material Transport Package Quality Plan (see Appendix 9.3.2).

8.2.1 Structural and Pressure Tests

Prior to shipment of the package, all critical components are visually inspected to ensure that they are undamaged and continue to meet the requirements of the applicable engineering drawings and specifications.

No pressure testing is required for the F-431 overpack.

8.2.2 Leak Tests

The GC1000 and GC3000 are leak tested at regular intervals, typically every six months, using a technique capable of detecting 185 Bq (0.005 microcurie) of removable contamination. A valid leak test certificate is a mandatory requirement for shipping.

No leak testing is required for the F-431 overpack.

8.2.3 Subsystem Maintenance

The inner braces inside the transport cavity are subjected to regular visual inspections. If these inspections reveal damage such as cracks, the components are repaired in accordance with the same standards that were used for manufacturing.

The lower inner brace is removed and the cavity is cleaned. Worn or cracked plywood is replaced.

On an annual basis, the screws on the hoist rings and on the tie-down collar shall be re-tightened to the specified torque.

8.2.4 Valves, Rupture Discs, and Gaskets on the Containment Vessel

The F-431 container undergoes inspection and maintenance prior to each shipment from Best Theratronics, Kanata, Ontario, Canada. The gaskets are visually examined for defects. The seal surfaces are visually examined for nicks or damage. New gaskets may be installed on the F-431 during the regular or annual inspection and maintenance.

8.2.5 Shielding

Radiation surveys are performed on the GC1000 or GC3000 and the F-431 prior to every shipment. With the GC1000 or GC3000 loaded inside the F-431, the acceptance criteria are as follows:

1. the maximum radiation fields on the external surface of the F-431 shall not exceed 200 mrem/h.
2. the maximum radiation fields at 1 m from any accessible external surface of the F-431 shall not exceed 10 mrem/h.

8.2.6 Thermal

No thermal testing is required on the F-431 overpack.

CHAPTER 9 – QUALITY ASSURANCE

This section describes the Quality Program in place at Best Theratronics Ltd., Kanata, Ontario, Canada, as it applies to the F-431 Transport Package. Best Theratronics Ltd. has an ISO90001 registered quality assurance program in place governing all aspects of the Transport Packaging (design, manufacturing, testing, use, inspection and maintenance etc.), and is approved by USNRC; (Quality Assurance Program Approval No. 0943, Docket No. 71-0943, dated August 28, 2015, refer to Appendix 9.3.1).

9.1 BEST THERATRONICS QUALITY ASSURANCE PROGRAM

The Quality Assurance Program at Best Theratronics is as per document 5.05-QA-01 "Radioactive Material Transport Package Quality Plan", attached in Appendix 9.3.2.

9.3 APPENDICES

This section contains the following appendices.

Appendix 9.3.1: USNRC Quality Assurance Program Approval for Radioactive Material Packages, Approval No. 0943.

Appendix 9.3.2: Best Theratronics Radioactive Material Transport Package Quality Plan

Appendix 9.3.3: Best Theratronics Sealed Source Quality Plan

APPENDIX 9.3.1: USNRC Quality Assurance Program Approval for Radioactive Material Packages, Approval No. 0943

NRC FORM 311 (07-2015) 10 CFR 71

U.S. NUCLEAR REGULATORY COMMISSION

QUALITY ASSURANCE PROGRAM APPROVAL
FOR RADIOACTIVE MATERIAL PACKAGES

1. APPROVAL NUMBER: 0943

REVISION NUMBER: 1

Pursuant to the Atomic Energy Act of 1954, as amended, the Energy Reorganization Act of 1974, as amended, and Title 10, Code of Federal Regulations, Chapter 1, Part 71, and in reliance on statements and representations heretofore made in Item 4 by the organization named in Item 2, the Quality Assurance Program identified in Item 4 is hereby approved. This approval is issued to satisfy the requirements of Section 71.101 of 10 CFR Part 71. This approval is subject to all applicable rules, regulations, and orders of the Nuclear Regulatory Commission now or hereafter in effect and to any conditions specified below.

2. NAME: Best Theratronics, Ltd.

STREET ADDRESS: 413 March Road

CITY	STATE	ZIP CODE	3. DOCKET NUMBER
Ottawa, Ontario, Canada	N/A	K2K 0E4	71-0943

4. QUALITY ASSURANCE PROGRAM APPLICATION DATE(S): February 27, 2009 and April 24, 2013

5. CONDITIONS

1. Activities conducted regarding transportation packagings are to be executed under applicable criteria of 10 CFR Part 71, Subpart H. Authorized activities include: design, procurement, fabrication, assembly, testing, modification, maintenance, repair, and use of transportation packagings.

2. Records shall be maintained in accordance with the provisions of 10 CFR Part 71. Specifically:

   a. Records of each shipment of licensed material shall be maintained for 3 years after that shipment [10 CFR 71.91(a)].

   b. Records providing evidence of packaging quality shall be maintained for 3 years after the life of the packaging [10 CFR 71.91(d)].

   c. Records describing activities affecting packaging quality shall be maintained for 3 years after this Quality Assurance Program Approval is terminated [10 CFR 71.135].

