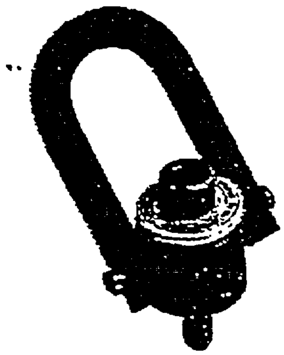
APPENDIX 2.10.6:

[redacted]

APPENDIX 2.10.7:
Hoist Rings

Page 146

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



U.S. Patent 5,352,056

Load Rated

Fatigue Rated

HR-125 M
Patented

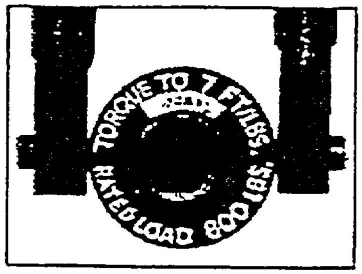
HR-125
Patented

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

[illegible]

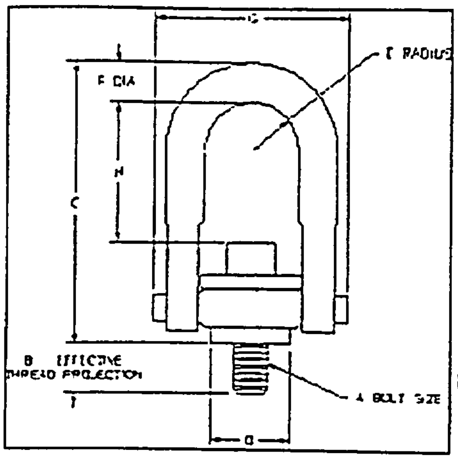
UNC THREADS

SEE APPLICATION AND WARNING INFORMATION
See Pages 144 - 145



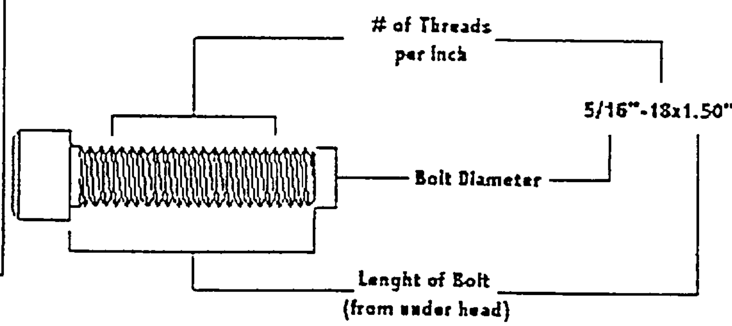
Top washer has the following features:

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



BOLT SIZE IDENTIFICATION

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



HR-125 Stock No	Working Load Limit* (lbs.)	Torque in Ft. Lbs.	Dimensions (in)								Est Weight Each (lbs)
			Bolt Size †† A	Effective Thread Projection Length B	C	D	Radius E	Diameter F	G	H	
1016887†	800	7	5/16 - 18 x 1.50	.59	2.69	1.00	.46	.38	1.69	1.11	.43
1016898†	1000	12	3/8 - 16 x 1.50	.59	2.69	1.00	.46	.38	1.69	1.09	.43
1016909	2500	28	1/2 - 13 x 2.00	.71	4 82	2 00	.88	.75	3 30	2.29	2 49
1016912†	2500	28	1/2 - 13 x 2.50	1.21	4.82	2 00	.88	75	3.30	2 29	2 52
1016920	4000	60	5/8 - 11 x 2.00	.71	4.82	2 00	.88	75	3.30	2.21	2 55
1016924†	4000	60	5/8 - 11 x 2.75	1 46	4.82	2 00	.88	75	3.30	2.21	2.70
1016931	5000	100	3/4 - 10 x 2.25	.96	4.82	2.00	.88	.75	3.30	2.05	2 65
1016935†	5000	100	3/4 - 10 x 2.75	1.46	4 82	2 00	88	.75	3.30	2.05	3 00
1016942	7000	100	3/4 - 10 x 2.75	.90	6.55	3 00	1.37	1 00	4.73	2.98	7 00
1016946†	7000	100	3/4 - 10 x 3.50	1.65	6 55	3.00	1.37	1 00	4.73	2.98	7 00
1016953	8000	160	7/8 - 9 x 2.75	.90	6 55	3.00	1.37	1.00	4.73	2.95	7.00
1016957†	8000	160	7/8 - 9 x 3.50	1 65	6.55	3.00	1.37	1 00	4 73	2.95	7.00
1016964	10000	230	1 - 8 x 3.00	1.15	6.55	3.00	1.37	1 00	4 73	2.73	7.50
1016969†	10000	230	1 - 8 x 4 00	2.15	6.55	3 00	1.37	1 00	4 73	2.73	7.50
1016975	15000	470	1-1/4 - 7 x 4.50	2.22	8.70	3 75	1.75	1.25	6.00	3 94	14.79
1016986	24000	800	1-1/2 - 6 x 6.50	2.98	12.39	4 75	2.25	1.75	8.00	5.93	33.00
1016997	30000	1100	2 - 4-1/2 x 6 50	2.98	12.39	4.75	2.25	1 75	8 00	5.43	36 00

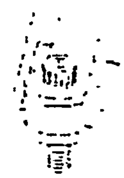
* Ultimate load is 5 times the Working Load Limit.
† Long bolts are designed to be used with soft metal (i.e., aluminum) work piece While the long bolts may also be used with ferrous metal (i e.,steel & iron) work piece, short bolts are designed for ferrous work pieces only
†† Bolt specification is a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

NOTE: For Special Applications see page 149.

CROSBY SWIVEL HOIST RING

WARNINGS AND APPLICATION INSTRUCTIONS

U.S. Patented 5,352,056



HR-125 (Red Washer) **HR-125 M** (Silver Washer)

WARNING

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

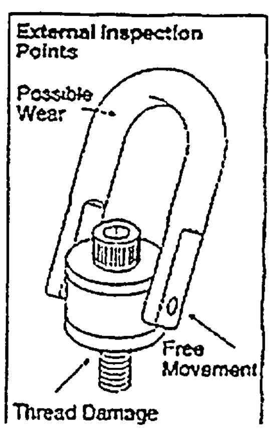
Hoist Ring Application Assembly Safety

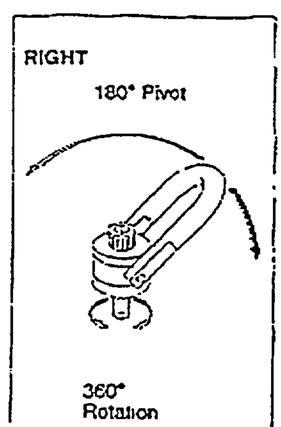
- Use swivel hoist ring only with a ferrous metal (steel, iron) or soft metal (i.e., aluminum) loads (work piece). Do not leave threaded end of hoist ring in aluminum loads for long time periods due to corrosion.
- After determining the loads on each hoist ring, select the proper size hoist ring using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

1. ASTM A-563 (A) Grade D Hex Thick (B) Grade DH Standard Hex
2. SAE Grade 8 — Standard Hex

Hoist Ring Inspection Maintenance

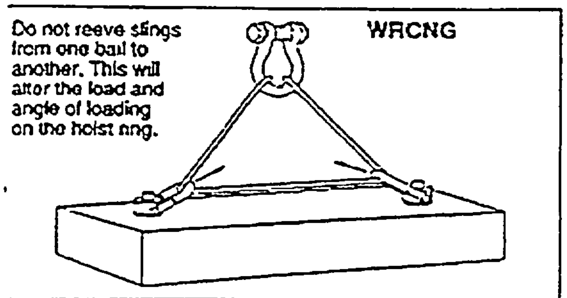
- Always inspect hoist ring before use.
- Regularly inspect hoist ring parts. (Fig. 3)
- Never use hoist ring that shows signs of corrosion, wear or damage.
- Never use hoist ring if bail is bent or elongated.
- Always be sure threads on shank and receiving holes are clean, not damaged, and fit properly.
- Always check with torque wrench before using an already installed hoist ring.
- Always make sure there are no spacers (washers) used between bushing flange and the mounting surface. Remove any spacers (washers) and retorque before use.
- Always ensure free movement of bail. The bail should pivot 180° and swivel 360°. (Fig. 4)
- Always be sure total work piece surface is in contact with hoist ring bushing mating surface. Drilled and tapped hole must be 90° to load (work piece) surface.





OPERATING SAFETY

- Never exceed the capacity of the swivel hoist ring, see Table 1 for UNC threads and Table 2 Metric threads.
- When using lifting slings of two or more legs, make sure the forces in the legs are calculated using the angle from the vertical to the leg and select the proper size swivel hoist ring to allow for the angular forces. (Note: Sling angles will de-rate sling members (chain, rope, or webbing) but will not de-rate swivel hoist ring capacity.)



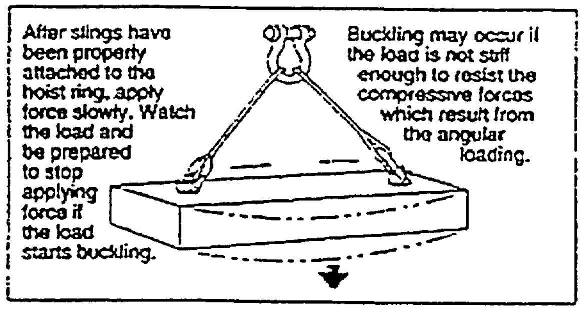


Table 1

HR-125 Swivel Hoist Rings

Working Load Limit* (lbs.)	Torque** in Ft. Lbs.	Bolt Size†† (in.)	Effective Thread Projection Length (in.)
800+	7	5/16 - 18 x 1.50	59
1000+	12	3/8 - 16 x 1.50	.59
2500	28	1/2 - 13 x 2.00	.71
2500+	28	1/2 - 13 x 2.50	1.21
4000	60	5/8 - 11 x 2.00	.71
4000+	60	5/8 - 11 x 2.75	1.46
5000	100	3/4 - 10 x 2.25	.96
5000+	100	3/4 - 10 x 2.75	1.46
7000	100	3/4 - 10 x 2.75	90
7000+	100	3/4 - 10 x 3.50	1 65
8000	160	7/8 - 9 x 2.75	90
8000+	160	7/8 - 9 x 3.50	1.65
10000	230	1 - 8 x 3.00	1.15
10000+	230	1 - 8 x 4.00	2.15
15000	470	1-1/4 - 7 x 4.50	2.22
24000	800	1-1/2 - 6 x 6.50	2.98
30000	1100	2 - 4-1/2 x 6.50	2.98

- * Ultimate load is 5 times the Working Load Limit. Individually proof tested to 2-1/2 times the working Load Limit.
- ** The tightening torque values shown are based upon threads being clean, dry and free of lubrication.
- † Long bolts are designed to be used with soft metal (i.e., aluminum) work piece. While the long bolts may also be used with ferrous metal (i.e., steel & iron) work pieces, short bolts are designed for ferrous work pieces only.
- †† Bolt specification is a Grade 8 Alloy socket head cap screw to ASTM A 574. All threads are UNC-3A.

Table 2

HR-125M Metric Swivel Hoist Rings*

Working Load Limit (Kg)		Torque** in Nm	Bolt Size†† (mm)	Effective Thread Projection Length (mm)
At a 5:1 Design Factor†	At a 4.1 Design Factor†			
400	500	10	M8 x 1.25 x 40	16.9
450	550	16	M10 x 1 50 x 40	16.9
1050	1300	38	M12 x 1.75 x 50	17.2
1900	2400	81	M16 x 2.00 x 60	27.2
2150	2700	136	M20 x 2.50 x 65	31.2
3000	3750	136	M20 x 2.50 x 75	28.1
4200	5250	312	M24 x 3 00 x 80	33.1
7000	8750	637	M30 x 3.50 x 100	45 1
11000	13750	1005	M36 x 4 00 x 150	60.6
12500	15600	1005	M42 x 4.50 x 160	70.6
13500	16900	1350	M48 x 5 00 x 160	70.6

- * Designed to be used with ferrous work piece only.
- ** The tightening torque values shown are based upon threads being clean, dry and free of lubrication.
- † Individually proof tested to 2-1/2 times the Working Load Limit based on the 4:1 design factor.
- †† Bolt specification is a Grade 12.9 Alloy socket head cap screw to DIN 912. All threads are metric (ASME/ANSI B18.3 1 m)

CHAPTER 3 – THERMAL EVALUATION

3.1 DISCUSSION

3.1.1 THERMAL DESIGN FEATURES

[redacted]

3.1.2 THERMAL ANALYSIS RESULTS

Thermal analysis of the F-430 is detailed in Appendix 3.7.1. The significant results of the thermal analysis are:

1. Temperatures of all accessible surfaces of the package will be less than 50°C in the shade. (Note: Maximum steady state temperature inside the container was measured at 29°C. An increase of only 5°C with ambient temperatures around 22°C.)
2. An insolation heat load of 800 W/m^2 on the top surface of the package, 400 W/m^2 on the sides, and ambient temperature of 38°C will not damage the containment and shielding systems.
3. The package is able to survive the regulatory fire test without damage to the shielding or containment systems.

3.1.3 DECAY HEAT

Thermal analysis for the F-430 container was done with the lower head of GC-40 irradiator which has a maximum capacity of 2000 Ci of Cesium-137. This is equivalent to 9.67W of decay heat generated as follows:

2000 Ci * (3.7e+10) dis/s/Ci * 816 keV/dis * (1.602e-16) J/keV * 1 W/J/s = 9.67 W

To demonstrate the thermal performance of the F-430 the decay heat of 100W was used for the thermal analysis (see Appendix 3.7.1).

3.2 SUMMARY OF THERMAL PROPERTIES OF MATERIALS

The general thermal properties of the materials used in the F-430 packaging as a function of temperature are given in Table 3.1 and Table 3. 2. These tables are reproduced from Appendix 3.7.1.

[redacted]

[redacted] increased to a value of 35 W/m°C (similar to lead).

Table 3.1: General Thermal Properties of F-430 Materials

#	Material Description	Density ρ (kg/m^3)				Thermal Conductivity k (W/m°C)				Specific Heat c (J/kg°C)			
1	Mild Steel [4]	8131				°C	k	°C	k	°C	c	°C	c
						-73	41.0	127	42.2	-73	434	127	487
						327	39.7	527	35.0	327	559	527	685
						727	27.6	927	27.6	727	1090	927	1090
8	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]			
		[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]				
		[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]				
		[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]				
2	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]			
		[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]				
		[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]				
		[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]				
3	Air [4]	°C	ρ	°C	ρ	°C	k	°C	k	°C	c	°C	c
		-73	1.75	127	0.87	-73	0.018	127	0.034	-73	1007	127	1014
		327	0.58	527	0.44	327	0.047	527	0.057	327	1051	527	1099
		727	0.35	927	0.29	727	0.067	927	0.076	727	1141	927	1175
5	[redacted]	[redacted]				[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
						[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
						[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
						[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]

Table 3. 2: Material Properties of Air, Lead, and Mild Steel

#	Material Description	Density ρ (kg/m^3)				Thermal Conductivity k (W/m°C)				Specific Heat c (J/kg°C)			
6	Air With Conduction and Convection Steady State [App. C]	°C	ρ	°C	ρ	°C	k	°C	k	°C	c	°C	c
		-73	1.75	127	0.87	-73	1.02	127	1.04	-73	1007	127	1014
		327	0.58	527	0.44	327	0.99	527	0.90	327	1051	527	1099
		727	0.35	927	0.29	727	0.75	927	0.75	727	1141	927	1175
6	Air With Conduction and Convection Transient [App. C]	°C	ρ	°C	ρ	°C	k	°C	k	°C	c	°C	c
		-73	1.75	127	0.87	-73	1.51	127	1.53	-73	1007	127	1014
		327	0.58	527	0.44	327	1.48	527	1.39	327	1051	527	1099
		727	0.35	927	0.29	727	1.24	927	1.24	727	1141	927	1175
7	Lead [8]	°C	ρ	°C	ρ	°C	k	°C	k	°C	c	°C	c
		20	11340	327	11005	-273	35	-27	35	-23	127	27	129
		330	10686	800	10686	123	34	227	33	127	132	227	136
						327	31	527	19	327	142	328	6188
						727	22	927	24	331	6188	332	159
12	Mild Steel Including Lead-Steel Contact Resistance [3, 4 and App. F]	8131				°C	k	°C	k	°C	c	°C	c
						-73	0.53	127	0.99	-73	434	127	487
						327	1.35	527	1.63	327	559	527	685
						727	1.86	927	2.11	727	1090	927	1090

3.3 TECHNICAL SPECIFICATIONS OF COMPONENTS

3.3.1 STANDARD CONSTRUCTION MATERIALS

The steel, lead, and neoprene are commercially available and meet the requirements of the standards specified in Table 3.3.

3.3.2 [redacted]

[redacted]

[redacted]

Table 3.3: Standards for F-430 Materials of Construction

Material	Applicable Standards
Structural Steel	ASTM A36, CSA G40.21-50W
[redacted]	[redacted]
[redacted]	[redacted]
Pure Lead	ASTM B29
Neoprene	ASTM D2000

Table 3.4: [redacted]

[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]

3.4 THERMAL EVALUATION FOR NORMAL CONDITIONS OF TRANSPORT

3.4.1 THERMAL MODEL

3.4.1.1 Analytical Model

A three dimensional solid model was made using Pro Engineer (Figure 3.1). One eight of the overpack was modeled (left-back side from upper half). This "quarter cylinder" has outer dimensions of 63cm (25") radius, and 63cm (25") height.

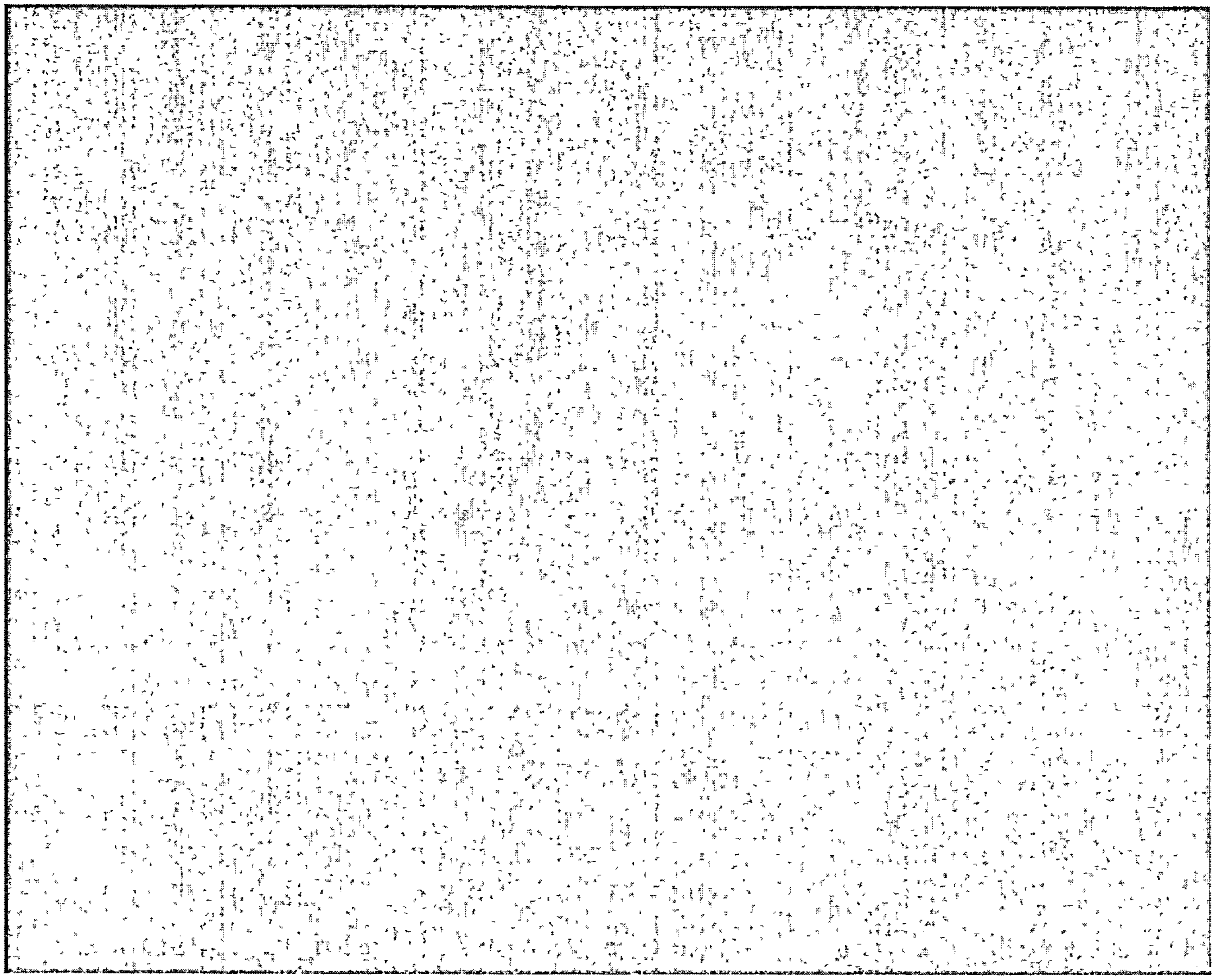


Figure 3.1: Analytical Model F430/GC40

[redacted]

3.4.1.2 Test Model

A full-scale prototype was built as per technical specification IN/TS 1467 F430, and drawing F143001-001. Testing procedures are described in F-430 Test Plan [12] and results are documented in the Test Report [13].(See Appendix 2.10.5.)

