Safety Analysis Report for F430/GC-40 Transport Package

Signatures

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Document History

Date	Version	Comments	Prepared by	Reviewed by	Approved by
Sept. 2000	1	A1297-C-00A	J. Krupka	M.A. Charette	M. Krzaniak
Oct. 2001	1a	DCN: A1297-D-10A Updates to Append. 1.3.2, Chap 2, Chap 3, Append 3 6 1	B. Menna	M.A. Charette	M. Krzaniak
Jul. 2002	2	DCN: A1297-D-12A	B. Menna	M.A. Charette	M. Krzaniak
Feb. 2003	2a	DCN: A1297-D-15A Updated Chapters 1, 2, 3, 7 and Appendices A1 3 1, 1.3.2, and 2.10.3			

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

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CHAPTER 1 - GENERAL INFORMATION

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

1.1 INTRODUCTION

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

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

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

Authorization is sought for shipment of F-430 Transport Package as a Type B(U)-96 package. Authorization is also sought for the use of F-430 overpack to transport other radioactive contents that satisfy specific criteria for weight, heat generation, shielding and containment.

1.2 PACKAGE DESCRIPTION

1.2.1 Packaging

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

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

Table 1.1: Summary of F-430/GC40 Weights

Component	Nominal Weight, Lower Head Configuration	Nominal Weight, Upper Head Configuration	Test Specimen Weight
GC40 Head	1241 kg (2735 lb.)	1157 kg (2550 lb.)	1740 kg (3835 lb.)
Inner Brace	209 kg (460 lb.)	170 kg (375 lb.)	209 kg (460 lb.)
F430 Overpack	1200 kg (2640 lb.)	1200 kg (2640 lb.)	1209 kg (2665 lb.)
Tie Down Collar	155 kg (340 lb.)	155 kg (340 lb.)	N/A
Total	**2810 kg (6200 lb.)**	**2675 kg (5900 lb.)**	**3158 kg (6960 lb.)**

[redacted]

For overhead lifting the F-430 overpack is equipped with four hoist rings on the top surface. Each hoist ring alone is rated for 32kN (7000lb) with a breaking strength of 156kN (35000lb), and the overpack can be lifted by any single hoist ring For tie-down, at the time of shipping. the F-430 is fitted with a tie-down collar which is not structurally part of the package.

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

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

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

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

1.2.2 Operational Features

[redacted]

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

[redacted]

1.2.3 Contents of Packaging

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

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

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

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

1.3 APPENDICES

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

This section contains the following appendices.

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

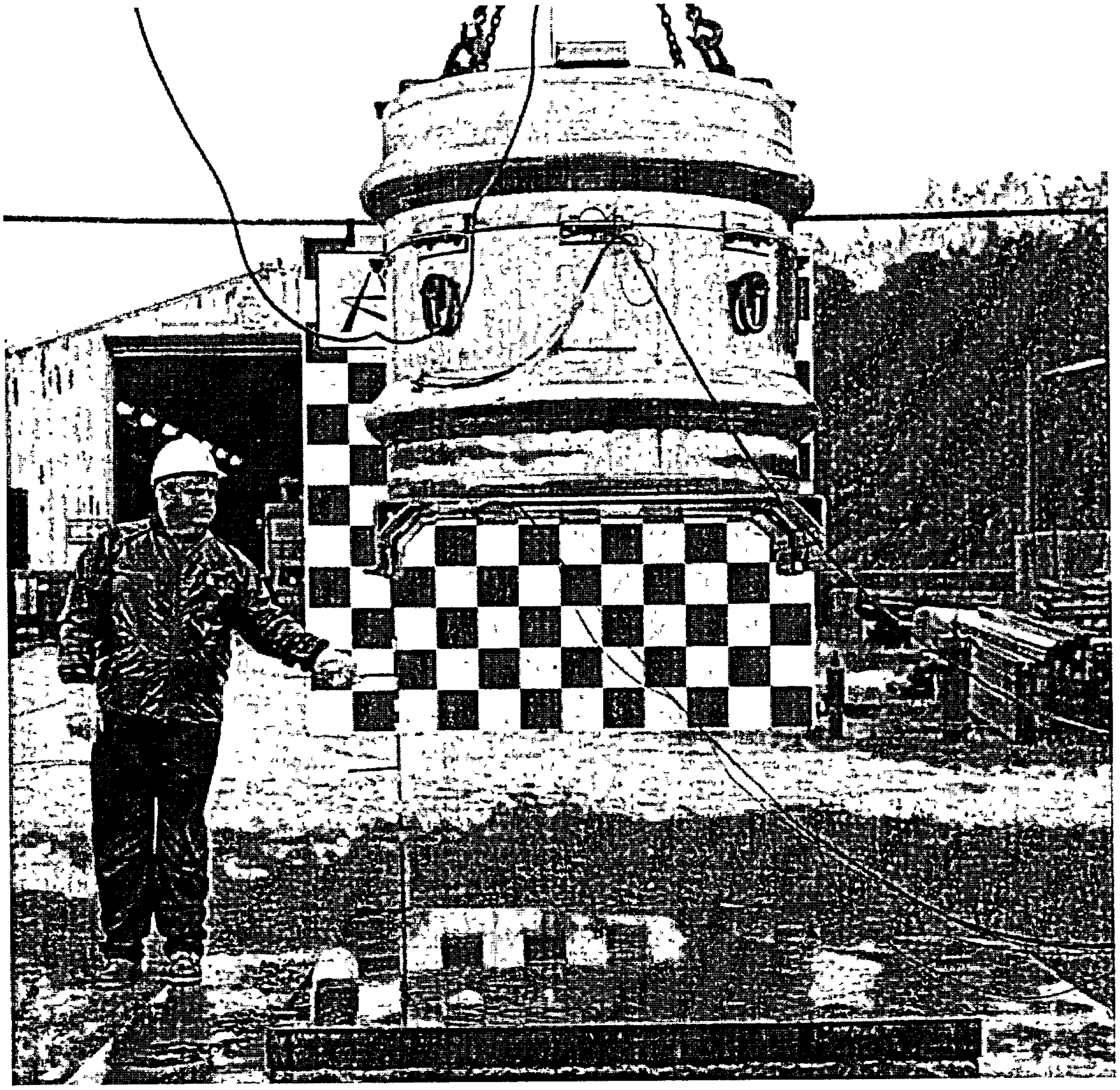


Figure 1.1: F-430 Overpack prior to 1.2m normal drop test (Photo 9910-23698-2)

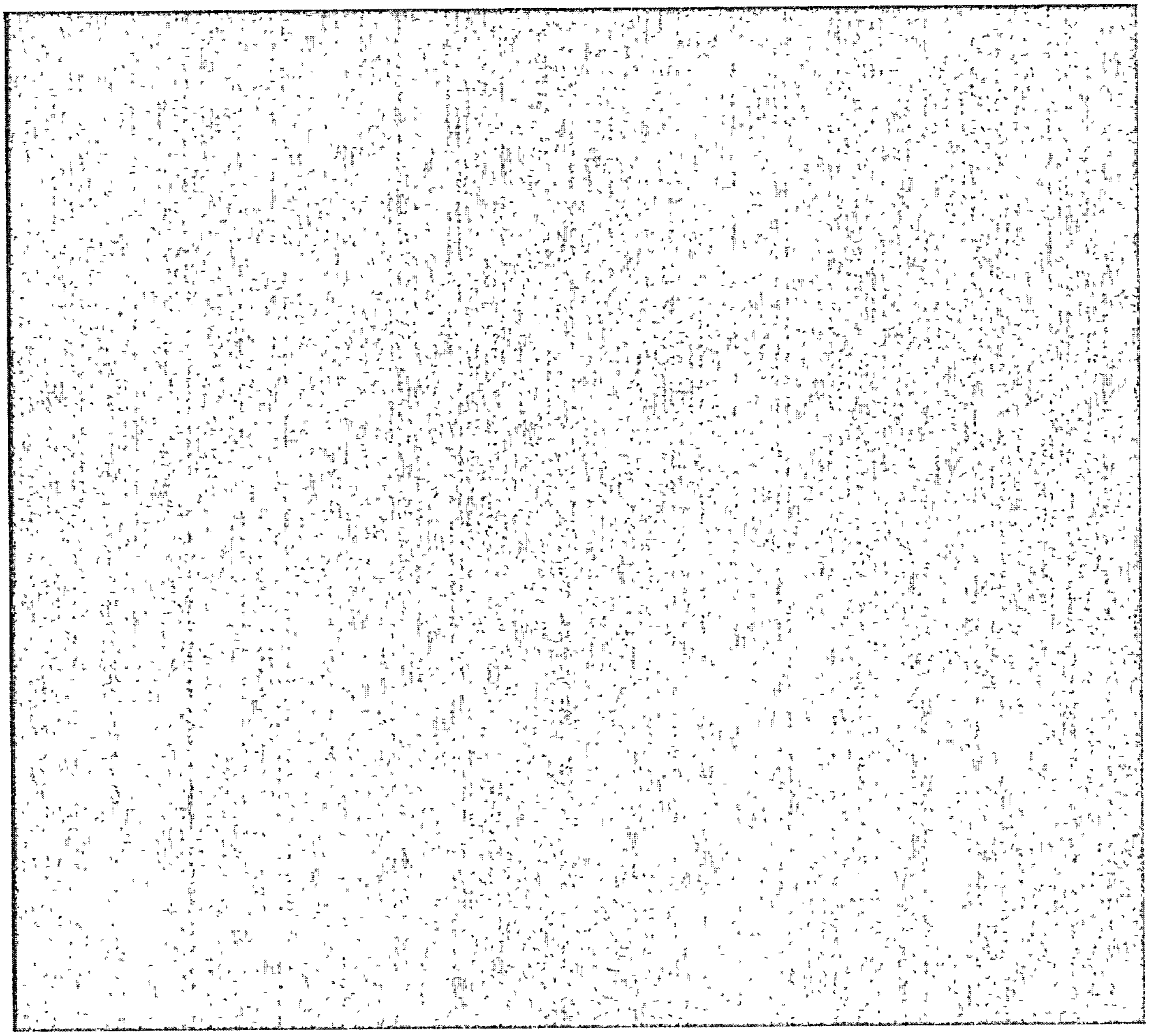


Figure 1.2: [redacted]

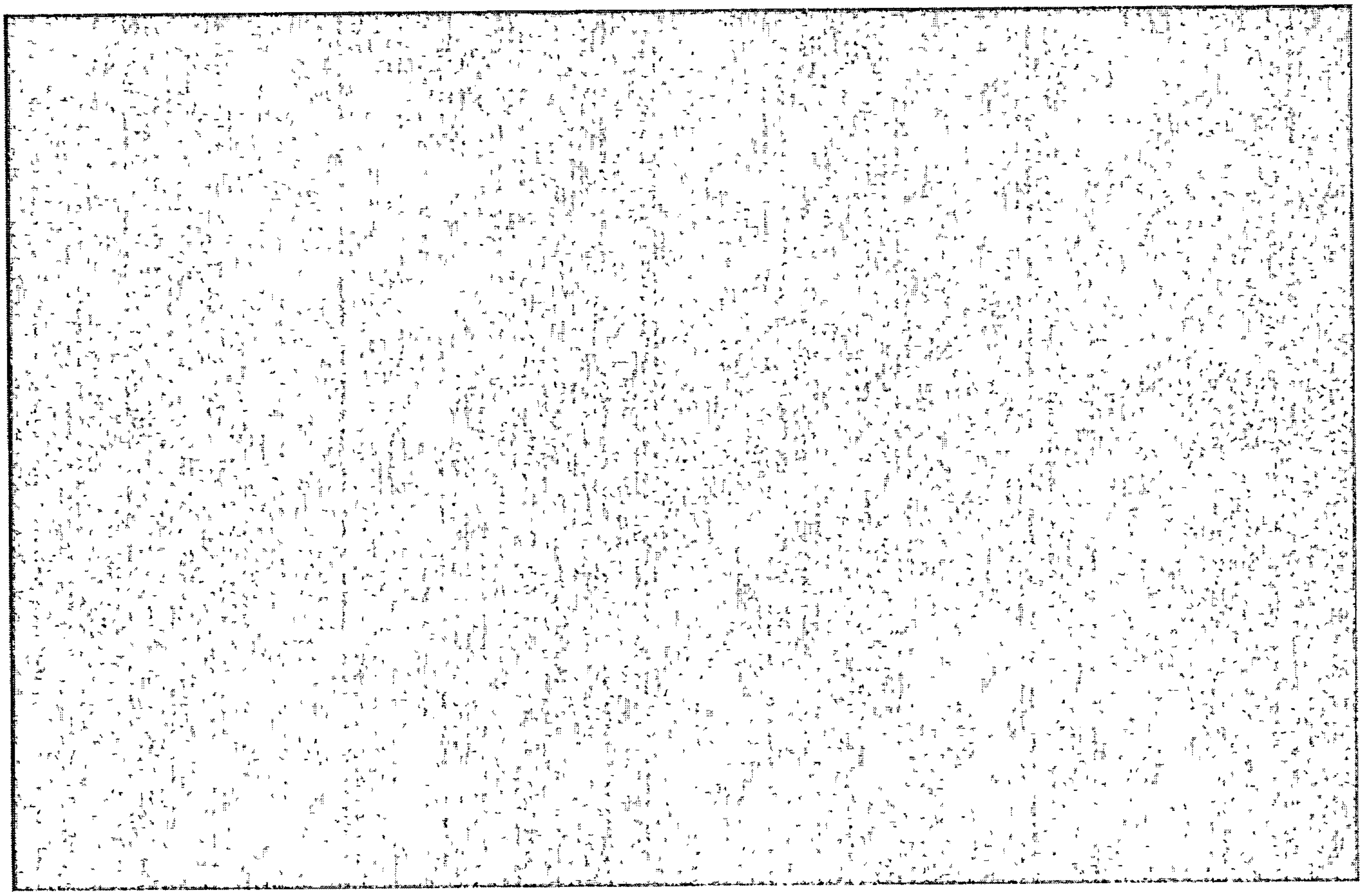


Figure 1.3: [redacted]

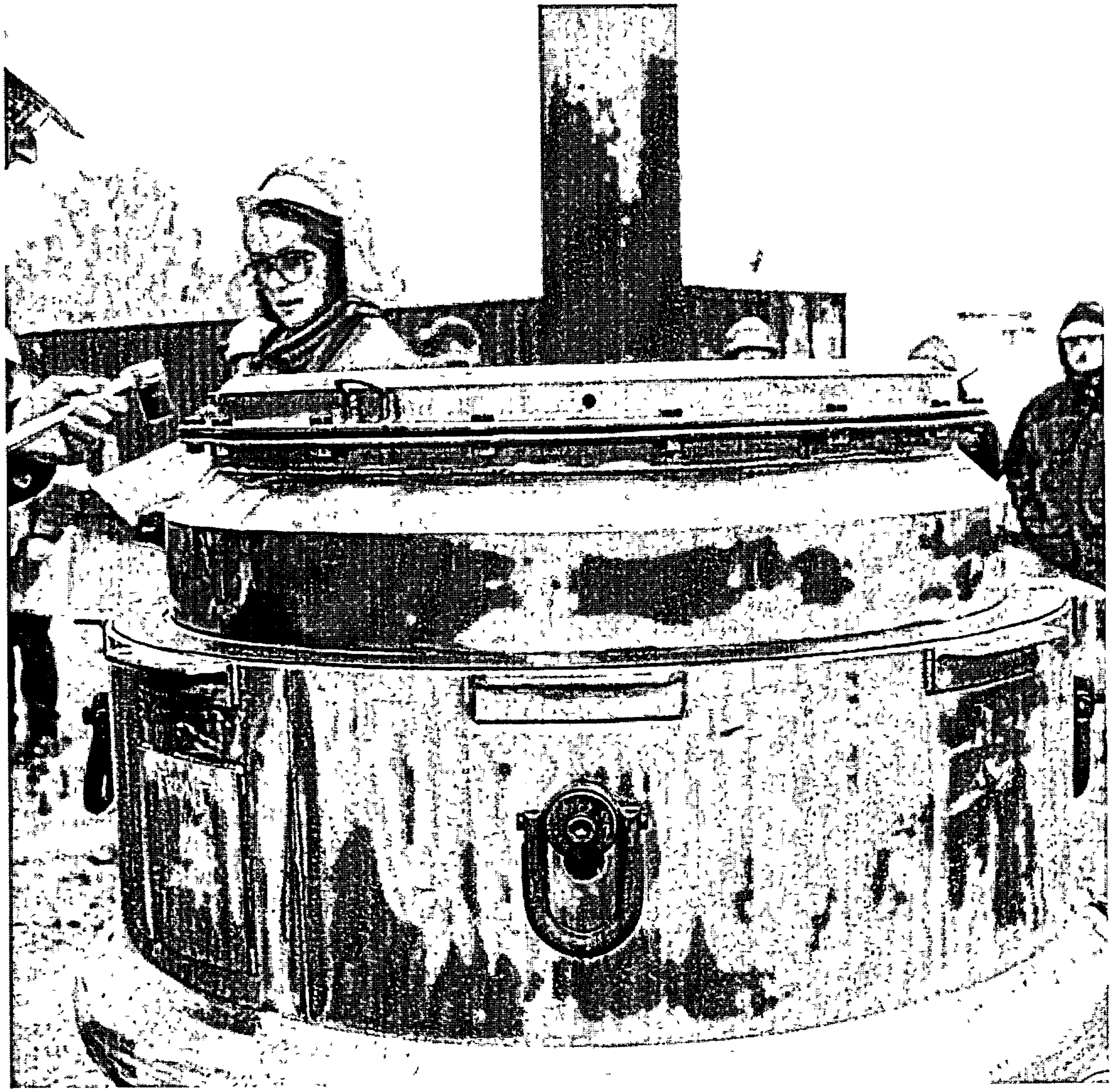


Figure 1.4: F-430, Main Cover Removed

APPENDIX 1.3.1:
Specification Sheet for the F-430/GC-40 Package

IN/SS 1682 F430 (3)

FIGURE WITHHELD UNDER 10 CFR 2.390

TITLE F-430 Transport Package		
REF. IN/SS 1682 F430	REVISED Jan 03	DCN A1297-D-16A
DATE September 2000	No F-430	ISSUE 3
DRAWN BW / CHECKED BM / APPROVED MK	SHEET 1 OF 1	

APPENDIX 1.3.2:

[redacted]

APPENDIX 1.3.3:
USNRC Device Registration for Gammacell-40

REGISTRY OF RADIOACTIVE SEALED SOURCES AND DEVICES
SAFETY EVALUATION OF DEVICE
(Amended in its Entirety)

NO. NR-220-D-101-S DATE: December 21, 1998

DEVICE TYPE: Gamma Irradiator

MODEL: Gammacell 40 **(Serial** No. **1 through 133)**
Gammacell 40 Exactor (Serial No. **134 and higher)**

MANUFACTURER/DISTRIBUTOR: MDS Nordion, Inc.
(formerly Atomic Energy of Canada, Ltd ., **and Nordion International, Inc.)**
447 March Road
Kanata, Ontario K2K IX8
Canada

SEALED SOURCE MODEL DESIGNATION: AECL C-161, Type 8
MDS Nordion C-161, Type 8
MDS Nordion C-440

ISOTOPE:	MAXIMUM ACTIVITY:
Cesium-137	4,200 curies (155.4 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 40 is a cesium-137 irradiator designed for use in an unshielded room. The unit provides a means for uniform gamma irradiation of samples while providing complete protection for operating personnel. Irradiation is accomplished by moving two lead filled cylindrical drawers, each containing a single radioactive source, simultaneously by **actuators** from the stored to the irradiate position. Source position is indicated by either an illuminated source ON (red) or source OFF (green) push-button switch located on the control panel **or by text messages on the display.** Each source directs a beam of radiation to the sample tray located in the center of the unit. While in the irradiate position, the radiation beam is entirely enclosed by lead shielding and while in the stored position the sources are shielded on all sides by lead. A mechanical interlock prevents the sample door from being opened while the sources are **not** in the **storage** position. Therefore, under normal circumstances the operator would not be exposed to a direct beam of radiation. **In the Gammacell 40 Exactor units (Serial No. 134 and higher), the head flanges incorporate grooves filled with lead to address localized radiation fields.**

A Model C-161, type 8 or Model C-440, cesium-137 (in the form of cesium chloride) source is housed in each of two cylindrical sliding drawers **approximately** 15 inches (38.1 cm) long by 2.5 inches (6.4 cm) in diameter. The drawers fit into lead cylinders about 29 inches (73.7 cm) long by 16 inches (40.6 cm) in diameter. The cylinders lie horizontally about **26** inches (**71** cm) **center to center**, one above and one below the sample cavity. A port in each cylinder wall about **11** inches (**29** cm) from the end leads to the sample cavity which is enclosed in a minimum of about 5 inches (12.7 cm) of lead. The source drawers are moved from the shielded position, which is approximately 9 inches (22.9 cm) from the end opposite the port end, to the irradiate position by means of pneumatic cylinders **in the Model Gammacell 40 units (Serial No. 1 through 133).**

DESCRIPTION (cont'd):

In the Model Gammacell 40 Exactor units (Serial No. 134 and higher) the drawers are driven by a DC electric motor through a timing belt. The electrical power source is a sealed 12 volt DC lead/acid battery. The battery is constantly charged by a charger connected to an AC power source. If AC power is lost while the unit is in operation, battery power is sufficient to complete the irradiation cycle in progress with reserve power for at least three subsequent cycles.

In the Model Gammacell 40 units the sample cavity **is sized to process small laboratory samples.** The ring is open at the top and the bottom and has hanger slots in the top rim to allow the user to suspend samples inside. The ring is secured to the hinged sample cavity door such that when the door is open, samples are easily accessible without reaching into the irradiation cavity. Three stainless steel access tubes lead into the sample cavity for ventilation and instrumentation.

The Gammacell 40 and Gammacell 40 Exactor are housed in an outer enclosure. The maximum dimensions are approximately 59 inches (150 cm) high, 37 inches long (94 cm) wide, and 49 inches (124 cm) deep. The maximum weight is approximately 7000 lbs (3180 kg).

The unit comes either with two Model C-161, Type 8 sealed sources or two Nordion C-440 sealed sources. The sources are doubly encapsulated using type 316L stainless steel. Nominal dimensions for each source are 1.57 inches (39.9 mm) diameter by 1.70 inches (43.3 mm) length. Nominal wall thickness for each capsule of the C-161 source is 0.020 inch (0.53 mm) and nominal thickness for each end cap is 0.085 inch (2.2 mm). Nominal wall thickness for each capsule of the C-440 source is 0.039 inch (1.0 mm) and nominal thickness for each end cap is **0.059** inch (1.5 mm). The capsules are sealed with active fusion welds.

Several safety features have been incorporated into the unit for protection of operating personnel:

DEVICE TYPE: Gamma Irradiator

DESCRIPTION (cont'd):

1. The source drawers are mechanically interlocked with the sample drawer. A square section steel rod is mounted on the front of each source drawer which will only align with slots in the tubular extension of the sample drawer hinge pin when the sample drawer is closed. This assures that the source drawers cannot move into the irradiate position when the sample drawer is open, or is not completely closed. **At the same time it prevents the sample drawer from opening unless both sources are in the safe position.**

2. A mechanical lock on the sample drawer is electrically interlocked to the source ON push-button to prevent the rawer from being opened when the sources are exposed.

3. A spring loaded locking bar on the sample chamber door lock activates a microswitch when fully engaged, completing the electrical circuit to the source drawer control solenoids. Disengaging the locking bar interrupts the circuit and this, in turn, returns the sources to the stored position.

4. **The Model Gammacell 40 Exactor units are equipped with electronic controls which also provide a software interlock system. The software interlock system uses sensors and compares them to a stored set of instructions, and processes the information to determine whether a requested operating step can be executed safely.**

LABELING:

The Gammacell 40 is labeled on the front of the device. The label consists of the phrase "CAUTION RADIOACTIVE MATERIAL", the radioactive trefoil symbol, isotope, date of measurement and the curie content. Additional labels attached to the device indicate the manufacturer (AECL or Nordion, **or MDS Nordion,** as applicable), the model number and the serial number.

DEVICE TYPE: Gamma Irradiator

LABELING (cont'd):

The Model C-440 sources are engraved on the upper endcap of the outer capsule with "CS-137D", source serial number, "NII" or "MDS," "C-440", and the radioactive trefoil symbol. **The Model C-161 sources are engraved on the upper end cap of the outer capsule with "CS-137A," source serial number, and the letters "AECL," "NII," or "MDSN."**

DIAGRAM:

See Attachments 1, 2, 3 and 4.

CONDITIONS OF NORMAL USE:

The Gammacell 40 is a low dose rate irradiator designed to irradiate biological or other samples requiring low dose rate. Typical environments associated with the use of this device include medical facilities and laboratories fit for human occupancy and in an unshielded room. Users are trained in the use of the irradiator equipment, safety interlock equipment and in radiation safety.

PROTOTYPE TESTING:

The Gammacell 40 has been in use since 1971 without any reported incidences. The manufacturer claims that a full program of prototype tests sufficient to establish that the safety features of the device will continue to function properly under the most adverse conditions was conducted.

The manufacturer claims that the C-440 sources have been tested to ANSI N542-1977 and achieved a classification of E65546.

DEVICE TYPE: Gamma Irradiator

EXTERNAL RADIATION LEVELS:

AECL conducted a survey of an irradiator containing two 1800 curie (66.6 TBq), Model C-161, type 8 sources. With the sources in the "OFF" position, no significant reading was detectable 39.4 inches (100 cm) from the center of the sources. The highest reading 1.97 inches (5 cm) from the surface of the irradiator was 0.3 mrem/hr (3 μSv/hr). The sample cavity door was opened and the maximum reading inside the cavity was 4.7 mrem/hr (47 μSv/hr).

With the sources in the "ON" position, the highest reading 39.4 inches (100 cm) from the center of the sources was 1.3 mrem/hr (13 μSv/hr). The highest reading 1.97 inches (5 cm) from the unit was 11 mrem/hr (110 μSv/hr).

The manufacturer reports the calculated radiation dose rates at varying distances from the Model C-440 source as follows:

Distance from source	Radiation Level R/hr	(Sv/hr)
5 cm/1.97 in	186,120	(1,861)
30 cm/11.8 in	5,172	(52)
100 cm/39.4 in	466	(4.7)

The manufacturer reports that the Model Gammacell 40 Exactor units have a maximum external radiation field of approximately 2 mrem/hr at a distance of 5 cm (1.97 inches) from any accessible surface of the device.

QUALITY ASSURANCE AND CONTROL:

Manufacture of Gammacell 40 **and Gammacell 40 Exactor** irradiators is covered under **MDS** Nordion's (formerly Atomic Energy of Canada, Ltd.) quality assurance and control program which has been deemed acceptable for licensing purposes by NRC. A copy of the program is on file with the **NRC**.

QUALITY ASSURANCE AND CONTROL (cont'd):

Quality control during manufacture of the C-440 sources is maintained under Amersham International's Quality Assurance Manual for radiation sources. The sources are manufactured by Amersham International according to Nordion's specifications. Upon receipt at Nordion, the sources are tested for removable contamination, dimensional conformity to design specifications, proper labeling and are measured for output.

LIMITATIONS AND/OR OTHER CONSIDERATIONS OF USE:

- Containment of samples should be ensured in order to protect the integrity of the sample chamber.
- The Model Gammacell 40 **and Gammacell 40 Exactor** shall be distributed only to persons specifically licensed by the NRC or an Agreement State.
- The device shall be leak tested at intervals not to exceed six months using techniques capable of detecting 0.005 microcurie (185 Bq) of removable contamination.
- Maximum source activity for the Model C-440 source is 2250 curies (83.3 TBq). However, maximum total activity allowed for the Gammacell 40 irradiator is 4200 curies (155.4 TBq) for two sources.
- Handling, storage use, transfer and disposal: To be determined by the licensing authority. In view that the sealed sources exhibit high surface dose rates when unshielded, they should be handled only be experienced licensed personnel using adequate remote handling equipment and procedures.
- The Model C-440 source is approved for use only in the Gammacell 40 irradiator.
- This registration sheet and the information contained within the references shall not be changed or transferred without the written consent of the NRC.

DEVICE TYPE: Gamma Irradiator

SAFETY ANALYSIS SUMMARY:

Based on our review of the information and test data cited below, and that the irradiator design was previously deemed acceptable by the NRC, we continue to conclude that the Gammacell 40 irradiator design is acceptable for licensing purposes. Furthermore, we continue to conclude from operational data since 1971, that this irradiator design would be expected to maintain its integrity for normal and accidental conditions of use which might occur during uses specified in this certificate.

Additionally, based on our review of the information and test data cited below as pertains to the Model C-440 source design and the manufacturers claimed ANSI classification of E65546, we **continue to** conclude the Model C-440 source design is acceptable for licensing purposes when used in the Gammacell 40 irradiator. Furthermore, we **continue to** conclude the Model C-440 source would be expected to maintain its integrity for normal and accidental conditions of use which might occur during uses specified in this certificate.

REFERENCES:

The following supporting documents for the Gammacell 40 irradiator and C-440 source capsule designs are hereby incorporated by reference and are a made a part of this registry document:

- Atomic Energy of Canada Limited letters dated August 24, 1970, October 21, 1970, and March 25, 1971, with enclosure thereto.
- Nordion International, Inc., letters dated November 2, 1992, December 1, 1992, and December 8, 1992, with enclosures thereto.

DEVICE TYPE: Gamma Irradiator

REFERENCES (cont'd):

- Amersham Corporation's letter, in support of Nordion's application, dated December 16, 1992, with enclosures thereto.

- **MDS Nordion's letter dated February 27, 1998, two letters dated April 3, 1998, and telefax dated May 26, 1998, with enclosures thereto.**

ISSUING AGENCY:

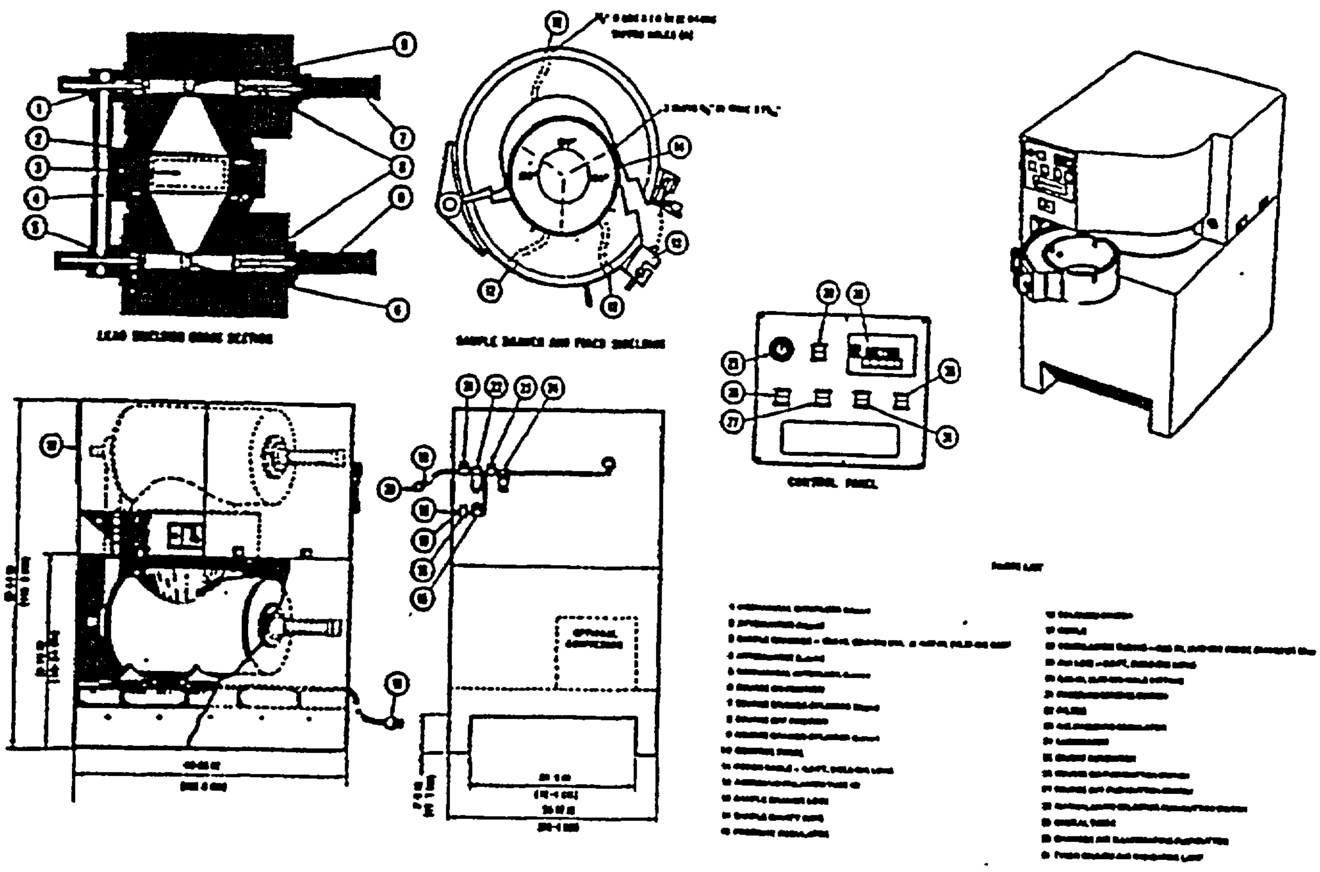
U.S. NUCLEAR REGULATORY COMMISSION

DATE: December 21, 1998 REVIEWER: John W. Lubinski

DATE: December 21, 1998 CONCURRENCE: Steven L. Baggett

REGISTRY OF RADIOACTIVE SEALED SOURCES AND·DEVICES
SAFETY EVALUATION OF DEVICE
(Amended in its Entirety)

NO.: NR-220-D-101-S DATE: December 21, 1998 ATTACHMENT 1



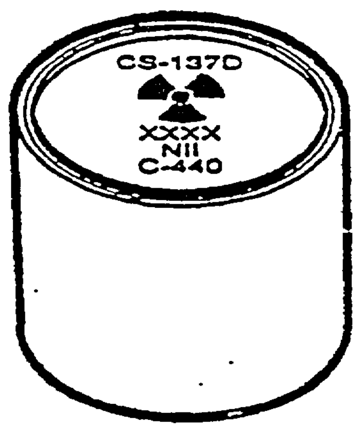
GAMMACELL 40 – GENERAL DIMENSIONS

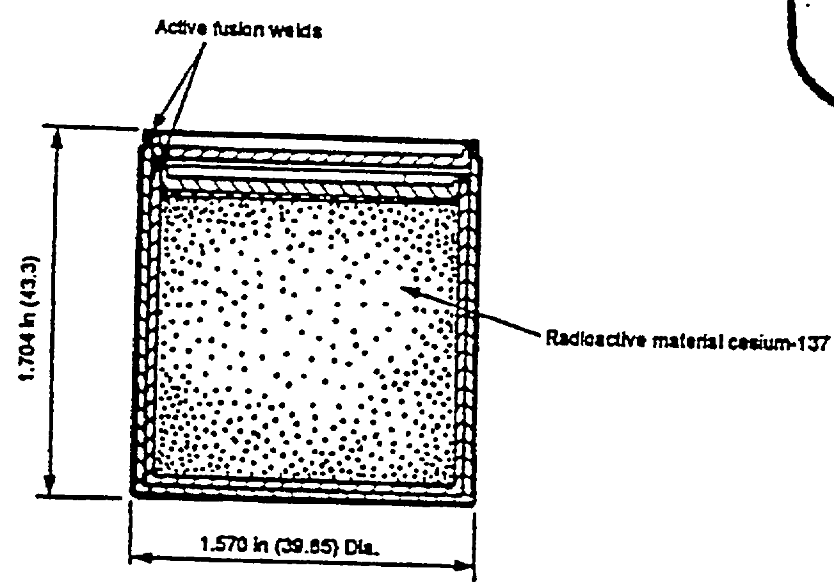
Model Gammacell 40 Irradiator
(Serial No. 1 through 133)
with pneumatic drive system

FIGURE WITHHELD UNDER 10 CFR 2.390

REGISTRY OF RADIOACTIVE SEALED SOURCES AND DEVICES
SAFETY EVALUATION OF DEVICE
(Amended in its Entirety)

NO.: NR-220-D-101-S DATE: December 21, 1998 ATTACHMENT 3



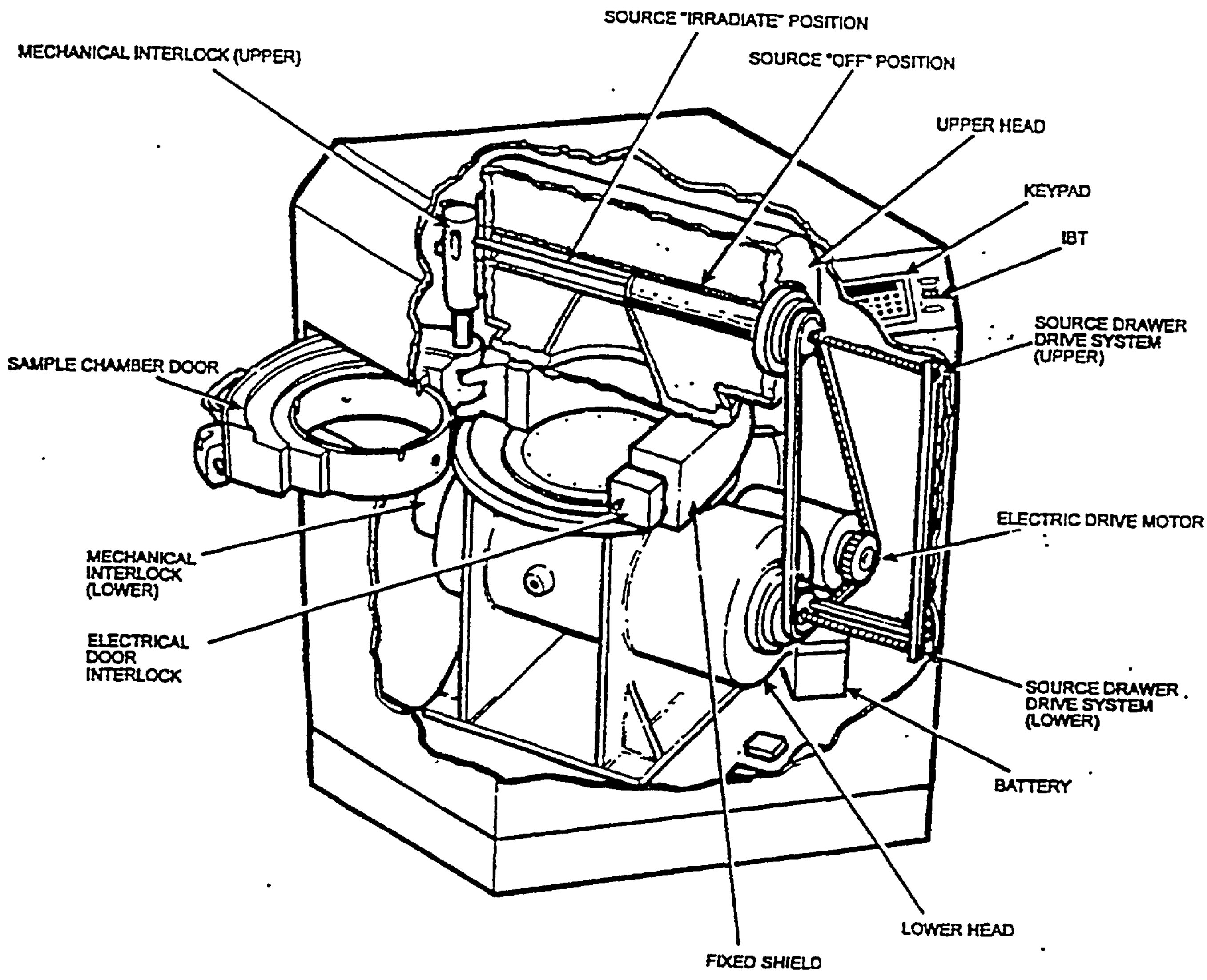


Notes

1. Conforms to I.A.E.A. Special Form requirements under United Kingdom Certificate No. GB/366/S-85
2. Fabricated to Amersham Dwg. 3A62547 capsule X2161
3. Material: stainless steel, Type 316L
4. Wall thickness: 0.039 in (1.0 mm)
5. Engraving on upper end cap
6. Dimensions in brackets are expressed in millimeters

REGISTRY OF RADIOACTIVE SEALED SOURCES AND DEVICES
SAFETY EVALUATION OF DEVICE
(Amended in its Entirety)

NO.: NR-220-D-101-S   DATE: December 21, 1998   ATTACHMENT 4



Gammacell 40 Exactor Irradiator
(Serial No. 134 and higher)
with electric motor drive system

CHAPTER 2 – STRUCTURAL EVALUATION

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

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

The test data are presented in the Appendices.