3. Planned and periodic audits of all aspects of the Quality Assurance Program shall be conducted in accordance with written procedures or checklists, by appropriately trained personnel not having direct responsibility in the areas being audited, in accordance with 10 CFR 71.137.

FOR THE U.S. NUCLEAR REGULATORY COMMISSION

SIGNATURE: [signature]

DATE: 8/28/15

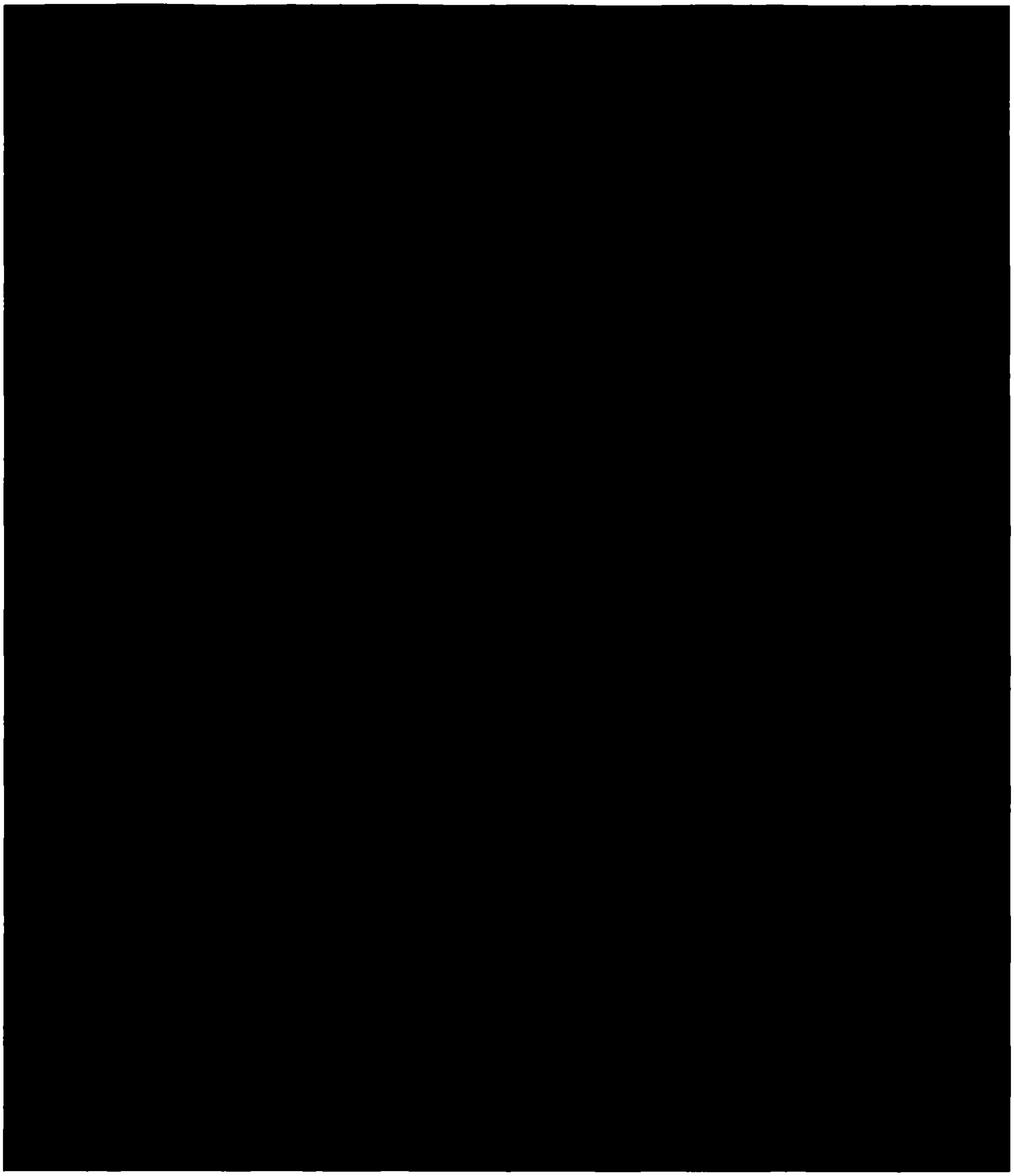
PATRICIA SILVA, CHIEF
INSPECTIONS AND OPERATIONS BRANCH
DIVISION OF SPENT FUEL MANAGEMENT
OFFICE OF NUCLEAR MATERIAL SAFETY AND SAFEGUARDS

NRC FORM 311 (07-2015)

APPENDIX 9.3.2:
Best Theratronics Radioactive Material Transport Package Quality Plan

5.05-QA-01 (C)

[redacted]



[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

APPENDIX 9.3.3:
Best Theratronics Sealed Source Quality Plan

5.05-QA-02 (2)

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]