The F-430 is a cylindrical package (127cm diameter, 127cm tall) on a square skid. [redacted]

Rubber gaskets are provided between the inner cover and body as well as between the outer cover and body.

3.4.2 MAXIMUM TEMPERATURES

Steady state temperature measurements, with 1,746 curies (8.4W) of Cesium-137 are reported in Appendix 3.7.1. With an ambient temperature around 21°C and no insolation load, a maximum temperature of 28.9°C was measured on the source. (This represents a temperature increase from 24.7°C in 224 hours). The interior cavity temperature rose from 22.2°C to 26.2°C. All other temperatures were between 26°C and the ambient (21 to 22°C). Table 3.5 lists steady-state temperatures of F-430 package.

The steady state temperatures were reached in [redacted]

The design capacity of the F-430 [redacted].

Using the thermal model depicted in Figure 3.1, the regulatory ambient temperature of 38°C, [redacted], and no insolation heat loads, the maximum temperatures are 90°C (source), 80°C inside the transport cavity, and 40°C on the outside of the F-430.

Since the surface temperature of the overpack in the shade is not greater than 50°C, the F-430 can be transported as a "non-exclusive use" shipment, and may be shipped by air.

Table 3.5: Temperature of Accessible Surface of the F-430 Package

Location on F-430 Container	Measured Temp. (°C) 21°C Amb.	Calculated Temp. (°C) 21°C Amb.	Calculated Temp. (°C) 38°C Amb.
Top External Surface of Container	[redacted]	[redacted]	[redacted]
Side External Surface of Container	[redacted]	[redacted]	[redacted]
Inside Main Cover	[redacted]	[redacted]	[redacted]
Transport Cavity (upper surface)	[redacted]	[redacted]	[redacted]
GC-40 Irradiator Surface	[redacted]	[redacted]	[redacted]
Source	[redacted]	[redacted]	[redacted]

3.4.3 *MINIMUM TEMPERATURES*

As there is no minimum activity specified, a minimum temperature of –40°C is defined.

3.4.4 *MAXIMUM INTERNAL PRESSURE*

There will be no pressure build up in the F-430 cavity as the covers are not pressure tight.

3.4.5 *MAXIMUM THERMAL STRESSES*

The maximum thermal stresses during the normal conditions of transport arise from the temperature distribution given in section 3.4.2 above. As the temperature gradients are very low there will be no significant thermal stresses in the F-430 overpack during normal conditions of transport.

3.4.6 *EVALUATION OF THE PACKAGE PERFORMANCE FOR NORMAL CONDITIONS OF TRANSPORT*

Table 3.6 lists the various materials used in the F-430 package with the corresponding expected and allowable temperatures.

Table 3.6 List of Materials used in F-430 and their Temperature Compatibility

Material	Temperature (°C)				Location
	Expected		Allowable		
	min	Max	Min	Max	
ASTM A-36	–40	143	–40	343[a]	Removable Skid, GC-40 Irradiator Housing
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
Lead	–40	143	–40	327	lead shielding
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]

[a] ASME Section VIII, Division I Tables for material properties, indicate that temperatures of up to 343°C do not seriously affect the material strength of mild steels.

[redacted] The Cs-137 material is double encapsulated within the structure of the capsules. The sealed source has been demonstrated to meet Special Form requirements and, in particular, the 800°C (472°F) temperature test.

The sealed source is defined as the containment system of the F-430 package. Finally, as the accessible surface temperatures of F-430 do not exceed 50 °C, the F-430 will be transported as non-exclusive use shipment (see Chapter 7).

3.5 HYPOTHETICAL ACCIDENT THERMAL EVALUATION

3.5.1 THERMAL MODEL

3.5.1.1 Analytical Model

[redacted]

3.5.1.2 Results

The analysis of the F-430 under the conditions of the regulatory fire test has been carried out analytically and is summarized in Appendix 3.7.1. Conservative assumptions are used throughout the analysis. It is concluded that there is a large margin of safety with regard to lead melt, which indicates that shielding will be maintained. The Special Form status of the sealed sources provides evidence that the containment function of the package will be maintained.

3.5.2 PACKAGE CONDITIONS AND ENVIRONMENT

After drop testing of the full scale [redacted]

[redacted]

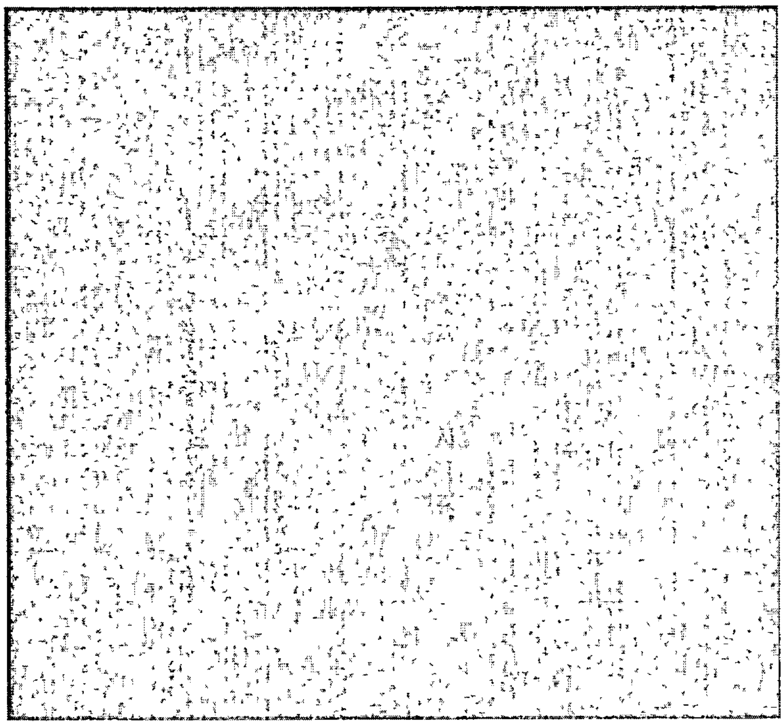


Figure 3.2: Damage to the Overpack after regulatory drop testing

3.5.3 PACKAGE TEMPERATURES

The results of the transient analyses are summarized in Appendix 3.7.1. Temperature histories for selected nodes are plotted in this Appendix. The maximum lead temperature was found to be 142°C which occurs in the region closest to the source in a steady state conditions with 38°C ambient temperature and insolation heat load of 800W on flat surfaces (the top) and 400W on curved surfaces (side). Following the accidental fire the maximum lead temperature is less than 142°C. The model used a series of conservative assumptions as discussed is 3.4.1.1. In spite of these assumptions, a substantial margin of safety exists relative to the 327°C melting point of lead. See Table 3. for temperatures at various locations of the F-430/GC-40.

Table 3.7: Comparison of Load Cases and Maximum Temperatures

[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted] °C	[redacted] °C	[redacted] °C	[redacted] °C	[redacted] °C	[redacted] °C	[redacted] °C
[redacted]	[redacted]	[redacted] °C	[redacted] °C	[redacted] °C	[redacted] °C	[redacted] °C	[redacted] °C	[redacted] °C
[redacted]	[redacted]	[redacted] °C	[redacted] °C	[redacted] °C	[redacted] °C	[redacted] °C	[redacted] °C	[redacted] °C
[redacted]	[redacted]	[redacted] °C	[redacted] °C	[redacted] °C	[redacted] °C	[redacted] °C	[redacted] °C	[redacted] °C
[redacted]	[redacted]	[redacted] °C	[redacted] °C	[redacted] °C	[redacted] °C	[redacted] °C	[redacted] °C	[redacted] °C
[redacted]	[redacted]	[redacted] °C	[redacted] °C	[redacted] °C	[redacted] °C	[redacted] °C	[redacted] °C	[redacted] °C
[redacted]	[redacted]	[redacted] °C	[redacted] °C	[redacted] °C	[redacted] °C	[redacted] °C	[redacted] °C	[redacted] °C
[redacted]	[redacted]	[redacted] °C	[redacted] °C	[redacted] °C	[redacted] °C	[redacted] °C	[redacted] °C	[redacted] °C

* [redacted].

** [redacted]

The effects of the conservative factors used in the analysis is discussed in Appendix 3.7.1. The most significant of these are the assumptions of zero contact resistance at the start of the fire, unimpeded flow of hot gases over the shielding vessel and the high thermal conductivity of the crushed foam.

These findings indicate a substantial margin of safety in the design. It is submitted that the F-430 meets the thermal requirements of the regulations under the normal and hypothetical accident conditions of transport.

3.5.4 MAXIMUM INTERNAL PRESSURES

In the cavity of F-430 there will be no pressure build up during accidental fire as the covers are not pressure-tight.

[redacted]

3.5.5 MAXIMUM THERMAL STRESSES

The maximum thermal stresses will occur during the fire, when the exterior temperatures have reached a maximum and the internal temperatures are still rising. However, no significant thermal stresses are expected as the package is free to expand and contract, [redacted]

3.5.6 EVALUATION OF PACKAGE PERFORMANCE FOR THE HYPOTHETICAL ACCIDENT THERMAL CONDITIONS

If the F-430 package was subjected to the environment of accidental fire (800°C for 30 minutes), it is estimated that the worst case temperature of the lead shield would be about 128°C. (Refer to Appendix 3.7.1)

Steady state finite element analysis of the F-430 has shown good agreement between measured and calculated temperatures.

Transient analysis has shown the F-430 to complete the regulatory fire test without the initiation of lead melt. In all cases, peak lead temperatures were found to be significantly less than the melting point, particularly in light of the conservative assumptions used in the model. For example, it is estimated that the effect of the contact resistance decreases the maximum lead temperatures by about 50°C.

[redacted]. It is submitted that the F-430 meets the thermal requirements of the regulations under the normal and hypothetical accident conditions of transport.

3.5.6.1 Sealed Source

The maximum temperature of the source during the hypothetical thermal test is 143°C. Since the source capsules C-440 and C-141 Type 8 are certified as Special Form and has been tested successfully to 800°C (1,472°F), the integrity of the source capsules is sound.

The C-440 temperature in the hypothetical thermal test is 143°C, which is less than the melting point of ss316L (1260°C). Therefore, the ss316L encapsulation shall not melt.

As the C-440 is free to expand, the thermal stresses are insignificant. The maximum growth from 20°C to 143°C is

$$\delta = L_{O,C\text{-}440} \times \alpha \times (143°C - 20°C)$$

$$= 37 \times 1.2E\text{-}5 \times (143°C - 20°C)$$

$$= 0.05mm$$

The amount of free room between the underside of the shield plug and the top of the C-440 is 0.5mm. As thermal growth of $\delta = 0.05mm$. is less than this clearance, during the hypothetical thermal test the C-440 capsules shall expand freely. Consequently, as there is no restraint, there are no significant thermal stresses in the outer body of the C-440.

Internal pressure build up due to temperature increase is calculated as follows:

$dP = P1(T2/T1) - P1 = 101.4*([273+143]/[273+20]) - 101.4 = 42.5kPa$ (6.1psi).

This is a very low pressure, which will not cause the capsule to fail.

Based on the above arguments, the integrity of the Special Form sealed sources C-440 and C-161 Type 8 is maintained during the fire test.

3.5.6.2 The Containment System

The Special Form sealed source is defined as the containment system of the F-430 package.

3.5.6.3 Shielding

[redacted], the thermal model calculates no lead melt. Consequently there is no loss of lead shielding from the F-430.

Therefore, the integrity of lead shielding of the F-430 is sound.

3.6 LIST OF REFERENCES FOR CHAPTER 3

[1] T. Baumeister, E. A. Avallone, T. Baumeister III, (Editors), *Mark's Standard Handbook for Mechanical Engineers*, McGraw- Hill Book Company, 8th edition, 1978.

[2] Lead Industries Association, *Lead in Modern Industry*, New York City, New York, 1952, p.184.

[3] General Plastics Manufacturing Company, "General Plastics Last-A-Foam FR-3700 for Crash and Fire Protection of Nuclear Material Shipping Containers", June, 1997.

[4] Chapman, Alan J., *Heat Transfer*, 3rd edition, Macmillan Publishing Company, Inc., New York, 1974, p.578 for 18-8 steel.

[5] Reference 4, p.576.

[6] Reference 1, pp.6-17.

[7] Holman, J.P., *Heat Transfer*, 5th edition, Mcgraw Hill Book Co., New York, 1981.

[8] Browne, E., Firestone, R.B., *Tables of Radioactive Isotopes*, John Wiley and Sons, New York, 1986.

[9] 10 CFR, Chapter 1, Part 71 - Packaging and Transportation of Radioactive Material, 1-1-91 Edition.

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

[11] Society of Automotive Engineers, Inc., (SAE), Aerospace Applied Thermodynamics Manual, 485 Lexington Ave., New York, N.Y., Published Feb. 1960, Revised Jan 1962 (Library of Congress catalog card No. 60-13450).

[12] IN/TP 1493 F430: F-430 Test Plan. A plan for regulatory tests on F-430 overpack.

[13] IN/TR 1604 F430: F-430 Test Report. Regulatory Tests Conducted on F-430 prototype.

3.7 APPENDICES

This section contains the following appendices.

APPENDIX 3.7.1:
Thermal Analysis of F-430 Overpack

IN/TR 1645 F-430 (2)

Thermal Analysis of F-430 Overpack

Signatures

Prepared by: [signature] J. Ramsay, Package Engineering Date: 01.10.12

Reviewed by: [signature] B. Menna, Package Engineering Date: 01/10/12

Approved by: [signature] M. Krzaniak, Manager, Package Engineering Date: 01 OCT 16

Document History

Date	Version	Comments	Prepared by	Reviewed by	Approved by
May 00	1	CCF A1297-C-00A	J. Ramsay	J. Krupka	M. Krzaniak
Oct 01	2	DCN A1297-D-10A Added sections 5.6 & 6.6 and Fig's 25 & 26. Minor editorial & fomatting changes			

TABLE OF CONTENTS

1. INTRODUCTION

This report is a summary of the analysis performed to determine the thermal behaviour of the F-430 overpack loaded with a Gammacell-40 before, during and after the IAEA regulatory fire test [1]. A three-dimensional eighth-section model was constructed, using the ANSYS finite element code Version 5.5.3 [2], to simulate the fire test. The solid model, finite element mesh, material properties, boundary conditions and load cases used in the ANSYS simulations are discussed. Results of physical testing performed on the package and the finite element simulations are presented and compared to verify the thermal model.

The results of the analysis show there is no lead melt in the Gammacell-40 contained in the F-430 overpack when it is subjected to the regulatory fire.

2. SOLID MODEL GEOMETRY

The F-430 overpack loaded with the Gammacell-40 is shown in Figure 1. A three-dimensional, eighth-section solid model of the main components of the F-430 overpack and Gammacell-40 was constructed, as shown in Figures 2 and 3. This model was generated from boolean solids and boolean operations (subtractions, unions) created within ANSYS. These solids were then assigned material properties, meshed, and boundary conditions and loading applied as described in the following sections. A one-eighth section was modelled to take advantage of the symmetry of the package and reduce the size and complexity of the model.

3. MATERIAL PROPERTIES

Material properties were required for mild steel, [redacted] lead, air and [redacted] as shown in Tables 1 and 2. The properties required included density, thermal conductivity and specific heat. The specific heat of lead incorporated the latent heat of fusion (24,750 J/g) to simulate the phase change when the material melts (note that lead melt was not encountered in any of the load case scenarios).

Convection coefficients and surface emissivities required to define the heat transfer by convection and radiation on the outside of the overpack are discussed in Section 4.3. The conduction, convection and radiation heat transfer across the air space between the Gammacell-40 and the overpack, and the required material properties, are discussed in Section 4.2.

[redacted]

[redacted]

4. FINITE ELEMENT MESH, BOUNDARY AND LOAD CONDITIONS

4.1 THREE-DIMENSIONAL EIGTH-SECTION MODEL MESH

The solid model was meshed using thermal three-dimensional tetragonal elements [2 and Appendix B], as shown in Figure 4. The optimal mesh density shown in the figures was achieved by refining the mesh to the point where the temperature results were not dependent on the mesh density. The mesh used for the simulations presented in this report contained 47,018 elements and 8,389 nodes. The integrity of the elements (connectivity, aspect ratios and internal angles) is automatically checked by ANSYS prior to the run.

4.2 HEAT TRANSFER ACROSS THE INTERNAL AIR SPACE

The heat transfer across the air space between the Gammacell-40 and the overpack inner frame is comprised of conduction, convection and radiation.

Heat transfer by conduction occurs through the air and through the steel support structure of the Gammacell-40. The total conduction area of the steel components is calculated in Appendix C to be about 2 percent of the overall conduction area. The remaining 98 percent of the conduction occurs through the air.

Convection heat transfer through the air is accounted for by an effective thermal conductivity [4], as calculated in Appendix C. The air inside the package will tend to circulate due to the temperature gradients across the air space transferring additional heat by free convection.
The effective thermal conductivity is the thermal conductivity that a stationary fluid should have to transfer the same amount of heat as the moving fluid.

A total thermal conductivity for the air space is calculated (Appendix C) to combine the contribution of the conduction and convection across the air space.

[redacted]

The actual radiation heat transfer across the air space will be less than that modelled, since the blocking effects of the Gammacell-40 support structure are neglected. The radiation heat transfer is, therefore, conservatively modelled.

4.3 CONVECTION AND RADIATION BOUNDARY CONDITIONS

Convection and radiation boundary conditions used in the model are shown in Figure 6.

Convection was applied on the outer surface of the overpack by selecting the external nodes and applying a convection coefficient (calculated in Appendix D) and ambient temperature as a surface load.

[redacted]

4.4 INTERNAL HEAT GENERATION

The decay of the Cs-137 carried inside the F-430 overpack generates 4.84 W of heat per kCi, based on 566 keV of photon energy, 62 keV of atomic electron energy and 188 keV of continuous radiation [6], as calculated below:

1000 Ci/kCi * 3.7e+10 dis/s/Ci * 816 keV/dis * 1.602e-16 J/keV * 1 W/J/s = 4.84 W/kCi

The overpack in the physical test used to verify the model [6] was loaded with 1.72 kCi of Cs-137 for a total heat output of 8.3 W (4.84*1.72). The maximum expected heat load to be transported in the F-430 overpack is about 50 W. Twice this heat load, or 100 W, was applied for all other load cases, including the simulation of the regulatory fire, as a worst-case internal heat load.

The internal heat generated in the Gammacell-40 was applied as a uniform heat generation on the inside of the Gammacell-40 source cavity. The heated elements and the applied heat generation rates are shown in Figure 7. Self-attenuation of the capsules generally results in lower radiation fields in the axial dimension and higher radial fields. This effect was ignored in the model due to the small size of the cavity and the low heat generation of the source.

4.5 SOLAR HEAT LOAD

Figure 7 shows the elements that were subjected to the solar heat flux required by the regulations [1]. A heat flux of 400 W/m^2 was applied to the side of the overpack and a heat flux of 800 W/m^2 was applied to the top of the overpack as per the regulations. This heat flux was applied both as a steady state load, and as a transient load over 12 hours as specified in the regulations for the Normal Conditions of Transport, to determine the response of the overpack to both conditions.

4.6 FIRE TEST TRANSIENT LOAD

The IAEA fire test [1] was applied by defining a transient temperature curve for the ambient temperature as shown in Figure 8. This curve was applied to the convection boundary conditions and the node representing the ambient temperature for the external radiation matrix (Section 4.3). The 30 minute, 800°C fire was followed by a one minute ramp-down to pre-fire ambient temperatures, followed by a 19.5 hour (1170 minute) cool-down period. This 1170 minutes of cooling was sufficient to allow all temperatures to reach their maximum values.

The solar heat flux discussed in Section 4.5 was applied for 12 of the 19.5 hour cool down period as required by the regulations [1].

To simulate the effects of increased convection to the environment, the convection heat transfer coefficient on the outside of the overpack was set to 18 W/m^2°C, as calculated in Appendix D.

To maximise the radiation heat transfer during the fire, a conservative emissivity of 1.0 was used for the outside stainless steel surface of the overpack.