2.1 STRUCTURAL DESIGN

2.1.1 DESCRIPTION

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

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

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

These features do not provide containment.

The **impact shield** [redacted]

[redacted]

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

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

The [redacted]

The [redacted]

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

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

2.1.2 DESIGN CRITERIA

2.1.2.1 Basic Design Criteria

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

Primary containment is provided by the special form sealed source.

2.1.2.1.1 Containment Structures

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

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

Structural analyses [redacted]

2.1.2.1.2 Non-Containment Structures

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

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

[redacted]

[redacted]

2.1.2.2 Miscellaneous Structural Failure Modes

2.1.2.2.1 Brittle Fracture

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

The closure bolts [redacted]

2.1.2.2.2 Fatigue

Normal operating [redacted]

[redacted]

2.1.2.2.3 Buckling

[redacted]

2.2 WEIGHTS AND CENTERS OF GRAVITY

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

2.3 MECHANICAL PROPERTIES OF MATERIALS

The MDS Nordion F-430 package [redacted]

Table 2.1: Mechanical Properties of Materials

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

* [redacted]
** [redacted]

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

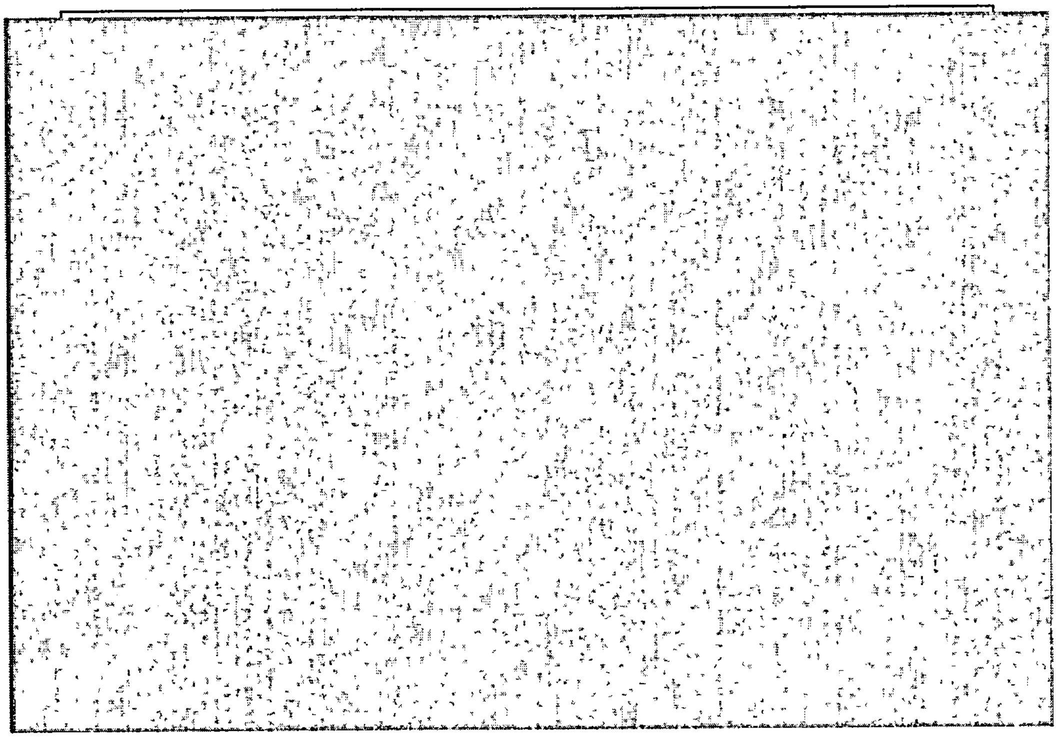


Figure 2.1: [redacted]

2.4 GENERAL STANDARDS FOR ALL PACKAGES

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

a) Minimum Package Size

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

b) Tamper-Indicating Feature

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

c) Positive Closure

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

d) Chemical and Galvanic Reactions

See section 2.4.1 for discussion on chemical and galvanic reactions.

e) **Valves**

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

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

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

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

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

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

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

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

2.4.1 CHEMICAL AND GALVANIC REACTIONS

The [redacted]

[redacted]

2.4.2 POSITIVE CLOSURE

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

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

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

2.4.3 LIFTING DEVICES

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

2.4.4 TIE-DOWN DEVICES

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

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

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

2.5 ADDITIONAL REQUIREMENTS FOR TYPE B PACKAGES

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

1) When subjected to the tests for Normal Conditions of Transport section 2.6 of this analysis shows,
   - the loss or dispersal of any radioactive material is less than $A_2 \times 10^{-6}$ per hour,
   - there is no significant increase in external radiation levels and
   - there is no substantial reduction in the effectiveness of the packaging.
   - there would be no increase in external radiation levels in excess of 20%.

2) When subjected to the tests for Hypothetical Accident Conditions of Transport section 2.7 of this analysis shows,
   - the loss or dispersal of any radioactive material is less than A_2 per week and
   - the external radiation dose rate is less than one rem per hour at one (1) meter from the external surface of the package.

3) The containment of the radioactive material after the tests for the Normal and Hypothetical Accident Conditions of Transport is demonstrated by the Special Form status of the sealed source.

2.5.1 LOAD RESISTANCE

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

The smallest area for normal stresses is the outer shell.

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

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

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

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

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

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

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

Bending stresses are

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

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

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

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

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

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

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

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

2.5.2 EXTERNAL PRESSURE

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

Safety Factor = Tested pressure/required pressure

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

2.6 NORMAL CONDITIONS OF TRANSPORT

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

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

2.6.1 HEAT

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

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

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

2.6.2 COLD

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

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

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

2.6.3 PRESSURE

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

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

2.6.4 VIBRATION

2.6.4.1 Special Form Sealed Sources

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

2.6.4.2 Fasteners

[redacted]

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

2.6.5 WATER SPRAY

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

2.6.6 FREE DROP

2.6.6.1 Demonstration of Compliance

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

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

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

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

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

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

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

2.6.6.2 Test Objectives

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

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

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

2.6.6.3 Test Temperature

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

2.6.6.4 Target

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

2.6.6.5 Extrapolation to other Package Contents

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

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

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

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

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

2.6.6.6 Internal Heating

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

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

2.6.6.7 Pressure Buildup

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

2.6.6.8 Normal Free Drop Test Orientations and Justification

2.6.6.8.1 Drop test height

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

2.6.6.8.2 Upright and top edge orientation

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

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

2.6.6.9 Pass/fail Criteria and Justification

1) Both main and internal covers attached.

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

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

   Justification: regulatory requirement.

2.6.6.10 Test Results

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

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

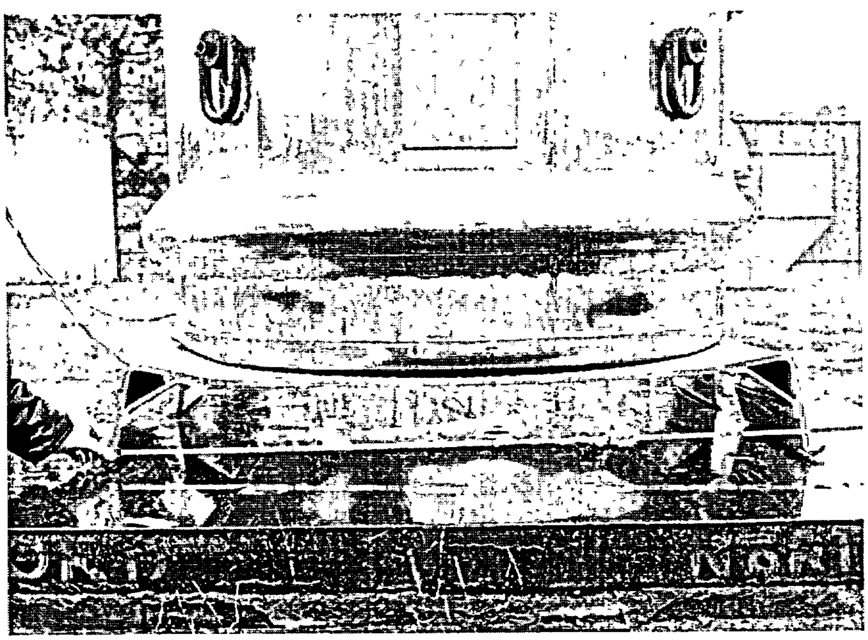


Figure 2.2: Test # 1, F-430 After 1.2m Upright Drop

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

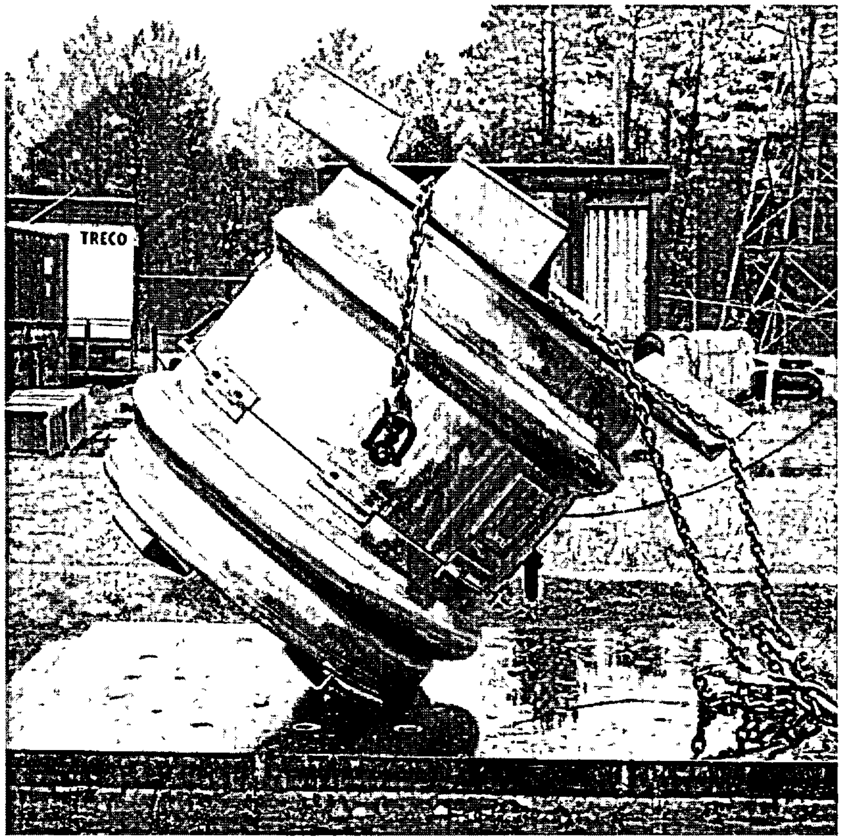


Figure 2.3: Test #2, F-430 After 1.2m Top Edge Drop

2.6.6.11 Shielding

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

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

2.6.6.12 Conclusions

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

2.6.7 CORNER DROP

Refer to Section 2.6.6.10 and Appendix 2.10.5.

2.6.8 PENETRATION

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

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

2.6.9 COMPRESSION

The effect of package compression are discussed in section 2.5.1

2.7 HYPOTHETICAL ACCIDENT CONDITIONS

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

2.7.1 FREE DROP

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

The [redacted].

2.7.1.1 Worst Drop Orientation

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

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

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

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

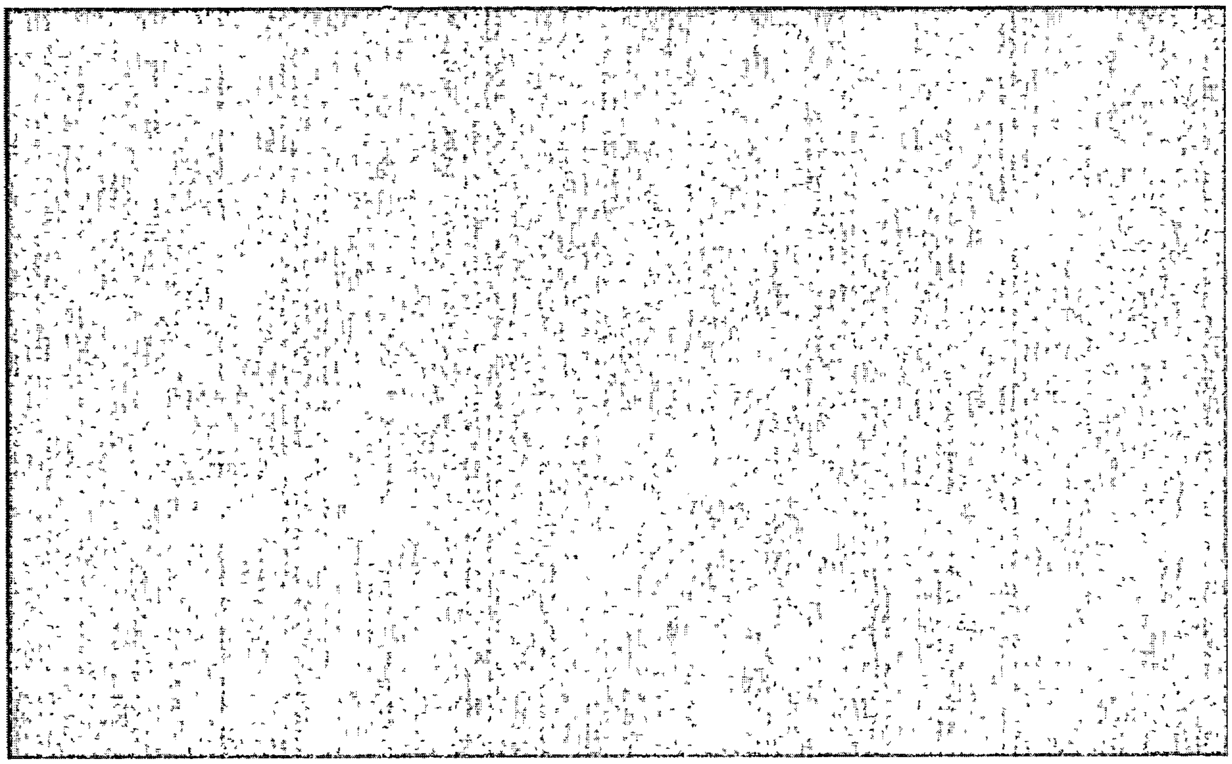


Figure 2.4: F-430 with GC-40 Irradiator (lower head)

[redacted]

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

Deceleration magnitude G can be theoretically approximated as

$$G = H / h$$

Where H = drop height (in)

h = deformation distance (in)

G = multiple of gravitational acceleration (no units)

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

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

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

Therefore, the largest deceleration is expected [redacted]

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

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

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

2.7.1.2 Prototype Testing

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

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

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

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

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

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

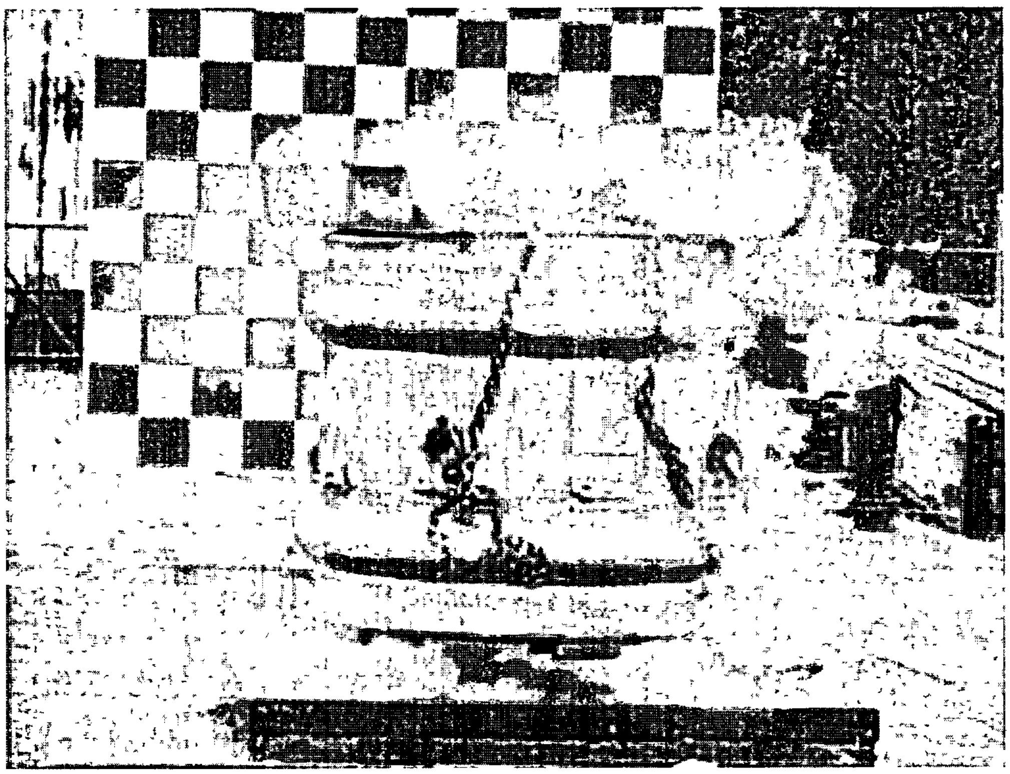


Figure 2.5: Test #3, 9m Drop with rebound

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

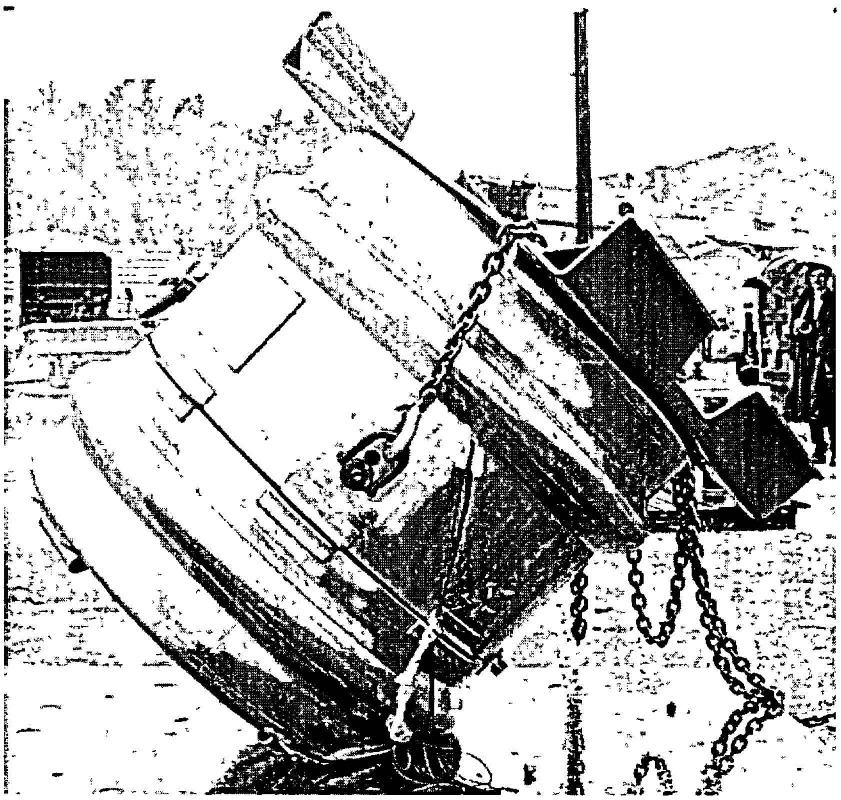


Figure 2.6: Test #4, 9m Top Edge Drop

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

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

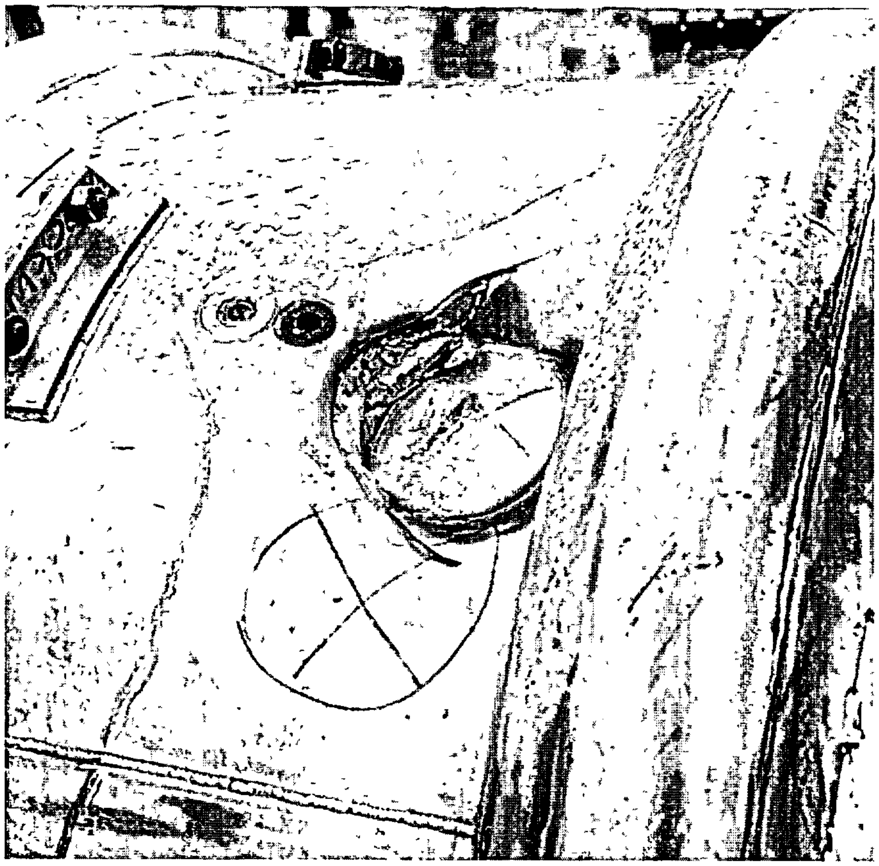


Figure 2.7: Test #6, 1m Pin Drop Test

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

The lowest point from which 9m height was measured was the skid's front left corner with the package in horizontal position. This resulted in additional 23cm of drop height when measured from the target surface to the bumpers (the next item to impact target after the skid). After the drop [redacted]. Nevertheless, no damage was noted that could significantly affect the results of the subsequent fire test.

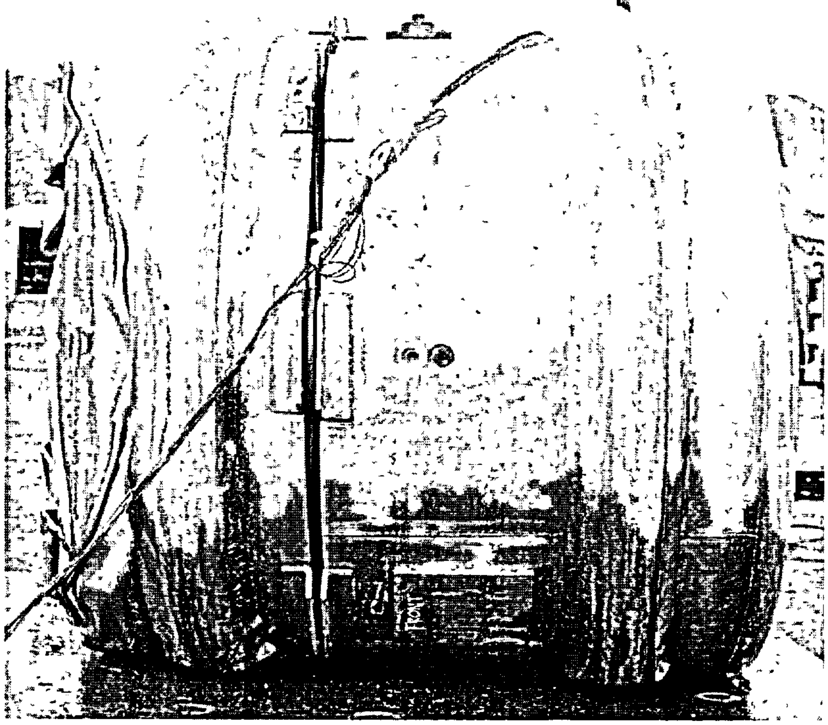


Figure 2.8: Test #7, 9m Side Drop

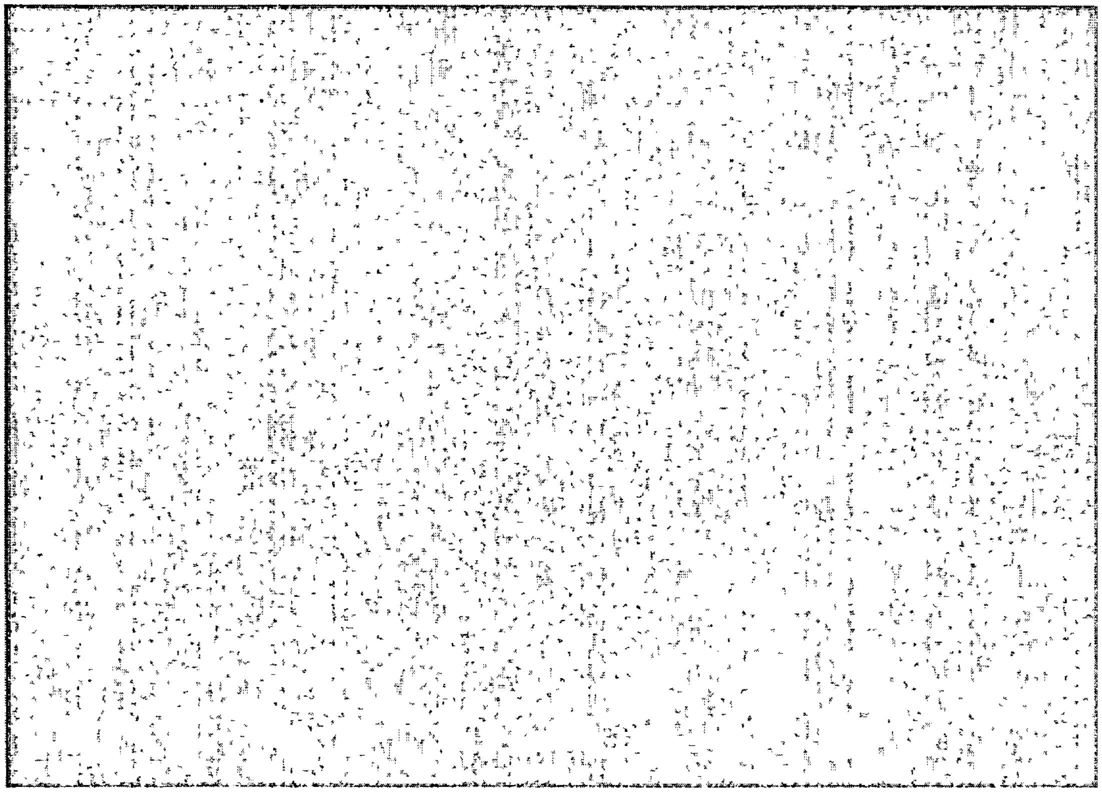


Figure 2.9: Test #7, [redacted]

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

[redacted]

[redacted]

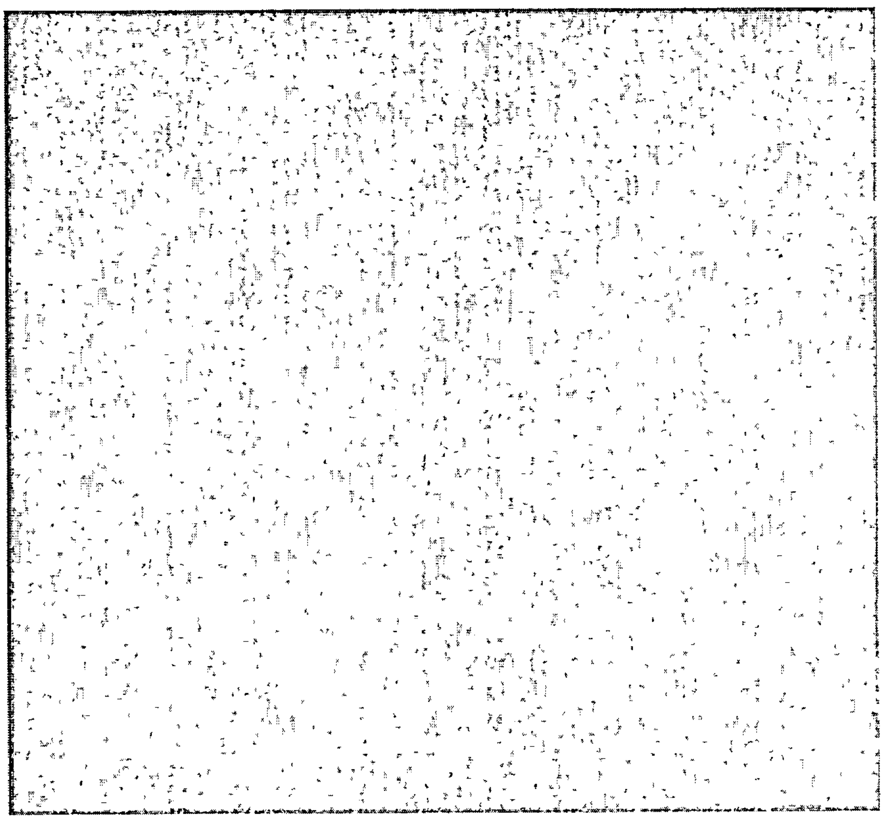


Figure 2.10: Test #8, 1m Oblique Pin Drop

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

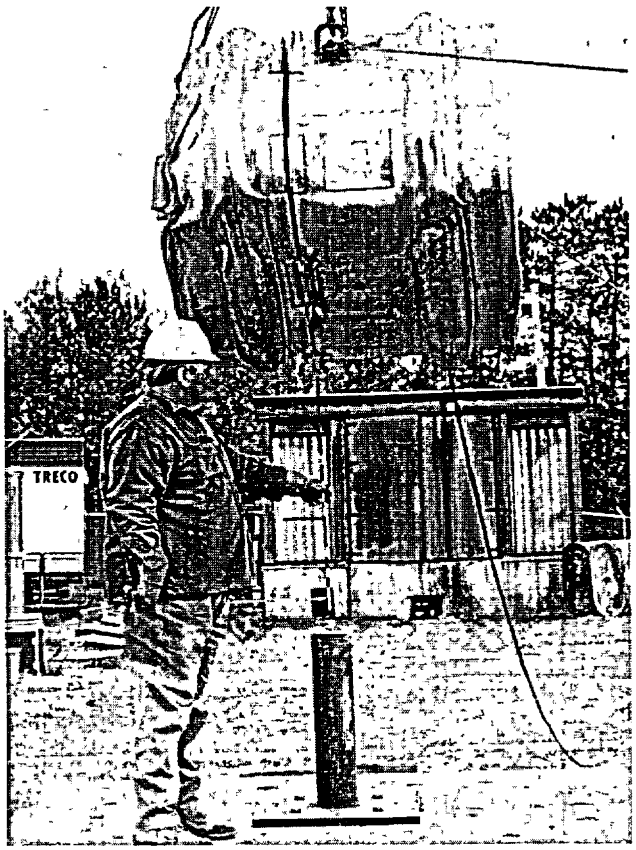


Figure 2.11: Test #9, Final Attempt To Open Main Cover (1m Pin Drop)

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

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

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

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

2.7.3 THERMAL

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

[redacted].

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

2.7.3.1 Summary of Pressures and Temperatures

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

2.7.3.2 Differential Thermal Expansion

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

2.7.3.3 Stress Calculations

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

2.7.3.4 Comparison with allowable stresses

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

2.7.4 WATER IMMERSION

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

1. The compressive strength of [redacted]

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

2.7.5 SUMMARY OF DAMAGE

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

[redacted]There were no cracks in the body of the GC-40 irradiator. The source drawer and the source capsule suffered no permanent damage. Both could be easily removed. The dimensions of the dummy C-440 did not change and the capsule passed the helium leak test. The lead housing had minor dents and scratches near the top flange of the irradiator. The [redacted]

2. The F430 cavity was not pierced by the contents. The inner lid did not lose any bolts and kept the contents shielded from fire.
3. The main cover stayed in place retained [redacted]).
4. Radiation levels following the drop testing did not increase by a measurable amount.

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

2.8 SPECIAL FORM

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

2.8.1 DESCRIPTION

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

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

2.9 FUEL RODS

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

2.10 APPENDICES

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

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

APPENDIX 2.10.1:
List of References for Chapter 2

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

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

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

[4] *Formula for Stresses and Strain*, Roark, 4th Edition

[5] *Formula for Stresses and Strains*, Roark, 5th Edition.

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

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

[8] *Cask Designers Guide*, ORNL-NSIC-68, L. B. Shappert

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

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

[11] 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", J. H. Evans, ORNL, pp. 232-243.

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[27] D. S. Clark & D. S. Wood, "The Tensile Impact Properties of some Metals and Alloys", *Transactions*, American Society for Metals, Vol. 42, 1950, pp. 45.

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

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

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

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[37] NRC Information Notice 96-54: Vulnerability of Stainless Steel to Corrosion when Stabilized, USNRC, Office of Nuclear Material Safety and Safeguards, Washington, DC 20555. October 1996.

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APPENDIX 2.10.2:
Lifting Analysis for F-430 Overpack

1. INTRODUCTION

For lifting analysis, the following case is analyzed to demonstrate that the container and its sub-components have adequate strength.

The F-430 container is designed for maximum weight of 7000 lb (estimated 2,800 lb empty container plus 500 lb internal fixtures) plus the maximum potential weight of the payload (estimated 3,700 lb), lifted up by four lift points (hoist rings) in normal lifting attitude.

2. ESTIMATE LIFTING FORCES

The lifting arrangement is depicted in Figure A2.1-1. In this case, the container is

- under normal lifting attitude
- under its own weight plus the weight of its contents (a total of 7000 lb)
- lifted using four lifting lugs.

Each lifting sling tension (F) is taken up by one lifting lug via the ¾" hoist ring (capacity 7000 lb in any direction).

Resolve forces vertically: $\Sigma F_Y = 0$

$$W = 4F \cos \alpha$$

where

W = weight of the container = 7000 pounds.

α = 45°, angle of sling with the vertical

Therefore

$$F = W/[4 \cos \alpha]$$

$$= 7000/[4 \times \cos 45°] = 2475 \text{ lb.}$$

Horizontal component, Fx

$$Fx = F \sin \alpha$$

$$= 2475 \times \sin 45° = 1750 \text{ lb}$$

Vertical component, Fy

$$Fy = F \cos \alpha$$

$$= 2475 \times \cos 45° = 1750 \text{ lb}$$

Similarly, the lifting force of 3500 lb (one half of the package loaded weight) will be exerted on the lifting pockets when picked up by a forklift.

3. STRESS ANALYSIS

3.1 STRESSES IN LIFTING BRACE

The following failure modes of the lifting lug in the normal lifting attitude are analyzed. Refer to Figure A2.1-2. Normal yield stress S_Y for 304L stainless steel is 30,000 psi and shear yield is $0.577S_Y$ or 17,310 psi.

3.1.1 LIFTING LUG BLOCK

The lifting lug is under tension due to force Fy. The area under tension, AT, is the fillet weld, size 3/16 (weld throat is 0.707 x 3/16), 8" long. The support by 12ga outer skin is neglected.

$$AT = 8 \times 0.707 \times 0.188 = 1.06 \text{ in}^2$$

Average tensile stress, σ

$$\sigma = Fy/AT$$

$$\sigma = 1750/1.06 = \underline{1646 \text{ psi}}$$

The lifting lug is under shear due to force Fx, the sheared area, AS, is the 3/16 fillet weld below and 3/32 fillet weld above the lifting lug (to outside skin), both fillet welds are 8" long

$$AS = 8 \times 0.707 \times (0.188 + 0.094) = 1.59 \text{ in}^2$$

Average shear stress, τ

$$\tau = Fx/AS$$

$$\tau = 1750/1.59 = \underline{1099 \text{ psi}}$$

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

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

$$\sigma_n = 1/2\,[1646 + \sqrt{(1646^2 + 4*1099^2)}] = \underline{2196 \text{ psi}}$$

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

$$\sigma_s = 1/2\sqrt{(1646^2 + 4*1099^2)}] = \underline{1373 \text{ psi}}$$

3.1.2 LOCATION "J"

At location "J" 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:

$$AS = 2 \times 5.63 \times 0.188 \times 0.707 = 1.49 \text{ in}^2$$

Average shear stress, τ

$$\tau = Fy/AS$$

$$\tau = 1750/1.49 = \underline{1174 \text{ psi}}$$

Tensile stress due to force Fx is taken mainly by the rib (3/4 x 4.00) and the lifting lug weld with the outside skin. Hence, force Fx is not considered here.

Average bending stress, σ

$$\sigma = 6LFy/[bh^2]$$

$$\sigma = 6 \times 2.63 \times 1750 / [2 \times 0.707 \times 0.188 \times 5.63^2] = \underline{3277 \text{ psi}}$$

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

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

$$\sigma_n = 1/2\ [3277 + \sqrt{}(3277^2 + 4*1174^2)] = \underline{3654 \text{ psi}}$$

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

$$\sigma_s = 1/2\sqrt{}(3277^2 + 4*1174^2)] = \underline{2016 \text{ psi}}$$

3.2 STRESSES IN FLANGE SEGMENT

The outer flange segment is a 2 x 2 x 3/8 angle (304L s.s.) 8" long, rolled to 25.1" radius, and welded to the outside skin of the overpack with a 3/32" fillet weld 12" long. There are 8 mating flanges around the circumference of the overpack, each flange segment carries 1/8 of the total overpack weight during normal lifting.

Average shear stress, τ (in the flange fillet weld) is

$$\tau = 7000 / 8 / (12 \times 0.707 \times 0.094) = \underline{1097 \text{ psi}}$$

Average tensile stress, σ (on horizontal fillet weld, 8" long, bolt is 1.25" from angle corner)

$$\sigma = 1.25\ (7000/8) / 2 / (8 \times 0.707 \times 0.094) = \underline{1028 \text{ psi}}$$

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

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

$$\sigma_n = 1/2\ [1028 + \sqrt{}(1028^2 + 4*1097^2)] = \underline{1725 \text{ psi}}$$

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

$$\sigma_s = 1/2\sqrt{}(1028^2 + 4*1097^2)] = \underline{1211 \text{ psi}}$$

3.3 STRESSES IN FLANGE BOLTS

Each segmented flange is held together with two 5/8" grade-5 bolts (min. proof strength 85,000 psi). The tensile stress area is 0.226 in^2, the tensile load during lifting is 1/16 of total weight.

Average tensile stress, σ

$$\sigma = 7000 / 16 / 0.226 = \underline{1936 \text{ psi}}$$

3.4 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.

3.4.1 POCKET WITH BASE

Four 3/16 fillet welds, 8" long, hold forklift pocket to its base plate.

Average tensile stress, σ

$$\sigma = 7000 / 2 / (4 \times 8 \times 0.188 \times 0.707) = \underline{823 \text{ psi}}$$

3.4.2 POCKET BASE WITH SKIN

3/32 fillet weld 30 long is used to weld forklift pocket to the outside overpack skin.

Average tensile stress, σ

$$\sigma = 7000 / 2 / (30 \times 0.094 \times 0.707) = \underline{1755 \text{ psi}}$$

3.4.3 LOCATION "K"

At location "K" 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 down to the pocket base plate (two forces W/4) as shown in Figure A2.1-2. The area under shear resulting from force Fy is:

$$AS = 4 \times 5.63 \times 0.188 \times 0.707 = 2.99 \text{ in}^2$$

Average shear stress, τ

$$\tau = W/2/AS$$

$$\tau = 7000 / 2 / 2.99 = \underline{1171 \text{ psi}}$$

Average bending stress, σ

$$\sigma = 6(L_1 + L_2)\, W/4 / [bh^2]$$

$$\sigma = 6 \times (9.75 + 1.5) \times 7000 / 4 / [4 \times 0.707 \times 0.188 \times 5.63^2] = \underline{7010 \text{ psi}}$$

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

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

$$\sigma_n = 1/2\,[7010 + \sqrt{(7010^2 + 4*1171^2)}] = \underline{7200 \text{ psi}}$$

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

$$\sigma_s = 1/2\sqrt{(7010^2 + 4*1174^2)}] = \underline{3695 \text{ psi}}$$

3.5 *FINITE ELEMENT ANALYSIS*

A finite element analysis was performed on the F-430 design using Pro/MECHANICA STRUCTURE Version 20 0.

3.5.1 Lifting Brace

The Lifting Brace in the top of the F-430, as shown in Figure A2.1-2, was modeled using 347 shell elements and 838 solid elements. The skin and cross brace were created with shell elements, and the hoist ring pads and the 3/8" band were created with solid elements. The skin edge was fully constrained and load of 7,000 lb was applied to only two hoist ring pads to demonstrate the capacity to lift the package with only two rings. Therefore, the results of the FEA should produce stresses twice as high as in the previous analysis.

Location J is in the area of the hoist ring pad as shown in Figure A2.1-2 and location K is under the lift pocket. Figure A2.1-3 shows the maximum stresses in the Lifting Brace in the top of the F-430. The results are conservative since the load was applied to only two hoist rings.

3.5.2 Lifting Pocket

The lifting pocket on top of the F-430, as shown in Figure A2.1-2, was modeled using 133 shell elements. Only one half of the Main Cover was modeled due to the symmetrical geometry. The skin edge was fully constrained and a load of 3,500 lb was applied to the lifting pocket inner surface.

Figure A2.1-4 shows the maximum stresses in the area of the Lifting Pocket

4. SUMMARY

The analysis has shown that the F-430 can be lifted safely. The table below summarizes the results of the lifting analysis.

Table A2.1-1: Summary of Lifting Stresses

	Calculated Stress [1000 psi]		Yield Stress [1000 psi]		SAFETY FACTOR	
LOCATION	*NORMAL*	*SHEAR*	*NORMAL*	*SHEAR*	*NORMAL*	*SHEAR*
LIFTING BRACE:						
Lifting Lug	2.2	1.4	30	17.3	14	12
Location "J"	3.6	2.0	30	17.3	8.3	8.7
FLANGE SEGMENT	1.7	1.2	30	17.3	18	14
FLANGE BOLT	1.1		92		84	
FORKLIFT POCKET:						
Pocket with Base	0.8		30	17.3	38	
Pocket Base with Skin	1.8		30	17.3	17	
Location "K"	7.2	3.7	30	17.3	4.2	4.7

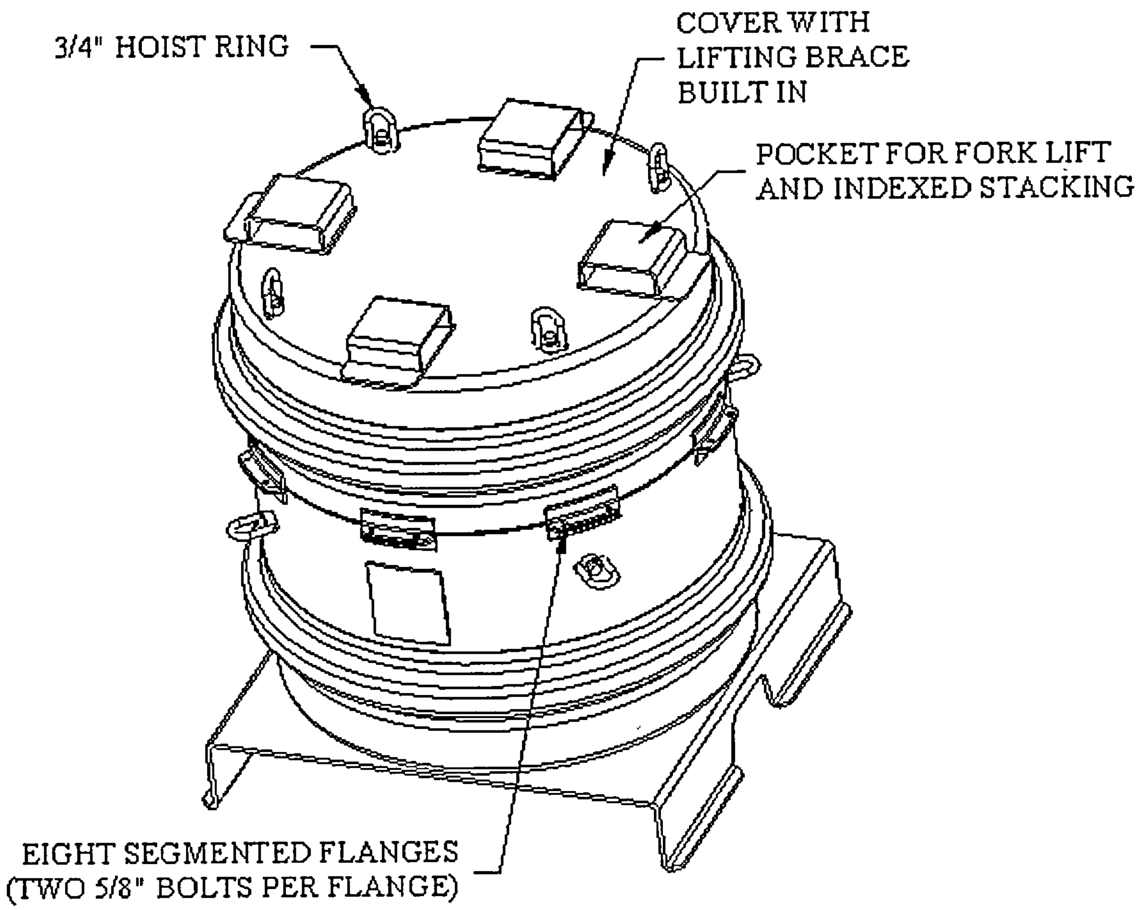

Figure A2.1-1: F-430 Overpack

FIGURE WITHHELD UNDER 10 CFR 2.390

Figure A2.1-2: Lifting Brace

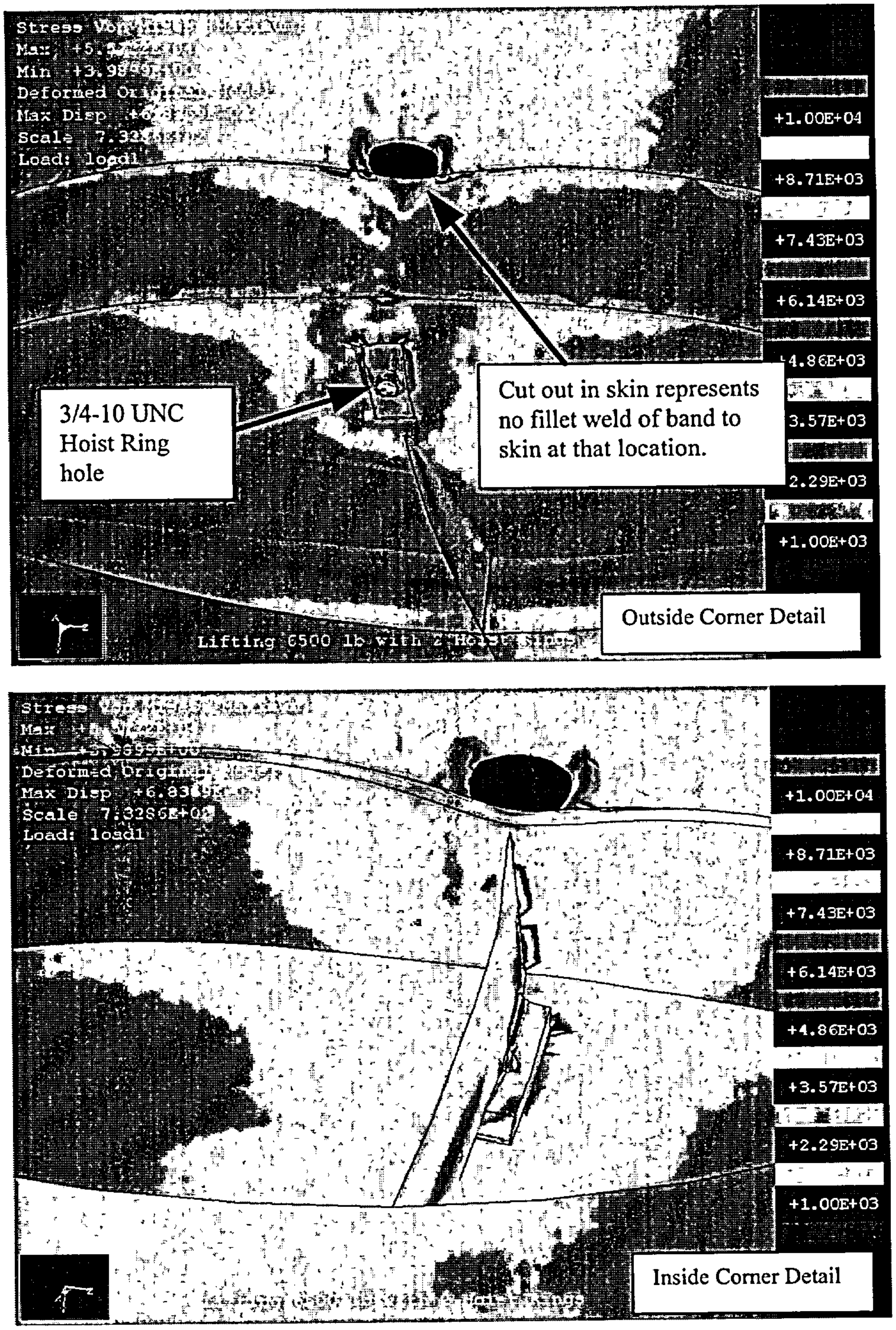

Figure A2.1-3: Lifting Brace – FEA Results

Figure A2.1-4: Forklift Pocket – FEA Results

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

(8 pages to follow)

TIE-DOWN ANALYSIS OF THE F-430/GC40 PACKAGE

1. INTRODUCTION

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

The F-430 is used in conjunction with a tie-down collar that is not structurally part of the package. The tie-down collar is a band that girdles the F-430 at mid-height. The tie-down collar incorporates four lugs to which the tie-down chains are attached. It rests on six oblong bosses welded to the circumference of the F-430.

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

Direction	Acceleration (g's)
Vertical	2
Horizontal, along direction of motion	10
Horizontal, in transverse direction	5

2. SHIPMENT DESCRIPTION

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

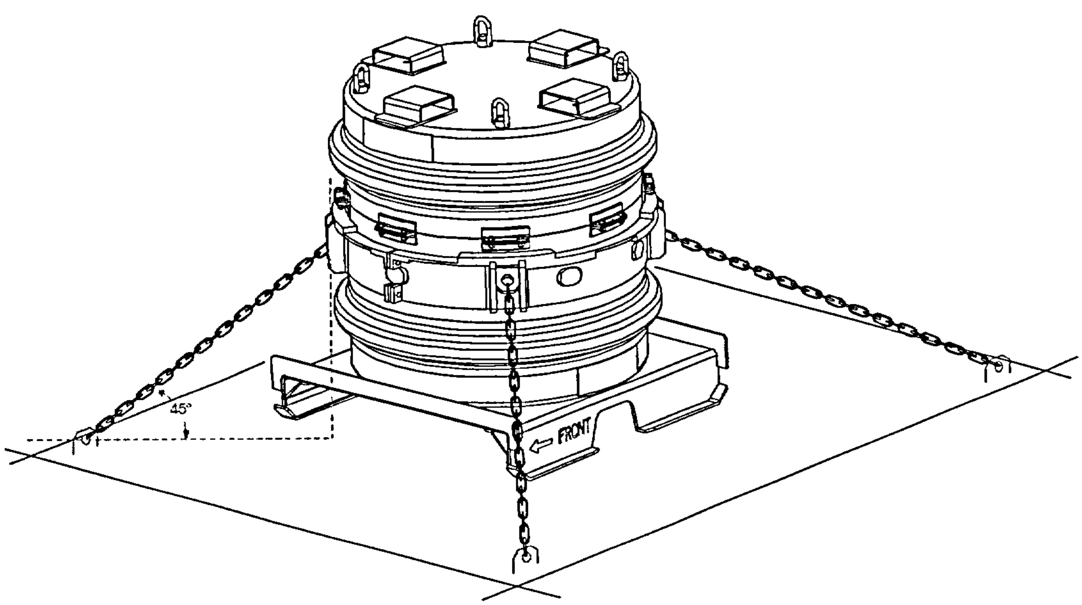

Figure A2.10.3-1
F-430 Tie-Down Arrangement

3. Stress Analysis of the F-430 with Maximum Tie-down Forces

The tie-down system was analysed with a three dimensional model constructed using ProMechanica Structure [2]. The F-430 was modeled as a right cylinder, made up of layers of stainless steel, polyurethane foam and lead. The features of the model and their properties are listed in Table A2.10.3-2. The payload (e.g. GC40) was simulated by a hollow cylinder made of lead. The lead thickness was selected in order to produce a payload mass of 4,001 lb. The total mass of the model was 7,036 lb. The exact geometry of the Tie-Down Collar and the shipping skid was modeled. The tie-down chains were modeled as beam elements. Only three chains were modeled, since the fourth was found to have no tensile load. The chocks were simulated by constraining the corners of the skid from translation. Similarly, the bottom of the tie-down chains were constrained from translation. The accelerations listed in Table A2.10.3-1 were applied to the model.

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

The results show that the stresses in the F-430 are highest in the oblong boss adjacent to the tie-down chain with the highest load (see Figure A2.10.3-4). The maximum stress is 21,630 psi. This is safely below the minimum yield strength of 25,000 psi (170 MPa) for 304L stainless steel.

The highest stress in the Tie-Down Collar occurs in the lug that is loaded with the tie-down chain with the highest load. In Figure A2.10.3-5, the maximum stress is 1,3810,000 psi. However this high stress is the result of a singularity caused by the chain load being applied at a single point. In order to analyze more accurately the stresses in this tie-down lug, a refined and more realistic model was created. In this case the load from the tie-down chain was applied over a 30° sector in the hole through the tie-down lug, as shown in Figure A2.10.3-6. The results of this analysis are shown in A2.10.3-7. The maximum stress in the tie-down lug is 52,990 psi. This is safely below the ultimate strength of 70,000 psi (480 MPa) for 304L stainless steel.

The maximum stress found anywhere in the Tie-Down Collar is 57,970 psi (refer to Figure A2.10.3-5). This is safely below the ultimate strength of 70,000 psi (480 MPa) for 304L stainless steel.

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

Feature	Material	Young's Modulus	Poisson's Ratio
Layer 1 (outer most)	Stainless steel skin	2.9×10^7 psi	0.27
Layer 2	Polyurethane foam (8 pcf)	7,000 psi	0.30
Layer 3	Polyurethane foam (40 pcf)	30,000 psi	0.30
Layer 4	Lead	2.42×10^6 psi	0.44
Tie-Down Collar	Stainless steel	2.8×10^7 psi	0.30
Skid	Mild steel	2.9×10^7 psi	0.27

Table A2.10.3-3
Finite Element Model Statistics

Model Entities	Points: 3937 Edges: 17257 Faces: 21991
Finite Elements	Type: P-element Beams: 3 Shells: 2840 Solids: 8682
Total Elements	11525
Contact Regions	26
Convergence Method	Single Pass Adaptive

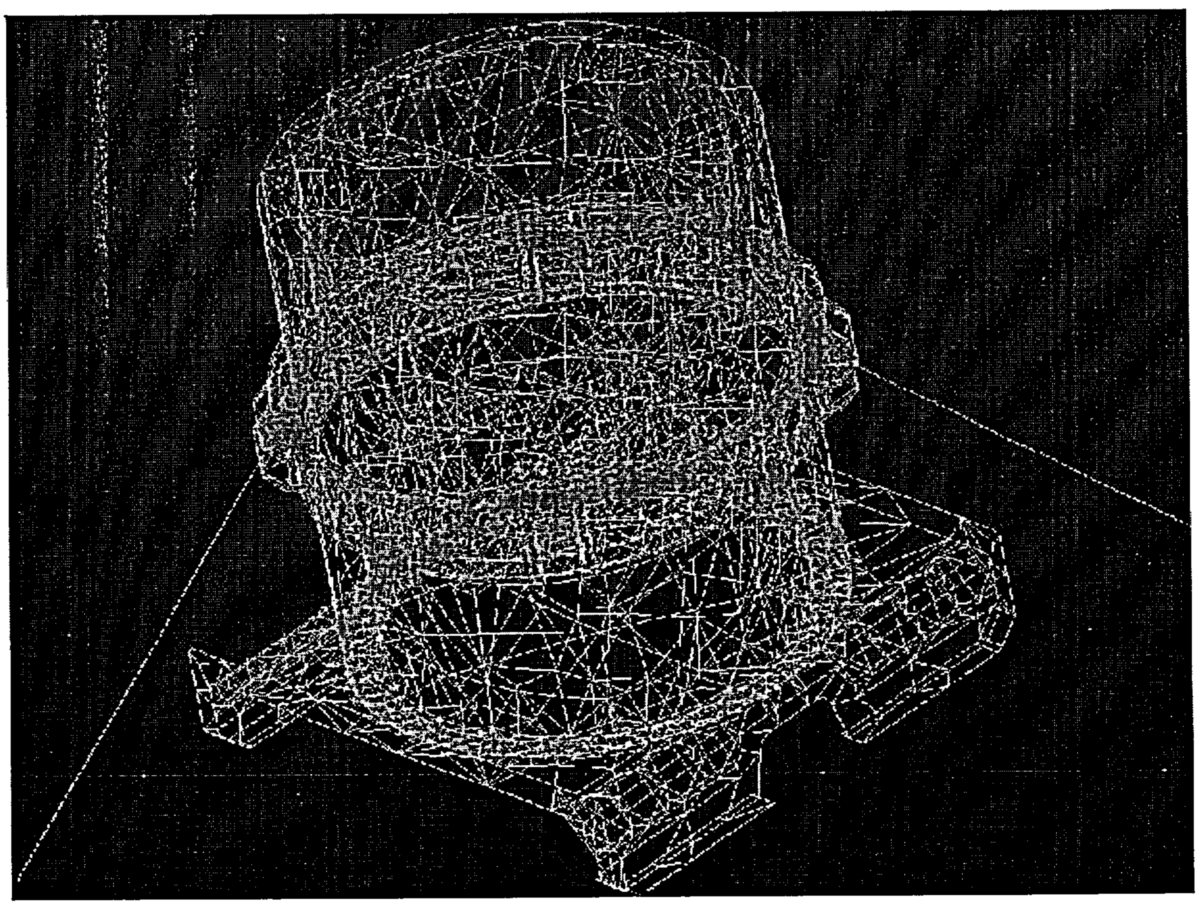

Figure A2.10.3-2
Finite Element Mesh

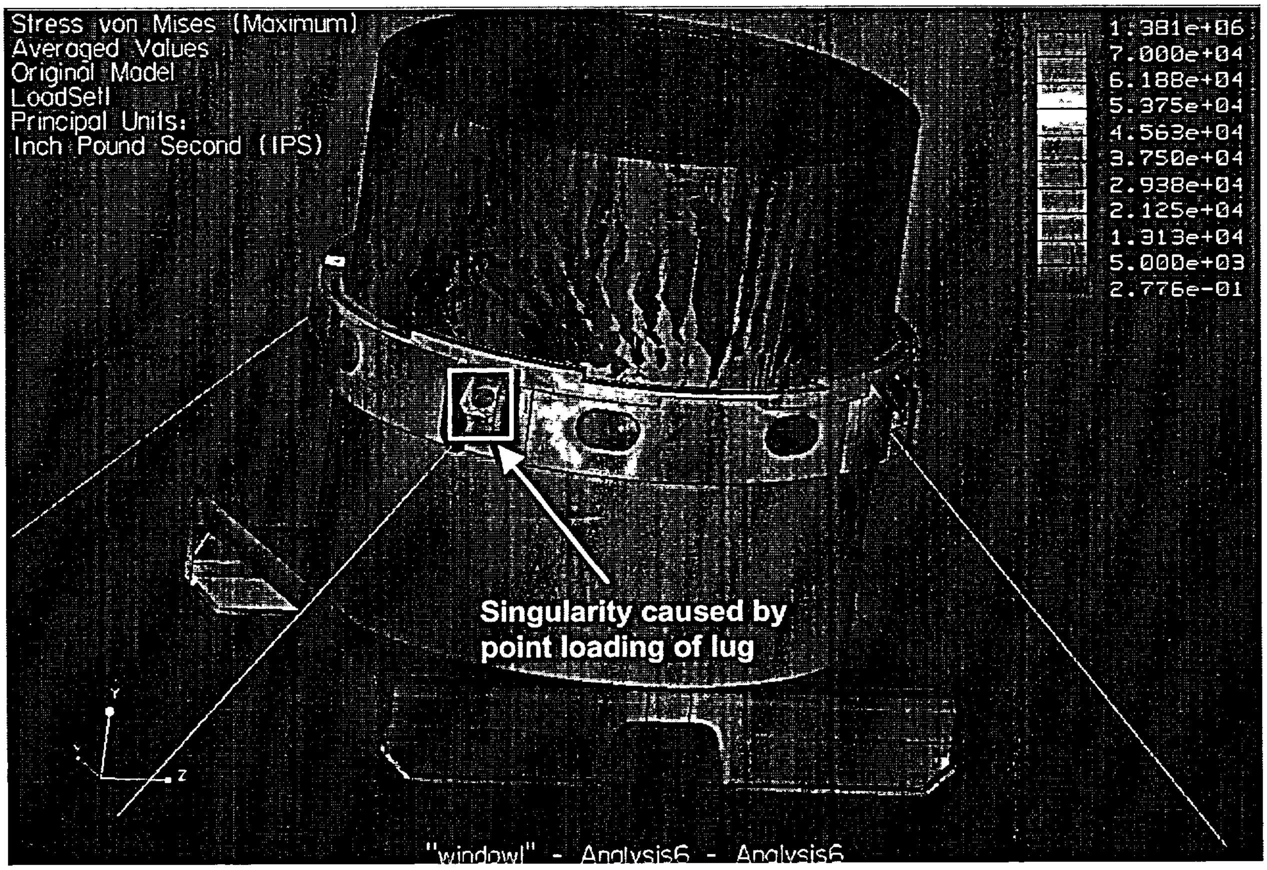

Figure A2.10.3-3
Tie-Down Stresses in the F-430

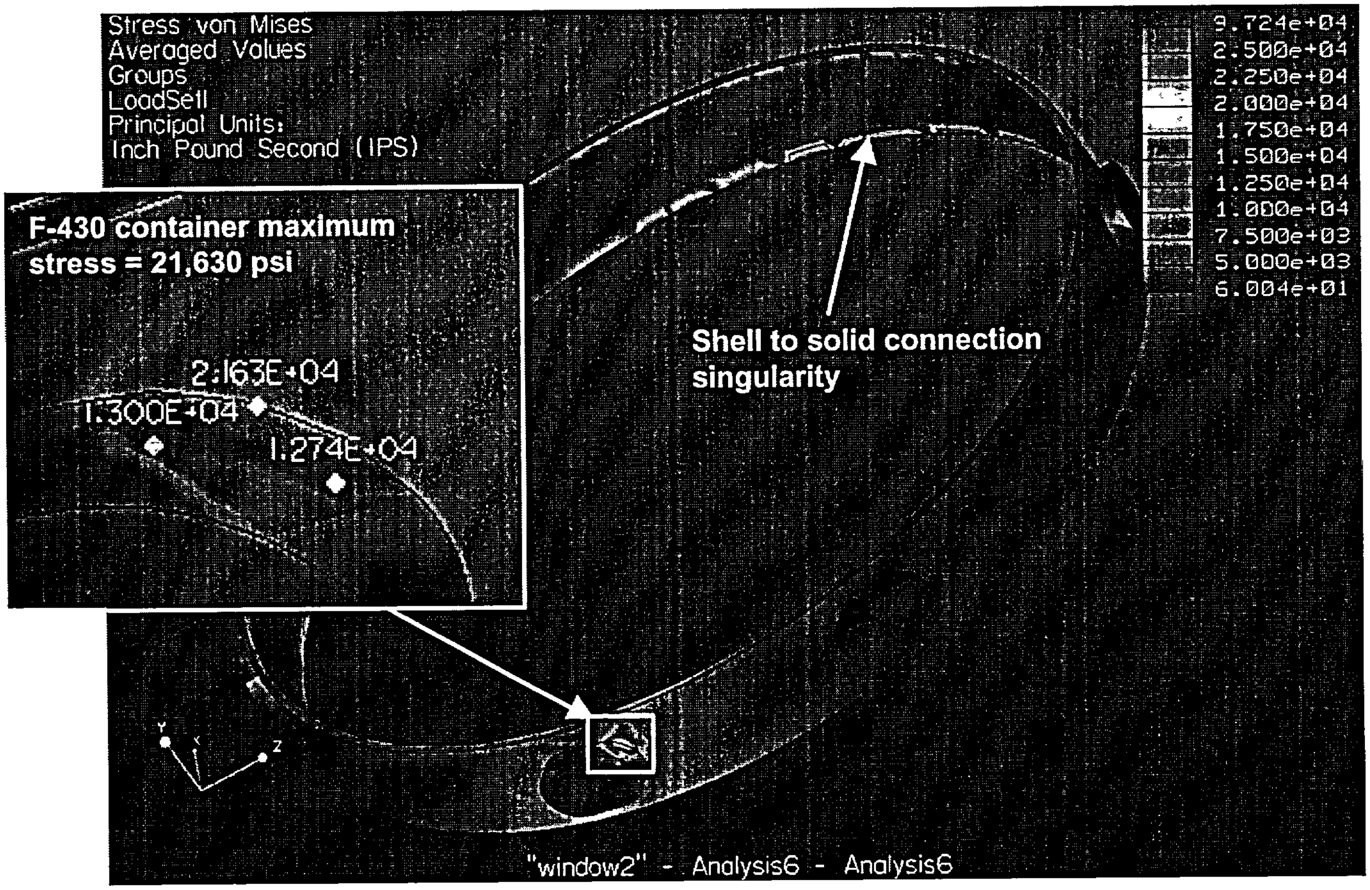

Figure A2.10.3-4
Tie-Down Stresses in the F-430 Ring and Oblong Bosses

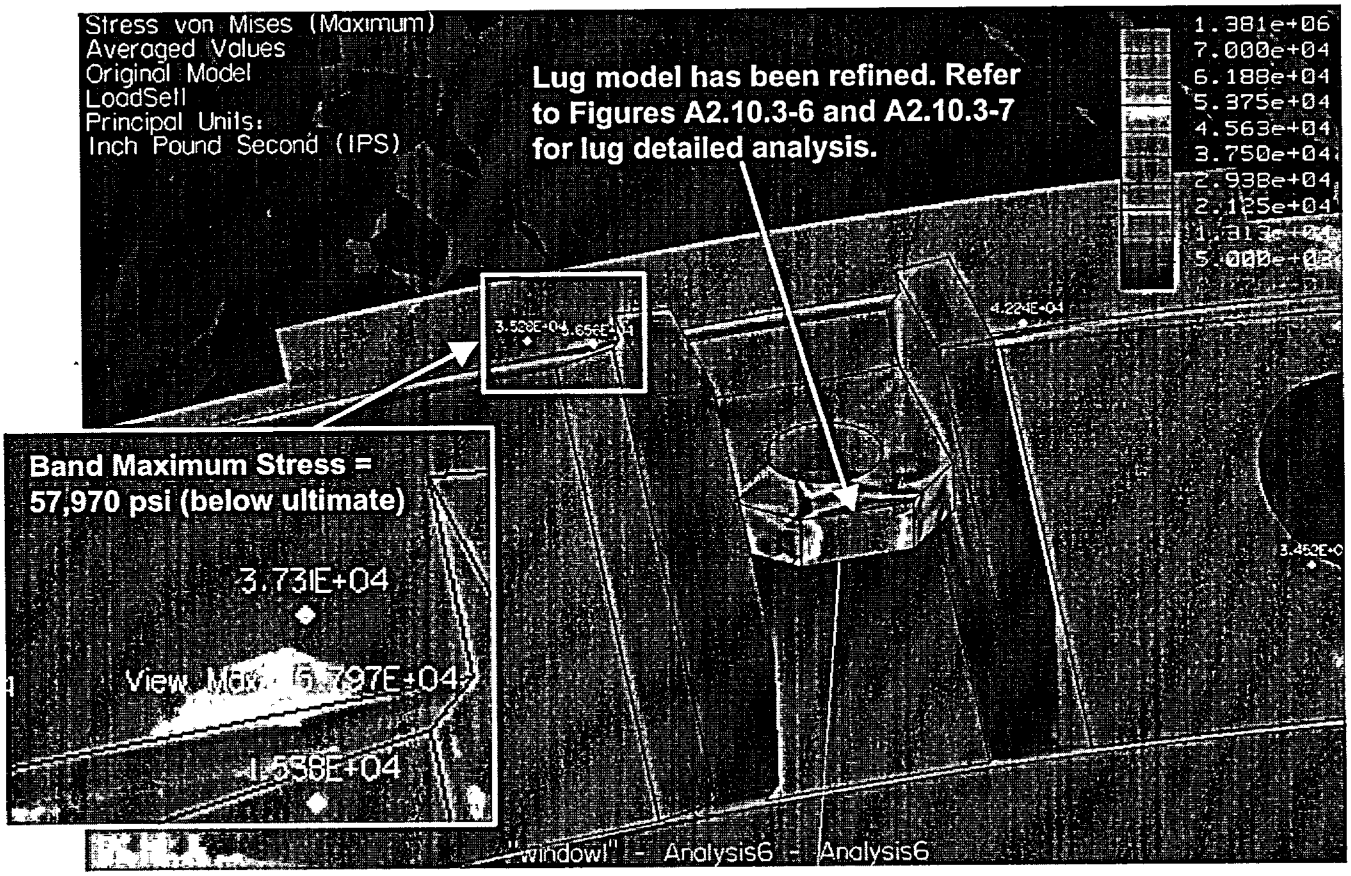

Figure A2.10.3-5
Tie-Down Stresses in the F-430 Tie-Down Collar

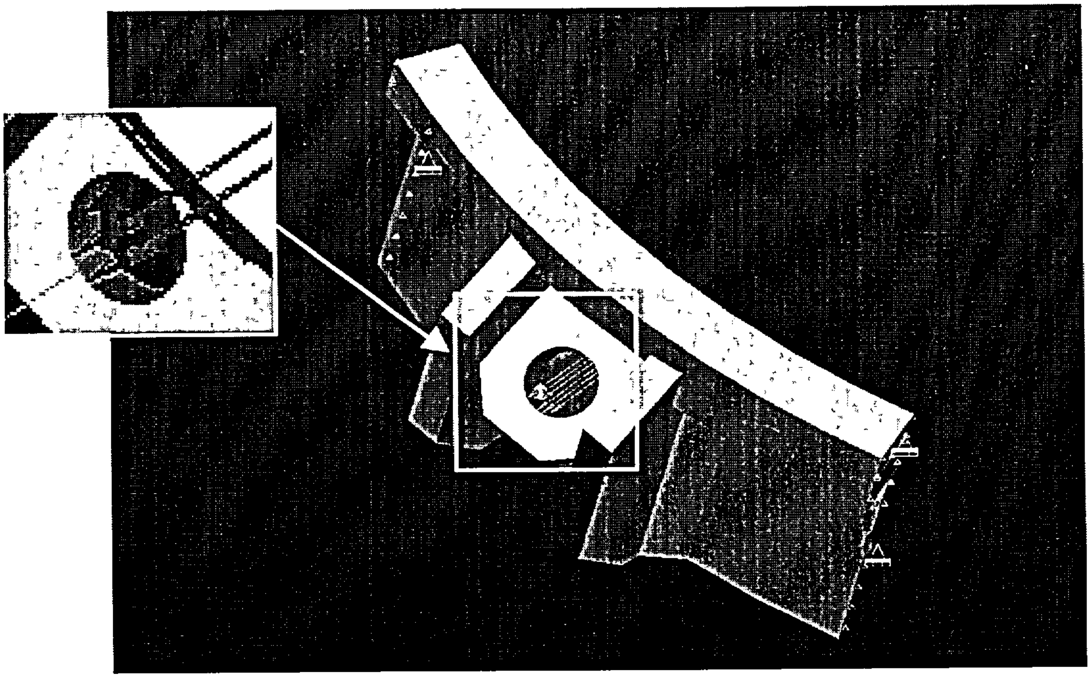

Figure A2.10.3-6
Tensile Load Applied to Tie-Down Lug

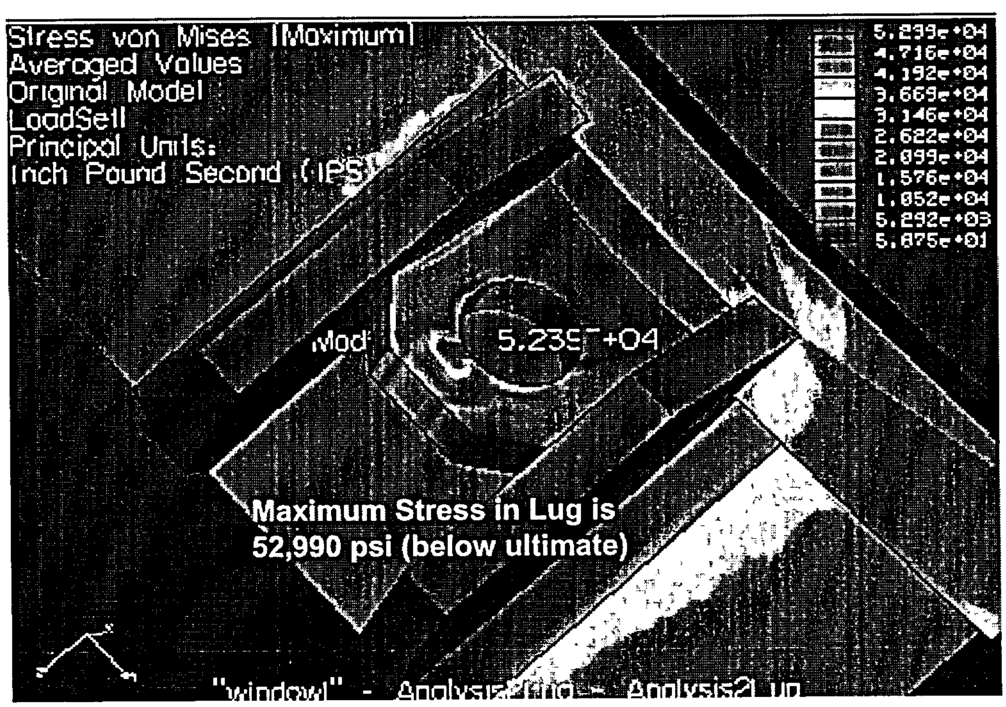

Figure A2.10.3-7
Tie-Down Stresses in the F-430 Tie-Down Lug

5. CONCLUSIONS

The maximum stress in any structural part of the F-430 package is 21,630 psi when the package and its payload are subjected to the prescribed accelerations. This stress is safely below the minimum yield strength of 25,000 psi (170 MPa) for 304L stainless steel.