Also to simulate a worst-case fire condition, the lead-to-steel contact resistance at the Gammacell-40 outer shell was removed.

5. LOAD CASES

The ANSYS input files for all of the following load case scenarios considered are listed in Appendix E.

5.1 LOAD CASE 1 (VALIDATION): STEADY STATE, 8.3 W Cs-137, NO SOLAR LOAD, 21°C AMBIENT

This load case was used to verify the steady state behaviour of the model. Steady state conditions were used with 1.72 kCi or 8.3 W (Section 4.4) of cobalt-60 loaded into the Gammacell-40. This was a simulation of a physical thermal test performed on the F-430 overpack containing a Gammacell-40 loaded with C-198's [6]. No solar load was applied as the physical test was conducted indoors.

The ambient temperature at the side and bottom of the overpack was taken from the physical test data to be 21°C.

5.2 LOAD CASE 2: STEADY STATE, 100 W Cs-137, NO SOLAR LOAD, 21°C AMBIENT

This load case is identical to Load Case 1 (Section 5.1), except the internal heat generation in the Gammacell-40 cavity was increased to 100 W from 8.3 W. An internal heat generation of 100 W was used as a worst-case condition and is twice the maximum expected heat load to be transported in the F-430 overpack (Section 4.4).

This load case shows the effect of the increased internal heat generation between the test and worst-case internal heat load conditions.

5.3 LOAD CASE 3: STEADY STATE, 100 W Cs-137, NO SOLAR LOAD, 38°C AMBIENT

This load case is identical to Load Case 2 (Section 5.3), except with the ambient temperature at the side and bottom of the overpack assumed to be 38°C as per the regulations [1].

This load case shows the effect of the increased ambient temperature between the test and regulatory ambient conditions.

5.4 LOAD CASE 4: STEADY STATE/TRANSIENT, 100 W Cs-137, SOLAR LOAD, 38°C AMBIENT

This load case is identical to Load Case 3 (Section 5.3), except that the solar heat load discussed in Section 4.5 was applied.

This load case shows the effect of the solar load with a 38°C ambient temperature under steady state conditions and applied as a 12 hour transient as required by the regulations [1].

5.5 LOAD CASE 5: FIRE TRANSIENT, 100 W Cs-137, SOLAR LOAD, 38°C AMBIENT

This load case shows the response of the F-430 overpack and Gammacell-40 to the IAEA regulatory fire test [1].

Transient conditions were used with initial temperatures from the steady state analysis in Load Case 3 (Section 5.3) above, with the ambient temperature at the side and bottom of the overpack assumed to be 38°C as per the regulations [1].

The transient loading consisted of the IAEA regulatory fire loading [1], as discussed in Section 4.6. The model was loaded with 100 W of cobalt-60 (Section 4.4) and had the solar load (Section 4.5) applied after the fire, during the cool-down of the overpack, as required by the regulations.

[redacted]

[redacted]

6. RESULTS AND DISCUSSION

6.1 LOAD CASE 1 (VALIDATION): STEADY STATE, 8.3 W Cs-137, NO SOLAR LOAD, 21°C AMBIENT

The calculated steady state temperature distribution in the overpack is shown in Figure 9. Table 3 lists the temperatures from the experiment and the analysis at the key locations shown in Figure 10, where thermocouple temperature readings were taken in the experiment. The correlation is good indicating the approximations used in the analysis are appropriate.

The largest differential between measured and calculated temperatures was for the Gammacell-40 cavity. The calculated Gammacell-40 cavity temperature was about 3°C lower than the experimental value. This difference was expected since the air space between the Gammacell-40 and the inner frame of the overpack was modelled as an open air space and none of the Gammacell-40 support structure was included to reduce the size and complexity of the model. Similarly, the steel lining of the internal cavity, and the subsequent lead-steel interface and air resistance, were not modelled. The heat flow out of the package was, therefore, slightly overestimated due to the approximation. This was considered an acceptable trade-off, however, in that the heat flow into the overpack during the fire transient would also be higher than in reality and, therefore, a worst-case condition is modelled.

6.2 LOAD CASE 2: STEADY STATE, 100 W Cs-137, NO SOLAR LOAD, 21°C AMBIENT

The calculated steady state temperature distribution in the overpack for this load case is shown in Figure 11. Temperature results at various points within the model are compared to those of Load Case 1 (Section 6.1), which is the same model with 8.3 W of Cs 137, in Table 4. The results show a 27-40°C temperature increase in the overpack and an approximately 50°C temperature increase in the Gammacell-40, whereas the temperatures on the outside of the overpack are similar. Therefore, the increase in internal heat generation from 8.3 to 100 W causes a significant increase in the internal temperatures of the overpack and Gammacell-40, which was expected due to the magnitude of the increase.

6.3 LOAD CASE 3: STEADY STATE, 100 W Cs-137, NO SOLAR LOAD, 38°C AMBIENT

The calculated steady state temperature distribution in the overpack for this load case is shown in Figure 12. Temperature results at various points within the model are compared to those of Load Case 2 (Section 6.2), which is the same model with a 21°C ambient temperature, in Table 4. The results show a 15-17°C increase in all of the model temperatures for an increase in ambient temperature of 17°C. Therefore, the model temperatures increase approximately in proportion with the ambient temperature in the steady state condition. This linear extrapolation was expected since heat transfer at these temperatures is primarily due to conduction and convection, which are linear relations.

6.4 LOAD CASE 4: STEADY STATE/TRANSIENT, 100 W Cs-137, SOLAR LOAD, 38°C AMBIENT

The calculated steady state temperature distribution in the overpack for this load case is shown in Figure 13. Temperature results at various points in the model are compared to those of Load Case 3 (Section 6.3), which is the same model without the solar load. The results show an approximately 50°C increase in the internal temperatures, an 87°C increase on the top and a 49°C increase on the side of the overpack when the solar load is applied. Therefore, the solar heat flux applied as a steady state load has a significant effect on the internal temperatures of the overpack. Note, however, that even for this worst-case condition, the maximum temperature in the lead shielding, 142°C, is still well below the melting point of lead, 327°C.

The regulations only require the solar load to be applied over a 12 hour period, or during daylight hours. So the solar heat flux was also applied as a transient load (Section 4.5) to determine how the maximum temperature reached in 12 hours compares to the steady state temperatures calculated.

Figure 14 shows the temperature distribution in the overpack at the end of the 12 hour transient. The maximum temperature reached in the lead shielding is 95°C, much lower than for the steady state case (142°C). The maximum surface temperature reached, 124°C, is virtually the same as that for the steady state case (126°C), however.

Therefore, the steady state model of the solar heat flux overestimates the internal overpack temperatures that would be reached in a 12 hour insolation period. The temperatures for the steady state model, however, are still all well below lead melt (maximum temperature of 142°C as compared to 327°C for lead melt), and therefore, show unequivocally that the overpack meets the requirements of the regulations under solar load.

6.5 LOAD CASE 5: FIRE TRANSIENT, 100 W Cs-137, SOLAR LOAD, 38°C AMBIENT

The calculated temperature distribution in the overpack 30 minutes into the transient (as the fire is turned off) is shown in Figure 15. The calculated temperature distribution in the overpack at the time of maximum lead temperature (64,800 s, 18 hrs) is shown in Figure 16. The calculated temperature distribution in the lead elements only, at the time of maximum lead temperature (64,800 s, 18 hrs), is shown in Figure 17.

The transient temperature results at the key locations shown in Figure 10 are shown in Figures 18 through 24. All of the temperature transients show temperatures below the melting temperature of lead, 327°C. The maximum temperature reached in the lead, 102°C at 64,800 s (18 hrs), was at the Gammacell-40 cavity.

[redacted]

[redacted]

[redacted]

7. CONCLUSIONS

Good agreement between the experimental measurements of the transport package steady state temperatures and the ANSYS simulated results was obtained.

The results of the IAEA fire test showed no lead melt in the Gammacell-40 modelled inside the F-430 overpack. The maximum lead temperature reached was 128°C, well below 327°C, the melting point of lead. In reality, the maximum lead temperature expected during such a regulatory fire would be much lower than this, considering the extremely conservative assumptions used in the model.

The F-430 overpack and Gammacell-40 analysed in this report passed the IAEA regulatory fire test.

8. REFERENCES

1. IAEA Safety Standard, Safety Series No. 6, "Regulations for the Safe Transport of Radioactive Material", 1985 Revised Edition (As Amended 1990).
2. ANSYS User's Manual, Revision 5.5, ANSYS Inc., Houston, PA, 1998.
3. E7515, Euratom Contract No. 024-65-ECIC, Transnucleaire, "Report on the Implications of the Test Requirements for Type B Packagings and a Study of Practical Solutions", Transnucleaire, Paris, France, Part II.
4. Incropera, F.P. and Dewitt, D.P., "Fundamentals of Heat and Mass Transfer", John Wiley and Sons, Inc., New York, 1985
5. Browne, E., Firestone, R.B., "Tables of Radioactive Isotopes", John Wiley and Sons, Inc., New York, 1986.
6. Krupka, J., "F-430 Test Report", MDS Nordion Inc. Report IN/TR 1604 F430/GC40.
7. Holman, J.P., "Heat Transfer", McGraw-Hill Book Company, 5th Edition, New York, 1981.
8. Lead Industries Association, "Lead in Modern Industry", New York City, New York, 1952.
9. Perry, R.H., Green, P.W. and Maloney, J.O., "Perry's Chemical Engineer's Handbook", McGraw-Hill Book Company, 6th Edition, New York, 1984.
10. Baumeister, T., Avallone, A., Baumeister III, T., Ed., "Mark's Standard Handbook for Mechanical Engineers", McGraw-Hill Book Company, 8th Edition, New York, 1978.
11. [redacted]

TABLE 1: Material Properties of Mild Steel, Insulating [redacted], Air and Stainless Steel

#	Material Description	Density ρ (kg/m³)				Thermal Conductivity k (W/m°C)				Specific Heat c (J/kg°C)			
1	Mild Steel [4]	8131				°C	k	°C	k	°C	c	°C	c
						-73	41.0	127	42.2	-73	434	127	487
						327	39.7	527	35.0	327	559	527	685
						727	27.6	927	27.6	727	1090	927	1090
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]			
		[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]				
		[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]				
		[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]				
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]			
		[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]				
		[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]				
		[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]						
3	Air [4]	°C	ρ	°C	ρ	°C	k	°C	k	°C	c	°C	c
		-73	1.75	127	0.87	-73	0.018	127	0.034	-73	1007	127	1014
		327	0.58	527	0.44	327	0.047	527	0.057	327	1051	527	1099
		727	0.35	927	0.29	727	0.067	927	0.076	727	1141	927	1175
[redacted]	[redacted]	[redacted]				[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
						[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
						[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
						[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]

TABLE 2: Material Properties of Air Including Conduction and Convection, Lead, and Mild Steel Including Contact Resistance

#	Material Description	Density ρ (kg/m³)				Thermal Conductivity k (W/m°C)				Specific Heat c (J/kg°C)			
6	Air With Conduction and Convection Steady State [App. C]	°C	ρ	°C	ρ	°C	k	°C	k	°C	c	°C	c
		-73	1.75	127	0.87	-73	1.02	127	1.04	-73	1007	127	1014
		327	0.58	527	0.44	327	0.99	527	0.90	327	1051	527	1099
		727	0.35	927	0.29	727	0.75	927	0.75	727	1141	927	1175
6	Air With Conduction and Convection Transient [App. C]	°C	ρ	°C	ρ	°C	k	°C	k	°C	c	°C	c
		-73	1.75	127	0.87	-73	1.51	127	1.53	-73	1007	127	1014
		327	0.58	527	0.44	327	1.48	527	1.39	327	1051	527	1099
		727	0.35	927	0.29	727	1.24	927	1.24	727	1141	927	1175
7	Lead [8]	°C	ρ	°C	ρ	°C	k	°C	k	°C	c	°C	c
		20	11340	327	11005	-273	35	-27	35	-23	127	27	129
		330	10686	800	10686	123	34	227	33	127	132	227	136
						327	31	527	19	327	142	328	6188
						727	22	927	24	331	6188	332	159
[redacted]	[redacted]	[redacted]				[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
						[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
						[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
						[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]

TABLE 3: Comparison of Load Case 1 Steady State Experimental and ANSYS Results

Description	ANSYS Node (see Figure 10)	Experiment (°C)	ANSYS (°C)
Inside Gammacell-40 cavity	6359/6423	29	26/26
Outside Gammacell-40 on cylindrical surface	26	27	25
Outside Gammacell-40 on end surface	178	26	25
Inside inner frame - top	14	26	25
Inside inner frame - side	1	26	25
Inside outer frame	2274	24	23
Outside overpack - top	5128	21	21
Outside overpack - side	5141/5444	21	21/21

TABLE 4: Comparison of Load Cases 1 Through 6

Description	ANSYS Node (Fig. 10)	Load Case 1 Steady State, 8.3 W Cs-137, No Solar Load, 21°C Ambient	Load Case 2 Steady State, 100 W Cs-137, No Solar Load, 21°C Ambient	Load Case 3 Steady State, 100 W Cs-137, No Solar Load, 38°C Ambient	Load Case 4A Steady State, 100 W Cs-137, Solar Load, 38°C Ambient	Load Case 4B Transient, 100 W Cs-137, Solar Load*, 38°C Ambient	Load Case 5 Fire Transient, 100 W Cs-137, Fire/Solar Load**, 38°C Ambient	Load Case 6 Simulation of Damaged Outer Foam Under Fire Transient**
Inside Gammacell-40 cavity	6359/ 6423	26/26	75/75	91/90	143/142	96/95	102/101 (64,800 s)	128/127 (15,600 s)
Outside Gammacell-40 on cylindrical surface	26	25	70	86	138	91	98 (64,800 s)	125 (15,600 s)
Outside Gammacell-40 on end surface	178	25	69	84	136	89	97 (64,800 s)	123 (15,600 s)
Inside inner frame - top	14	25	64	80	133	86	94 (57,600 s)	138 (8,400 s)
Inside inner frame - side	1	25	63	80	132	86	94 (57,600 s)	191 (3,000 s)
Inside outer frame	2274	23	50	66	125	80	89 (32,400)	779 (1,860 s)
Outside overpack - top	5128	21	22	39	126	124	797 (1,860 s)	790 (1,860 s)
Outside overpack - side	5141/ 5444	21/21	23/23	40/40	89/89	86/86	798/797 (1,860 s)	783/783 (1,860 s)

* Temperatures are taken at end of 12 hour transient.
** Temperatures are maximum values during the fire transient at the given time in parentheses.

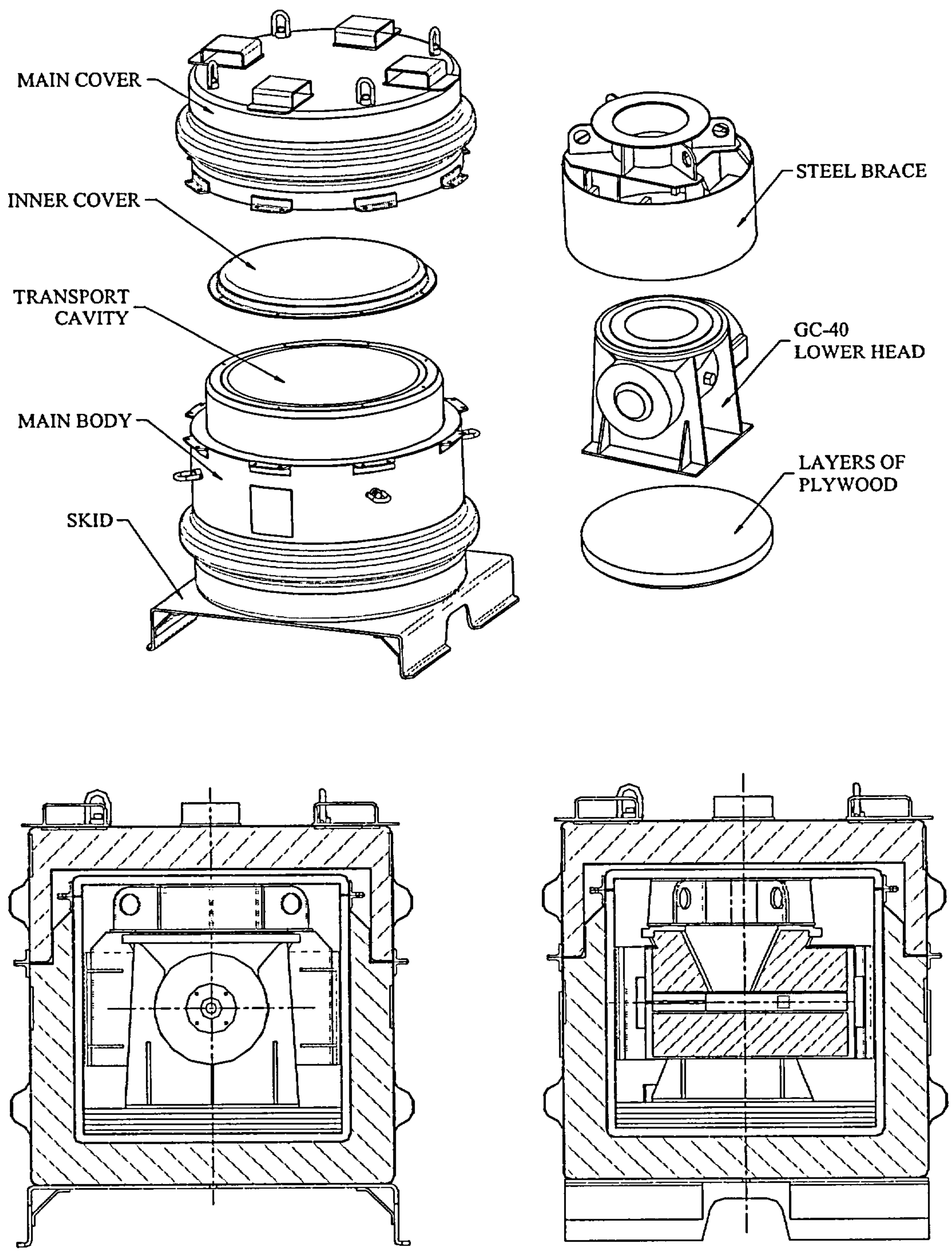
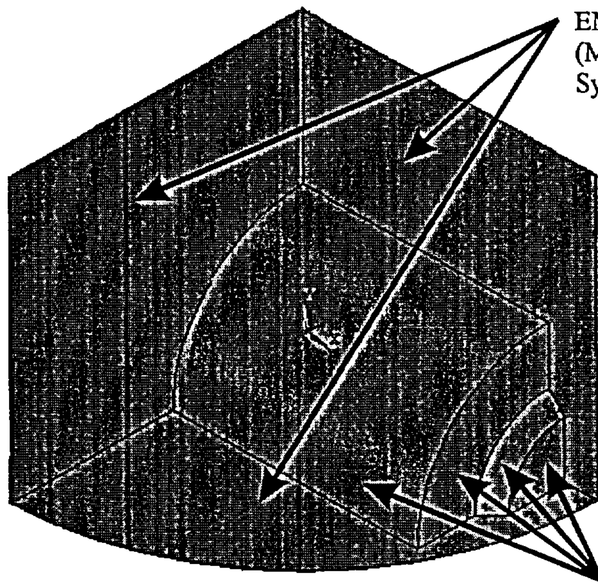


FIGURE 1: F-430/GAMMACELL-40 TRANSPORT PACKAGE (TEST SPECIMEN)