The maximum stress in the Tie-Down Collar is 57,970 psi when the package and its payload are subjected to the prescribed accelerations. This is safely below the ultimate strength of 70,000 psi (480 MPa) for 304L stainless steel.

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

6. REFERENCES FOR APPENDIX 2.10.3

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

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

APPENDIX 2.10.4:
Stresses in Removable Skid

1. SOLID MODEL

Figure 1 depicts the solid model used to determine the stresses in the skid. It is a 12.7mm (0.5in) thick plate, made from A-36 hot rolled steel. The plate is 127cm (50in) wide, bent up to provide 127cm (50in) wide, 20cm (8in) high clearance for fork lifting. The feet are 5cm (2in) wide, and the internal bend radius is 12.7mm (0.5in).

Material properties were: $E = 207{,}000$MPa (30,000,000psi)

$\mu = 0.3$

$\rho = 7{,}800 kg/m^3$ ($0.283\ lb/in^3$)

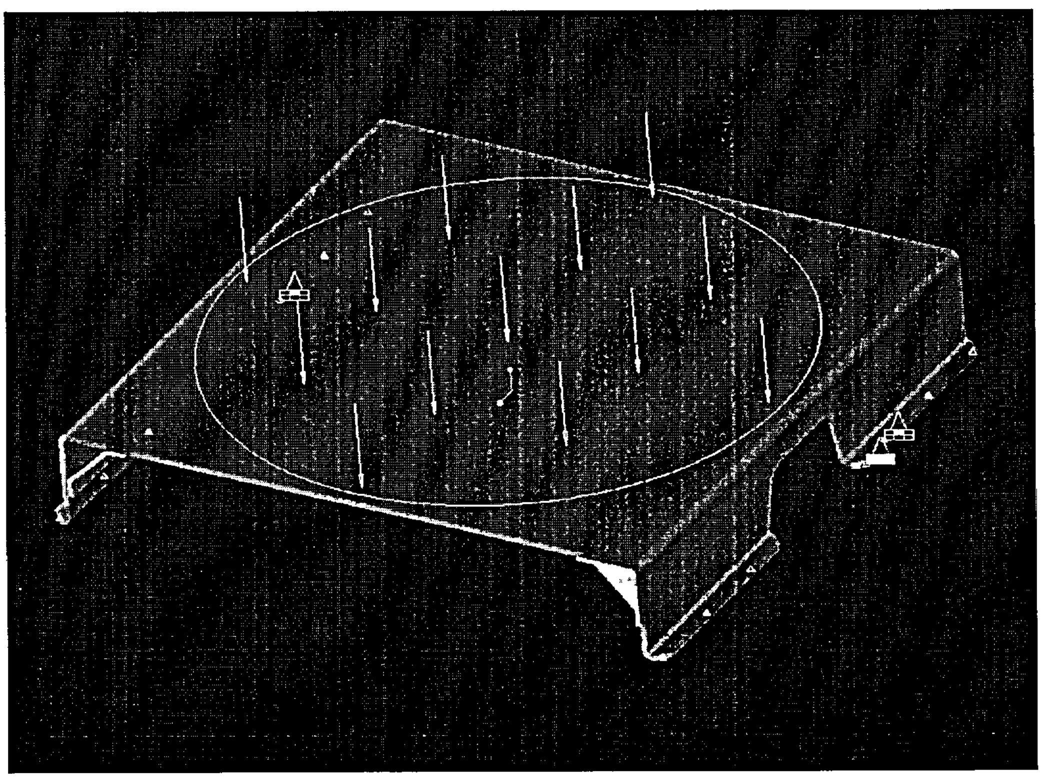

Figure 1: Solid Model of Removable Skid

2. LOADS AND SUPPORTS

A circular loading region (1.22m [48in] diameter) was created on the top surface to represent the "footprint" of the overpack. This region was loaded five times the total weight of the fully loaded overpack (35,000lb or 15,880kg).

The bottom surfaces of the feet were constrained in the y-direction (up and down), and one edge of one foot (rear right) was fully constrained. This way the feet were free to spread outwards as observed during drop testing.

3. FINITE ELEMENT ANALYSIS

Pro/Mechanica 2000 was used to generate the mesh and calculate the stresses in the model. Pro/Mechanica AutoGEM generated 8040 ten-node tetrahedral elements. The results are represented in the color fringe plot in Figure 2.

4. RESULTS

The skid can support 15880kg (35000lb) without large deformation. The highest stresses are in the bottom radius. Local yielding in fact occurs on the bottom surface of the feet at the beginning of the radius on contact with ground.In reality, the edge of the foot tends to lift up transferring the weight from the bottom surface to the curved surface (radius). In practice, yield will not occur from this load case.

Most of the load from the overpack is concentrated along the sides (red regions in Figure 2), which decreases the plate bending in mid-span and also around the highly stressed foot region (bottom of feet is constrained up and down).

In conclusion, the skid strength conforms to the requirements of IAEA Safety Series No 6 and 10 CFR 71.32.

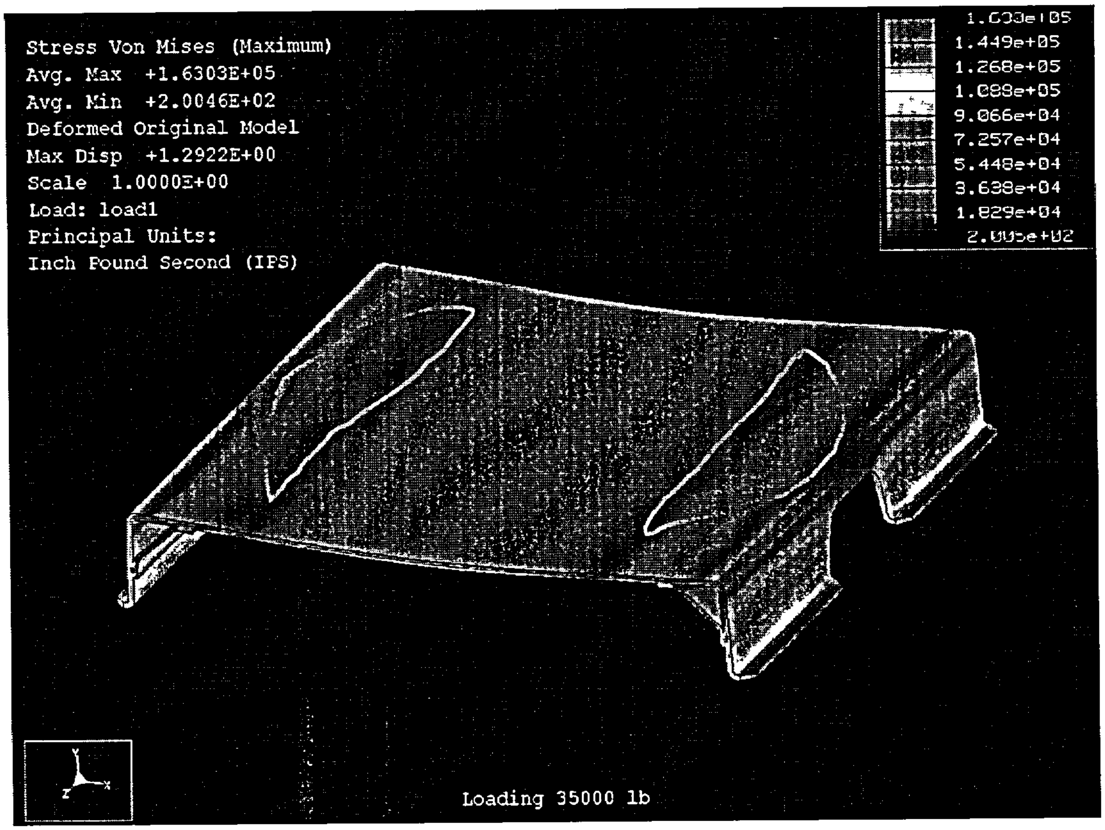

Figure 2: FEA Results for Removable Skid

APPENDIX 2.10.5:
F-430 Test Report

IN/TR 1604 F430

F-430 Test Report

Signatures

Prepared by: B. Menna, Package Engineering Date: 02/08/28

Reviewed by: J. Smith, Quality Assurance Date: 2-8-28

Approved by: M. Krzaniak, Manager, Package Engineering 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)			

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

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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 [redacted]
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	00/06/19
Reviewed by:	Benjamin Prieur	QC Technician	2000/06/15
Approved by:	Dave Whitby	Senior QC Technician	00.06.15

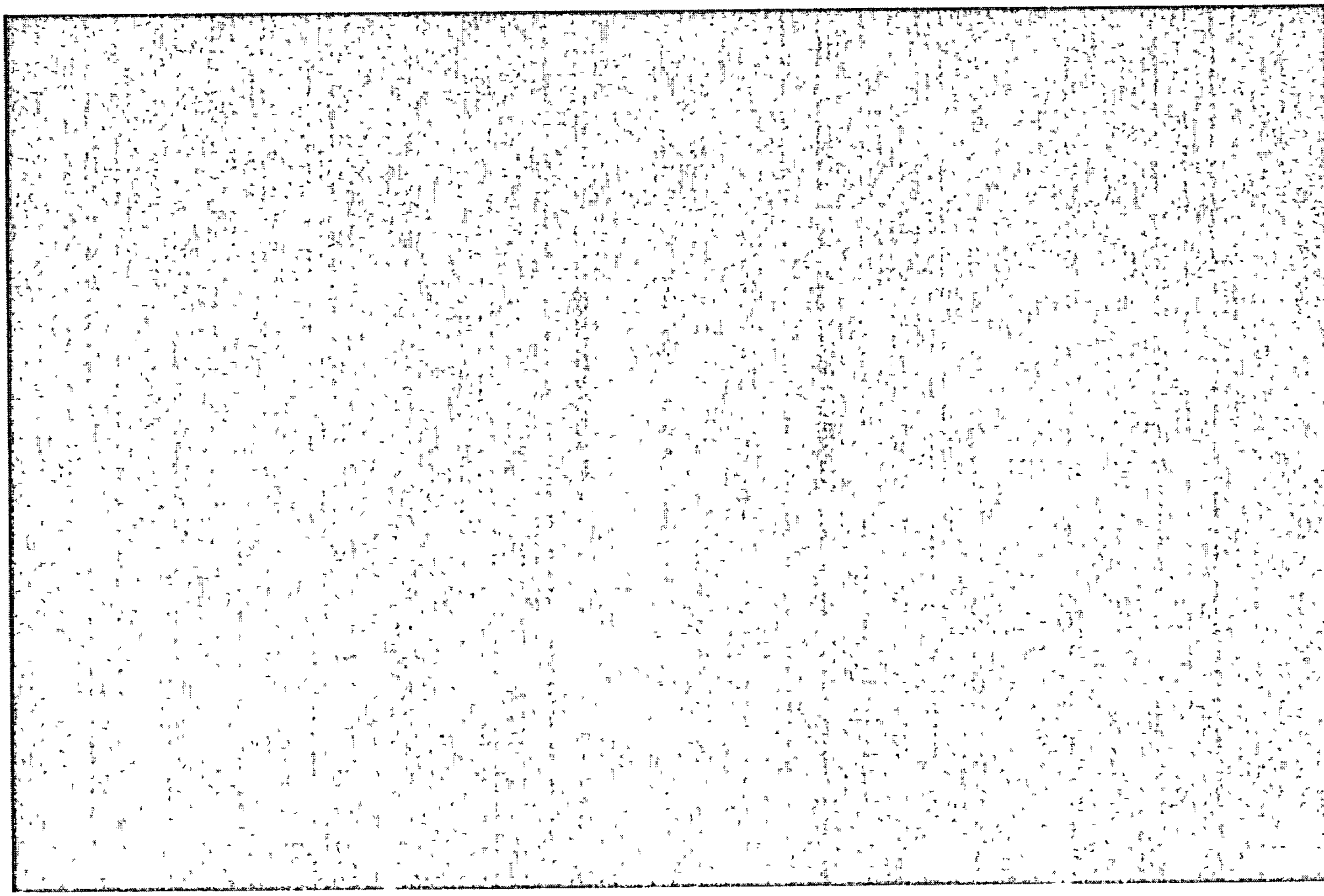


Figure 1, Orientation of GC-40 and Bolt Numbering

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	

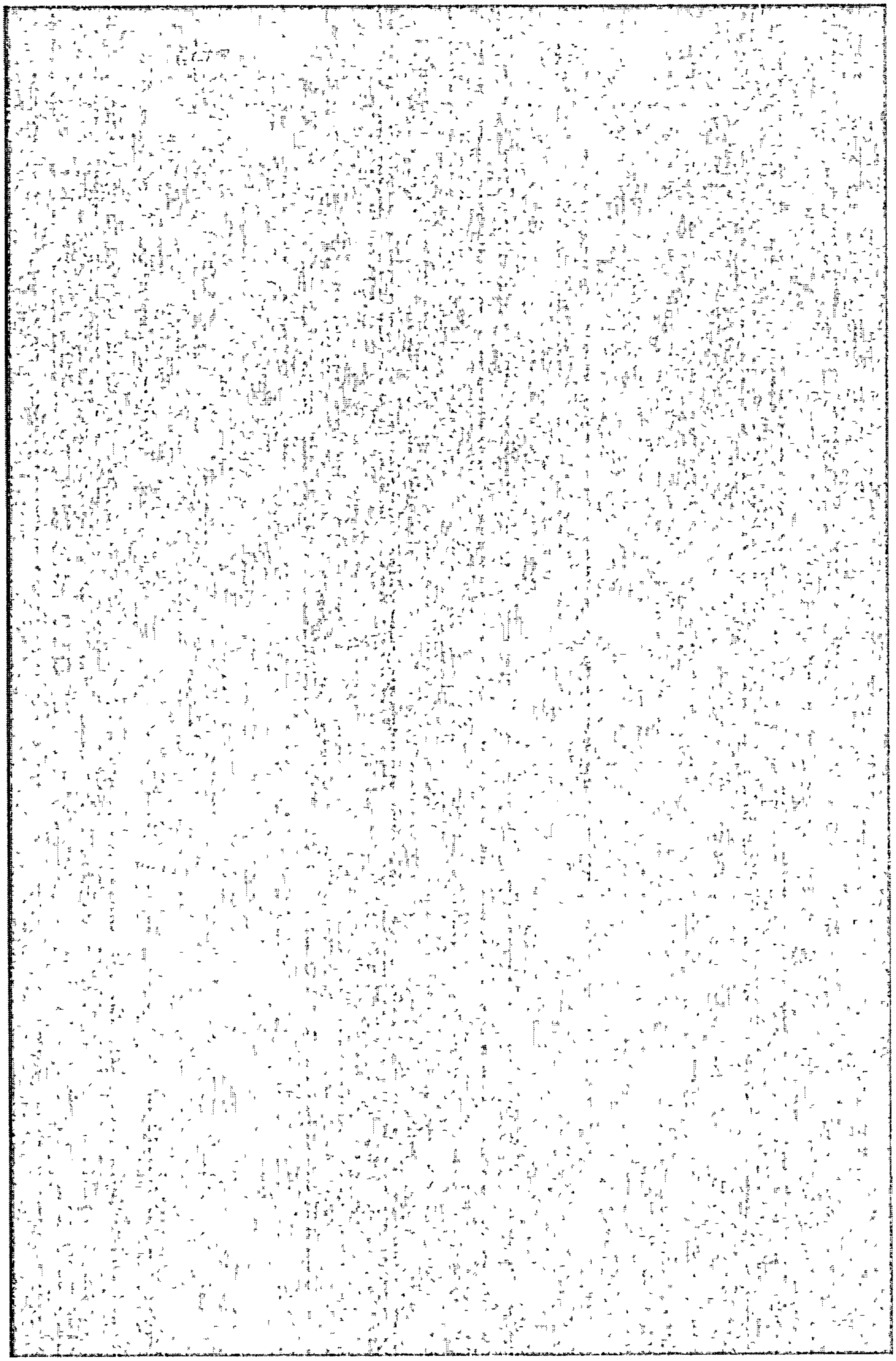


Figure 2, F-430 Container, Pre-Drop Dimensions

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	

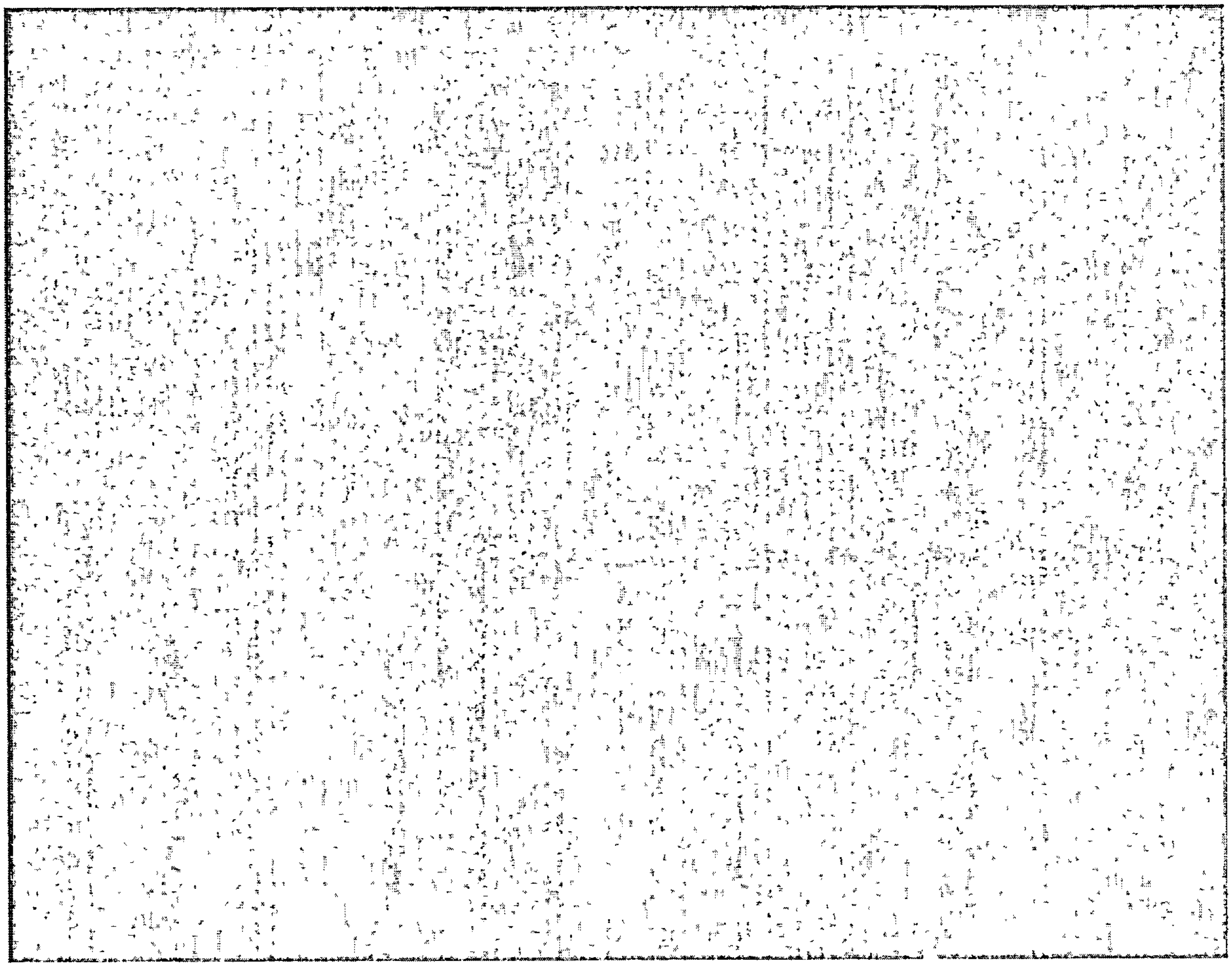


Figure 3, GC-40 Lower Head, Pre-Drop Dimensions

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.

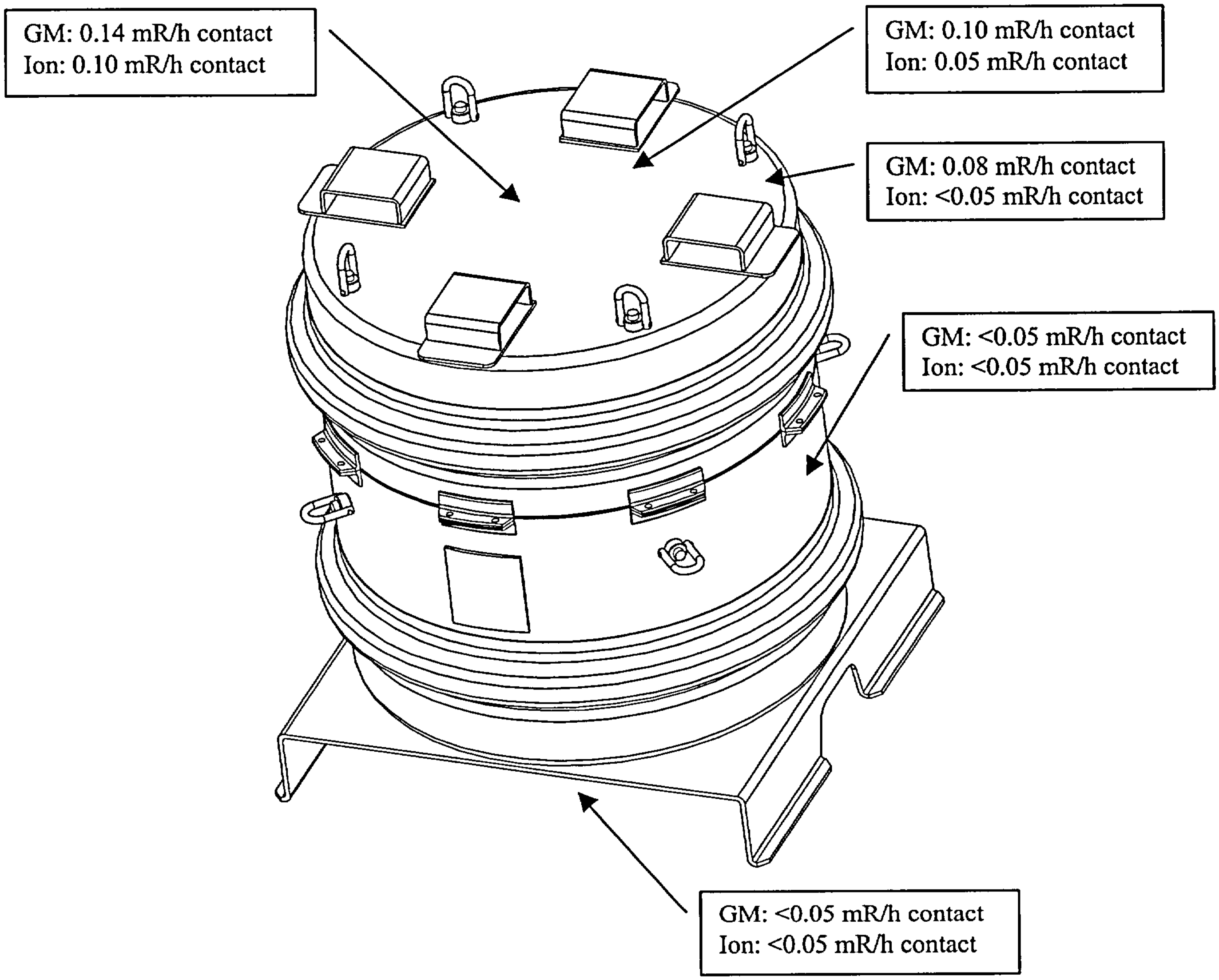
The instrumentation used for the survey is as follows:

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.

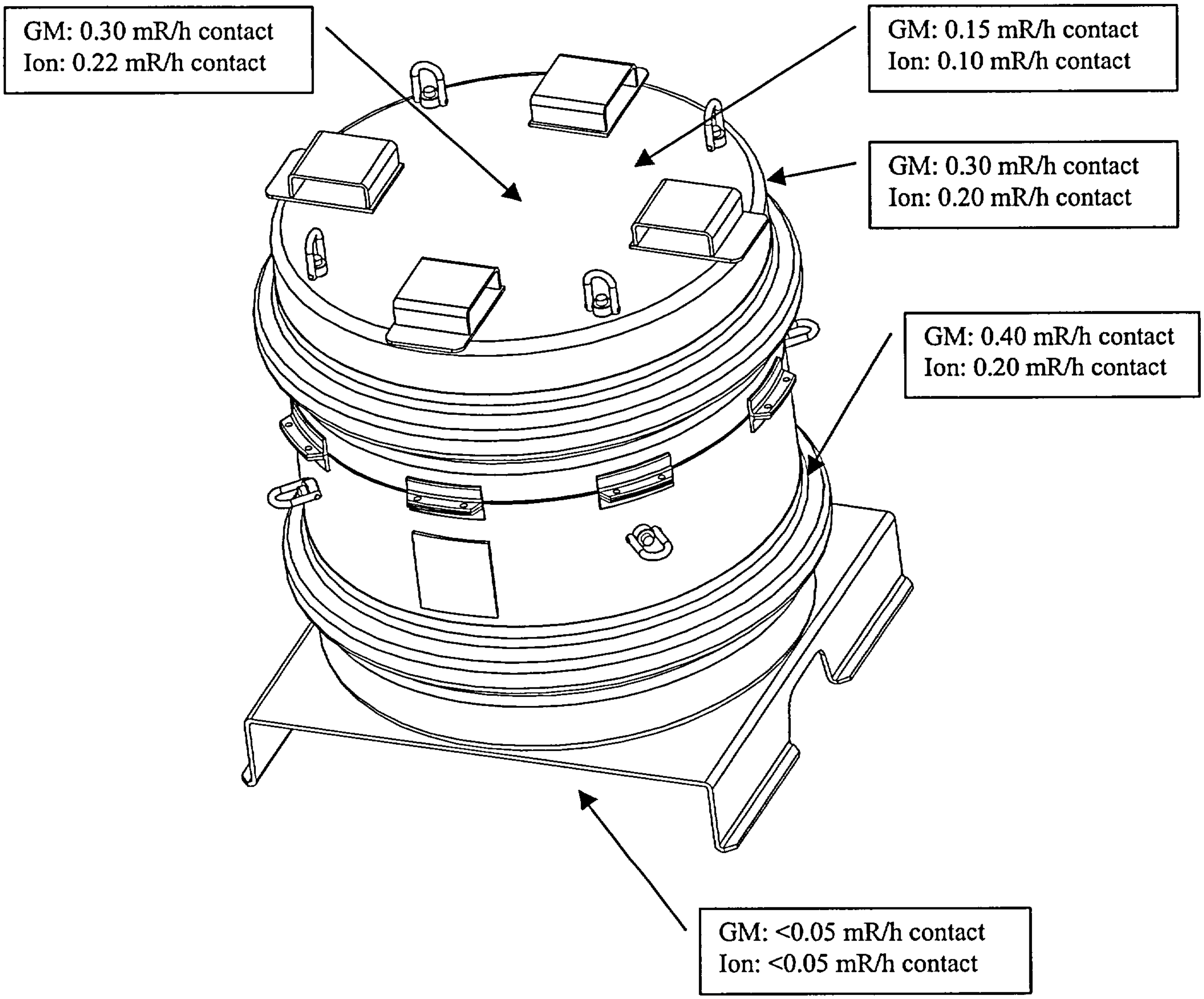
Comments

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

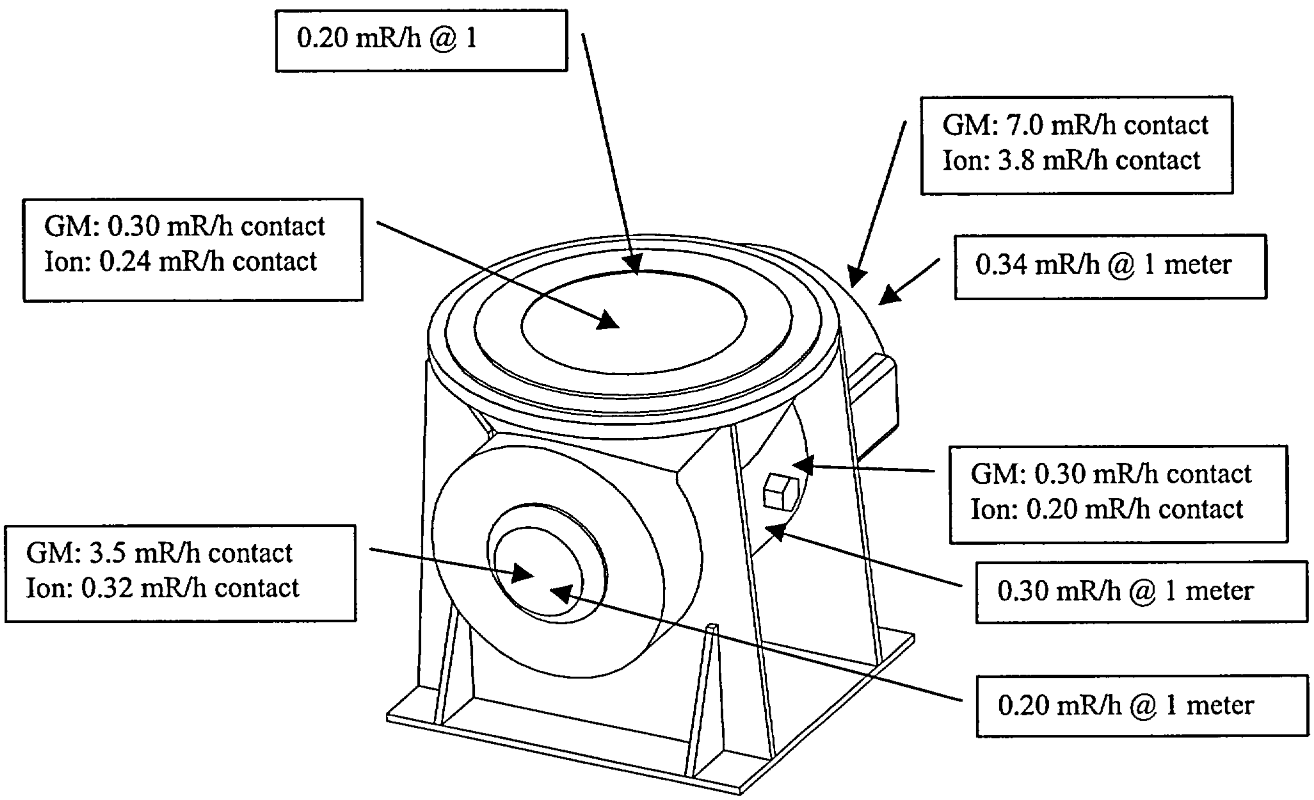


Figure 6, GC-40 (Specimen A), Pre-Drop Survey

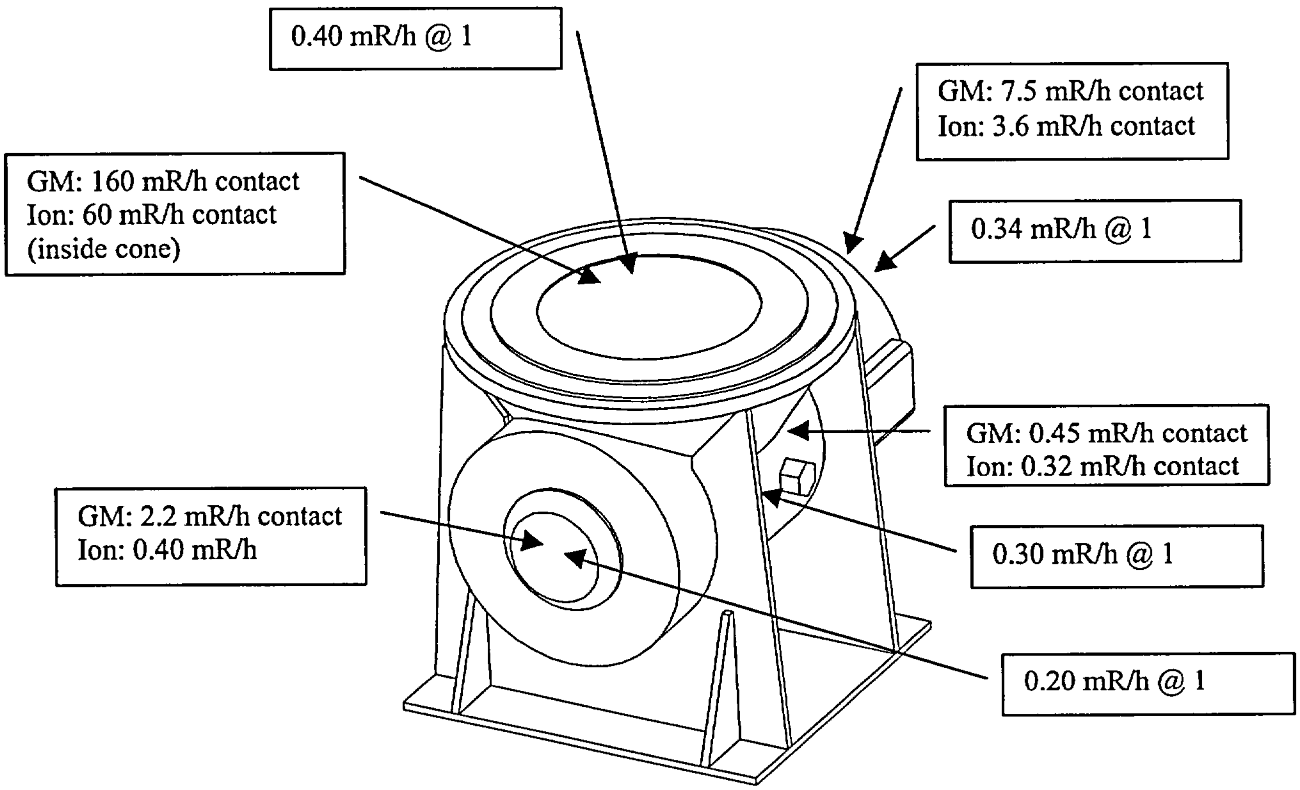


Figure 7, GC-40 (Specimen B), Pre-Drop Survey

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)

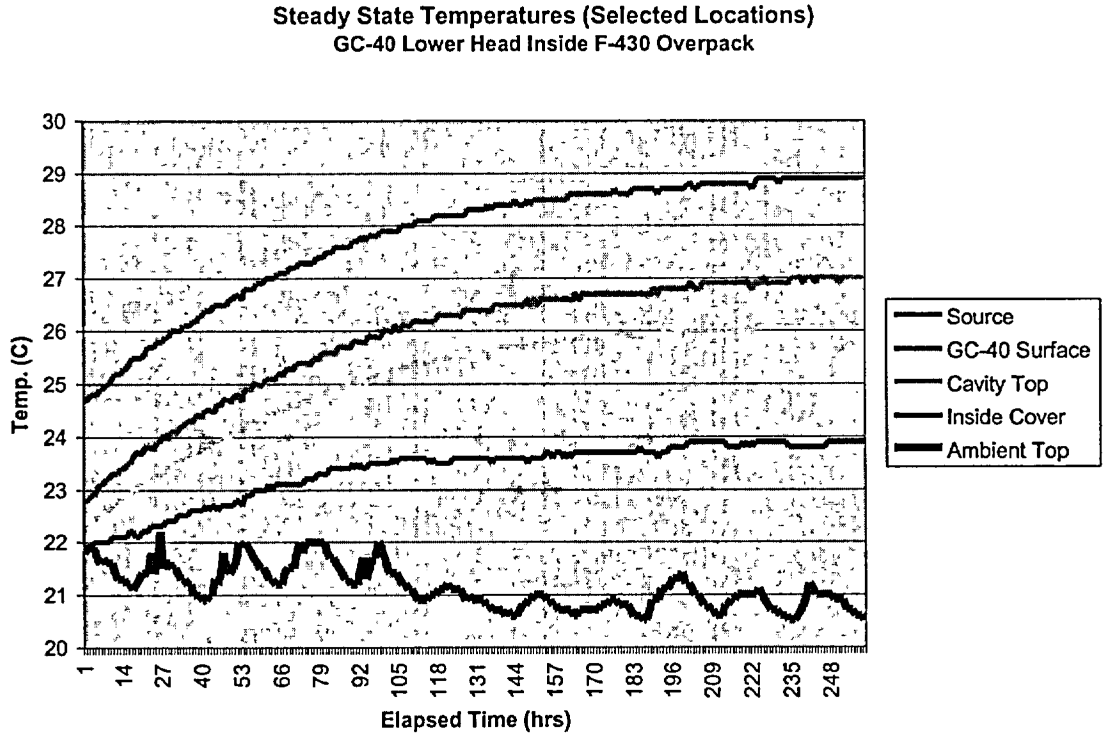
THERMOCOUPLE INSTALLATION:
Twenty thermocouples were installed at locations shown in Figure 9, and held in position with a duct tape.
A hole was drilled (0.50" diameter) through the main cover and inner cover to reach points inside the container. The hole was then sealed with a duct tape.
To measure 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)



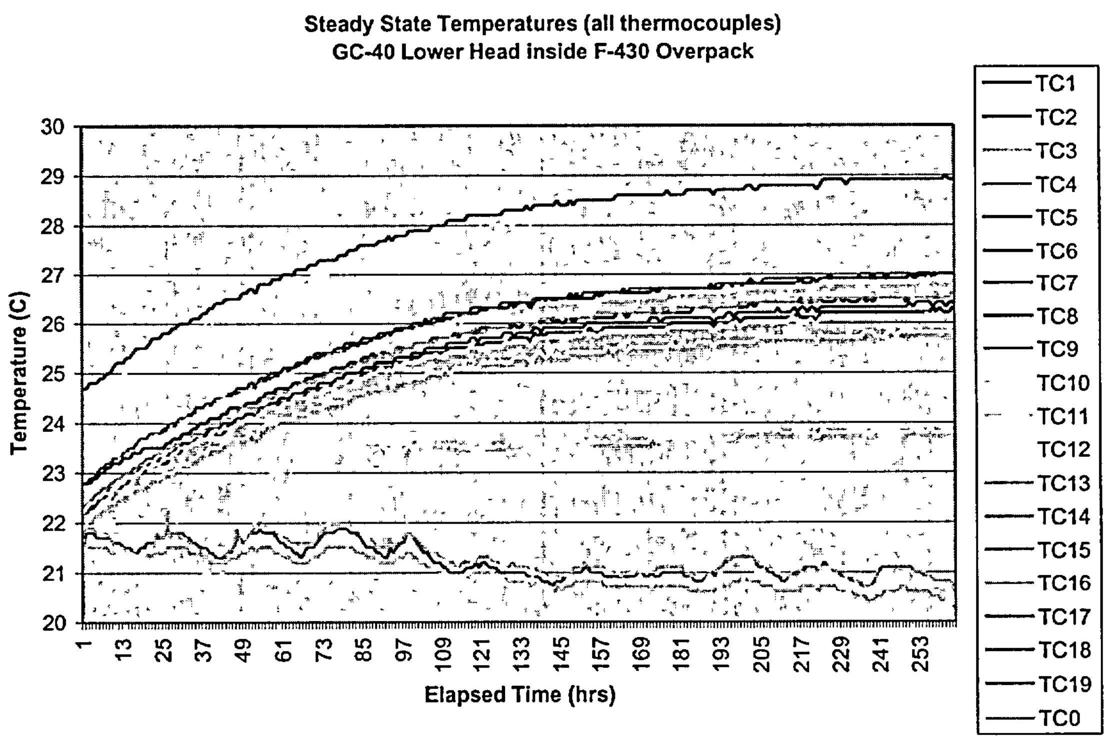


Figure 8, Steady State Temperatures, F-430/GC-40

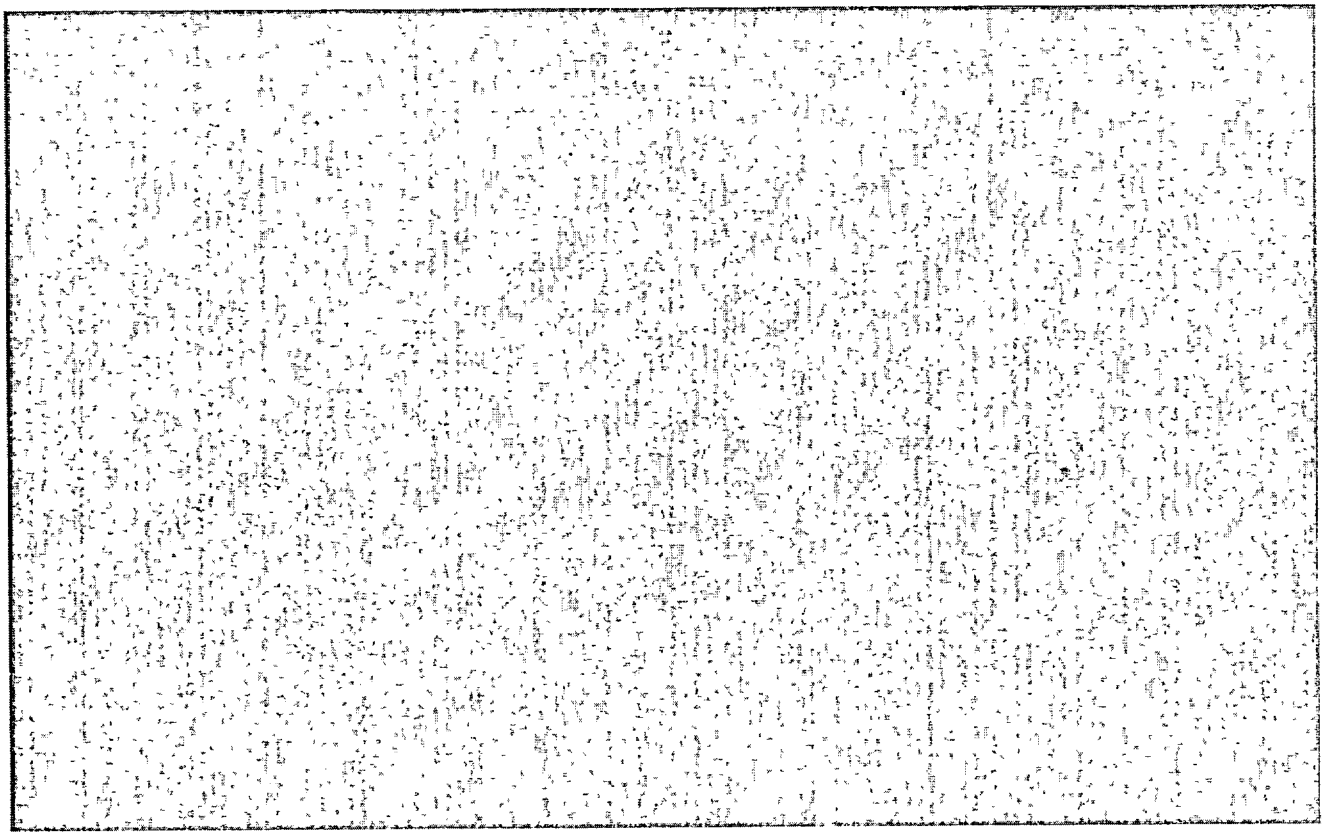


Figure 9, Thermocouple Locations

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

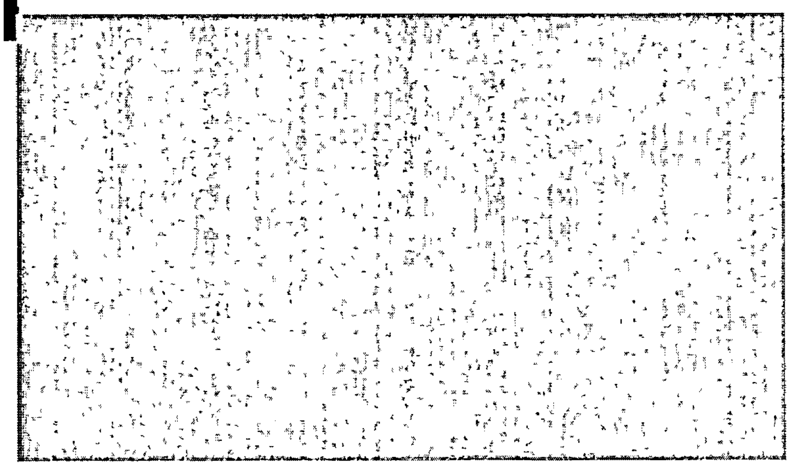
Report Type	**Date of Test**	
Pre-Drop	September 9, 1999	
Test Name/Description	**Test Number**	**Test Plan**
Penetration Test	5.1.10	IN/TP 1493 F430 (2)

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

[redacted]



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

[redacted]

[redacted]

[redacted]

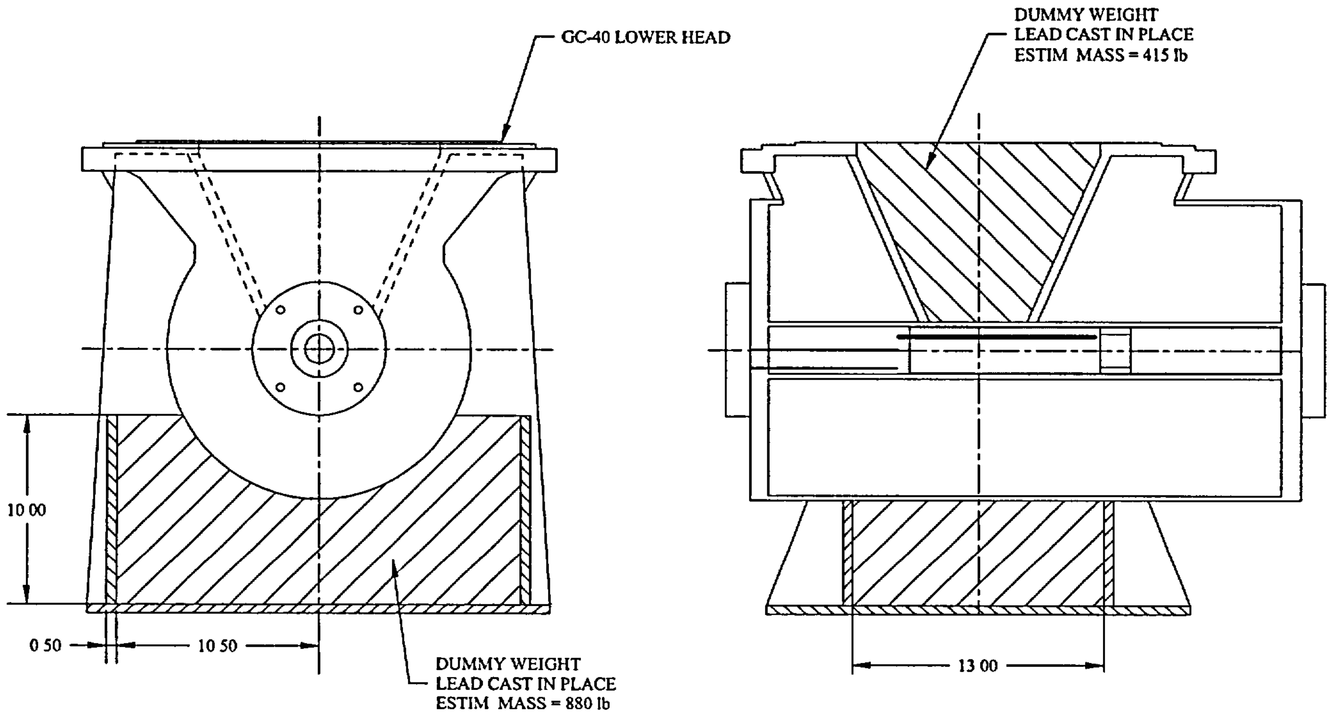


Figure 10, Dummy Weights On GC-40

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)

[redacted]
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
[redacted]

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

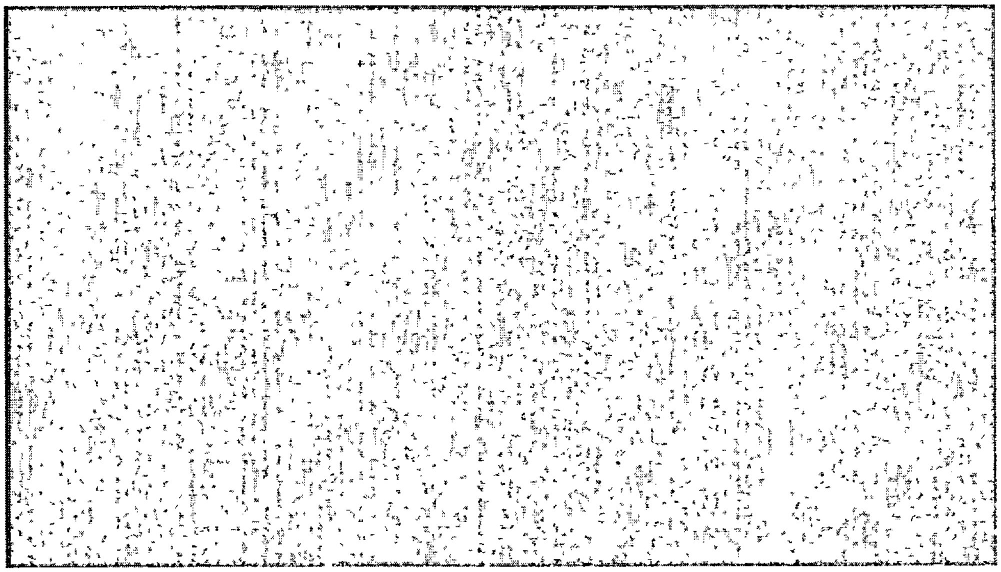


Figure 11, Brace position after drop test #1 ***(original position marked with black line)***

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).

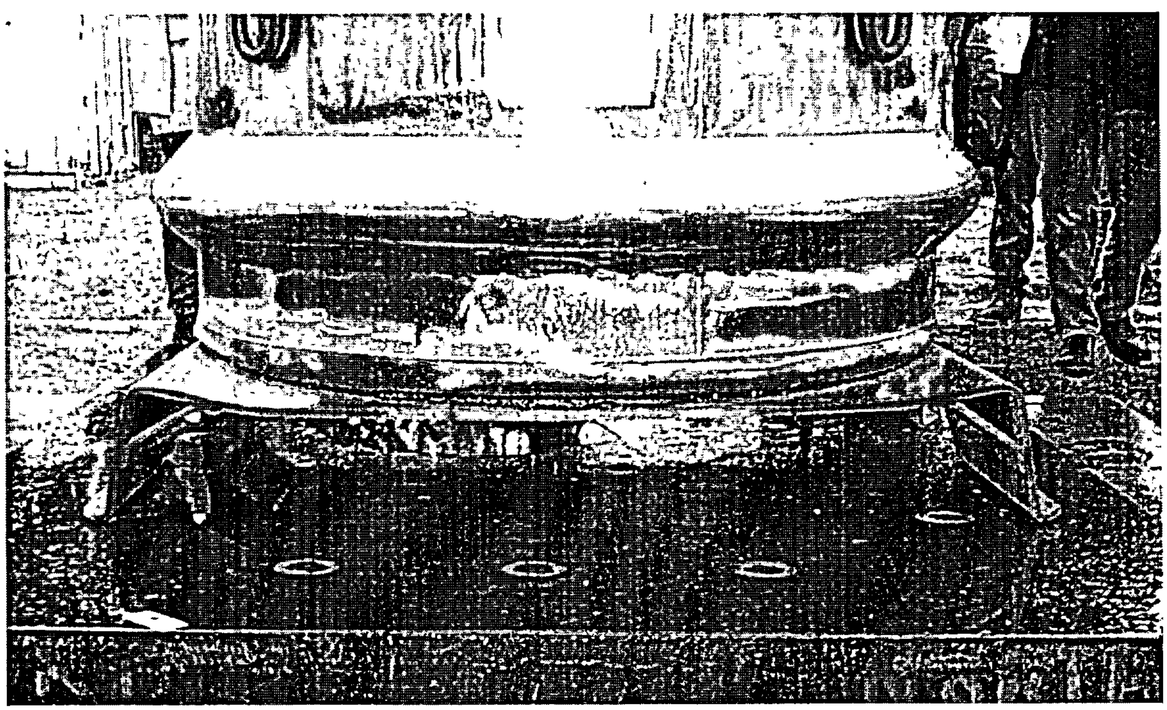


Figure 12, Damage after 1.2m normal drop.

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 [redacted]. 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	

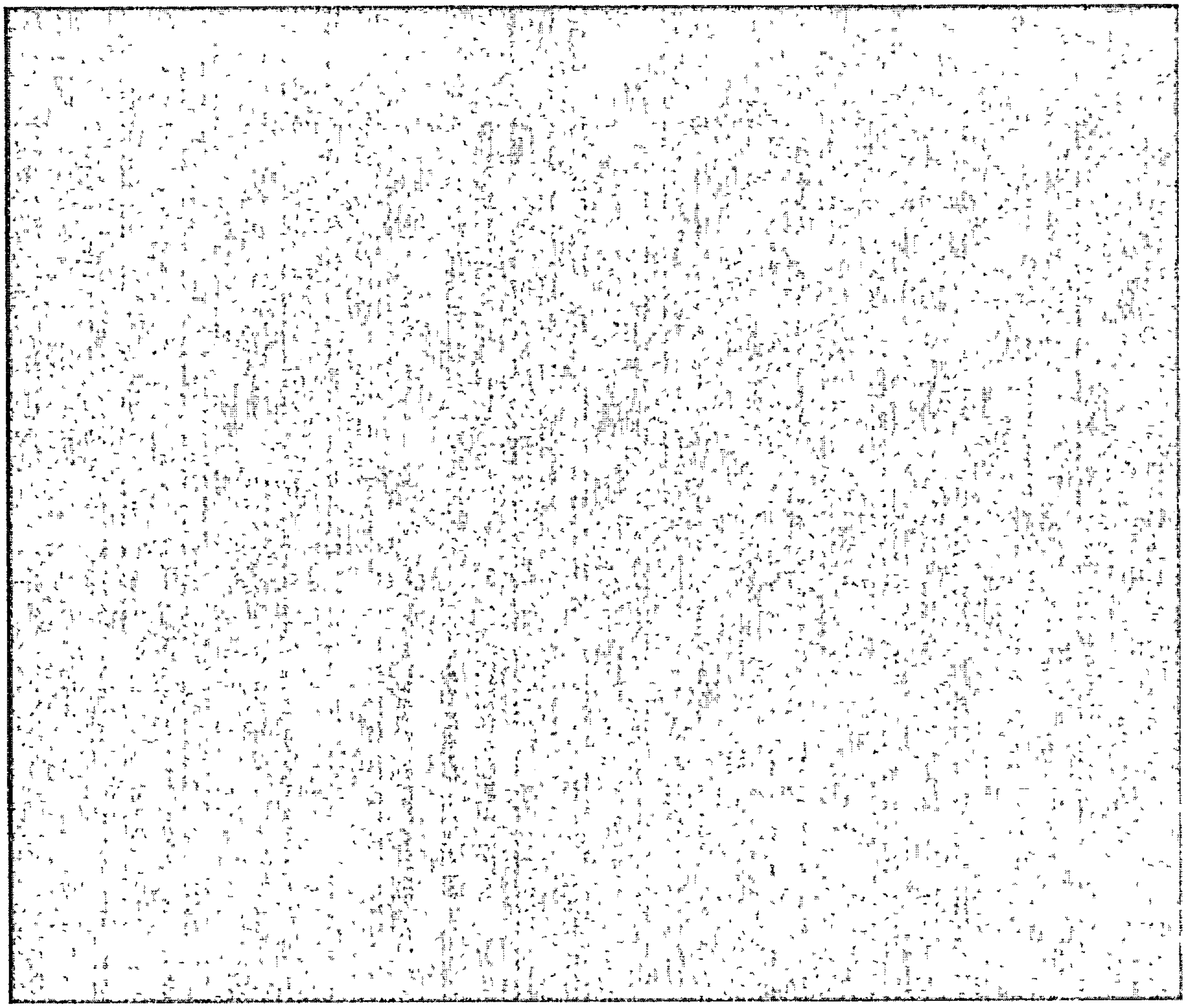


Figure 13, F-430 Post-Drop, Front View

(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 ([redacted].

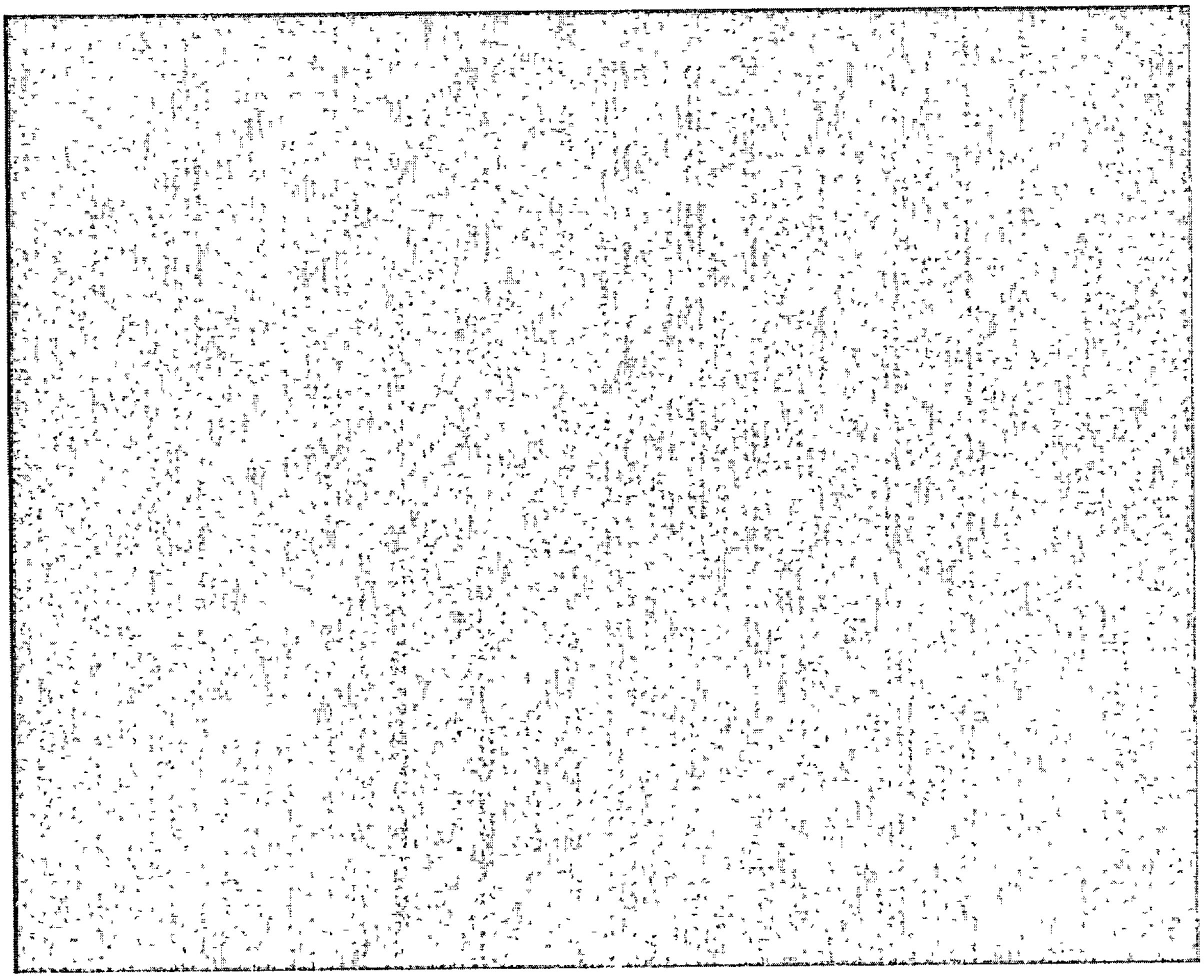


Figure 14, F-430 Post-Drop, Front-Right View

(4" squares in background)

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

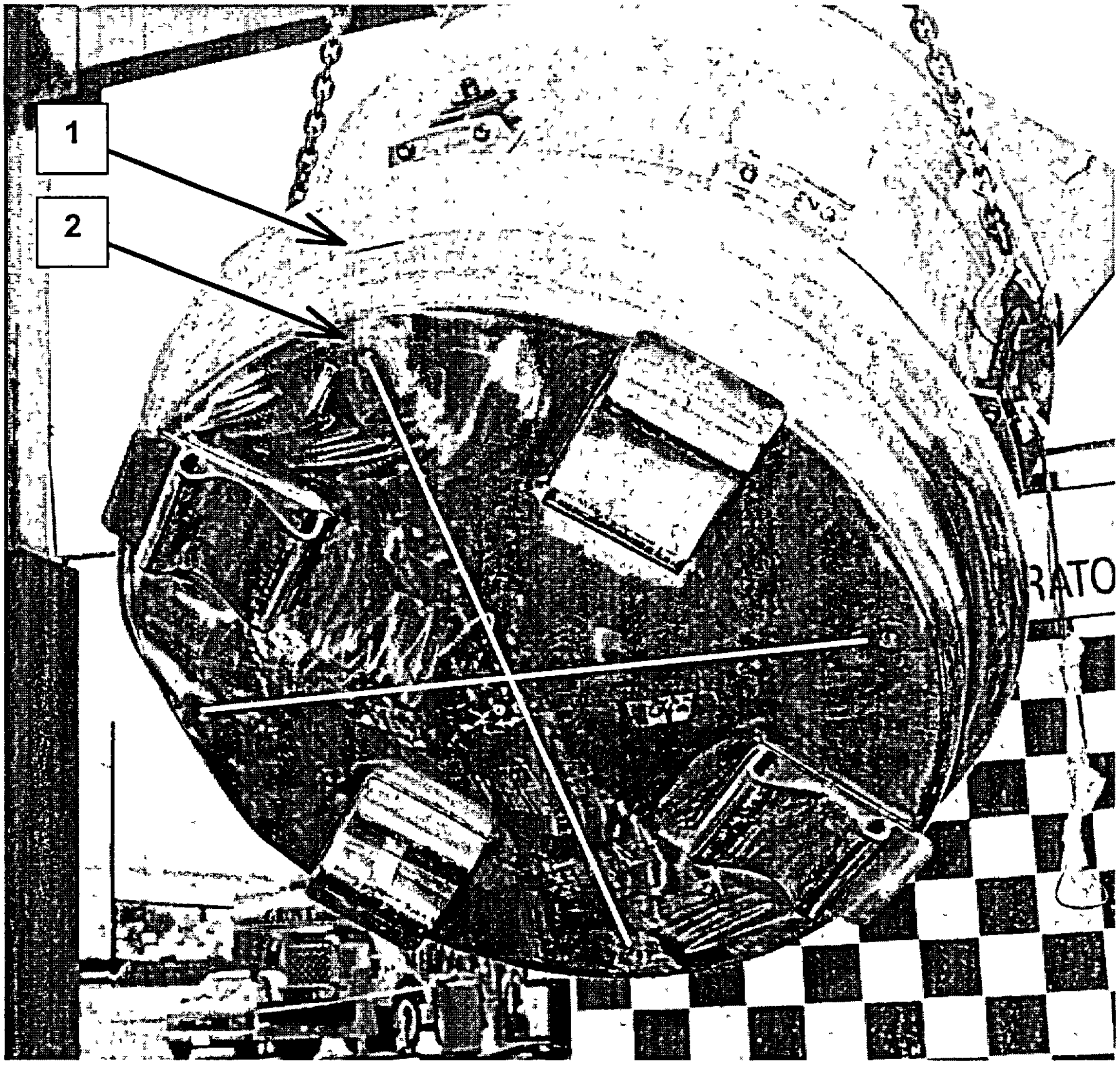


Figure 15, After 9m Inverted Drop Test (#3)

1. [redacted]
2. [redacted].

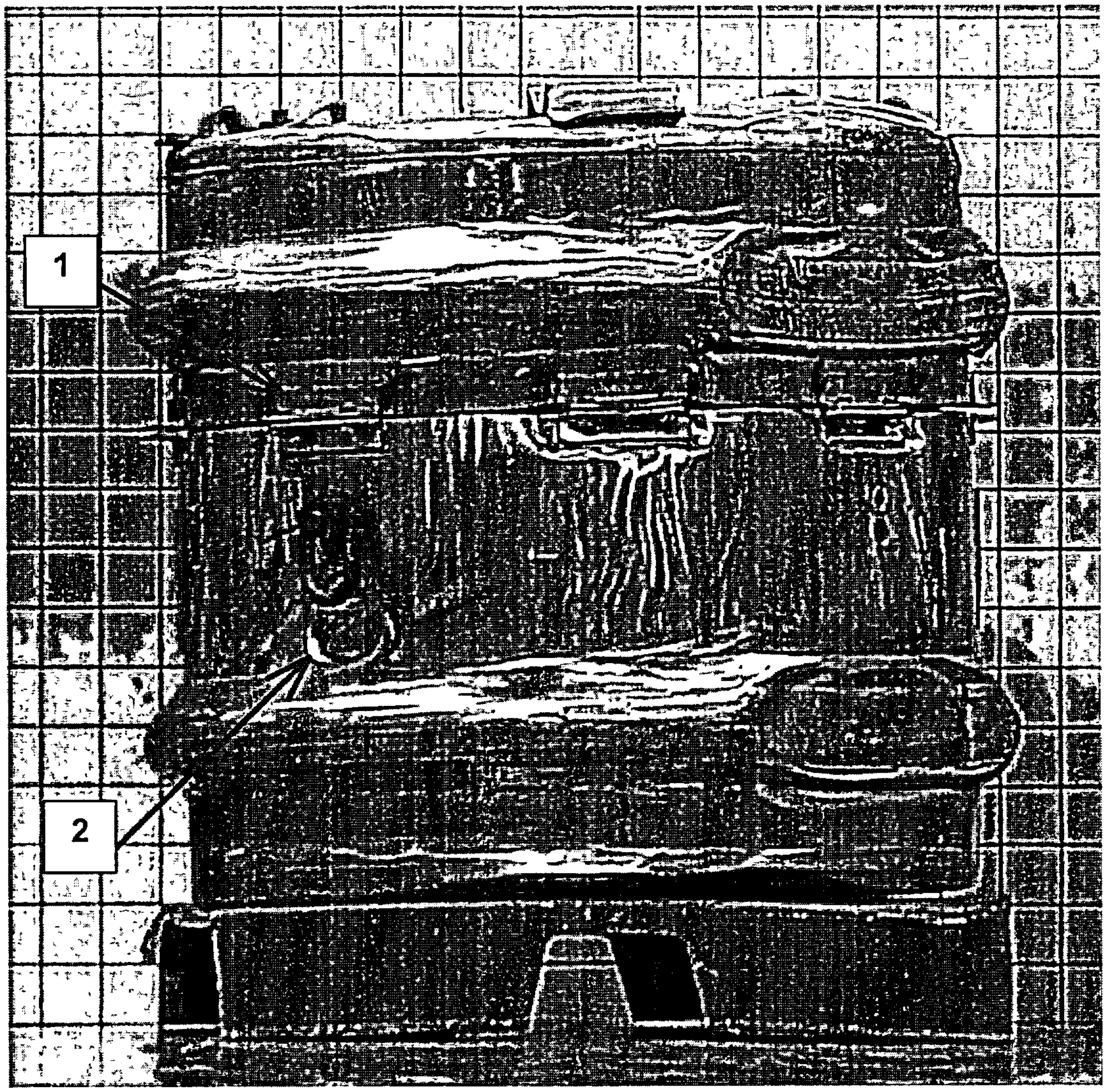


Figure 16, F-430 Post Drop, Left View

(4" squares in background)

1. [redacted].
2. [redacted].