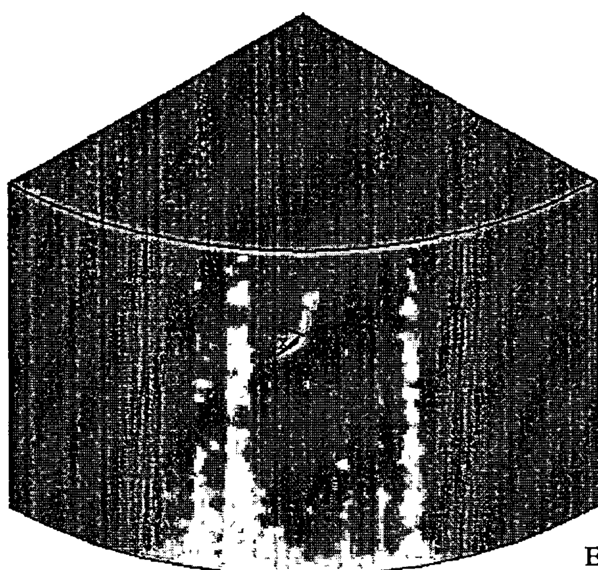
FIGURE 2: F-430 OVERPACK SOLID MODEL

FIGURE 3: F-430 OVERPACK SOLID MODEL COMPONENTS

FIGURE 4: F-430 OVERPACK FINITE ELEMENT MESH



FRONT VIEW OF ENCLOSURE



BACK VIEW OF ENCLOSURE

FIGURE 5: RADIATION ENCLOSURE FOR INTERNAL AIR SPACE

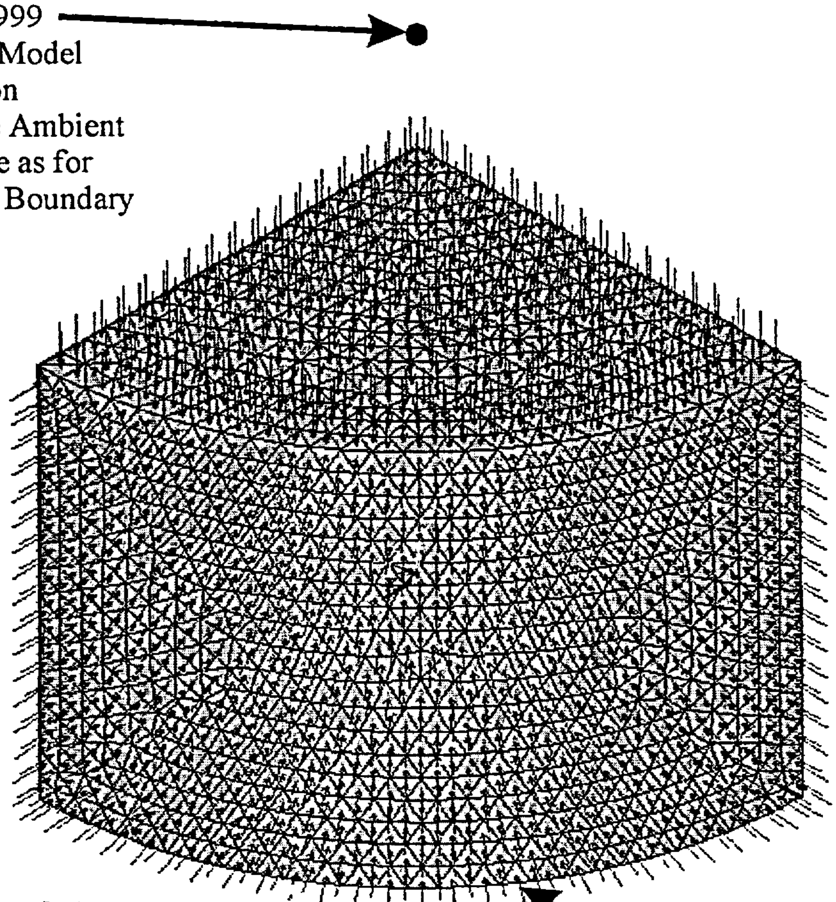


FIGURE 6: RADIATION AND CONVECTION BOUNDARY CONDITIONS

FIGURE 7: INTERNAL HEAT GENERATION AND SOLAR HEAT LOAD

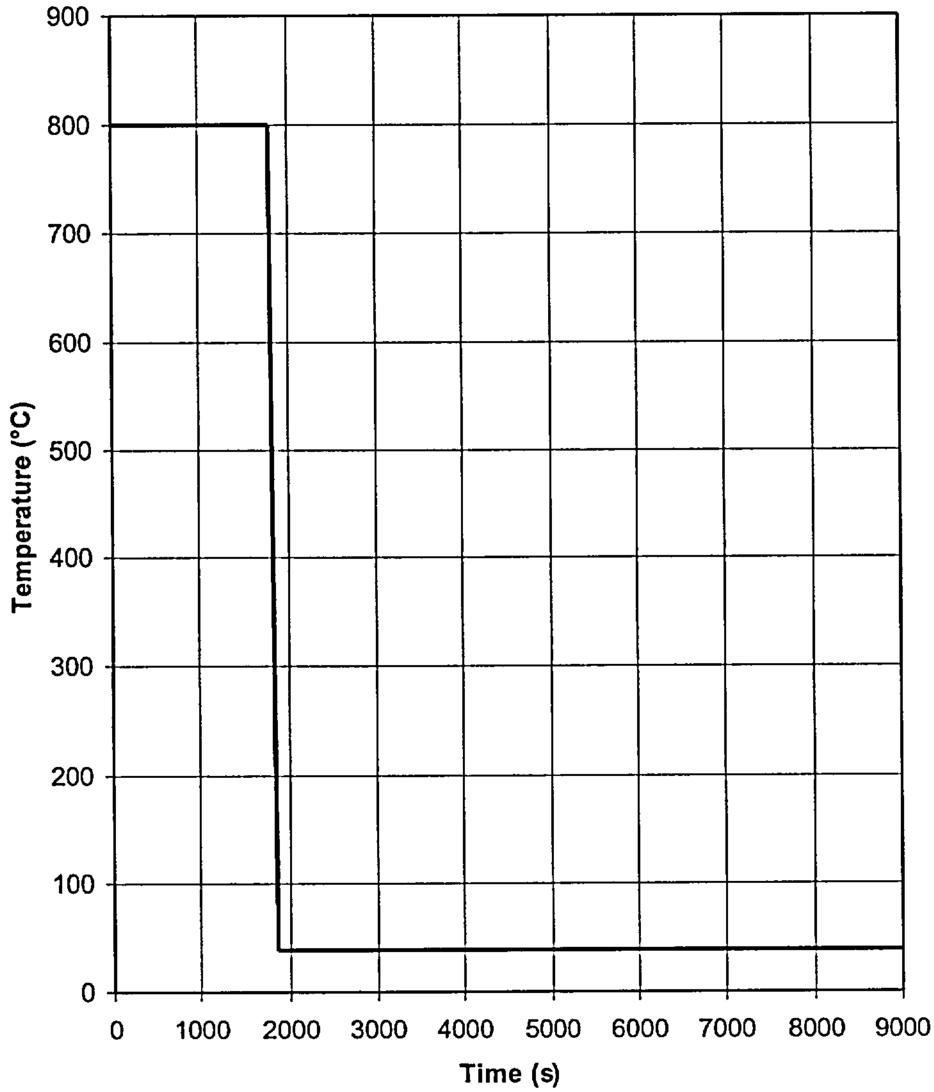


FIGURE 8: IAEA REGULATORY FIRE CURVE

FIGURE 9: STEADY STATE TEMPERATURE DISTRIBUTION FOR F-430 MODEL WITH 8.3 W CS-137, NO SOLAR LOAD AND 21°C AMBIENT: LOAD CASE 1

FIGURE 10: KEY NODAL TEMPERATURE LOCATIONS

FIGURE 11: STEADY STATE TEMPERATURE DISTRIBUTION FOR F-430 MODEL WITH 100 W CS-137, NO SOLAR LOAD AND 21°C AMBIENT: LOAD CASE 2

FIGURE 12: STEADY STATE TEMPERATURE DISTRIBUTION FOR F-430 MODEL WITH 100 W CS-137, NO SOLAR LOAD AND 38°C AMBIENT: LOAD CASE 3

FIGURE 13: STEADY STATE TEMPERATURE DISTRIBUTION FOR F-430 MODEL WITH 100 W CS-137, SOLAR LOAD AND 38°C AMBIENT: LOAD CASE 4

FIGURE 14: TEMPERATURE DISTRIBUTION FOR F-430 MODEL WITH 100 W CS-137, SOLAR LOAD AND 38°C AMBIENT AFTER 12 HOUR TRANSIENT: LOAD CASE 4

FIGURE 15: TEMPERATURE DISTRIBUTION AT END OF FIRE (1860 S)
FOR F-430 MODEL: LOAD CASE 5

FIGURE 16: TEMPERATURE DISTRIBUTION AT MAXIMUM LEAD TEMPERATURE (64,800 S, 18 HRS) FOR F-430 MODEL: LOAD CASE 5

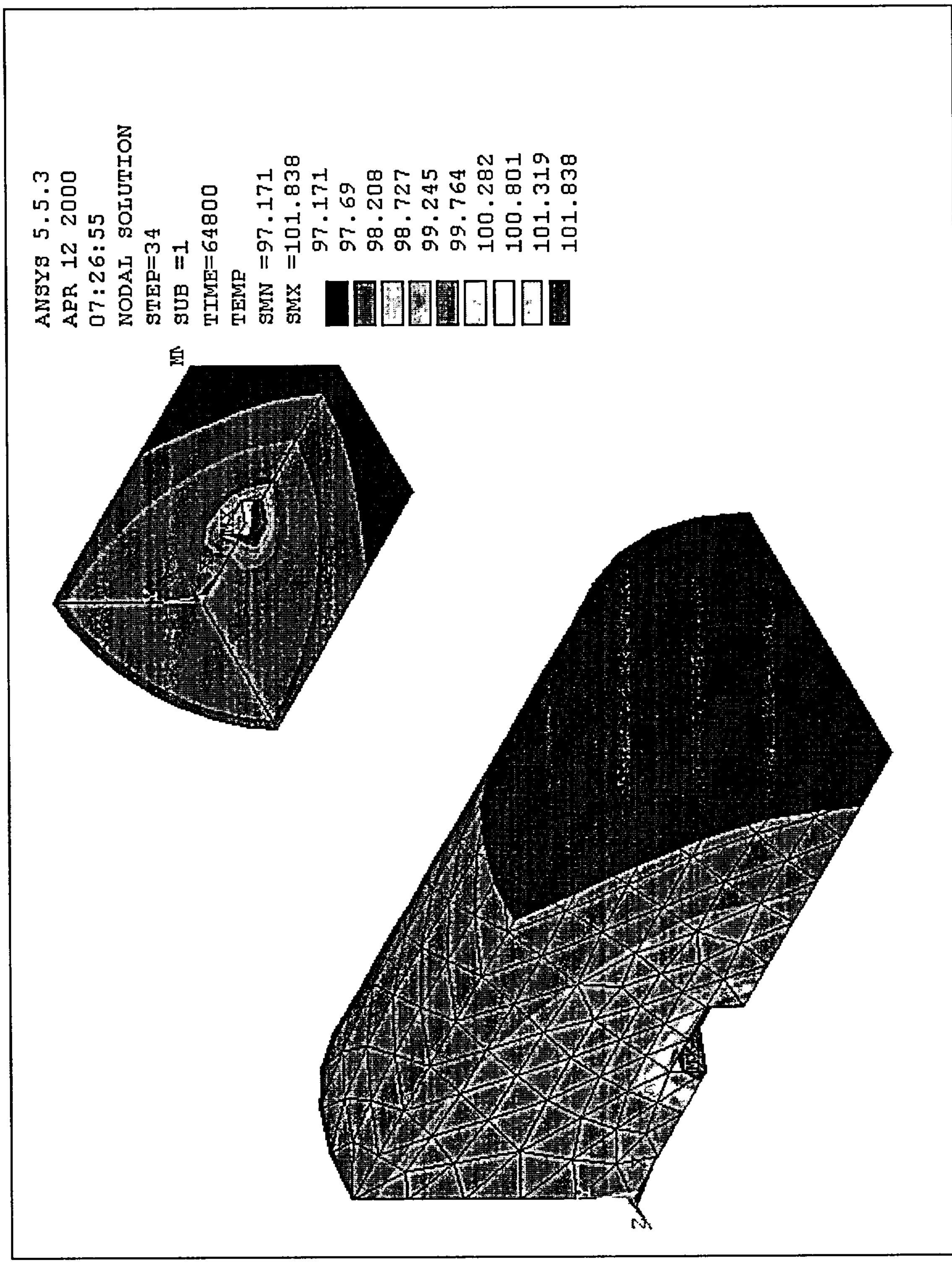


FIGURE 17: TEMPERATURE DISTRIBUTION IN LEAD ELEMENTS AT MAXIMUM LEAD TEMPERATURE (64,800 S, 18 HRS) FOR F-430 MODEL: LOAD CASE 5