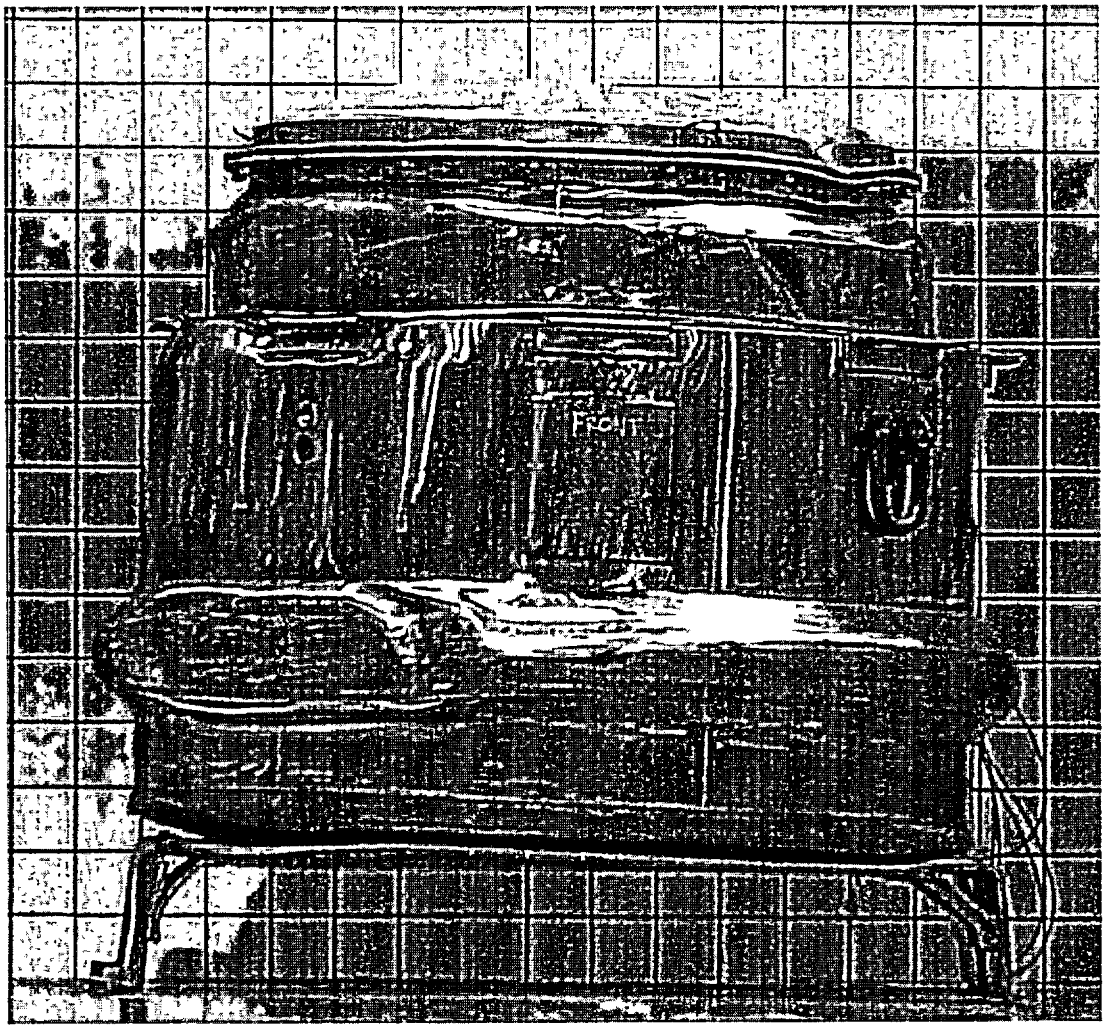


Figure 17, Front View without Main Cover
(4" squares in background)

[redacted].

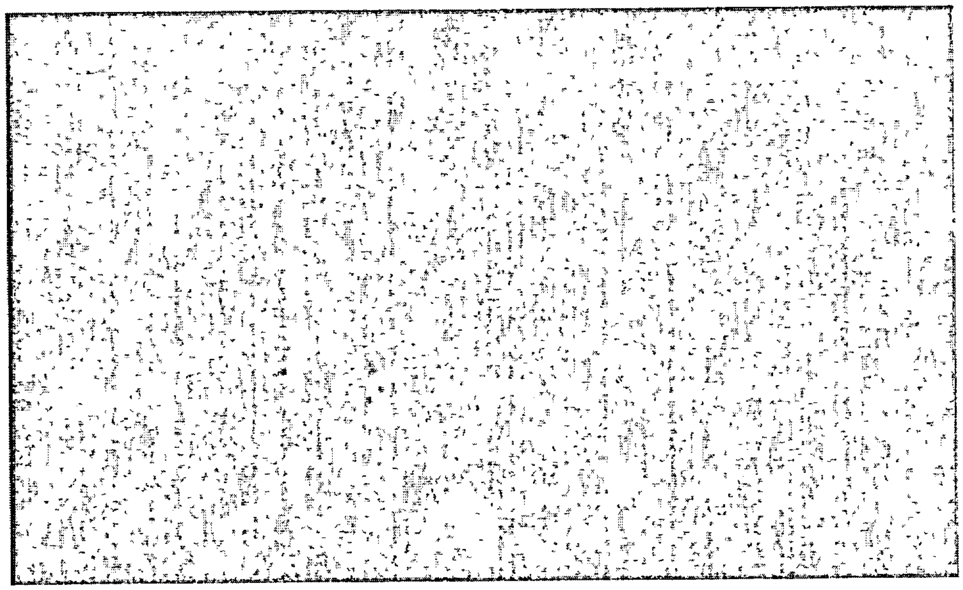


Figure 18, Top Part of Inner Brace

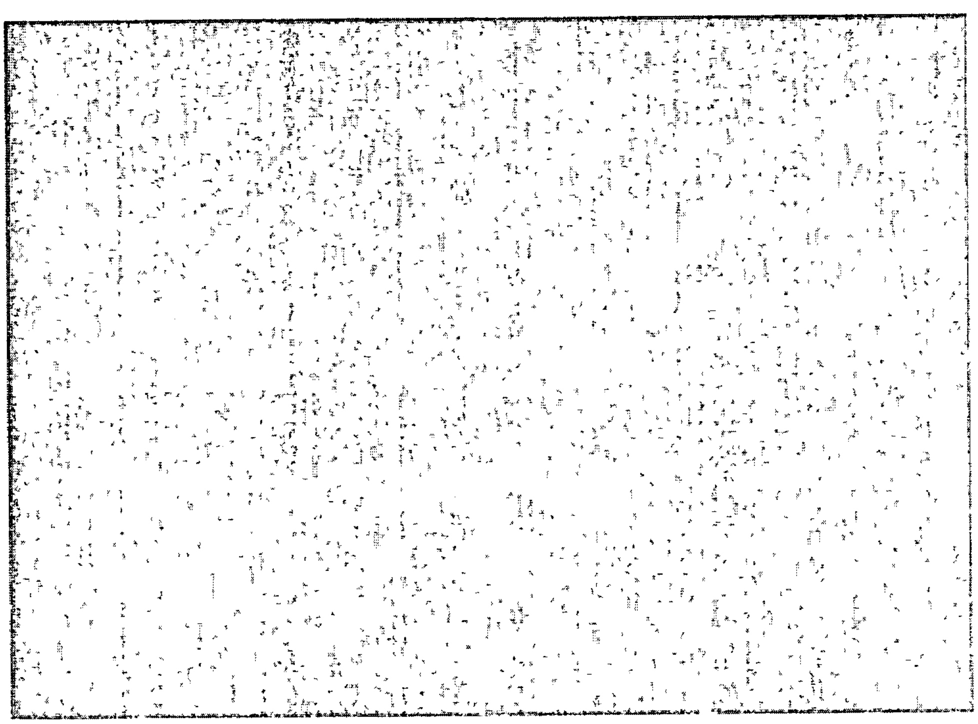


Figure 19, Lower Part of Inner Brace with GC40 Inside F-430

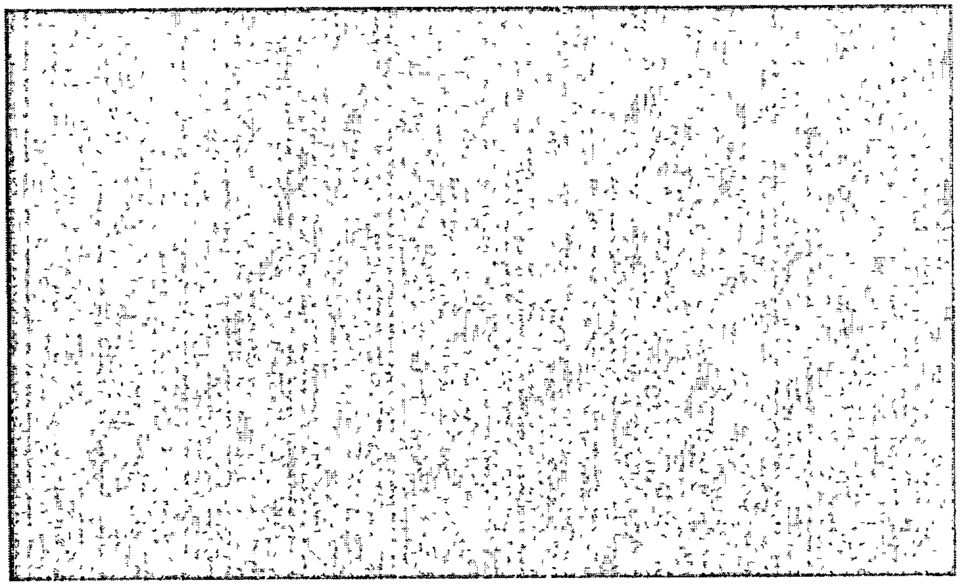


Figure 20, Detail of Skin Damage after Oblique Pin Drop

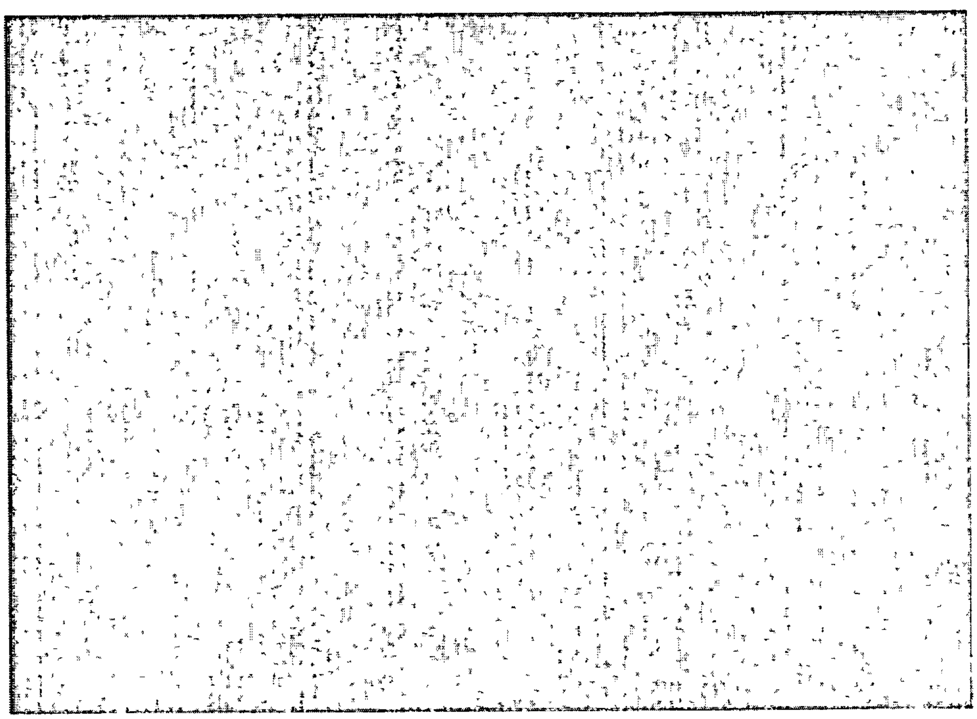


Figure 21, Detail of Skin Damage after Side Pin Drop

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	

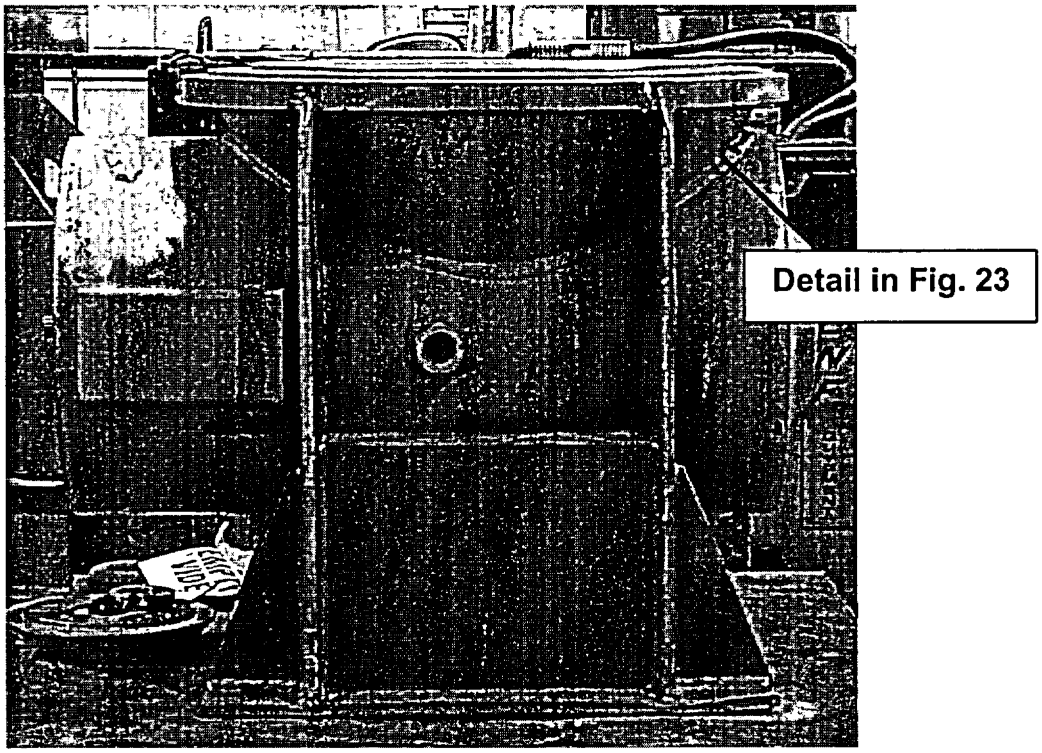


Figure 22, GC40 After Drop Testing (Left Side)

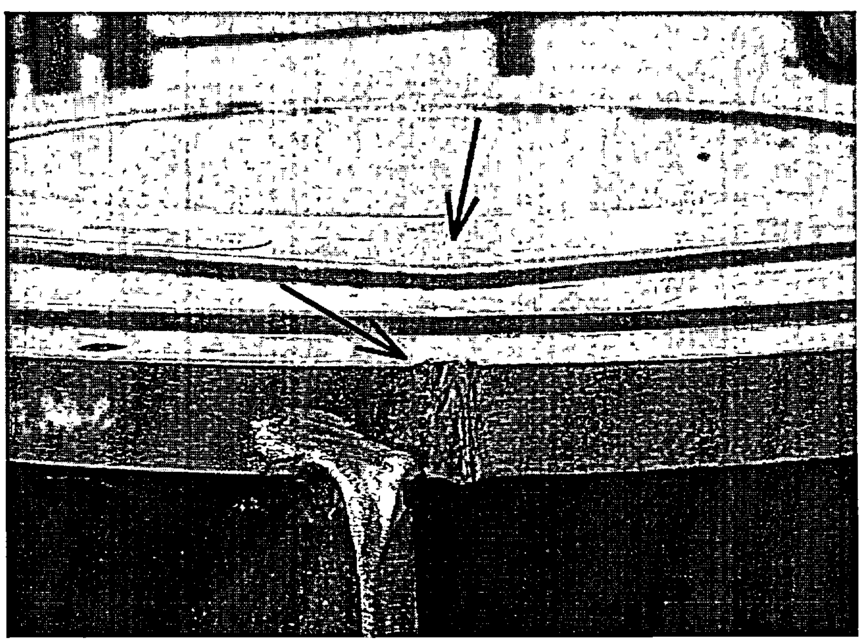


Figure 23, Detail of GC40 Flange

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

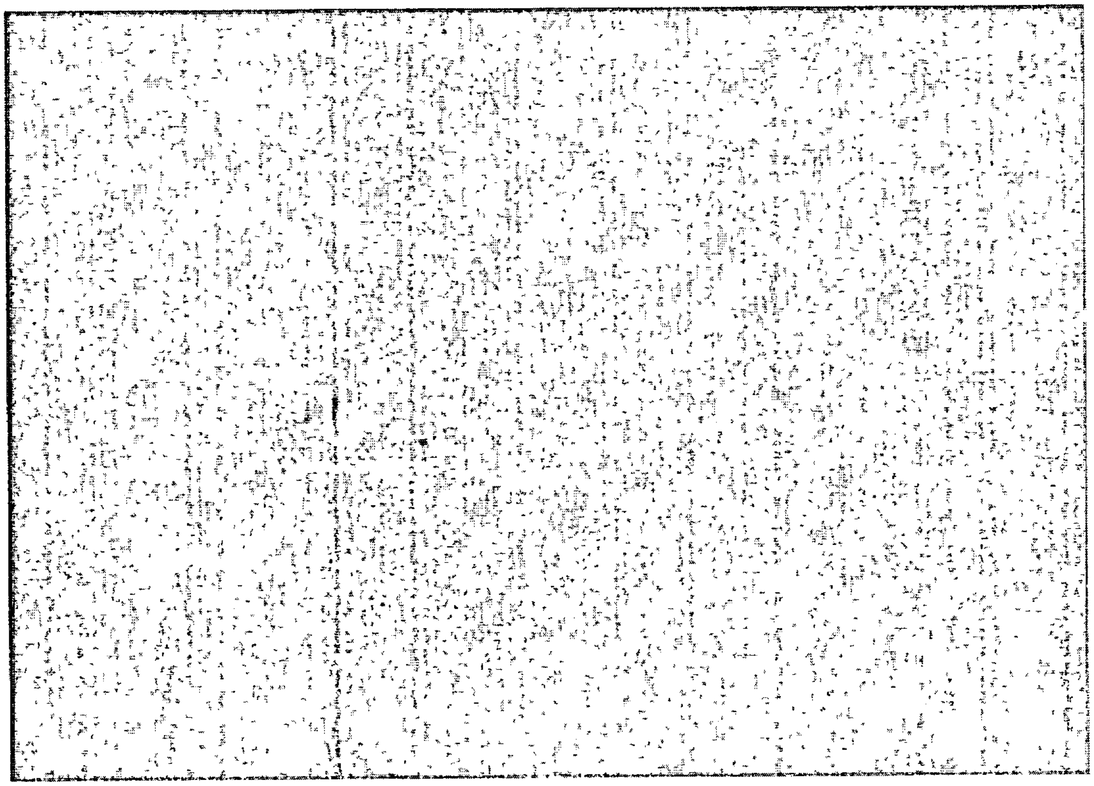


Figure 24, GC40 Back View (Drawer with Dummy Source)

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

[redacted]

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:

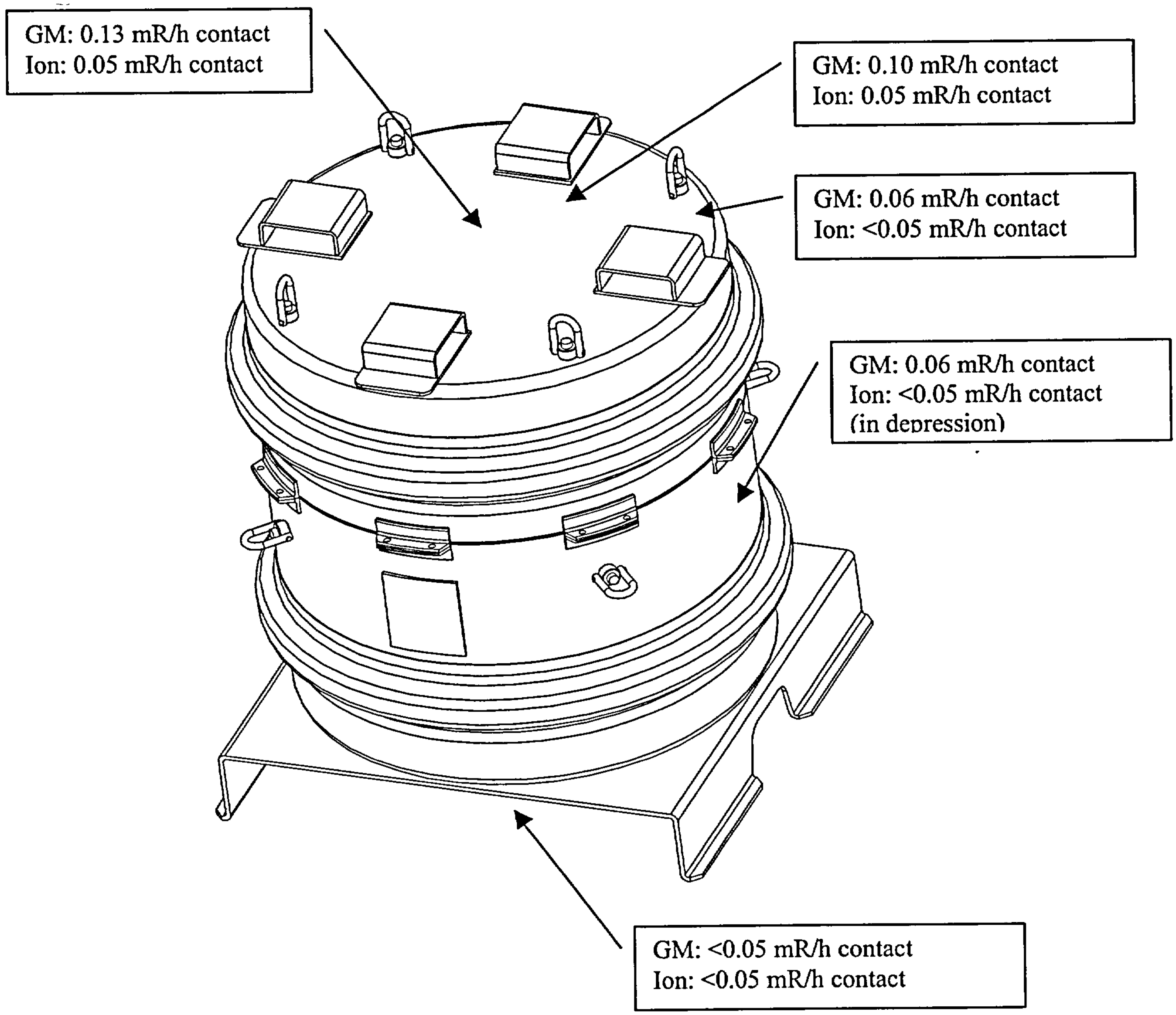
Make	Model	Serial No.	Calibration Date	Chamber Type
Victoreen	471	1432	1999 July 23	Ion Chamber
Bicron	Surveyor	B611W	1999 Nov 11	Geiger Mueller

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

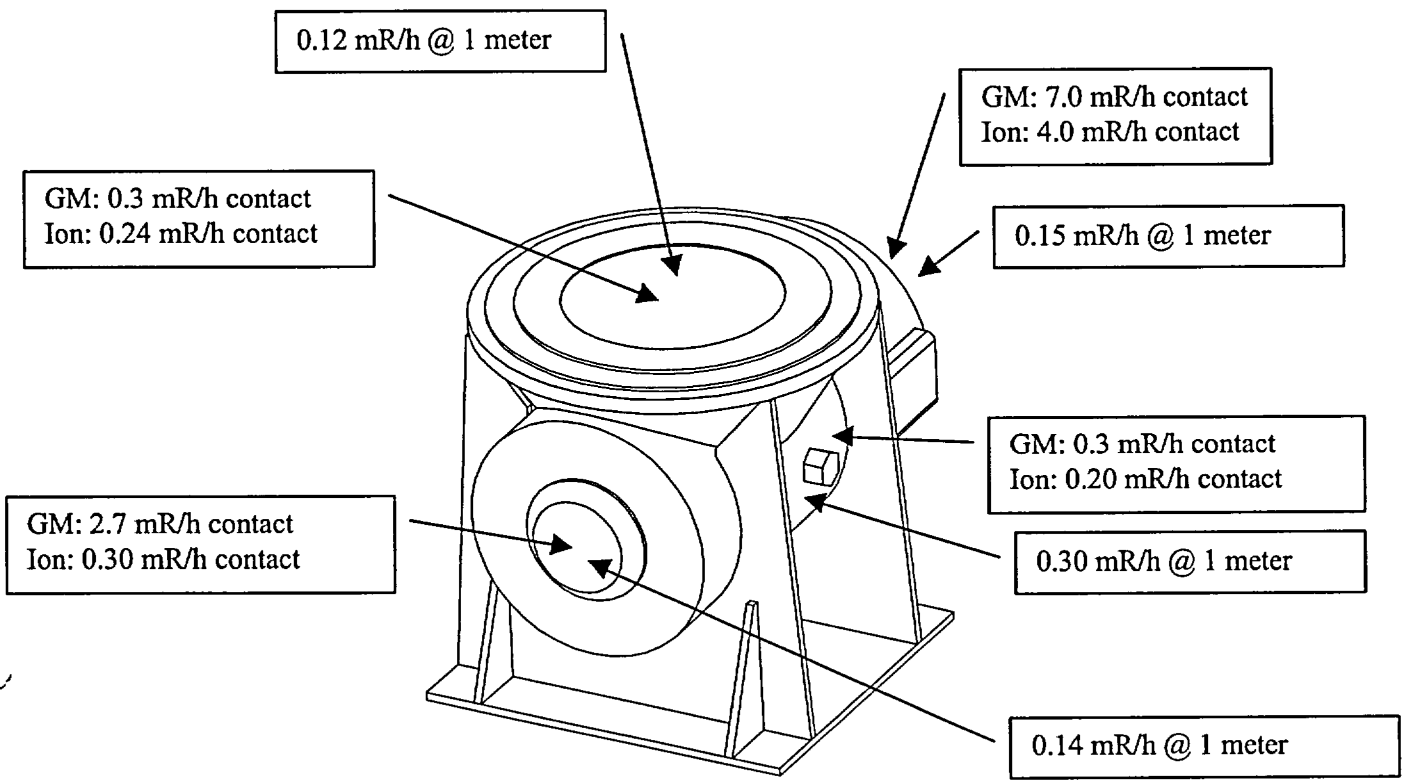
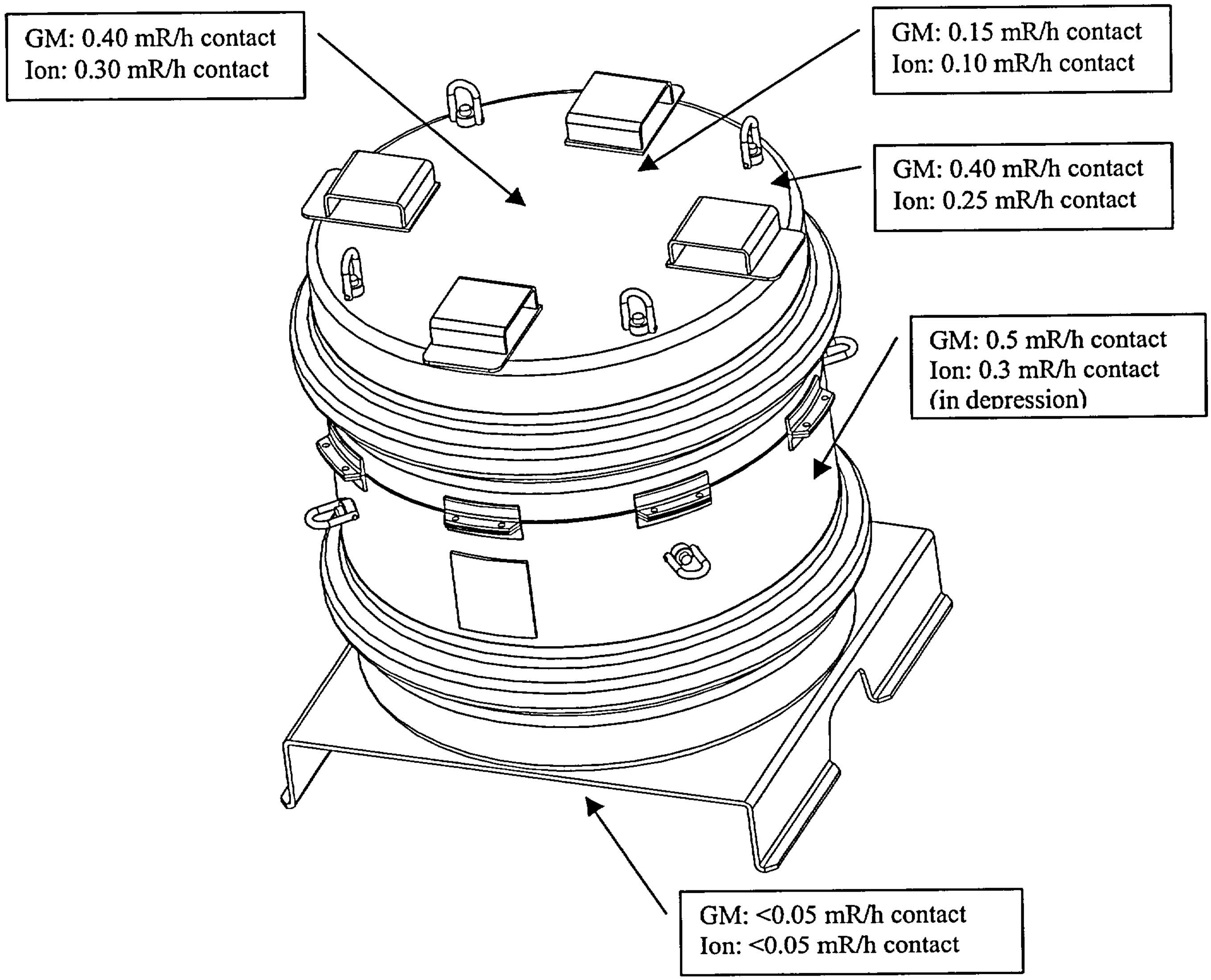


Figure 26, GC-40 (Specimen A), Post-Drop Survey



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.

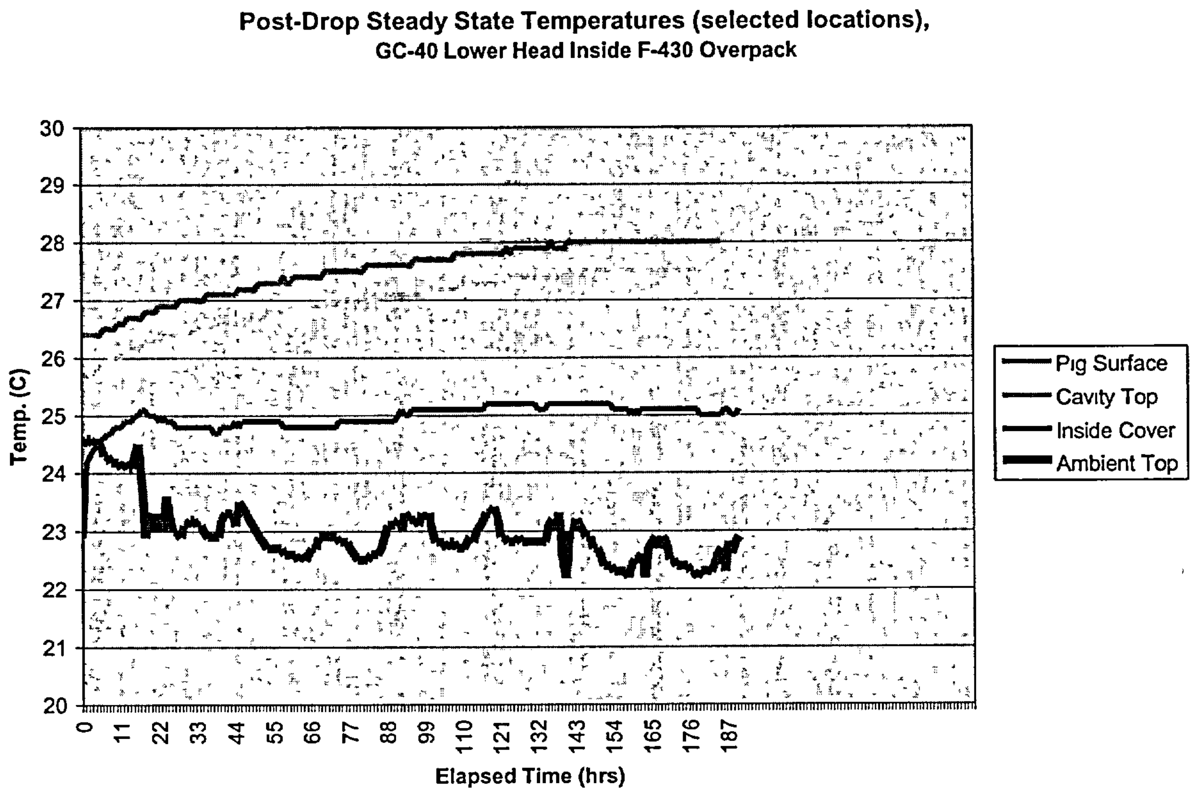


Figure 28, Post-Drop Steady State Temperatures, F-430/GC-40

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.
[redacted]
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

[redacted]. 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. [redacted]). 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, [redacted]

[redacted] 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. [redacted] 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. [redacted]. 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 [redacted]. 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. [redacted] 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.

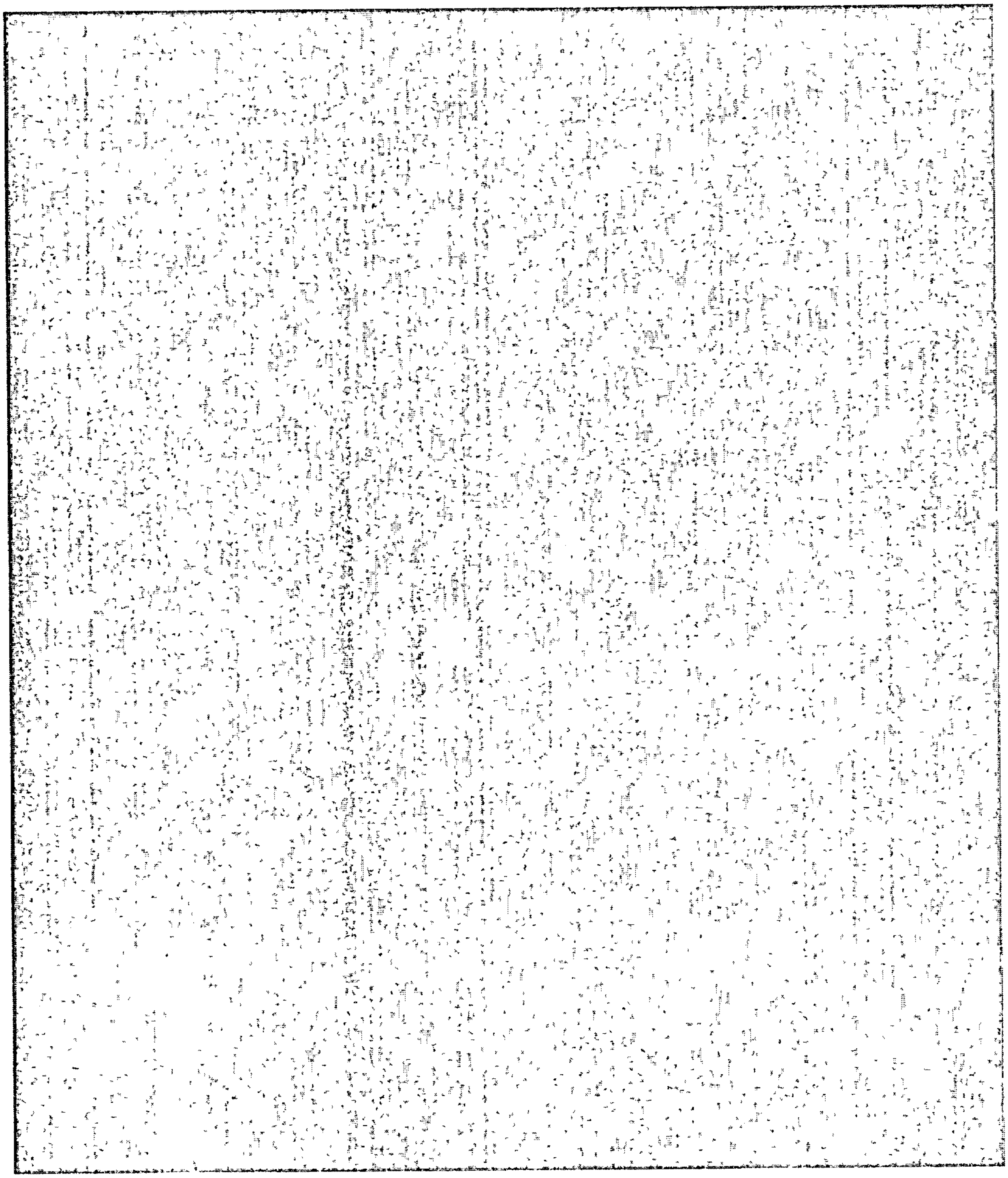


Figure 29, F-430 / GC-40 Main Components

In Test #6: 1m Side Pin Drop (to penetrate side curved surface) [redacted].

Test #7: 9m Side Drop (to split open the package) This orientation [redacted]). 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 [redacted]" 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 [redacted]. 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) [redacted]. 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. [redacted]). 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. [redacted].