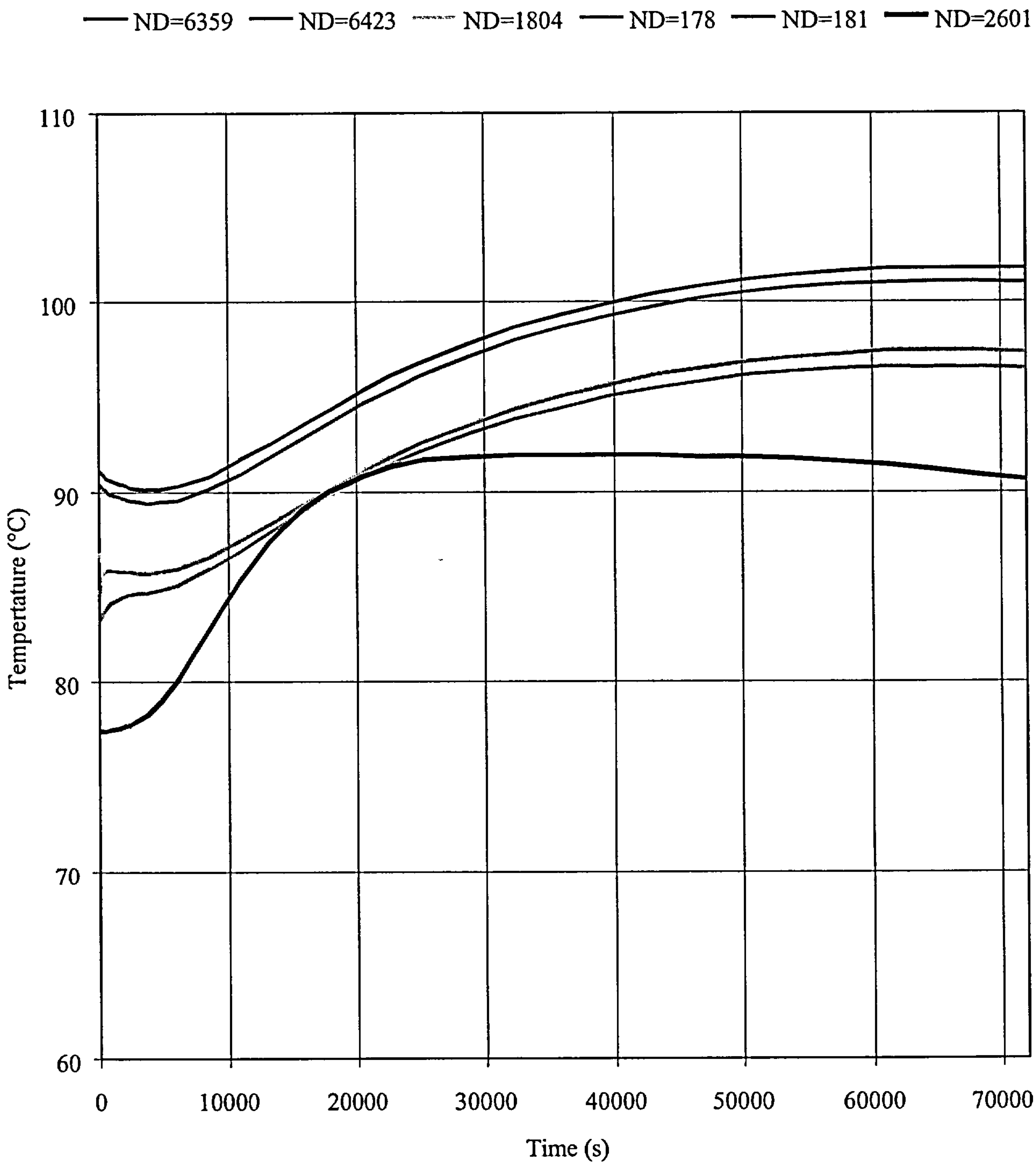


FIGURE 18: TEMPERATURE TRANSIENTS FOR SELECTED NODES FROM FIGURE 10

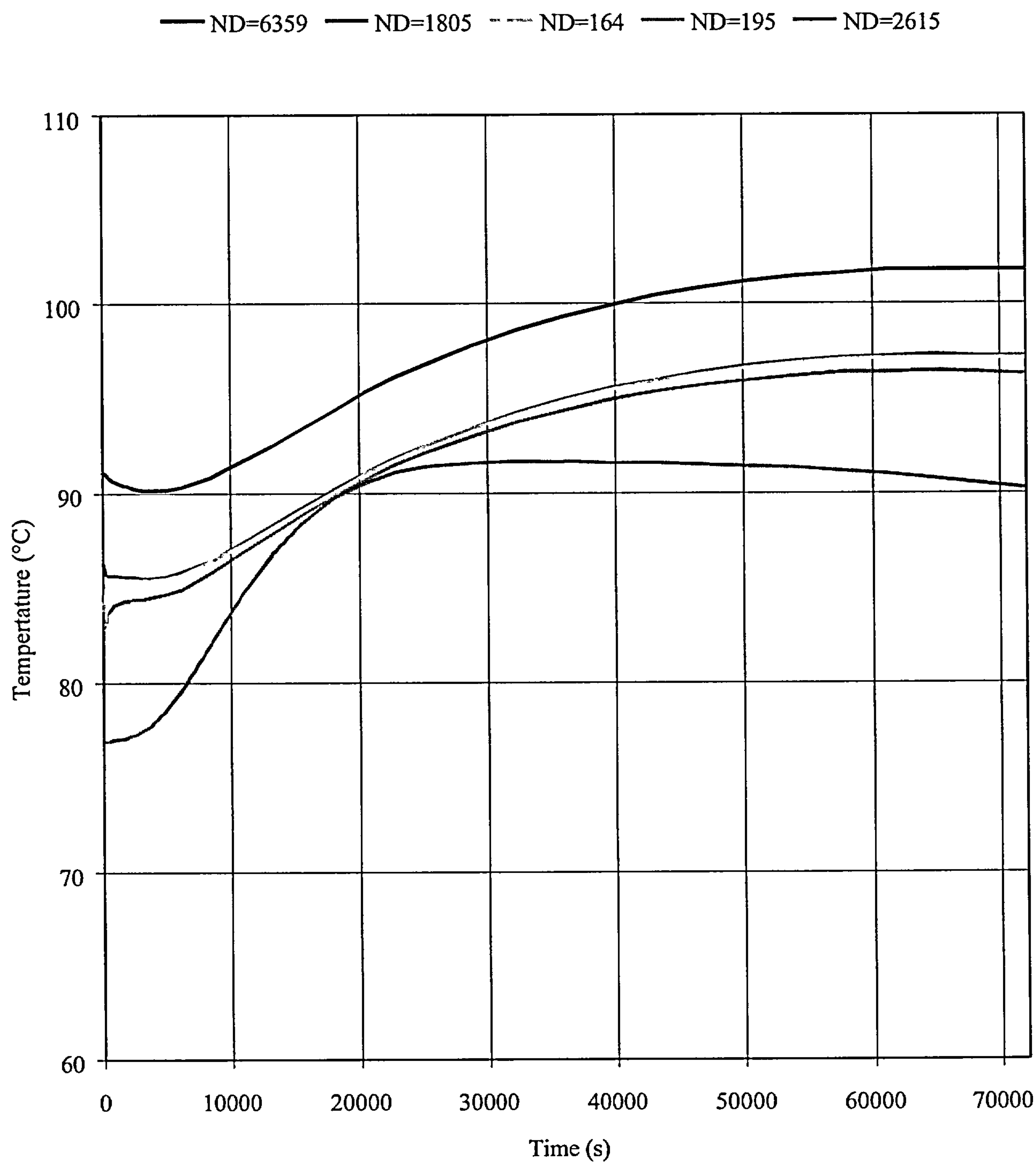


FIGURE 19: TEMPERATURE TRANSIENTS FOR SELECTED NODES FROM FIGURE 10

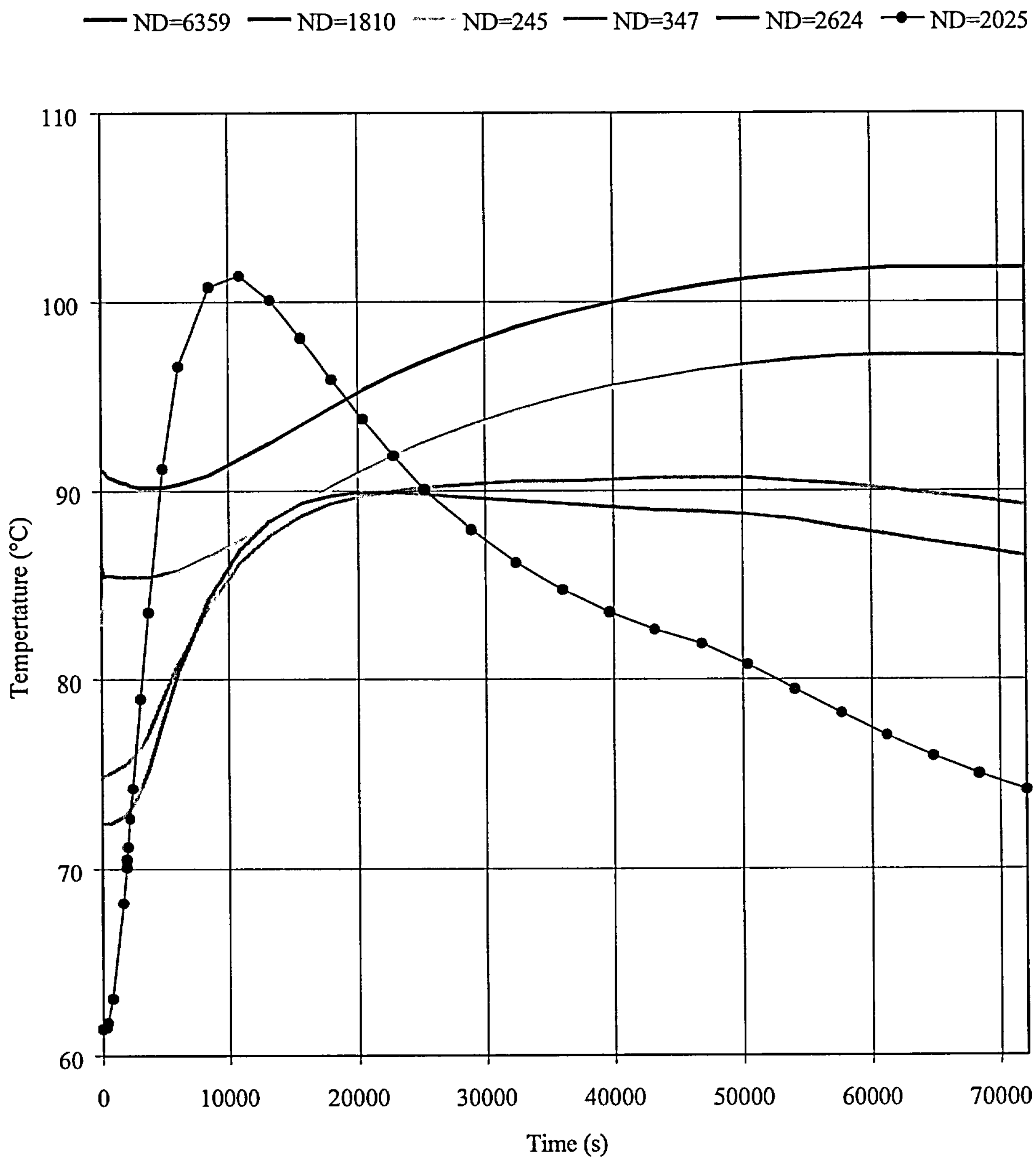


FIGURE 20: TEMPERATURE TRANSIENTS FOR SELECTED NODES FROM FIGURE 10

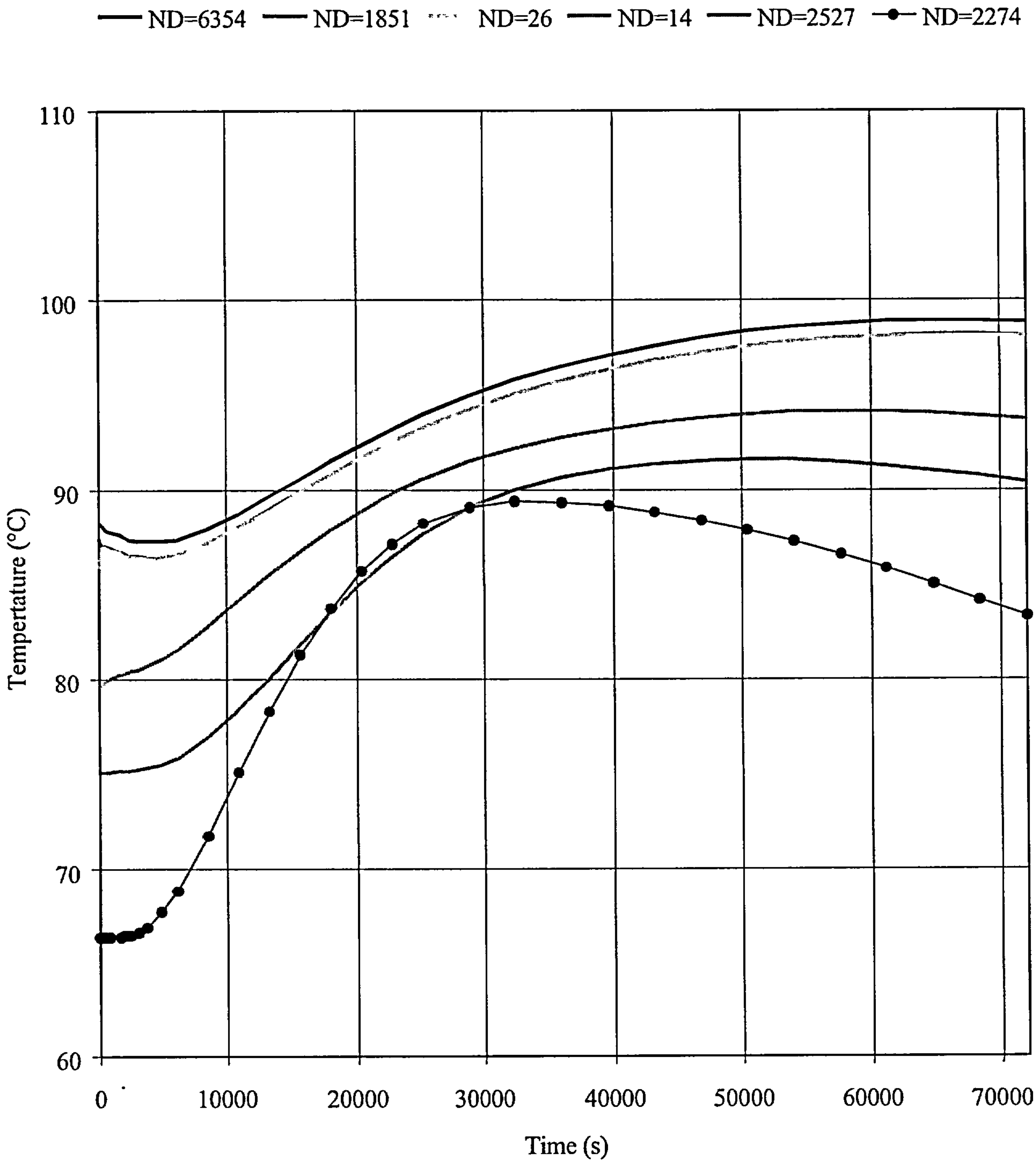


FIGURE 21: TEMPERATURE TRANSIENTS FOR SELECTED NODES FROM FIGURE 10

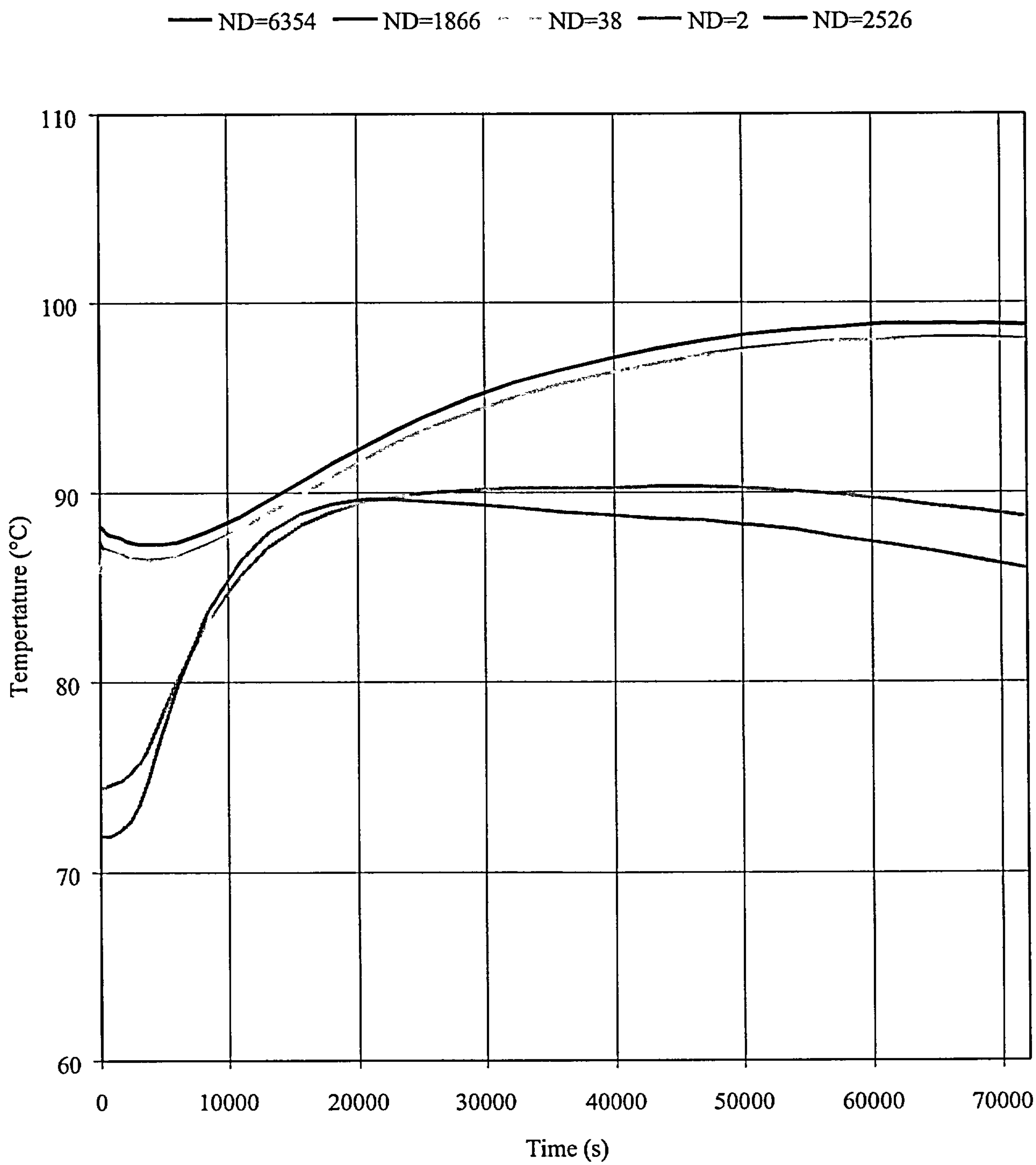


FIGURE 22: TEMPERATURE TRANSIENTS FOR SELECTED NODES FROM FIGURE 10

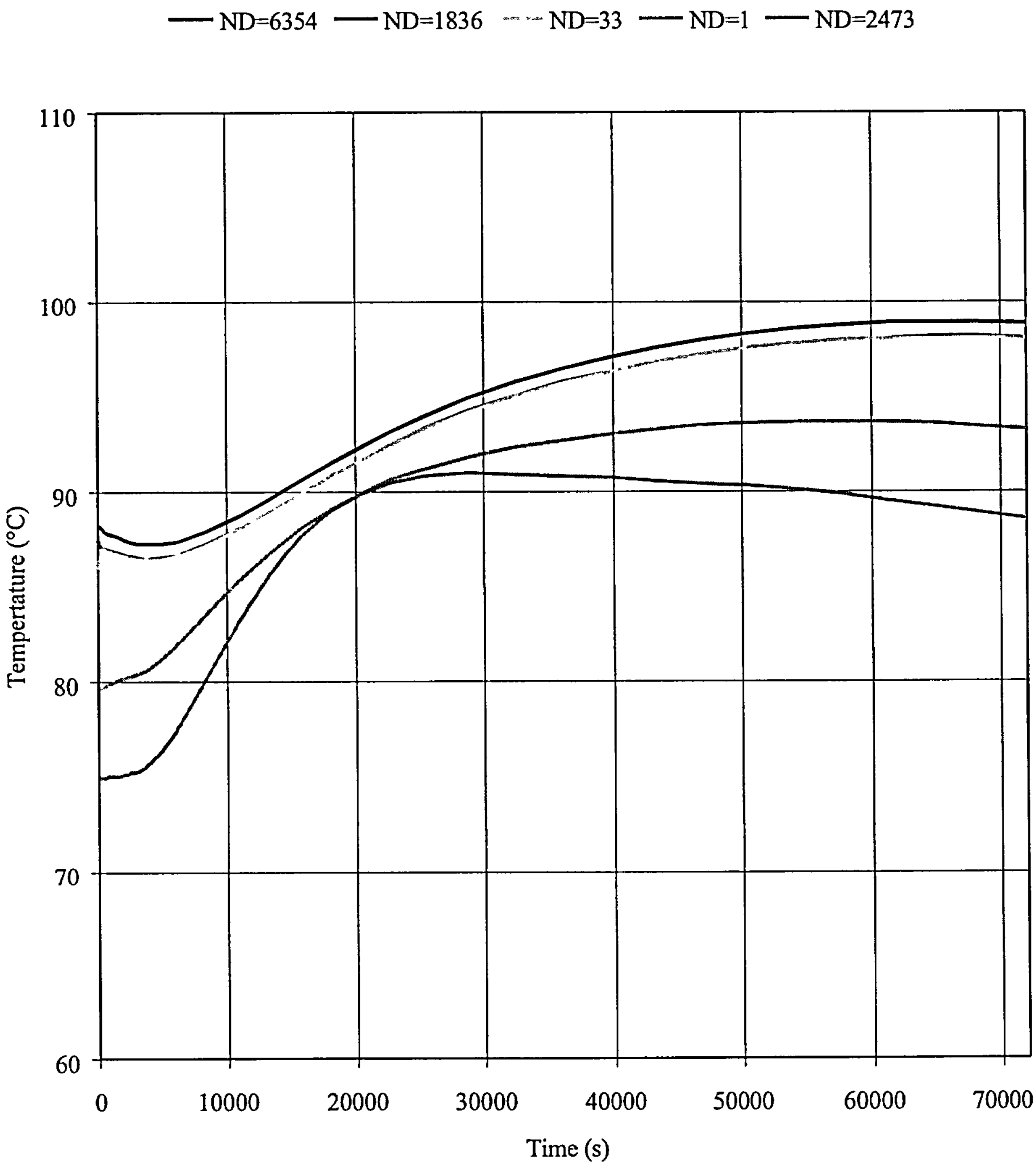


FIGURE 23: TEMPERATURE TRANSIENTS FOR SELECTED NODES FROM FIGURE 10

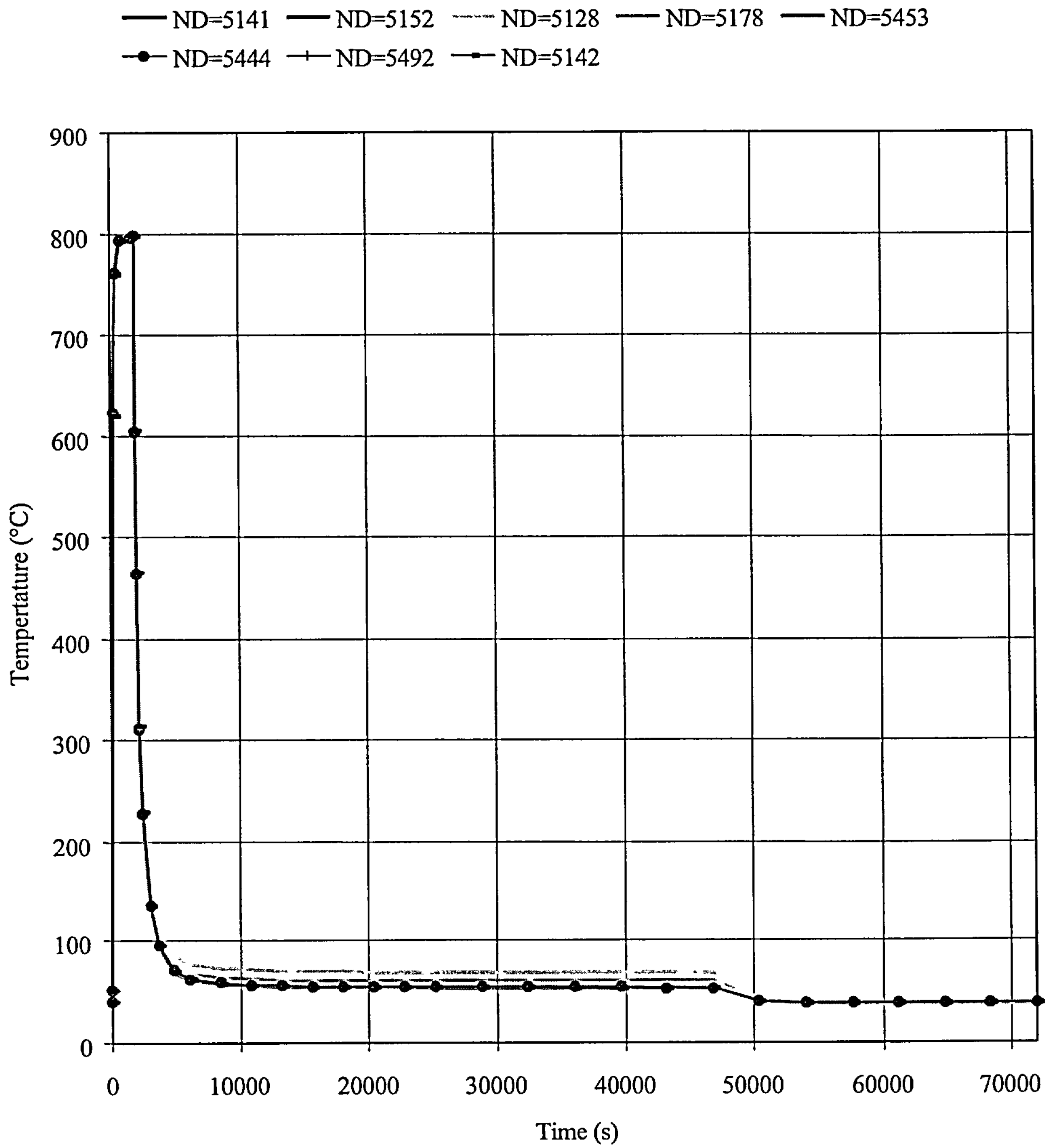


FIGURE 24: TEMPERATURE TRANSIENTS FOR SELECTED NODES FROM FIGURE 10

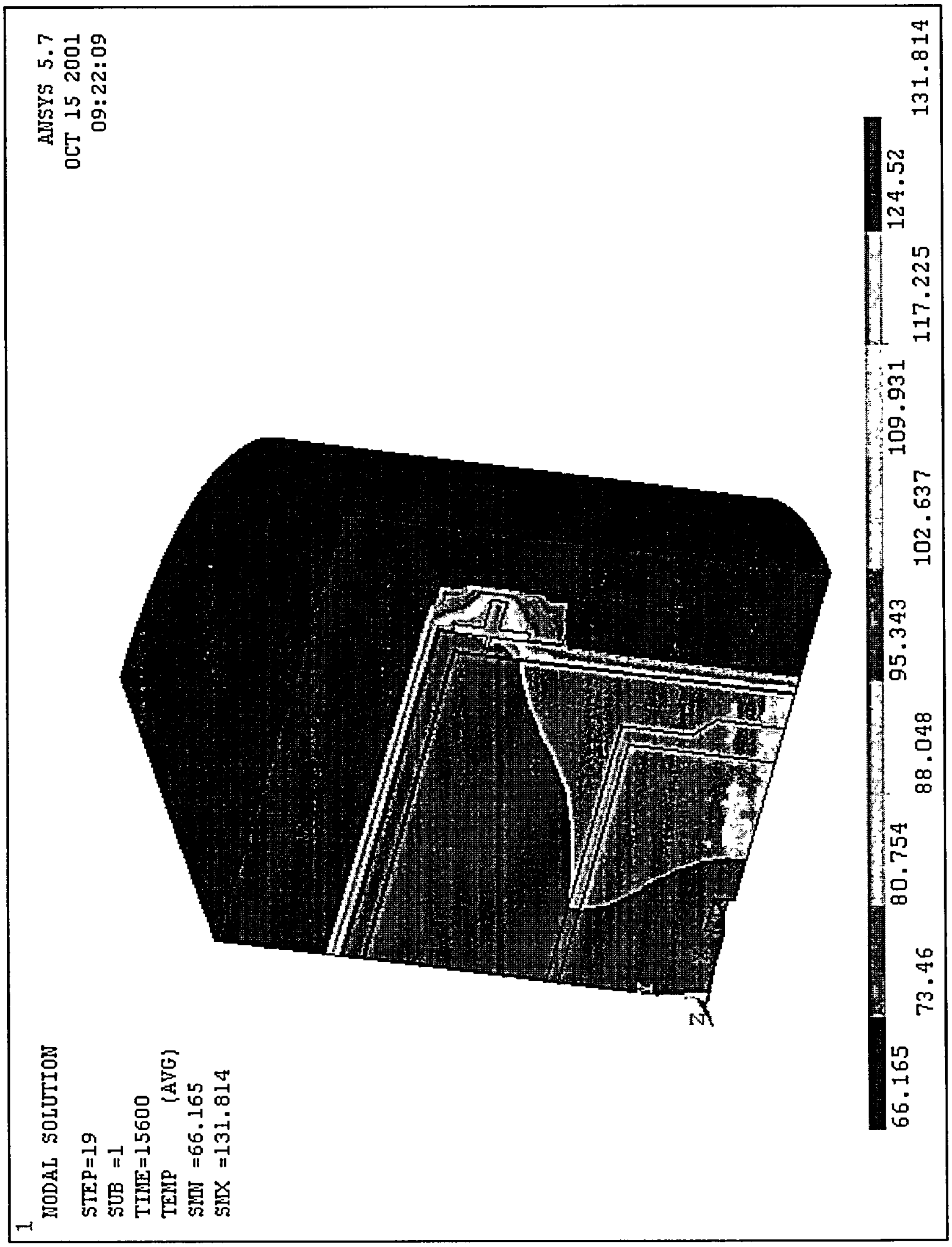


FIGURE 25: CALCULATED TEMPERATURE DISTRIBUTION IN THE OVERPACK AT TIME OF MAXIMUM LEAD TEMPERATURE (15,600 S, 4 HRS 20 MIN.)