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

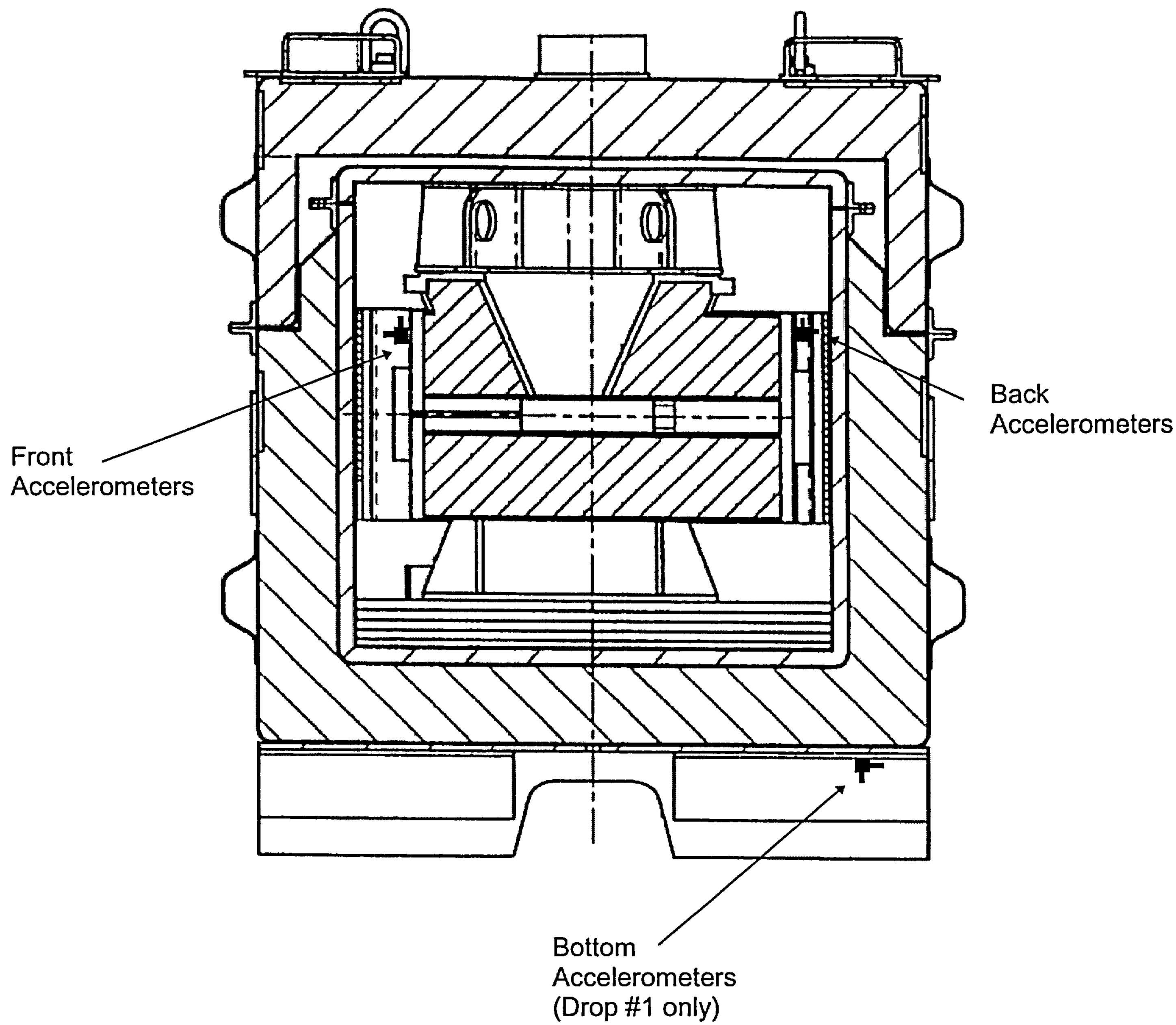


FIGURE #1: Location of Accelerometers

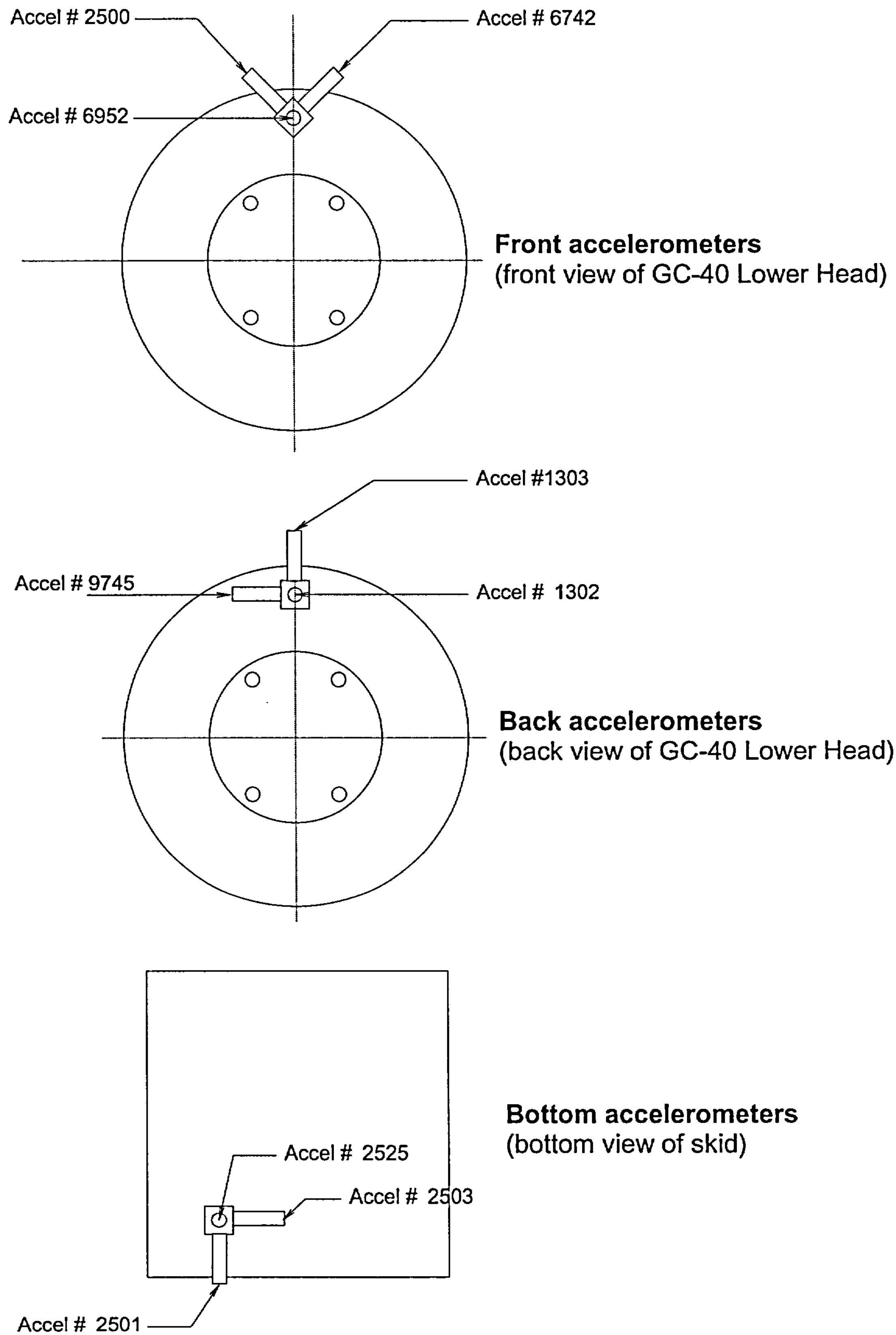
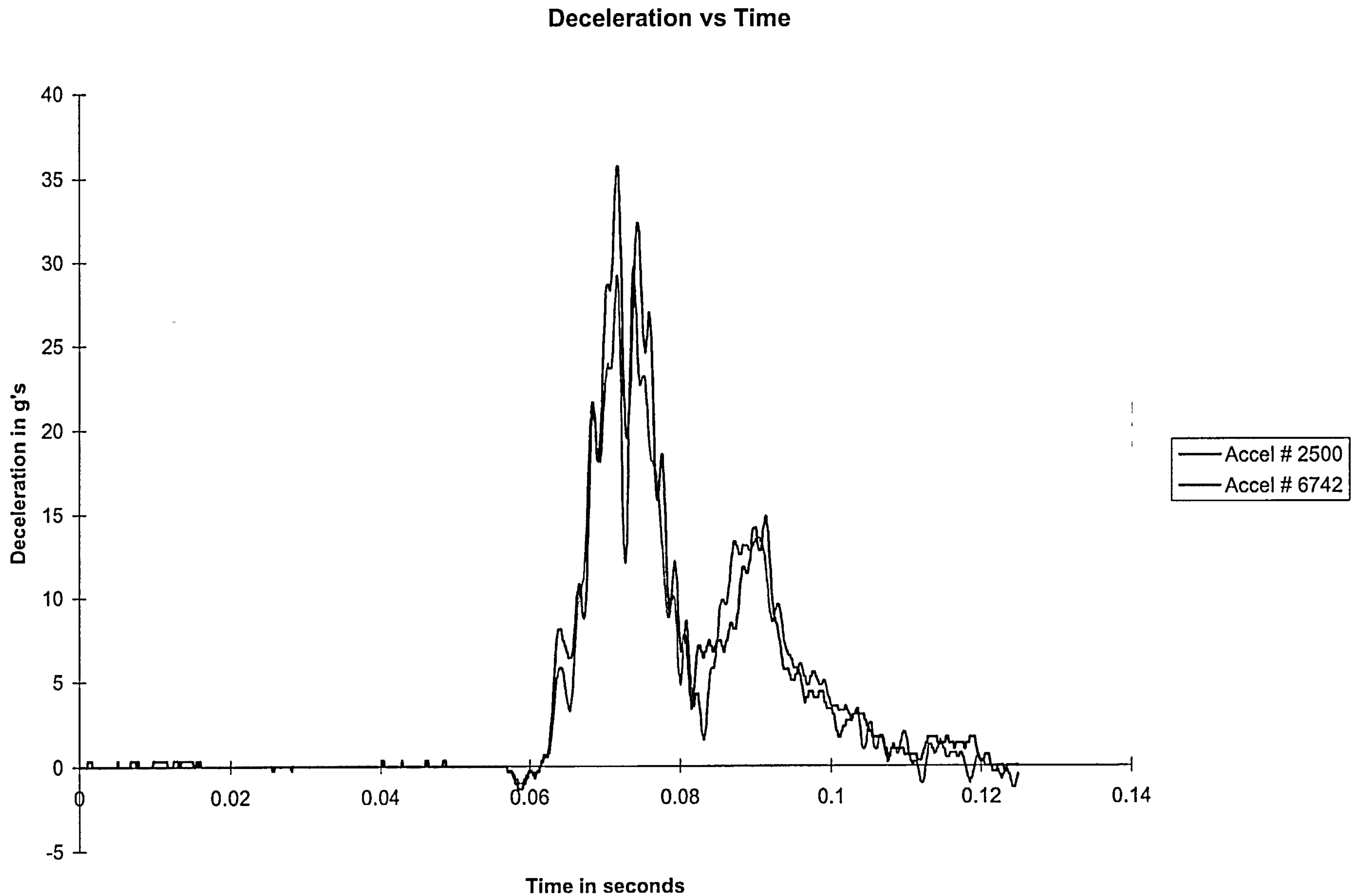
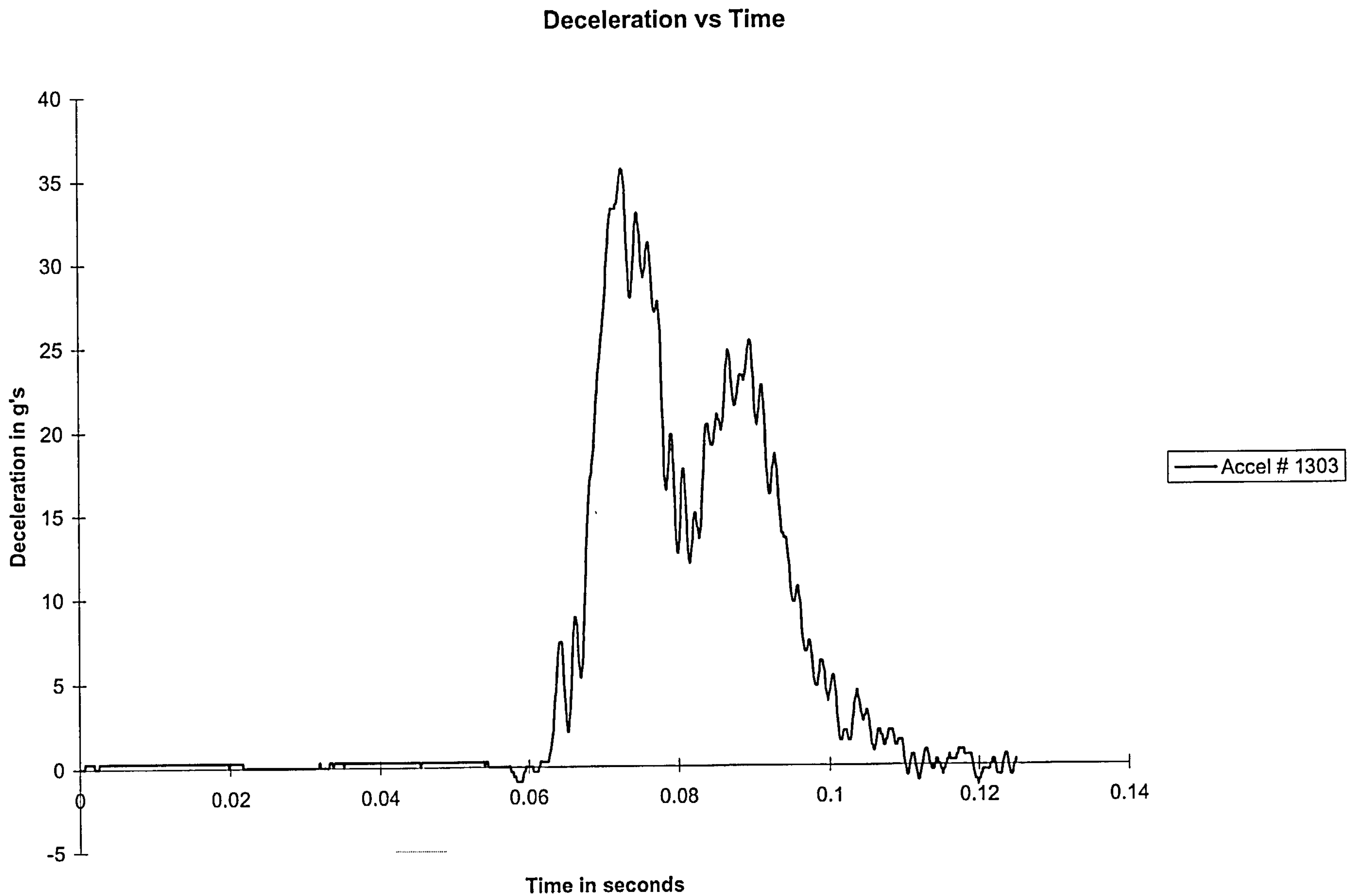
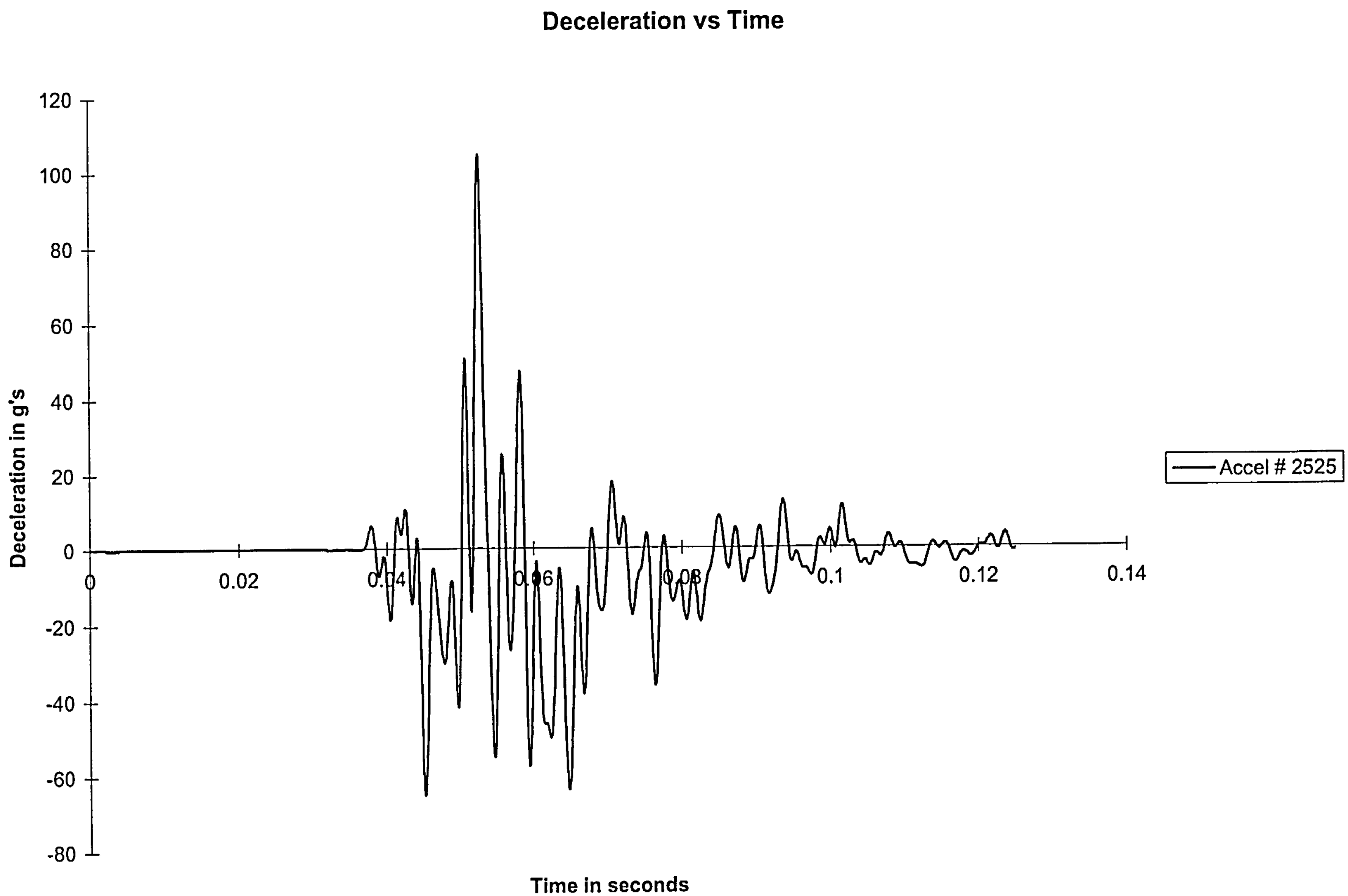
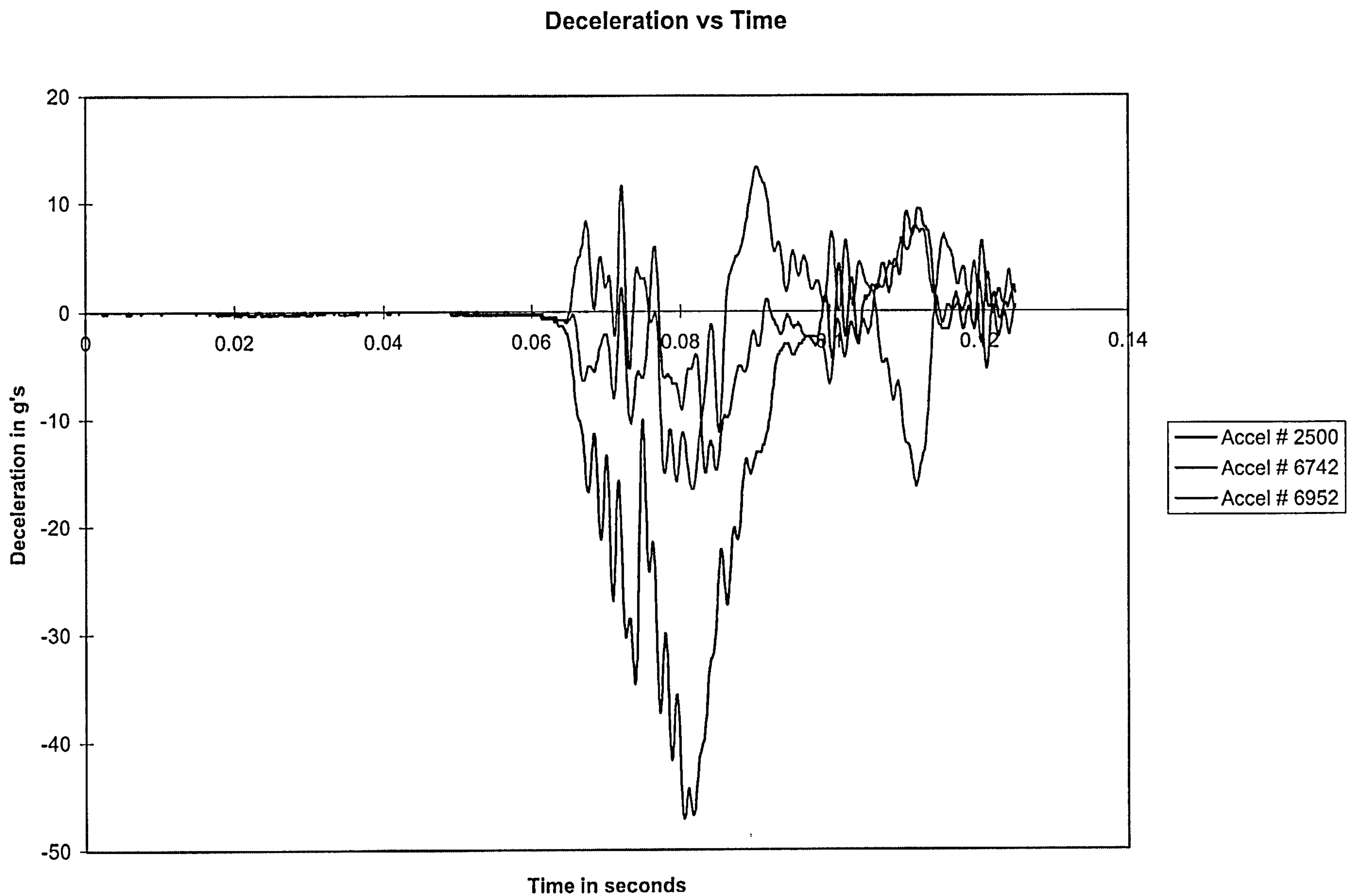


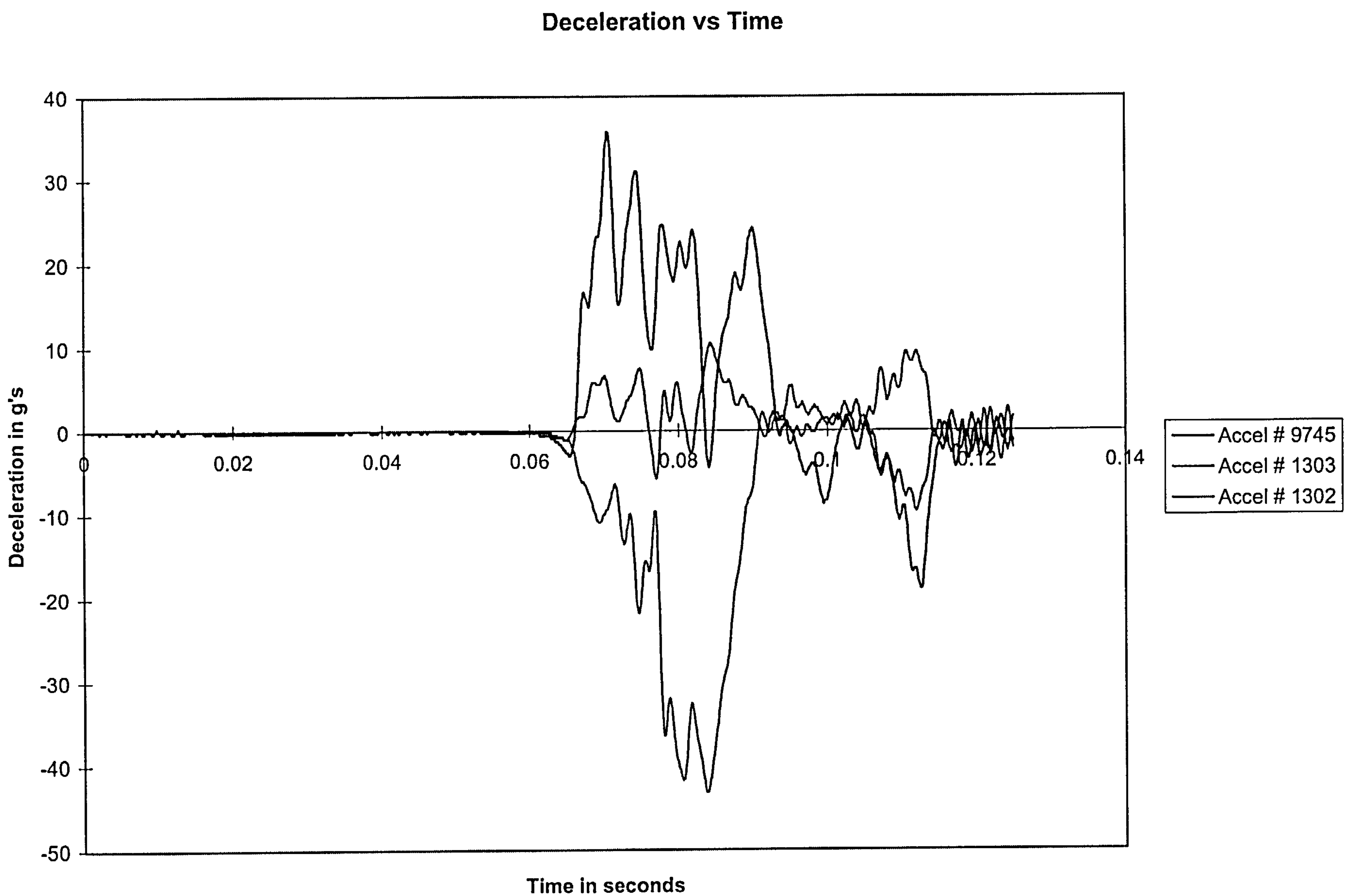
FIGURE #2: Orientation of Accelerometers

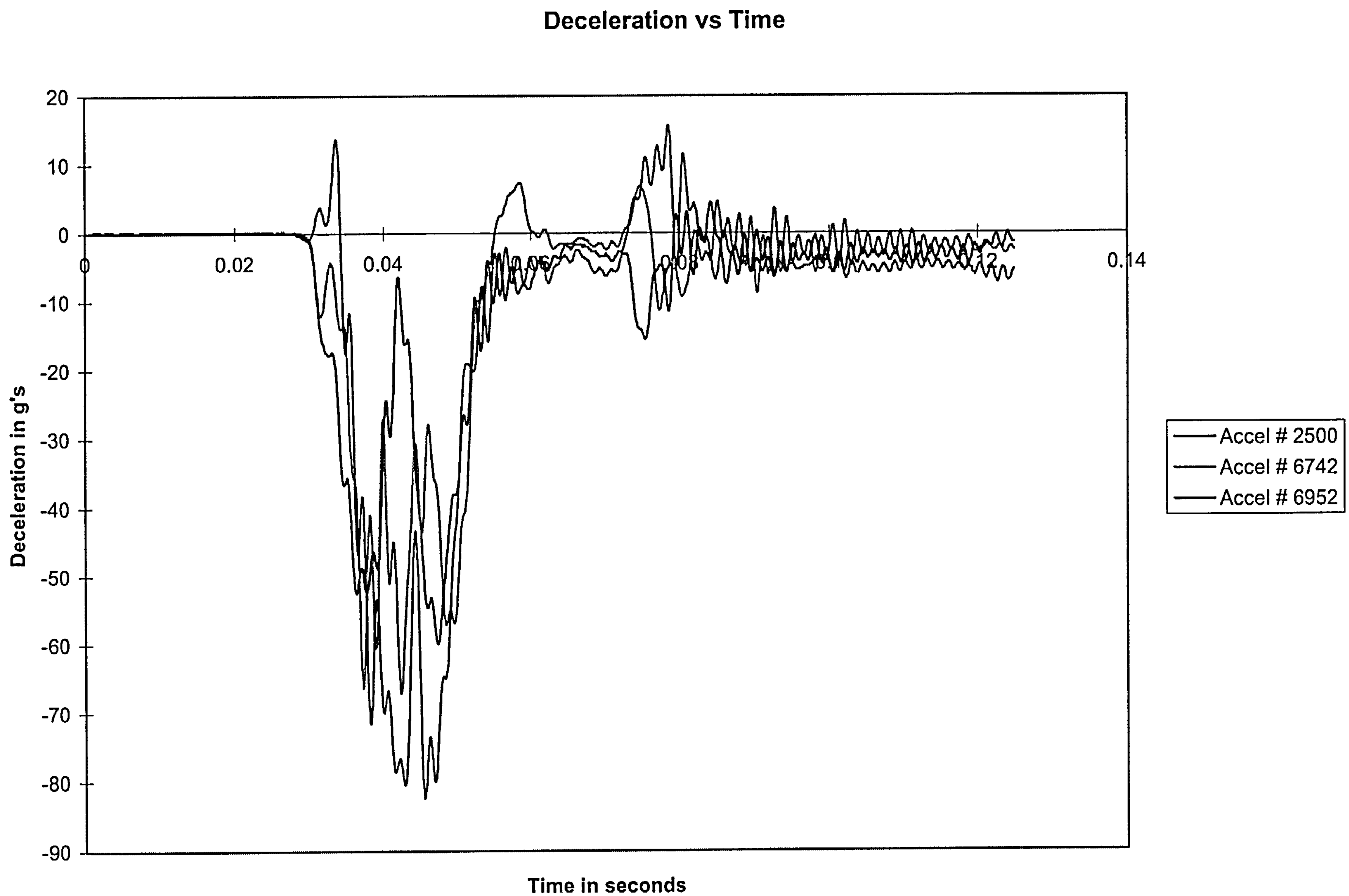

Deceleration vs Time
Deceleration in g's
40
35
30
25
20
15
10
5
0
-5
0
0.02
0.04
0.06
0.08
0.1
0.12
0.14
Time in seconds
Accel # 2500
Accel # 6742

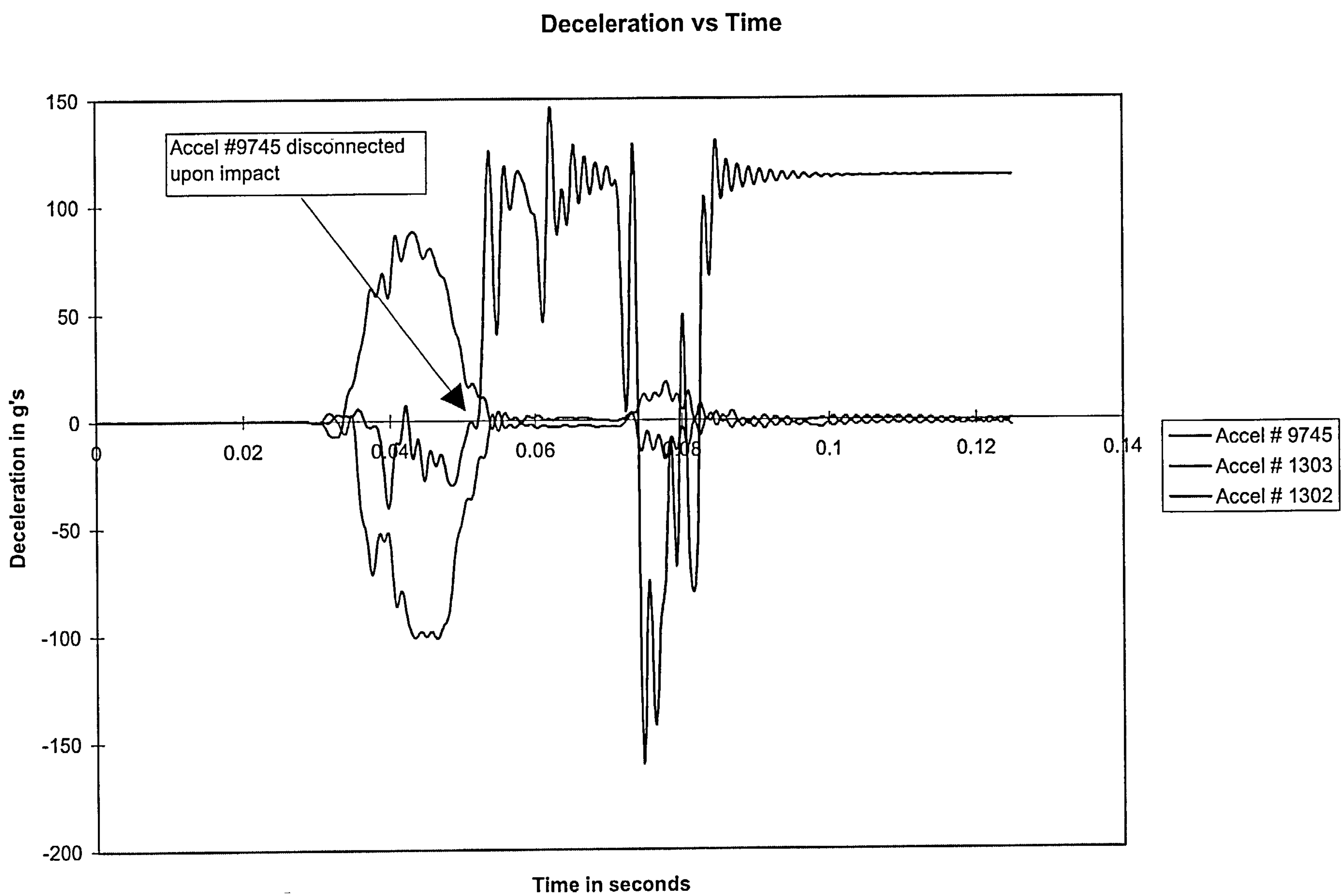

Deceleration vs Time
Deceleration in g's
40
35
30
25
20
15
10
5
0
-5
0
0.02
0.04
0.06
0.08
0.1
0.12
0.14
Time in seconds
Accel # 1303

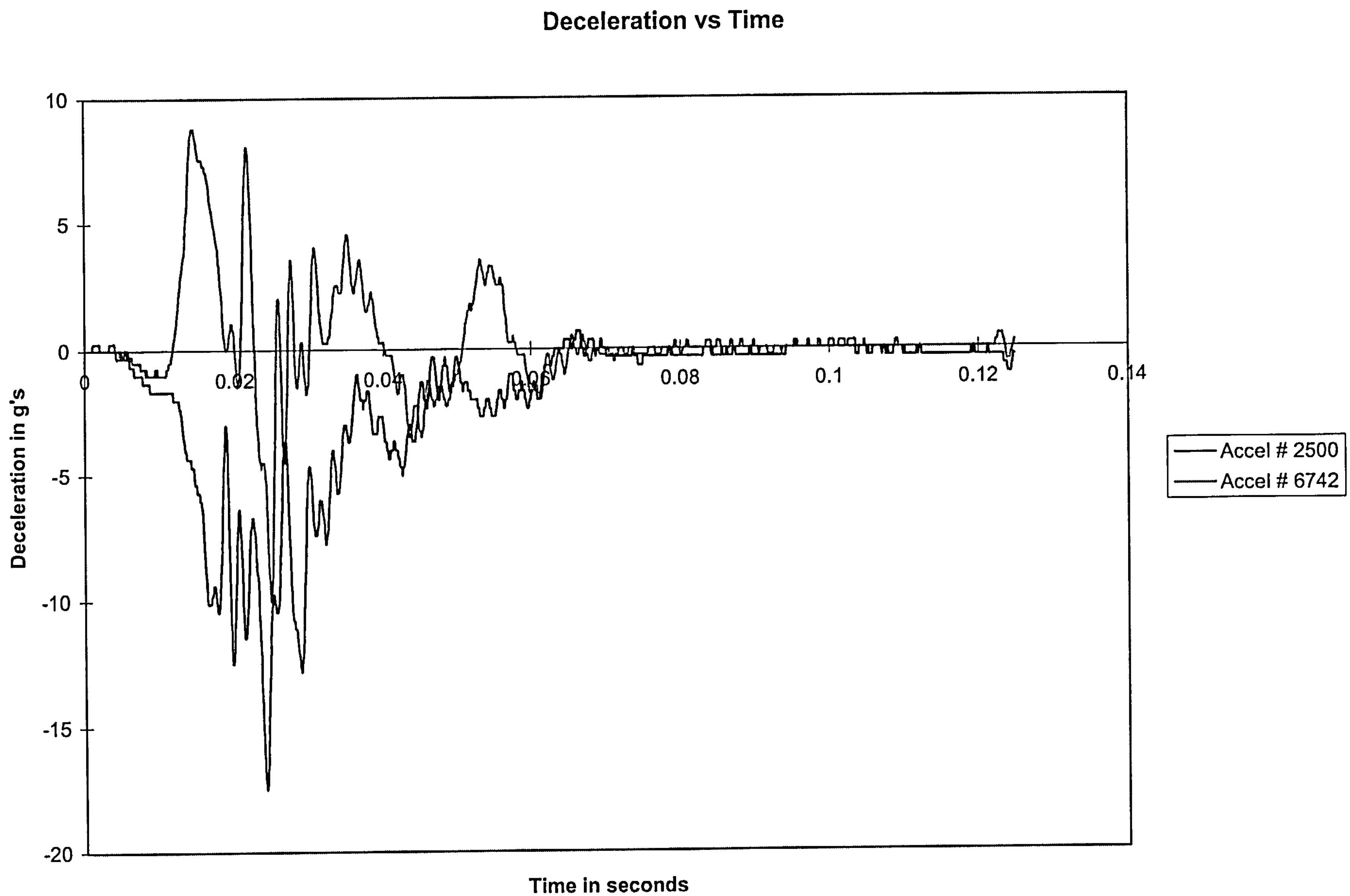

Deceleration vs Time
120
100
80
60
40
20
0
-20
-40
-60
-80
Deceleration in g's
0
0.02
0.04
0.06
0.08
0.1
0.12
0.14
Time in seconds
Accel # 2525