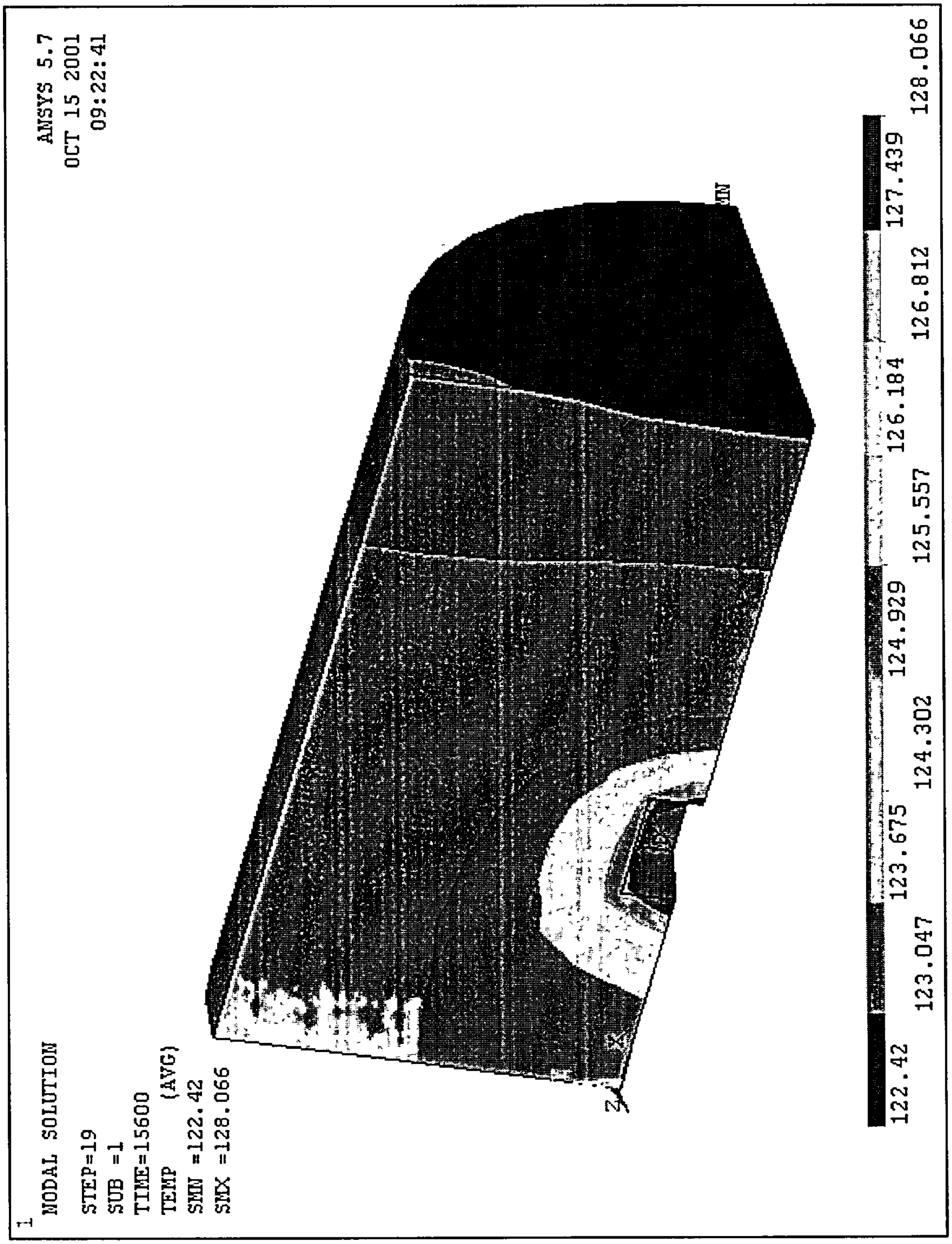


FIGURE 26: CALCULATED TEMPERATURE DISTRIBUTION IN THE LEAD ELEMENTS ONLY, AT TIME OF MAXIMUM LEAD TEMPERATURE (15,600 S, 4 HRS 20 MIN.)

Appendix A
Excerpt From Transnucleaire Report on Package Analysis [3]

5 7818

REPORT ON THE IMPLICATIONS OF THE TESTS REQUIREMENTS FOR TYPE B PACKAGINGS AND A STUDY OF PRACTICAL SOLUTIONS

EURATOM CONTRACT N° 074 - 65 - E.C.I.C.

TRANSNUCLEAIRE

11 & 11 bis Rue Christophe Colomb
Paris - 8e
Tel. 225 14 77
225 08 86
Telex 28 992

7 West 57th Street
New York, NY 10019
355 7320

170.-

3 - LEAD-STEEL JUNCTION -

a) No bond -

When fabrication is made without trying to obtain bonding between lead and outer shell, shrinkage occurs during cooling after casting due to the difference of dilatation coefficients of lead and steel.

The importance of shrinkage depends on casting methods and outer shell dimensions and materials.

With a stainless steel outer shell and adequate casting method, shrinkage is on the order of 4°/oo, i.e. for instance 2 mm at the radius for a packaging of 1 m diameter.

With a mild steel outer shell, whose dilatation coefficient is lower than for stainless steel, shrinkage may be greater.

b) Lead bonded -

Bonding can be obtained by various processes, which we will not explain here.

Let us say only that bonding can be easily achieve on an open steel wall ; it is much more difficult inside a steel vessel practically closed. It is also more difficult with stainless steel than with mild steel.

If bonding is perfect, which can be checked by ultra-sonic inspection, thermal bond should also be perfect.

This is actually obtained for instance with a plane steel wall and a certain thickness of lead bonded, the outer surface of the lead being bare.

On the other hand, our experience shows us that in the case of packagings and in spite of a perfect bonding to the outer shell, ultra-sonic checked, there is always some discrepancy between thermal test and calculations for the heat transmission through the inner shell/lead/outer shell assembly.

Compared with calculations based on a perfect thermal bonding, tests show that in fact there is a certain extra resistance to the passage of heat.

Thus, on a series of six identical cylindrical 20 ton packagings (constructed by the Société Lyonnaise de Plomberie Industrielle), an extra resistance to the passage of heat compared with calculations is found equivalent to an air gap of 0.5mm varying slightly around this value according to the packaging. Ultrasonic inspection, however, showed perfect outer shell/lead bonding.

There are a number of possible explanations :

- The calculation cannot be very accurate particularly when there is a great difference between the outer shell surface area and the inner cavity surface area. This was the case for the six packagings mentionned above.

  If the heat flux introduced in the calculation is the flux on the inner cavity, there is then good agreement between tests and calculation.

- Bonding to the outer shell has a tendency to work against hooping on the inner shell.

- Lack of homogeneity in the lead mass which is being drawn both towards the outer shell and towards the inner shell.

- Traces of oxide over a varying surface area at the outside shell/lead interface (which does not shown up with ultra-sonic controls).

We have no knowledge of the results obtained by other constructors.

c) Behavior in the thermal test -

In the case of not bonded lead, an air gap of say, 2 mm, corresponds to a temperature drop of several hundred degrees, for the initial heat fluxes involved in the thermal test.

172.-

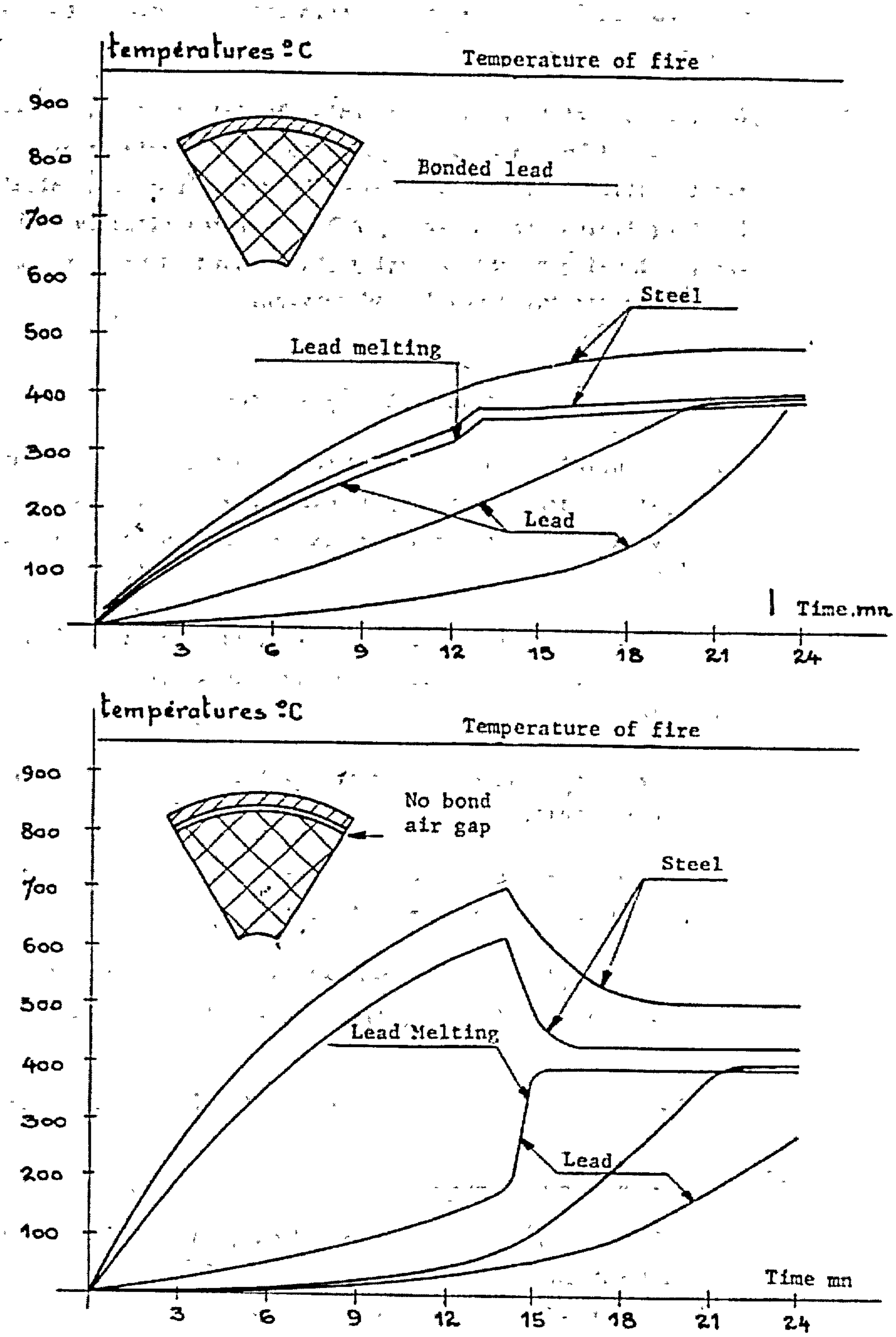

températures °C
Temperature of fire
900
800
700
600
500
400
300
200
100
Bonded lead
Steel
Lead melting
Lead
Time,mn
3
6
9
12
15
18
21
24
températures °C
Temperature of fire
900
800
700
600
500
400
300
200
100
No bond
air gap
Steel
Lead Melting
Lead
Time mn
3
6
9
12
15
18
21
24

FIG. A.2

Appendix B
Ansys Finite Element Descriptions [2]

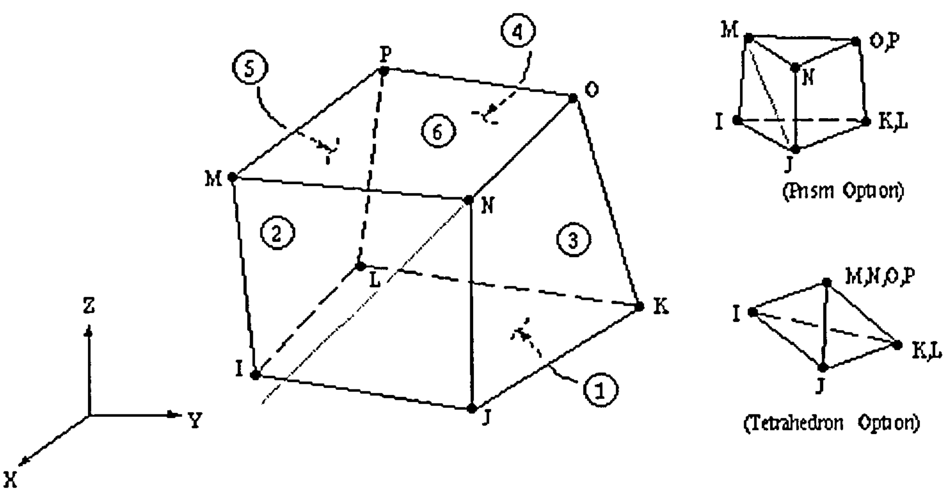
4.70 SOLID70 3-D Thermal Solid

Multiphysics	✓
Mechanical	✓
Structural	
LS-DYNA	
LinearPlus	
Thermal	✓
Emag 3-D	
Emag 2-D	
FLOTRAN	
PrepPost	✓
ED	✓

SOLID70 has a three-dimensional thermal conduction capability. The element has eight nodes with a single degree of freedom, temperature, at each node. The element is applicable to a three-dimensional, steady-state or transient thermal analysis. The element also can compensate for mass transport heat flow from a constant velocity field. If the model containing the conducting solid element is also to be analyzed structurally, the element should be replaced by an equivalent structural element (such as SOLID45). A similar thermal element, with mid-edge node capability, is described in Section 4 90 (SOLID90).

An option exists that allows the element to model nonlinear steady-state fluid flow through a porous medium. With this option, the thermal parameters are interpreted as analogous fluid flow parameters. For example, the temperature degree of freedom becomes equivalent to a pressure degree of freedom. See Section 14.70 of the *ANSYS Theory Reference* for more details about this element.

Figure 4.70-1 SOLID70 3-D Thermal Solid



4.70.1 Input Data

The geometry, node locations, and the coordinate system for this element are shown in Figure 4 70-1. The element is defined by eight nodes and the orthotropic material properties. Orthotropic material directions correspond to the element coordinate directions. The element coordinate system orientation is as described in Section 2 3. Specific heat and density are ignored for steady-state solutions. Properties not input default as described in Section 2 4.

Element loads are described in Section 2.7. Convections or heat fluxes (but not both) may be input as surface loads at the element faces as shown by the circled numbers on Figure 4 70-1.

Heat generation rates may be input as element body loads at the nodes. If the node I heat generation rate HG(I) is input, and all others are unspecified, they default to HG(I).

The nonlinear porous flow option is selected with KEYOPT(7)=1. For this option, temperature is interpreted as pressure and the absolute permeabilities of the medium are input as material properties KXX, KYY, and KZZ. Properties DENS and VISC are used for the mass density and viscosity of the fluid. Properties C and MU are used in calculating the coefficients of permeability as described in Section 14.70 of the *ANSYS Theory Reference*. Temperature boundary conditions input with the D command are interpreted as pressure boundary conditions, and heat flow boundary conditions input with the F command are interpreted as mass flow rate (mass/time).
A mass transport option is available with KEYOPT(8). With this option the velocities VX, VY, and VZ must be input as real constants (in the element coordinate system). Also, temperatures should be specified along the entire inlet boundary to assure a stable solution With mass transport, you should use specific heat (C) and density (DENS) material properties instead of enthalpy (ENTH).
A summary of the element input is given in Table 4 70-1. A general description of element input is given in Section 2 1.

Table 4.70-1 SOLID70 Input Summary

Element Name	SOLID70
Nodes	I, J, K, L, M, N, O, P
Degrees of Freedom	TEMP
Real Constants	VX, VY, VZ IF KEYOPT (8) > 0
Material Properties	KXX, KYY, KZZ, DENS, C, ENTH, VISC, MU (VISC and MU used only if KEYOPT (7) = 1. Do not use ENTH with KEYOPT(8)=1).
Surface Loads	Convections: face 1 (J-I-L-K), face 2 (I-J-N-M), face 3 (J-K-O-N), face 4 (K-L-P-O), face 5 (L-I-M-P), face 6 (M-N-O-P) Heat Fluxes: face 1 (J-I-L-K), face 2 (I-J-N-M), face 3 (J-K-O-N), face 4 (K-L-P-O), face 5 (L-I-M-P), face 6 (M-N-O-P)
Body Loads	Heat Generations:HG (I), HG (J), HG (K), HG (L), HG (M), HG (N), HG (O), HG (P)
Special Features	Birth and death.
KEYOPT(2)	0 - Evaluate film coefficient (if any) at average film temperature, (TS + TB)/2 1 - Evaluate at element surface temperature, TS 2 - Evaluate at fluid bulk temperature, TB 3 - Evaluate at differential temperature | TS-TB |
KEYOPT(4)	0 - Evaluate film coefficient (if any) at average film temperature, (TS + TB)/2 1 - Evaluate at element surface temperature, TS
KEYOPT(7)	0 - Standard heat transfer element 1 - Nonlinear steady-state fluid flow analogy element (temperature degree of freedom interpreted as pressure)
KEYOPT(8)	0 - No mass transport effects 1 - Mass transport with VX, VY, VZ

4.70.2 Output Data

The solution output associated with the element is in two forms:

- nodal temperatures included in the overall nodal solution
- additional element output as shown in Table 4 70-2

Heat flowing out of the element is considered to be positive. If KEYOPT(7)=1, the standard thermal output should be interpreted as the analogous fluid flow output. The element output directions are parallel to the element coordinate system. A general description of solution output is given in Section 2.2. See the *ANSYS Basic Analysis Procedures Guide* for ways to view results.
The following notation is used in Table 4 70-2:
A colon (:) in the Name column indicates the item can be accessed by the Component Name method [ETABLE, ESOL] (see Section 2 2 2). The O and R columns indicate the availability of the items in the file *Jobname* OUT (O) or in the results file (R), a Y indicates that the item is *always* available, a number refers to a table footnote which describes when the item is *conditionally* available, and a - indicates that the item is *not* available.

Table 4.70-2 SOLID70 Element Output Definitions

Name	Definition	O	R
EL	Element number	Y	Y
NODES	Nodes - I, J, K, L, M, N, O, P	Y	Y
MAT	Material number	Y	Y
VOLU:	Volume	Y	Y
CENT: X, Y, Z	Center location XC, YC, ZC	-	Y
HGEN	Heat generations HG(I), HG(J), HG(K), HG(L), HG(M), HG(N), HG(O), HG(P)	Y	-
TG: X, Y, Z, SUM	Thermal gradient components and vector sum at centroid	Y	Y
TF: X, Y, Z, SUM	Thermal flux (heat flow rate/cross-sectional area) components and vector sum at centroid	Y	Y
FACE	Face label	1	-
AREA	Face area	1	1
NODES	Face nodes	1	-
HFILM	Film coefficient at each node of face	1	-
TBULK	Bulk temperature at each node of face	1	-
TAVG	Average face temperature	1	1
HEAT RATE	Heat flow rate across face by convection	1	1
HEAT RATE/AREA	Heat flow rate per unit area across face by convection	1	-
HFAVG	Average film coefficient of the face	-	1
TBAVG	Average face bulk temperature	-	1
HFLXAVG	Heat flow rate per unit area across face caused by input heat flux	-	1
HFLUX	Heat flux at each node of face	1	-
PRESSURE GRAD	Total pressure gradient and its X, Y, and Z components	2	-
MASS FLUX	Mass flow rate per unit cross-sectional area	2	-
FLUID VELOCITY	Total fluid velocity and its X, Y, and Z components	2	-

1. Output if a surface load is input
2. Output if KEYOPT(7)=1

Table 4 70-3 lists output available through the ETABLE command using the Sequence Number method. See Chapter 5 of the *ANSYS Basic Analysis Procedures Guide* and Section 2 2 2 2 of this manual for more information. The following notation is used in Table 4 70-3:

Name - output quantity as defined in the Table 4 70-2

Item - predetermined *Item* label for ETABLE command

FC*n* - sequence number for solution items for element Face *n*

Table 4.70-3 SOLID70 Item and Sequence Numbers for the ETABLE and ESOL Commands

Name	Item	FC1	FC2	FC3	FC4	FC5	FC6
AREA	NMISC	1	7	13	19	25	31
HFAVG	NMISC	2	8	14	20	26	32
TAVG	NMISC	3	9	15	21	27	33
TBAVG	NMISC	4	10	16	22	28	34
HEAT RATE	NMISC	5	11	17	23	29	35
HFLXAVG	NMISC	6	12	18	24	30	36

4.70.3 Assumptions and Restrictions

The element must not have a zero volume. This occurs most frequently when the element is not numbered properly. Elements may be numbered either as shown in Figure 4 70-1 or may have the planes IJKL and MNOP interchanged. A prism or tetrahedron shaped element may be formed by defining duplicate node numbers as described in Section 2 8

The specific heat and enthalpy are evaluated at each integration point to allow for abrupt changes (such as for melting) within a coarse grid. If the thermal element is to be replaced by a SOLID45 structural element with surface stresses requested, the thermal element should be oriented such that face IJNM and/or face KLPO is a free surface.

A free surface of the element (*i e.*, not adjacent to another element and not subjected to a boundary constraint) is assumed to be adiabatic. Thermal transients having a fine integration time step and a severe thermal gradient at the surface will also require a fine mesh at the surface.
If KEYOPT(8)>0, unsymmetric matrices are produced.

4.70.4 Product Restrictions

When used in the product(s) listed below, the stated product-specific restrictions apply to this element in addition to the general assumptions and restrictions given in the previous section.

ANSYS/Thermal

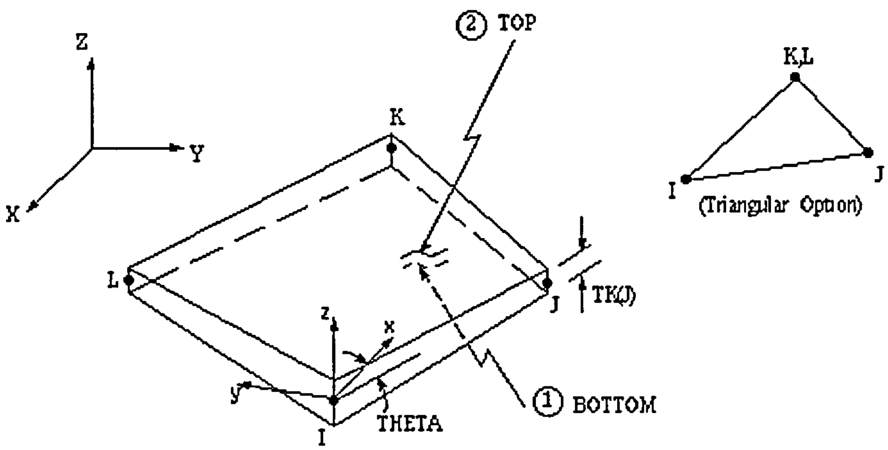
- This element does not have the mass transport or fluid flow options KEYOPT(7) and KEYOPT(8) can only be set to 0 (default)
- The VX, VY, and VZ real constants are not applicable.
- The VISC and MU material properties are not applicable.
- The element does not have the birth and death feature.

4.57 SHELL57 Thermal Shell

Multiphysics	✓
Mechanical	✓
Structural	
LS-DYNA	
LinearPlus	
Thermal	✓
Emag 3-D	
Emag 2-D	
FLOTRAN	
PrepPost	✓
ED	✓

SHELL57 is a three-dimensional element having in-plane thermal conduction capability. The element has four nodes with a single degree of freedom, temperature, at each node. The conducting shell element is applicable to a three-dimensional, steady-state or transient thermal analysis. See Section 14.57 of the *ANSYS Theory Reference* for more details about this element.
If the model containing the conducting shell element is to be analyzed structurally, the element should be replaced by an equivalent structural element (such as SHELL63). If both in-plane and transverse conduction are needed, a thermal solid element (such as SOLID70 or SOLID90) should be used.

Figure 4.57-1 SHELL57 Thermal Shell



Note—x and y are in the plane of the element

4.57.1 Input Data

The geometry, node locations, and coordinate systems for this element are shown in Figure 4 57-1. The element is defined by four nodes, four thicknesses, a material direction angle, and the material properties.
The element may have variable thickness. The thickness is assumed to vary smoothly over the area of the element, with the thickness input at the four nodes. If the element has a constant thickness, only TK(I) need be input. If the thickness is not constant, all four thicknesses must be input.
Orthotropic material directions correspond to the element coordinate directions. The element coordinate system orientation is as described in Section 2 3. Properties not input default as described in Section 2 4. The element x-axis may be rotated by an angle THETA (in degrees).
Element loads are described in Section 2 7. Convections may be input as surface loads at the element faces as shown by the circled numbers on Figure 4 57-1.
Heat generation rates may be input as element body loads at the nodes. If the node I heat generation rate HG(I) is input, and all others are unspecified, they default to HG(I).
A summary of the element input is given in Table 4 57-1. A general description of element input is given in Section 2 1.

Table 4.57-1 SHELL 57 Summary Input

Element Name	SHELL57
Nodes	I, J, K, L
Degrees of Freedom	TEMP
Real Constants	TK (I), TK (J), TK (K), TK (L), THETA (TK (J), TK (K), TK (L) default to TK (I))
Material Properties	KXX, KYY, DENS, C, ENTH
Surface Loads	Convections: face 1 (I-J-K-L) (bottom, -Z side), face 2 (I-J-K-L) (top, +Z side) Heat Fluxes: face 1 (I-J-K-L) (bottom, -Z side) face 2 (I-J-K-L) (top, +Z side)
Body Loads	Heat Generations: HG (I), HG (J), HG (K), HG (L)
Special Features	Birth and death
KEYOPT(2)	0 - Evaluate film coefficient (if any) at average film temperature, (TS + TB)/2 1 - Evaluate at element surface temperature, TS 2 - Evaluate at fluid bulk temperature, TB 3 - Evaluate at differential temperature, |TS - TB|

4.57.2 Output Data

The solution output associated with the element is in two forms:

- nodal temperatures included in the overall nodal solution
- additional element output as shown in Table 4.57-2

Heat flowing out of the element is considered to be positive. The element output directions are parallel to the element coordinate system. A general description of solution output is given in Section 2.2. See the *ANSYS Basic Analysis Procedures Guide* for ways to view results. The following notation is used in Table 4.57-2:

A colon (:) in the **Name** column indicates the item can be accessed by the Component Name method **[ETABLE, ESOL]** (see Section 2.2.2). The **O** and **R** columns indicate the availability of the items in the file *Jobname*.OUT (**O**) or in the results file (**R**), a Y indicates that the item is *always* available, a number refers to a table footnote which describes when the item is *conditionally* available, and a - indicates that the item is *not* available.

Table 4.57-2 SHELL 57 Element Output Definitions

Name	Definition	O	R
EL	Element number	Y	Y
NODES	Nodes - I, J, K, L	Y	Y
MAT	Material number	Y	Y
AREA	Convection face area	Y	Y
CENT: X, Y, Z	Center location XC, YC, ZC	-	Y
HGEN	Heat generations HG(I), HG(J), HG(K), HG(L)	Y	-
TG: X, Y, SUM	Thermal gradient components and vector sum at centroid	Y	Y
TF: X, Y, SUM	Thermal flux (heat flow rate/cross-sectional area) components and vector sum at centroid	Y	Y
FACE	Face label	1	1
AREA	Face area	1	1
NODES	Face nodes	1	1
HFILM	Film coefficient	1	1
TAVG	Average face temperature	1	1
TBULK	Fluid bulk temperature	1	-
HEAT RATE	Heat flow rate across face by convection	1	1
HFAVG	Average film coefficient of the face	-	1
TBAVG	Average face bulk temperature	-	1
HFLXAVG	Heat flow rate per unit area across face caused by input heat flux	-	1
HEAT RATE/AREA	Heat flow rate per unit area across face by convection	1	-
HEAT FLUX	Heat flux at each node of face	1	-

1. If a surface load is input

Table 4 57-3 lists output available through the ETABLE command using the Sequence Number method See Chapter 5 of the *ANSYS Basic Analysis Procedures Guide* and Section 2 2 2 2 of this manual for more information The following notation is used in Table 4 57-3:

Name - output quantity as defined in the Table 4 57-2

Item - predetermined *Item* label for ETABLE command

Table 4.57-3 SHELL57 Item and Sequence Numbers for the ETABLE and ESOL Commands

Name	Item	BOT	TOP
AREA	NMISC	1	7
HFAVG	NMISC	2	8
TAVG	NMISC	3	9
TBAVG	NMISC	4	10
HEAT RATE	NMISC	5	11
HFLXAVG	NMISC	6	12

4.57.3 Assumptions and Restrictions

Zero area elements are not allowed. This occurs most frequently when the elements are not numbered properly. The element must not taper down to a zero thickness at any corner. The four nodes defining the element should lie in an exact flat plane; however, a small out-of-plane tolerance is permitted so that the element may have a slightly warped shape. A warning message will be produced if an element is more than slightly warped (i.e., if any of the three global Cartesian components of any corner normal differs from the corresponding component of the element normal by more than .00001). A triangular element may be formed by defining duplicate K and L node numbers as described in Section 2 8.

4.57.4 Product Restrictions

When used in the product(s) listed below, the stated product-specific restrictions apply to this element in addition to the general assumptions and restrictions given in the previous section.

ANSYS/Thermal

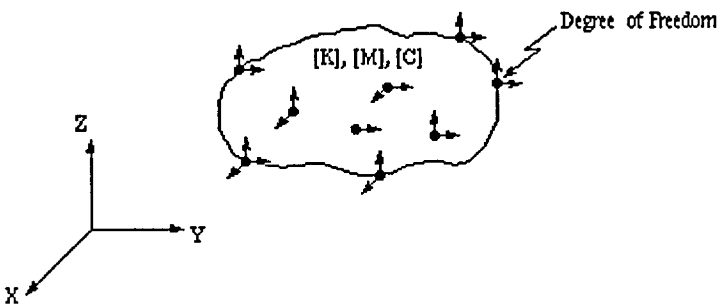
The birth and death special feature is not allowed.

4.50 MATRIX50 Superelement

Multiphysics	✓
Mechanical	✓
Structural	✓
LS-DYNA	
LinearPlus	
Thermal	✓
Emag 3-D	
Emag 2-D	
FLOTRAN	
PrepPost	✓
ED	✓

MATRIX50 is a group of previously assembled ANSYS elements that is treated as a single element. The superelement, once generated, may be included in any ANSYS model and used in any analysis type for which it is applicable. The superelement can greatly decrease the cost of many analyses. Once the superelement matrices have been formed, they are stored on a file and can be used in other analyses as any other ANSYS element. Multiple load vectors may also be stored with the superelement matrices, thereby allowing various loading options. See Section 14.50 of the *ANSYS Theory Reference* for more details about this element.

Figure 4.50-1 MATRIX50 Superelement



4.50.1 Input Data

The superelement, which is a mathematical matrix representation of an arbitrary structure, has no fixed geometrical identity and is conceptually shown in Figure 4 50-1. Any analysis using a superelement as one of its element types is called a superelement use pass (or run). The degrees of freedom are the master degrees of freedom specified during the generation pass.
The element name is MATRIX50 (the number 50 or the name MATRIX50 should be input for the variable *ENAME* on the ET command). The SE command is used to define a superelement. SE reads the superelement from *Jobname*.SUB (defaults to file.SUB) in the working directory. The material number [MAT] is only used when material dependent damping [MP,DAMP] is present. The real constant table number [REAL] is not used. The appropriate element type number [TYPE], however, must be entered.
An element load vector is generated along with the element at each load step of the superelement generation pass. Up to 31 load vectors may be generated. Load vectors may be proportionately scaled in the use pass. The scale factor is input on the element surface load command [SFE]. The load label is input as SELV, the load key is the load vector number, and the load value is the scale factor. The load vector number is determined from the load step number associated with the superelement generation. If a superelement load vector has a zero scale factor (or is not scaled at all), this load vector is not included in the analysis. Any number of load vector-scale factor combinations may be used in the use pass
The KEYOPT(1) option is for the special case where the superelement is to be used with a T^4 nonlinearity, such as for radiation. The File.SUB for this case may be constructed directly by the user or may be generated by AUX12, the radiation matrix generator.
A summary of the element input is given in Table 4 50-1. A general description of element input is given in Section 2 1.

Table 4.50-1 MATRIX50 Input Summary

Element Name	MATRIX50
Nodes	None input (supplied by element)
Degrees of Freedom	As determined from the included element types (a mixture of multi-field degrees of freedom is not allowed)
Real Constants	None
Material Properties	DAMP
Surface Loads	Surface load effects may be applied through a generated load vector and scale factors. Use the SFE command to supply scale factors with *LAB* = SELV, *LKEY* = load vector number (31 maximum), and *VAL1* = scale factor.
Body Loads	Body loads may be applied through a generated load vector and scale factors as described for surface loads.
Special Features	Radiation (if KEYOPT(1) = 1), Large rotation
KEYOPT(1)	0 - Normal substructure 1 - Special radiation substructure
KEYOPT(6)	0 - Do not print nodal forces 1 - Print nodal forces

4.50.2 Output Data

Displacements and forces may be printed for each (master) degree of freedom in a structural superelement in the "use" pass. The nodal forces may be output if KEYOPT(6)=1. The stress distribution within the superelement and the expanded nodal displacements can be obtained from a subsequent stress pass. In addition to the database and substructure files from the generation run, File.DSUB must be saved from the superelement "use" pass and input to the expansion pass (if an expansion pass is desired) A general description of solution output is given in Section 2 2.

4.50.3 Assumptions and Restrictions

A superelement may contain elements of any type. See the D command for degree of freedom field groups. Superelements of different field types may be mixed within the use run. The nonlinear portion of any element included in a superelement will be ignored and any bilinear element will maintain its initial status throughout the analysis. Superelements may contain other superelements
The PCG solver does not support MATRIX50 elements.
The relative locations of the superelement attachment points in the nonsuperelement portion of the model (if any) should match the initial superelement geometry.
If the superelement contains a mass matrix, acceleration [ACEL] defined in the use run will be applied to the superelement. If a load vector containing acceleration effects is also applied in the use run, *both* accelerations (the ACEL command and the load vector) will be applied to the superelement. Similarly, if the superelement contains a damping matrix (as specified in the generation run) and α and β damping multipliers [ALPHA and BETA] are defined in the use run, additional damping effects will be applied to the superelement. Care should be taken to avoid duplication of acceleration and damping effects.
Pressure and thermal effects may be included in a superelement only through its load vectors.
The dimensionality of the superelement correspond to the maximum dimensionality of any element used in its generation Two-dimensional superelements should only be used in two-dimensional analyses, and three-dimensional superelements in three-dimensional analyses.
See Section 17 6 of the *ANSYS Theory Reference* for a discussion of the substructure matrix assembly procedure

4.50.4 Product Restrictions

When used in the product(s) listed below, the stated product-specific restrictions apply to this element in addition to the general assumptions and restrictions given in the previous section.

ANSYS/Structural

KEYOPT(1)=0

ANSYS/Thermal

- This element may be used as a radiation substructure only. KEYOPT(1) defaults to 1 instead of 0 and cannot be changed.
- The DAMP material property, surface loads, and body loads are not applicable.
- The large rotation special feature is not applicable.

Chapter 4: Radiation

4.1 What Is Radiation?

Radiation is the transfer of energy via electromagnetic waves. The waves travel at the speed of light, and energy transfer requires no medium. Thermal radiation is just a small band on the electromagnetic spectrum. Because the heat flow that radiation causes varies with the fourth power of the body's absolute temperature, radiation analyses are highly nonlinear.

4.2 Analyzing Radiation Problems

The ANSYS program provides three methods for radiation analysis, each meant for a different situation:

- You can use LINK31, the radiation link element, for simple problems involving radiation between two points or several pairs of points.
- You can use the surface effect elements, SURF19, SURF22, SURF151, and SURF152 for radiation between a surface and a point.
- Use the AUX12 radiation matrix generator for more generalized radiation problems involving two or more surfaces. (Only the ANSYS/Multiphysics, ANSYS/Mechanical, and ANSYS/Thermal programs offer AUX12.)

You can use the three radiation analysis methods for either transient or steady-state thermal analyses. Radiation is a nonlinear phenomenon, so you will need an iterative solution to reach a converged solution.
The unit of temperature also plays an important role in radiation analysis; you perform radiation calculations in absolute temperature units. Therefore, if you define your model data in terms of degrees Fahrenheit or degrees Celsius, you must specify a temperature offset: 460° for the Fahrenheit system and 273° for the Centigrade system
To specify a temperature offset, use either of the following:

Command(s):
TOFFST

GUI:
Main Menu>Preprocessor>Loads>Analysis Options
Main Menu>Solution>Analysis Options

4.3 Using LINK31, the Radiation Link Element

LINK31 is a two-node, nonlinear line element that calculates the heat flow caused by radiation between two points. The element requires you to specify, in the form of real constants.

- An effective radiating surface area
- Form factor
- Emissivity
- The Stefan-Boltzmann constant.

Limit your use of the LINK31 analysis method to simple cases where you know, or can calculate easily by hand, the radiation form factors.

4.4 Using the Surface Effect Elements

A convenient way to model radiation between a surface and a point is to use surface effect elements superimposed on surfaces that emit or receive radiation. ANSYS provides such elements: SURF19 and SURF151 for two-dimensional models, and SURF22 and SURF152 for three-dimensional models The element option KEYOPT(9) activates radiation for these elements The form factor can be specified as a real constant (defaults to 1) using KEYOPT(9)=1, or you can calculate a cosine effect (using KEYOPT(9)=2 or 3) from the basic element orientation and the extra node location.

4.5 Using AUX12, the Radiation Matrix Generator

Offered in the ANSYS/Multiphysics, ANSYS/Mechanical, and ANSYS/Thermal programs only, this method works for generalized radiation problems involving several surfaces receiving and emitting radiation. The method involves generating a matrix of form factors (view factors) between radiating surfaces and using the matrix as a superelement in the thermal analysis You also can include hidden or partially hidden surfaces, as well as a "space node" that can absorb radiation energy.
The AUX12 analysis method consists of three steps:

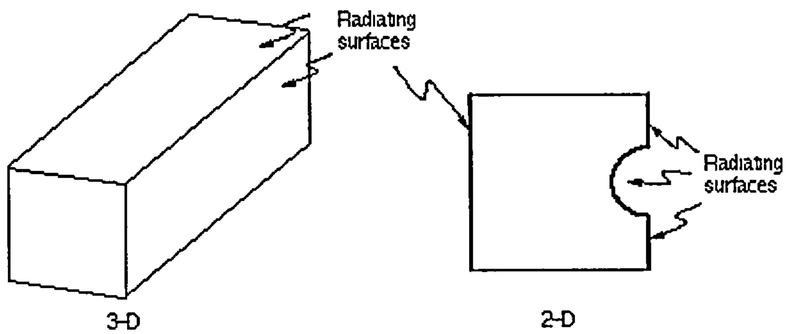
1. Define the radiating surfaces.
2. Generate the radiation matrix.
3. Use the radiation matrix in the thermal analysis.