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

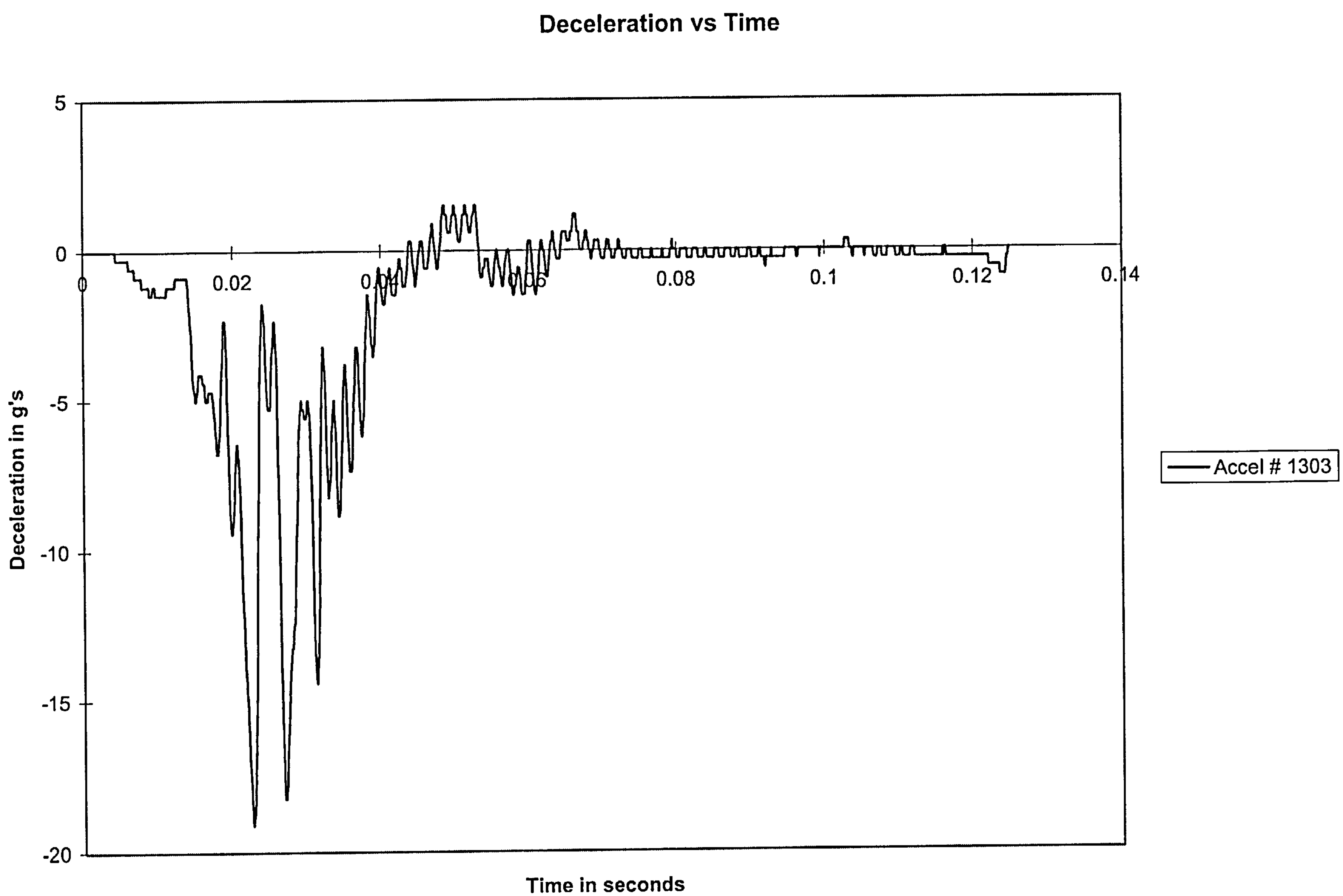

Deceleration vs Time
40
30
20
10
0
-10
-20
-30
-40
-50
Deceleration in g's
0
0.02
0.04
0.06
0.08
0.1
0.12
0.14
Time in seconds
Accel # 9745
Accel # 1303
Accel # 1302

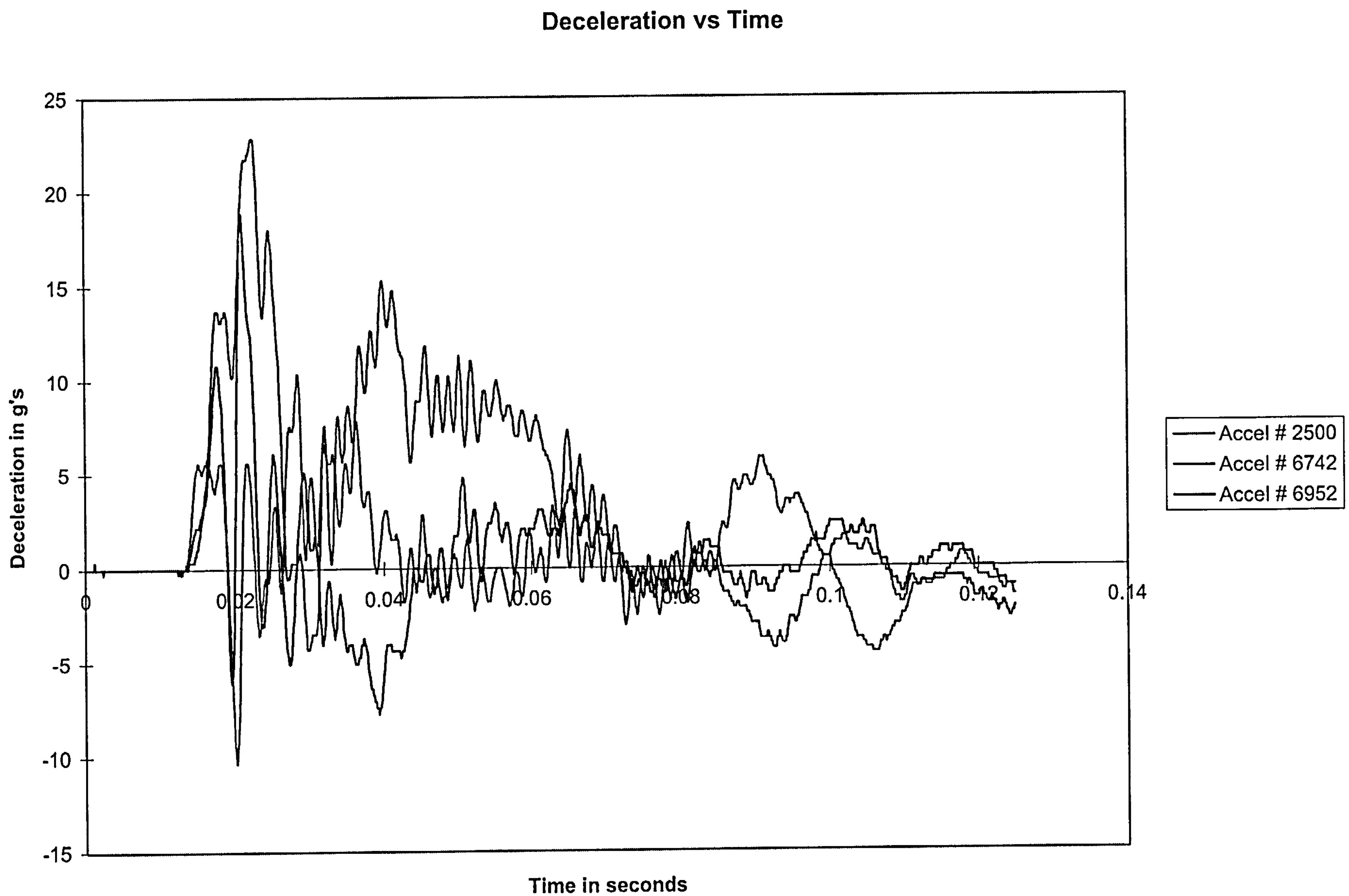

Deceleration vs Time
20
10
0
-10
-20
-30
-40
-50
-60
-70
-80
-90
0
0.02
0.04
0.06
0.08
0.1
0.12
0.14
Deceleration in g's
Time in seconds
Accel # 2500
Accel # 6742
Accel # 6952

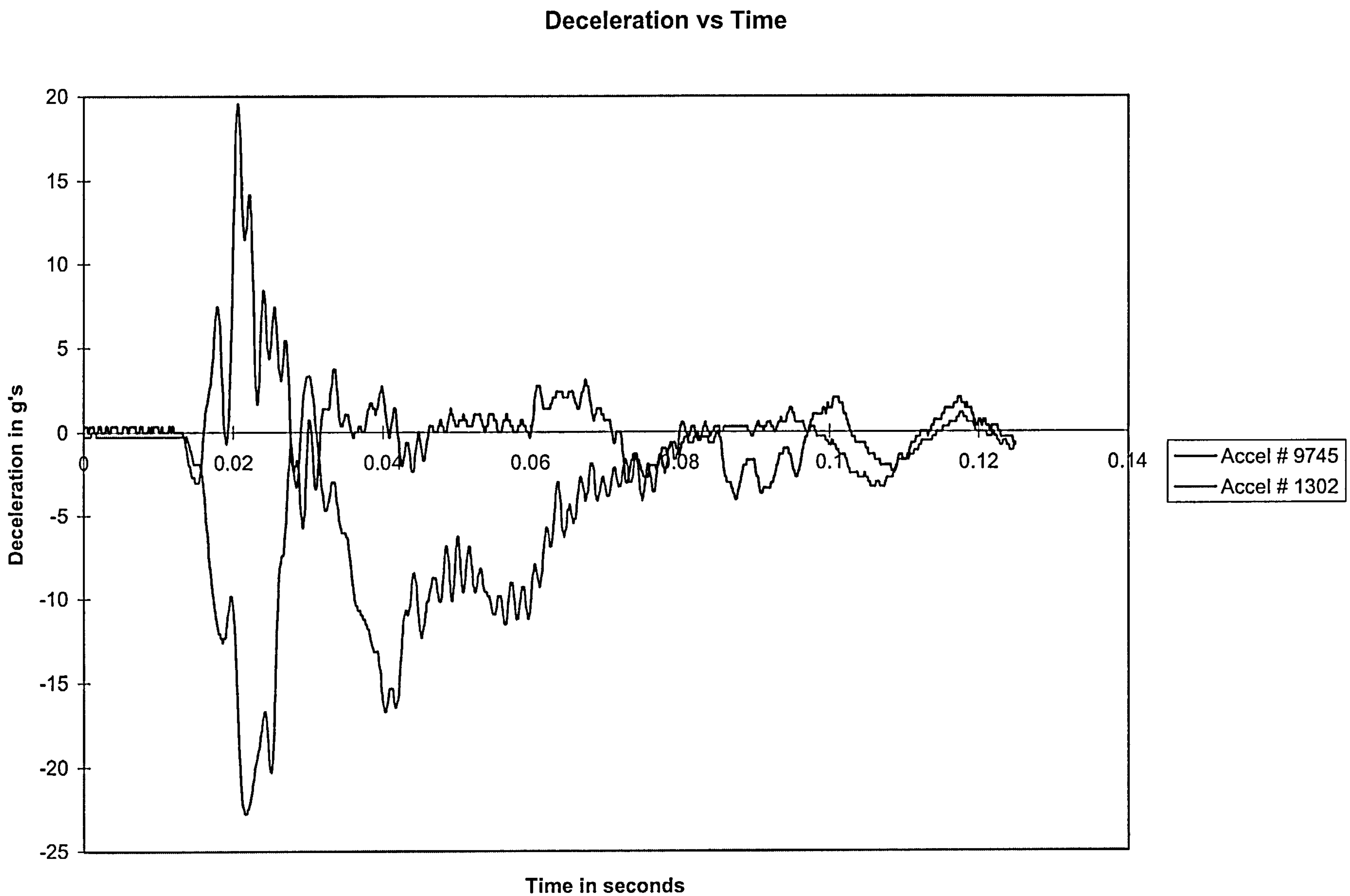

Deceleration vs Time
Accel #9745 disconnected upon impact
150
100
50
0
-50
-100
-150
-200
0
0.02
0.04
0.06
0.08
0.1
0.12
0.14
Deceleration in g's
Time in seconds
Accel # 9745
Accel # 1303
Accel # 1302

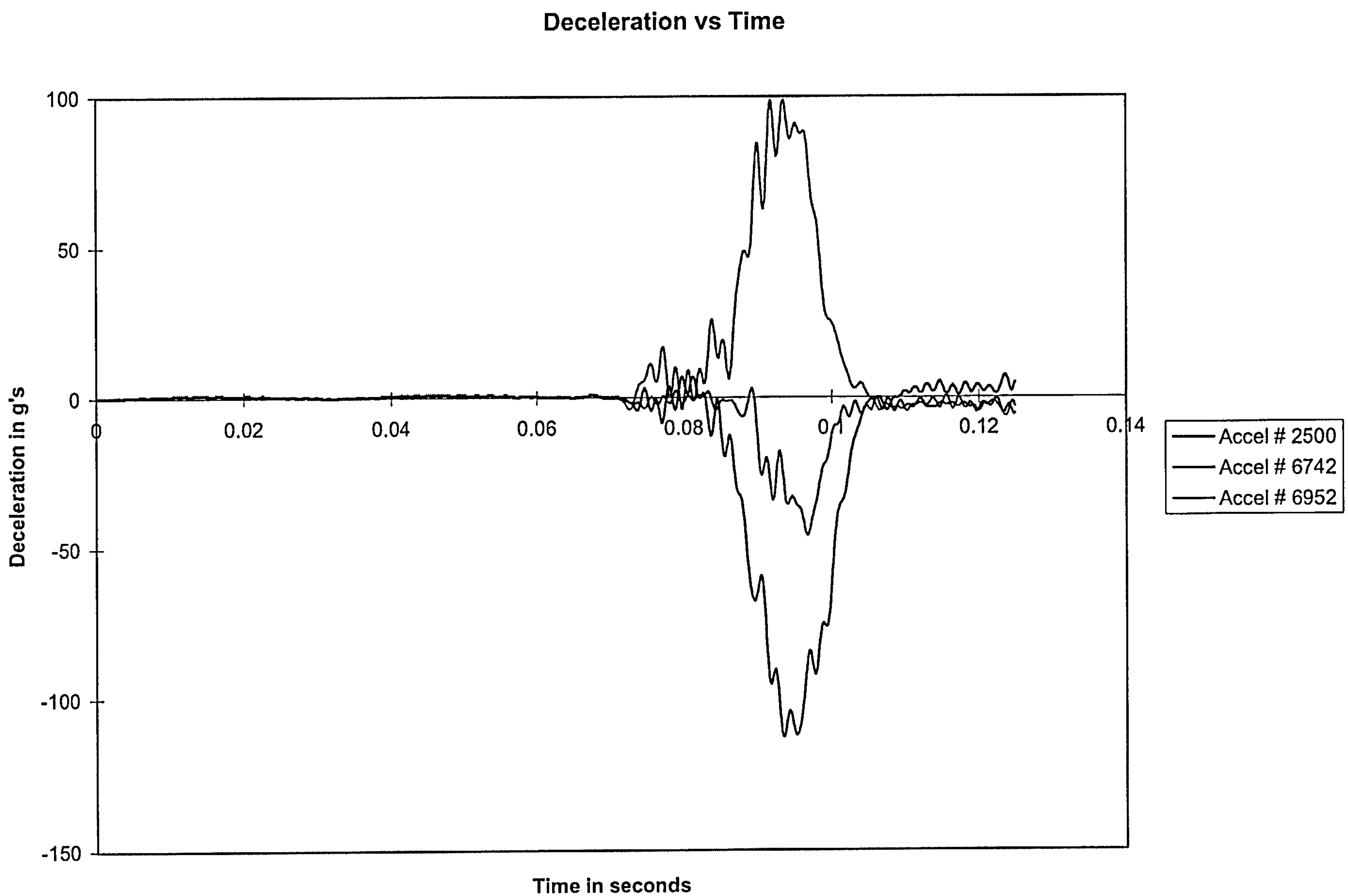

Deceleration vs Time
10
5
0
-5
-10
-15
-20
Deceleration in g's
0
0.02
0.04
0.06
0.08
0.1
0.12
0.14
Time in seconds
Accel # 2500
Accel # 6742

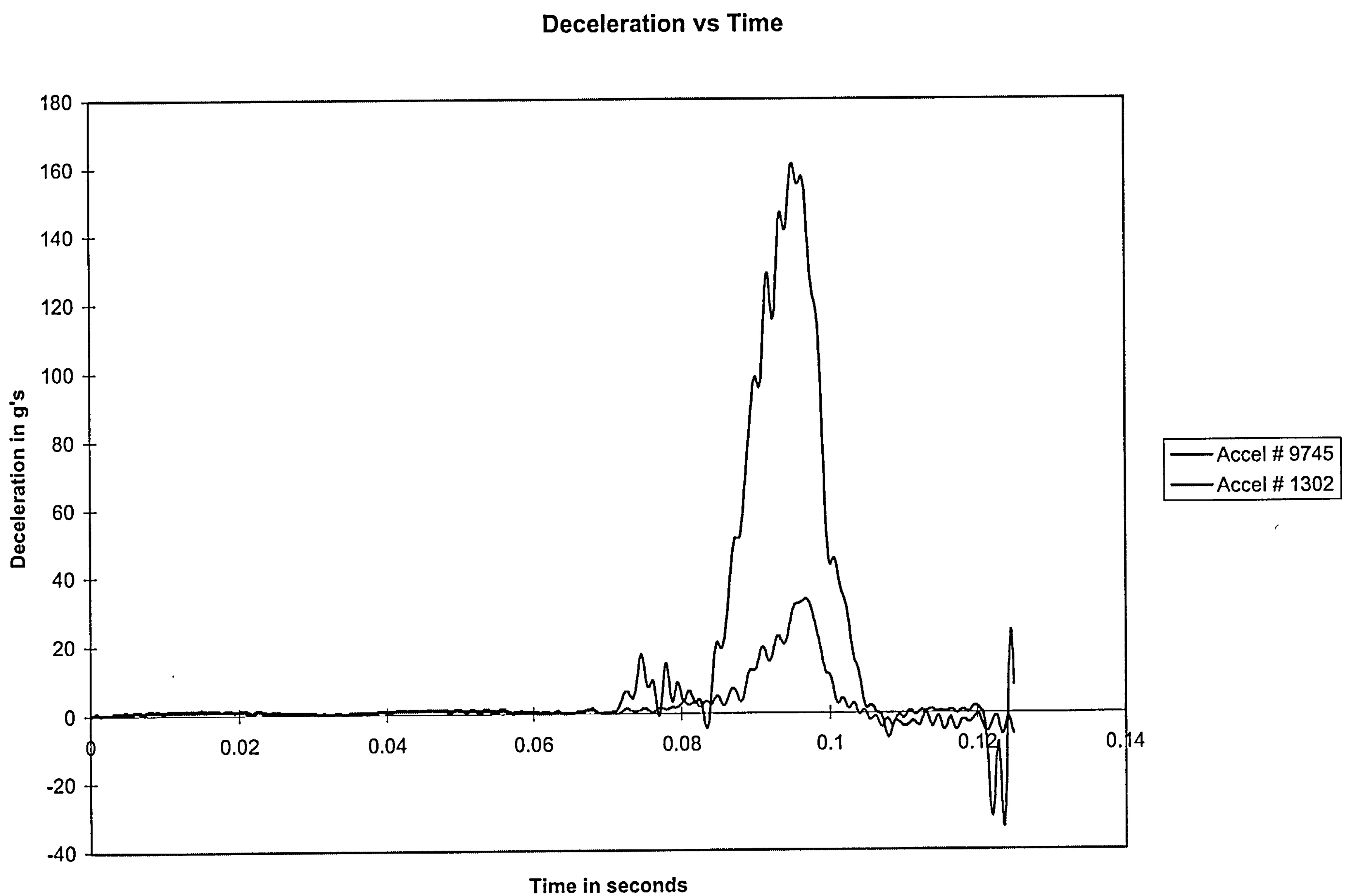
Back Accelerometer Drop # 5

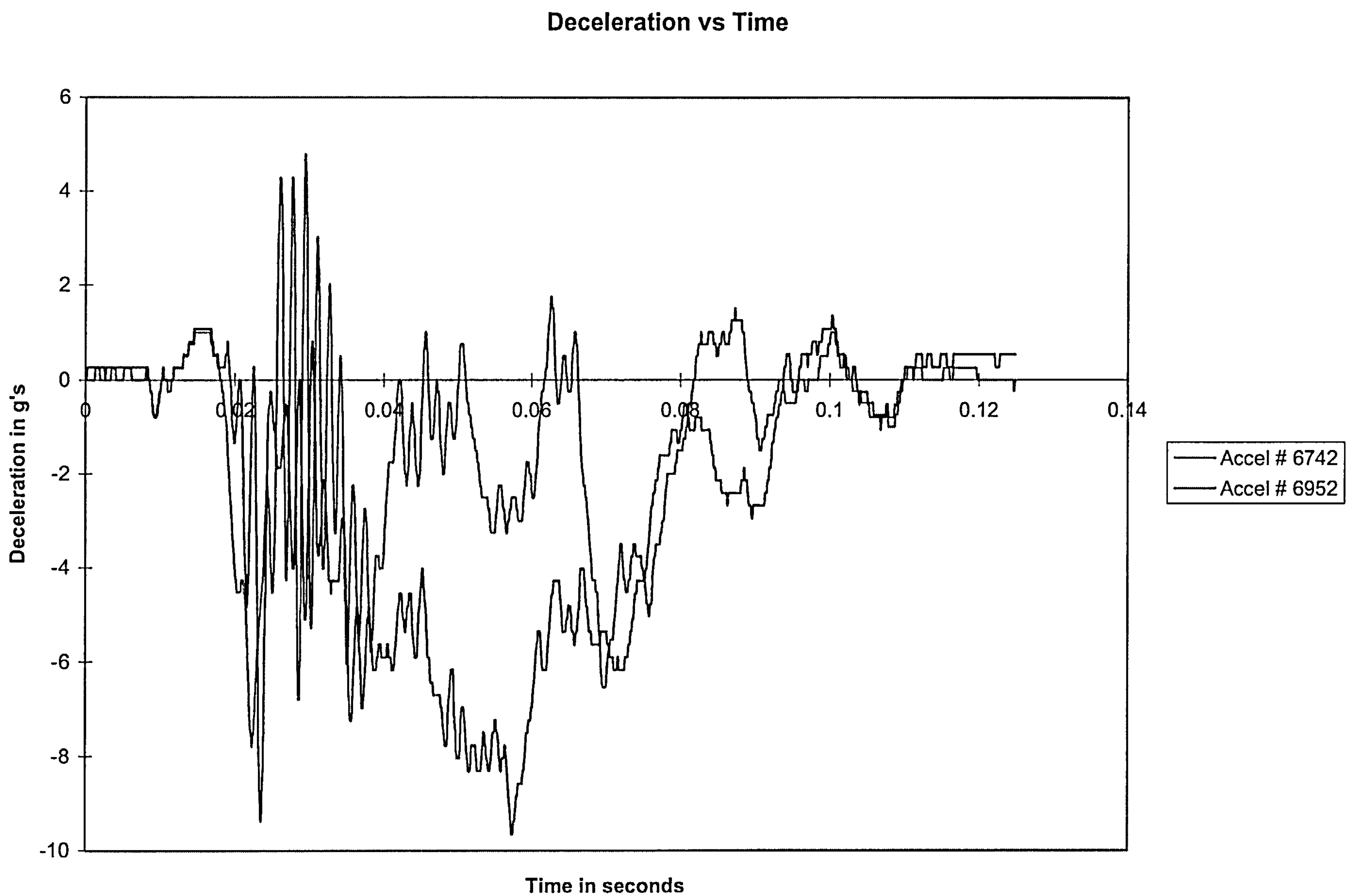


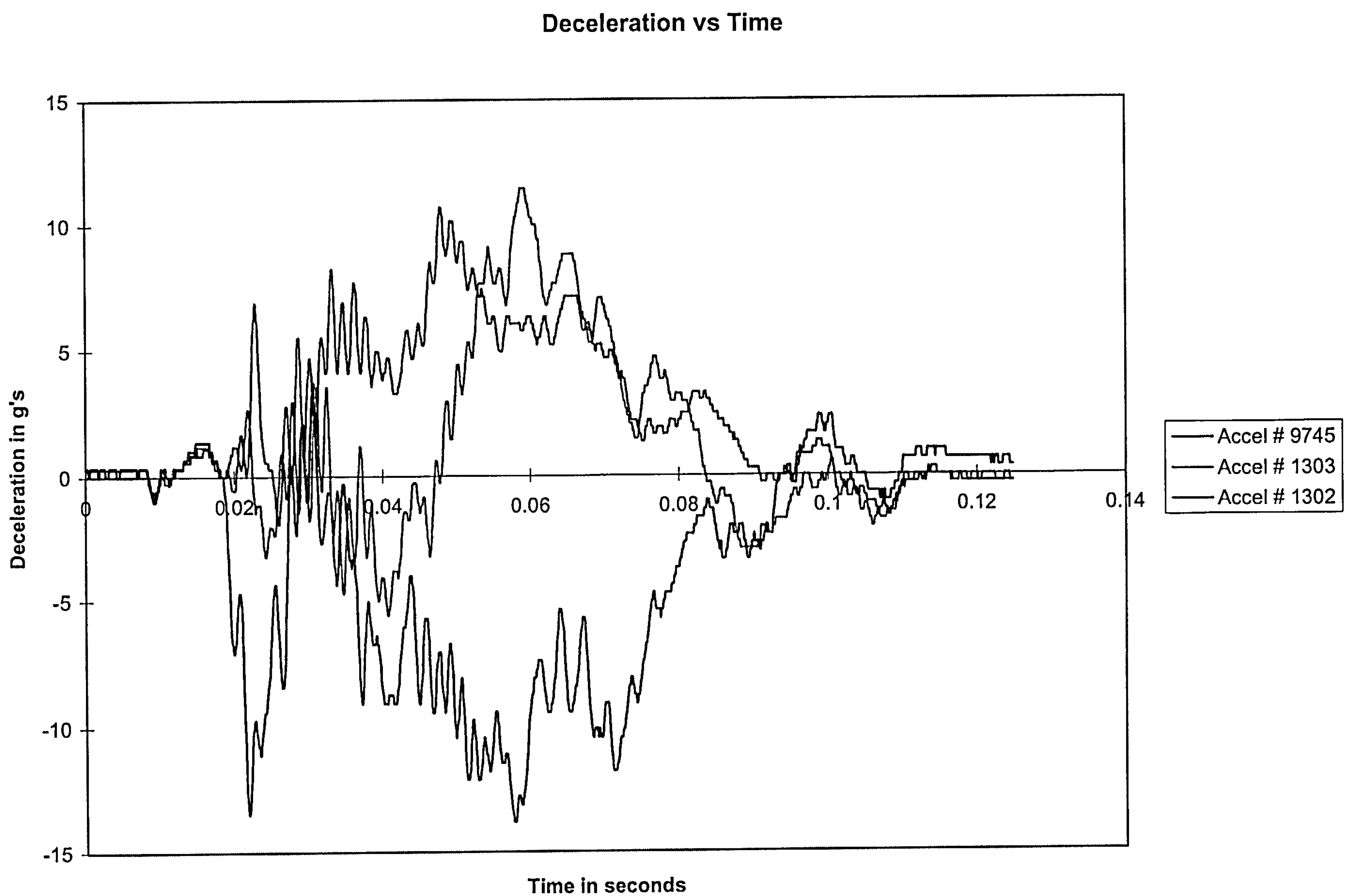

Deceleration vs Time
25
20
15
10
5
0
-5
-10
-15
Deceleration in g's
0
0.02
0.04
0.06
0.08
0.1
0.12
0.14
Time in seconds
Accel # 2500
Accel # 6742
Accel # 6952


Deceleration vs Time
20
15
10
5
0
-5
-10
-15
-20
-25
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 # 1302

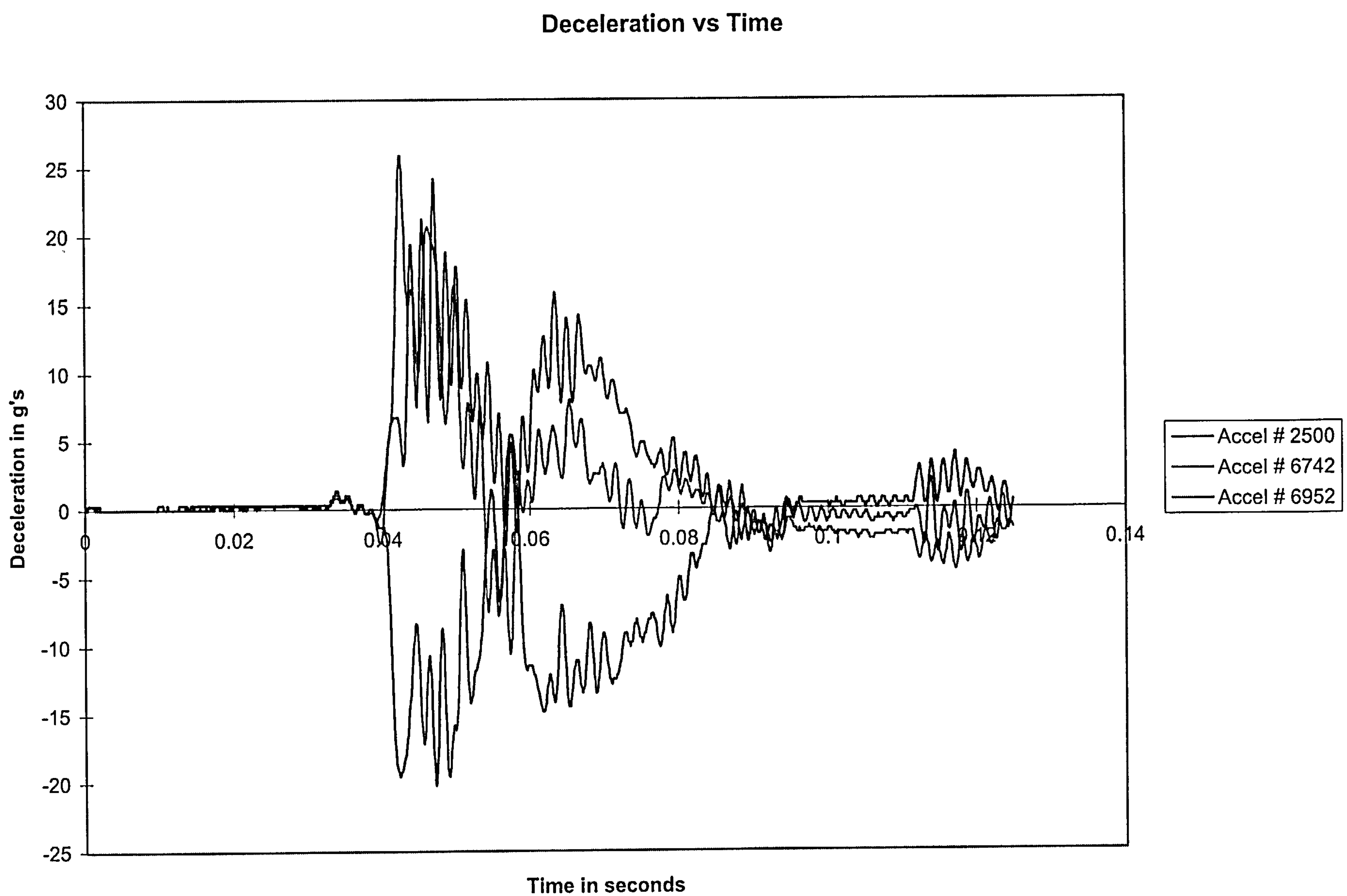

Deceleration vs Time
100
50
0
-50
-100
-150
0
0.02
0.04
0.06
0.08
0.1
0.12
0.14
Deceleration in g's
Time in seconds
Accel # 2500
Accel # 6742
Accel # 6952

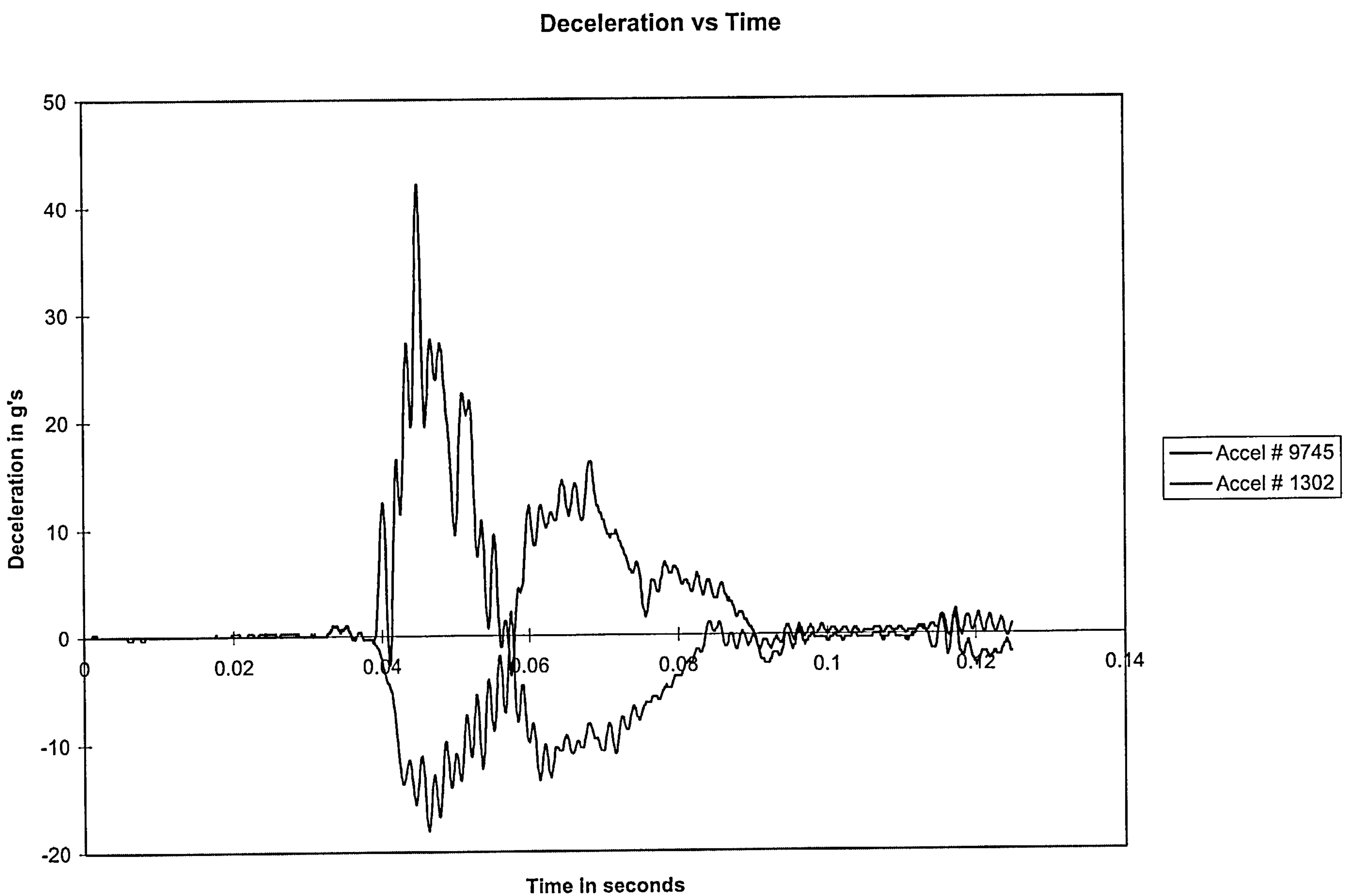

Deceleration vs Time
Deceleration in g's
180
160
140
120
100
80
60
40
20
0
-20
-40
0
0.02
0.04
0.06
0.08
0.1
0.12
0.14
Time in seconds
Accel # 9745
Accel # 1302


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

Front Accelerometers Drop # 9




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

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

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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

ISTOMER 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