4.5.1 Defining the Radiating Surfaces

To define the radiating surfaces, you create a superimposed mesh of LINK32 elements in 2-D models and SHELL57 elements in 3-D models. To do so, perform the following tasks:

1. Build the thermal model in the preprocessor (PREP7) Radiating surfaces do not support symmetry conditions, therefore models involving radiating surfaces can not take advantage of geometric symmetry and must therefore be modeled completely. The radiating surfaces usually are *faces* of a 3-D model and *edges* of a 2-D model, as shown below:

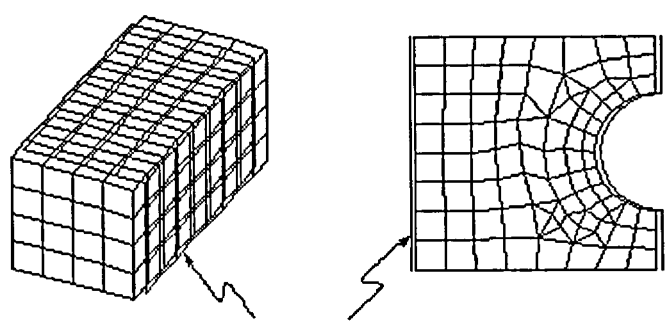
Figure 4-1 Radiating surfaces for 3-D and 2-D models



2. Superimpose the radiating surfaces with a mesh of SHELL57 elements in 3-D models or LINK32 elements in 2-D models, as shown in the graphic below. The best way to do this is to first create a subset of the surface nodes, and then generate the surface elements using one of the following

Command(s):
ESURF
GUI:
Main Menu>Preprocessor>Create>Elements>Surf Effect>Extra Node
Main Menu>Preprocessor>Create>Elements>Surf Effect>No extra Node
Make sure to first activate the proper element type for the surface elements. Also, if the surfaces are to have different emissivities, assign different material reference numbers before creating the elements

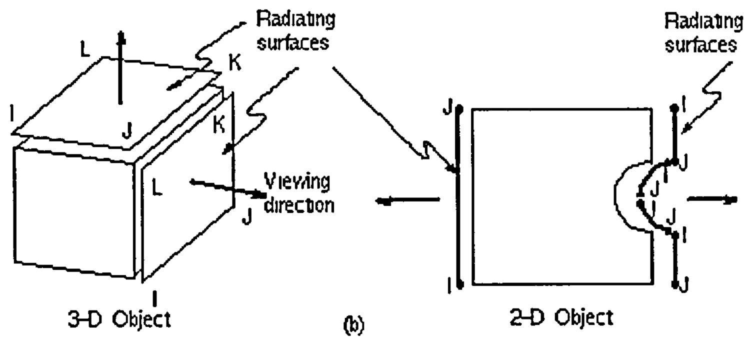
Figure 4-2 Superimposing elements on radiating surfaces



Caution· *Radiating surface mesh of* SHELL57 *or* LINK32 *elements must match (node for node) the underlying solid element mesh If it does not match, the resulting thermal solution will be incorrect*

The orientation of the superimposed elements is important. AUX12 assumes that the "viewing" direction (that is, the direction of radiation) is along $+Z_e$ for SHELL57 elements and along $+Y_e$ for LINK32 elements (where *e* denotes the outward normal direction of the element coordinate system) Therefore, you must mesh the superimposed elements so that the radiation occurs from (or to) the proper face. The order in which the element's nodes are defined controls the element orientation, as shown below:

Figure 4-3 Orienting the superimposed elements



3. Define a space node, which simply is a node that absorbs radiant energy not received by other surfaces in the model. Location of this node is not important. An open system usually requires a space node. However, *you should not specify a space node for a closed system.*

4.5.2 Generating the AUX12 Radiation Matrix

Calculating the radiation matrix requires the following inputs:

- Nodes and elements that make up the radiating surfaces
- Model dimensionality (2-D or 3-D)
- Emissivity and Stefan-Boltzmann constant
- The method used to calculate the form factors (hidden or visible)
- A space node, if desired.

To generate the matrix, perform these steps:

1. Enter AUX12 using one of these methods

Command(s):
/AUX12

GUI
Main Menu>Radiation Matrix

2. Select the nodes and elements that make up the radiation surfaces. An easy way to do this is to select elements by type and then select all attached nodes. To perform these tasks, use the GUI path **Utility Menu> Select>Entities** or the commands ESEL,*S,TYPE* and NSLE. If you have defined a space node, remember to select it.

3. Specify whether this is a 2-D model or a 3-D model, using either of the following

Command(s):
GEOM

GUI:
Main Menu>Radiation Matrix>Other Settings

AUX12 uses different algorithms to calculate the form factors for 2-D and 3-D models respectively. AUX12 assumes a 3-D model by default. Two-dimensional models may be either planar (NDIV value =0), or axisymmetric (NDIV value > 0), with planar as the default. Axisymmetric models are expanded internally to a 3-D model, with NDIV representing the number of axisymmetric sections For example, setting NDIV to 10 indicates 10 sections, each spanning 36 degrees.

4. Define the emissivity using either method shown below. Emissivity defaults to unity (1.0)

Command(s):
EMIS

GUI:
Main Menu>Radiation Matrix>Emissivities

5. Define the Stefan-Boltzmann constant using either method shown below. The Stefan-Boltzmann constant defaults to 0 119E-10 Btu/hr-in^2-R^4. (In S.I. Units, the constant has the value 5.67E-8 W/m^2-K^4.)

Command(s):
STEF

GUI.
Main Menu>Radiation Matrix>Other Settings

6. Specify how to calculate form factors, using either of the following·

Command(s)·
VTYPE

GUI:
Main Menu>Radiation Matrix>Write Matrix
You can choose between the hidden and non-hidden methods:

- The non-hidden method calculates the form factors from every element to every other element regardless of any blocking elements.
- The hidden method (default) first uses a hidden-line algorithm to determine which elements are "visible" to every other element. (A "target" element is visible to a "viewing" element if their normals point toward each other and there are no blocking elements.) Then, form factors are calculated as follows:
- Each radiating or "viewing" element is enclosed with a unit hemisphere (or a semicircle in 2-D).
- All target or "receiving" elements are projected onto the hemisphere or semicircle.
- To calculate the form factor, a predetermined number of rays are projected from the viewing element to the hemisphere or semicircle. Thus, the form factor is the ratio of the number of rays incident on the projected surface to the number of rays emitted by the viewing element. In general, accuracy of the form factors increases with the number of rays. You can increase the number of rays via the NZONE field on the VTYPE command or the **Write Matrix** menu option, both indicate the number of radial sampling zones.

7. If necessary, designate the space node using either of the methods shown below:

Command(s).
SPACE

GUI:
Main Menu>Radiation Matrix>Other Settings

8. Use either the WRITE command or the **Write Matrix** menu option to write the radiation matrix to the file *Jobname*.SUB. If you want to write more than one radiation matrix, use a separate filename for each matrix. To print your matrices, issue the command MPRINT,1 before issuing the WRITE command.

9. Reselect all nodes and elements using either of the following:

Command(s):
ALLSEL

GUI:
Utility Menu>Select>Everything
You now have the radiation matrix written as a superelement on a file.

4.5.3 Using the Radiation Matrix in the Thermal Analysis

After writing the radiation matrix, re-enter the ANSYS preprocessor (PREP7) and read the matrix in as a superelement To do so, perform these steps:

1. Re-enter the preprocessor using one of these methods·
Command(s):
/PREP7
GUI:
Main Menu>Preprocessor
Specify MATRIX50 (the superelement) as one of the element types.

2. Switch the element type pointer to the superelement using either of the following·
Command(s)·
TYPE
GUI:
Main Menu>Preprocessor>-Modeling-Create>Elements>Elem Attributes

3. Read in the superelement matrix using one of these methods·
Command(s):
SE
GUI·
Main Menu>Preprocessor>-Modeling-Create>Elements> -Superelements-From .SUB File

4. Either unselect or delete the superimposed mesh of SHELL57 or LINK32 elements, using either of the following:
Command(s):
EDELE
GUI:
Main Menu>Preprocessor>-Modeling-Delete>Elements
(The thermal analysis does not require these elements.)

5. Exit from the preprocessor and enter the SOLUTION processor.

6. Assign the known boundary condition to the space node using either of the following:
Command(s):
D, F
GUI:
Main Menu>Solution >-Loads-Apply...(etc.)
This boundary typically is a temperature (such as ambient temperature), but also may be a heat flow. The boundary condition value should reflect the actual environmental conditions being modeled.

7. Proceed with the thermal analysis as explained in the other chapters of this manual.

4.6 Recommendations for Using Space Nodes

Although modeling radiation does not always require a space node, the decision to or not to use one can affect the accuracy of your thermal analysis results. Keep the following recommendations about space node usage in mind as you build your model

4.6.1 Considerations for the Non-hidden Method

The non-hidden method of form factor calculation usually is accurate enough for any system without requiring special attention to space nodes Generally, you *should not* specify a space node for a closed system, but you *should* specify one for an open system Only one situation requires special attention· when modeling an open system which includes gray body radiation (emissivity is less than 1), you *must* use a space node to ensure accurate results.

4.6.2 Considerations for the Hidden Method

For the hidden method of form factor calculation, the accuracy of the form factor calculations within AUX12 can affect the accuracy of the radiation calculated to the space node. Because inaccuracies in the calculations accumulate at the space node, the relative error in the space node form factor can be exaggerated in a closed or nearly closed system.
When using the hidden method, you may need to increase the number of rays used in the form factor calculation and to refine the mesh in order to make the form factors more accurate. If this is not possible, consider the following tips when defining the space node:

- For a closed system in which all radiating surfaces form an enclosure and do not radiate to space, do not use a space node.
- If the nature of the problem makes it acceptable to simulate radiation between the radiating surfaces only (ignoring radiation to space), then do not specify a space node. This approach is valid only when modeling black body radiation (where emissivity = 1).
- For a nearly closed system, if you must account for radiation to space, then mesh the opening and constrain the temperature of the nodes in the opening to the temperature of space. The form factor to space will then be calculated explicitly and more accurately
- For an open system where there are significant losses to space, you can use a space node (with a specified boundary condition) to capture the lost radiation with acceptable accuracy using moderate mesh refinement and a moderate number of rays

4.7 General Guidelines for AUX12

Below are some general guidelines for using the AUX12 approach to radiation analysis:

- The non-hidden method should be used if and only if all the radiating surfaces see each other fully. If the non-hidden method is used for cases where *any* blocking effect exists, there will be significant inaccuracies in view factor calculations, and the subsequent thermal analysis results can be physically inaccurate, or the problem might not even converge.
- The hidden method requires significantly longer computer time than the non-hidden method. Therefore, use it only if blocking surfaces are present or if surfaces cannot be grouped.
- In some cases, you may be able to group radiating surfaces so that each group is isolated completely from the other groups in terms of radiation heat transfer. In such cases, you can save significant time by creating a separate radiation matrix for each group using the non-hidden method. (This is true so long as no blocking effects exist within a group.) You can do this by selecting the desired group of radiating surfaces before writing the matrix.
- For the hidden method, increasing the number of rays usually produces more accurate form factors
- For both hidden and non-hidden methods, the finer the mesh of the radiating surface elements, the more accurate are the form factors. However, when hidden method is used, it is particularly important to have a fairly refined mesh in order to obtain the same level of accuracy in view factor computation as the non-hidden method. Event though increasing the number of rays used (controlled by NZONE argument of the VTYPE command) helps in accuracy, for a coarse mesh, increasing NZONE to even its maximum limit might not yield an accurate solution for the hidden method.
- For axisymmetric models, about 20 axisymmetric sectors provide reasonably accurate form factors. Elements should have reasonable aspect ratios whey they are expanded to a 3-D model
- LINK32 elements, which are used as superimposed radiation surface elements in 2-D planar or axisymmetric models, do not directly support the axisymmetric option. In axisymmetric models, therefore, be sure to delete (or unselect) them before doing the thermal analysis.

Theoretically, the summation of view factor from any radiating surface to all other radiating surfaces should be 1.0 for a closed system. This is printed as ***** FORM FACTORS ***** TOTAL= *Value* for each radiating surface if the view factors for radiating surfaces are printed using the MPRINT,1 command. For open systems, the summation should always be less than 1.0. One way of checking whether the view factor calculations are correct or not is to use the MPRINT,1 command, and check if the summation of view factors for any radiating surface exceeds 1.0. This can happen if the non-hidden method is inadvertently used for calculating view factors between radiating surfaces with blocking effects

Appendix C
Internal Air Space Heat Transfer Calculations

EFFECTIVE K TO ACCOUNT FOR CONVECTION ACROSS AIR SPACE

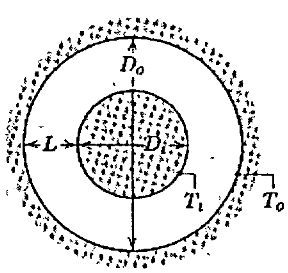
Free convection heat transfer across the air space between the Gammacell-40 and the inner wall of the overpack can be represented by an effective thermal conductivity, k_{eff}, which is the thermal conductivity that a stationary fluid should have to transfer the same amount of heat as the moving fluid [4]. The air space is approximated as the annular space between long concentric cylinders or concentric spheres. The correlation for k_{eff} is then of the form:

$$\frac{k_{eff}}{k} = 0.386\left(\frac{\Pr}{0.861+\Pr}\right)^{1/4} \left(Ra_c^*\right)^{1/4}$$

where, k is the thermal conductivity of the fluid at the film temperature,
Pr is the Prandtl number for the fluid at the film temperature, and

$$Ra_c^* = \frac{[\ln(Do/Di)]^4}{L^3\left(Di^{-3/5}+Do^{-3/5}\right)^5} Ra_L \quad \text{and } 10^2 < Ra_c^* < 10^7.$$

where Di, Do and L are defined in the following figure,



and,

$$Ra_L = \frac{g\beta(Ti-To)L^3}{\nu\alpha}$$

where, g is the acceleration due to gravity = 9.8 m/s^2,
β is the inverse of the film temperature in degrees Kelvin,
ν is the kinematic viscosity of the fluid at the film temperature,
α is the thermal diffusivity of the fluid at the film temperature,
Ti and To are the temperature of the surfaces as defined in the figure above, and
the film temperature, T = (Ti + To)/2.

EFFECTIVE K UNDER STEADY STATE CONDITIONS

Under steady state conditions for Load Cases 1 through 5 (Sections 5.1 through 5.5, respectively), Ti is the temperature measured on the outside of the Gammacell-220, while To is the temperature measured on the inside wall of the overpack. From the experimental measurements, Ti ≅ 27°C and To ≅ 26°C.

Therefore, the film temperature, T = (27+26)/2 = 26.5°C, and the required air properties are [4],

β = 1/(26.5+273) = 0.0033 K^{-1}, k = 0.026 W/m°C, ν = 15.9x10-6 m^2/s, α = 26.3x10-6 m^2/s, and Pr = 0.707.

The outer diameter of the Gammacell-40 lead casing, Di = 16.2 in = 0.41 m.

The diameter to the inside wall of the overpack, Do, is the distance from the center of the Gammacell-40 to the inner overpack wall multiplied by two.
This yields, Do = 17.5*2 = 35 in = 0.89 m.

The distance L is then, (Do – Di)/2 = (0.89-0.41)/2 = 0.24 m.

From the equations in the previous section,

$$Ra_L = \frac{9.81*0.0033*(27-26)(0.24)^3}{15.9x10^{-6}*26.3x10^{-6}} = 1.07x10^6$$

$$Ra_c^* = \frac{[\ln(0.89/0.41)]^4}{(0.24)^3\left((0.41)^{-3/5}+(0.89)^{-3/5}\right)^5}*1.07x10^6 = 1.68x10^5$$

$$\frac{k_{eff}}{k} = 0.386\left(\frac{0.707}{0.861+0.707}\right)^{1/4}\left(1.68x10^5\right)^{1/4} = 6.4$$

k_{eff} is then: $$k_{eff} = 6.4*0.026 = 0.2 \quad W/m°C$$

EFFECTIVE K UNDER REGULATORY FIRE CONDITIONS

Under regulatory fire conditions for Load Case 5 (Section 5.5), Ti is the temperature on the outside of the Gammacell-40, while To is the temperature on the inside wall of the overpack. These temperatures are conservatively estimated as, Ti = 27°C (steady state temperature) and To = 800°C (fire temperature).

Therefore, the film temperature, T = (27+800)/2 = 414°C, and the required air properties are [4],

β = 1/(414+273) = 0.0015 K^{-1}, k = 0.052 W/m°C, ν = 68.0x10-6 m^2/s, α = 98.0x10-6 m^2/s, and Pr = 0.7.

The dimensions Do, Di and L are as in the previous section.

From the previous equations,

$$Ra_L = \frac{9.81*0.0015*(800-27)(0.24)^3}{68.0x10^{-6}*98.0x10^{-6}} = 2.36x10^7$$

$$Ra_c^* = \frac{[\ln(0.89/0.41)]^4}{(0.24)^3((0.41)^{-3/5}+(0.89)^{-3/5})^5} * 2.36x10^7 = 3.71x10^6$$

$$\frac{k_{eff}}{k} = 0.386\left(\frac{0.7}{0.861+0.7}\right)^{1/4} (3.71x10^6)^{1/4} = 13.9$$

k_{eff} is then: $$k_{eff} = 13.9*0.052 = 0.7 \quad W/m°C$$

CONTRIBUTION OF HEAT TRANSFER THROUGH STEEL ACROSS AIR SPACE

Heat transfer by conduction occurs through the air and through the steel support structure of the Gammacell-40, specifically the top steel brace. The contribution of the conduction through the top steel brace is calculated as follows:

The area of the inside top of the overpack inside the inner frame is $\pi*(18")^2 = 1018$ in^2.

The conduction area of the top steel brace is about,

Number of fins around diameter = 6, Width of fins = 0.5", Length of fins = 8"
Conduction area of the steel brace is, therefore, 6 * 0.5 * 8 = 24 in^2.

Percentage of total area is then 100*(24/1018) = 2 %.

TOTAL THERMAL CONDUCTIVITY OF AIR SPACE

The total thermal conductivity of the air space is calculated by combining the effective thermal conductivity to account for convection and the contribution of conduction through the steel support structure of the Gammacell-40.

For all temperatures, the combined thermal conductivity, k, is calculated as follows;

$$k = k_{eff}*0.98 + k_{st}*0.02$$

where, k_{eff} is the effective thermal conductivity to account for convection, and
k_{st} is the thermal conductivity of steel.

Appendix D
Derivation of Heat Transfer Coefficients

The heat transfer coefficients used in the analysis were chosen to match the empirical results. This appendix demonstrates that the values used are reasonable in comparison with approximate relations for air. It also calculates bounding values for the heat transfer coefficient for a cylinder in a fire environment. For all steady state calculations, the temperatures of the applicable surfaces are taken from the steady state analysis of the F-430 overpack, Load Case 1, Sections 5.1 and 6.1.

HEAT TRANSFER COEFFICIENT FOR STEADY STATE AND SOLAR LOAD ANALYSES

The F-430 overpack can be approximated as a cylinder in the cross flow of the air with a diameter, D, of 50.22" = 1.28 m. The flow of gas over the outside of the overpack is estimated to take place at a low velocity of 1.0 m/s (3.3 ft/s).

From Incropera and Dewitt [4], the heat transfer coefficient takes the form:

$$h = k/D * C(uD/\nu)^n Pr^{0.333}$$

where: D is the average width of cross section of the overpack = 1.28 m
C,n are constants that depend on the Reynolds number (uD/ν)
k = thermal conductivity of the fluid
ν = kinematic viscosity of the fluid
Pr = Prandtl number for the fluid
u = free stream velocity

The property values of k,ν and Pr are evaluated at the film temperature, which is defined as the mean of the wall and free stream fluid temperatures.

The wall temperature was measured as 21 °C on the outside of the overpack, while the ambient temperature was 21°C. The film temperature is, therefore, 21 °C and, from Incropera and Dewitt [4], the property values are k = 0.026 W/m °C, ν = 1.6E-5 m^2/s and Pr = 0.707. This yields a Reynolds number of about 80,000. At this value of Re, the constants C and n are 0.027 and 0.805, respectively [4]. Substituting in the appropriate values in the above equation yields a heat transfer coefficient of :

$$h = \frac{0.026(0.027)(1.0*1.28/1.6E\text{-}5)^{0.805}.707^{0.333}}{1.28} = 4.3 \text{ W/m}^2\,°C$$

A value of 4.0 W/m^2 °C was used in the analysis.

HEAT TRANSFER COEFFICIENT DURING THE FIRE TEST

At the start of the fire, the wall temperature is 21 °C on the outside of the overpack. The film temperature is, therefore, 411 °C and, from Incropera and Dewitt [4], the property values are k = 0.052 W/m °C, ν = 6.6E-5 m^2/s and Pr =0.693. This yields a Reynolds number of about 200,000. At this value of Re, the constants C and n are 0.027 and 0.805, respectively [4]. The flow of hot gases over the outside of the overpack is assumed to take place at a high velocity of 10.0 m/s (32.8 ft/s) [12].

Substituting in the appropriate values in the equation from the previous section yields a heat transfer coefficient of :

$$h = \frac{0.052(0.027)(10.0*1.28/6.6E\text{-}5)^{0.805}.693^{0.333}}{1.28} = 17.5\ W/m^2\ {}^{\circ}C$$

A value of 18.0 W/m^2 °C was conservatively used in the analysis of the regulatory fire.

Appendix E
ANSYS Input Files for Load Cases

This appendix includes all of the input files used in the analyses of the F-430 overpack. Each of the input files (*.inp) perform different tasks as described below. See Section 5 of the main body of this report for descriptions of the Load Cases.

Input File	Description
Modela.inp	Model of F-430 overpack for Load Cases 1, 2, 3 and 4
Loada.inp	Load input for steady state Load Cases 1, 2, 3 and 4
Loadsolar.inp	Load input for transient solar loading (12 hour insolation) for Load Case 4
Modfire.inp	Model of F-430 overpack for regulatory fire transient Load Case 5
Loadfire.inp	Load input for regulatory fire transient Load Case 5

The file bff430.inp listed in the transient load input files (loadsolar.inp and loadfire.inp) is a file containing the initial steady state temperature condition of the model from Load Case 3.

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

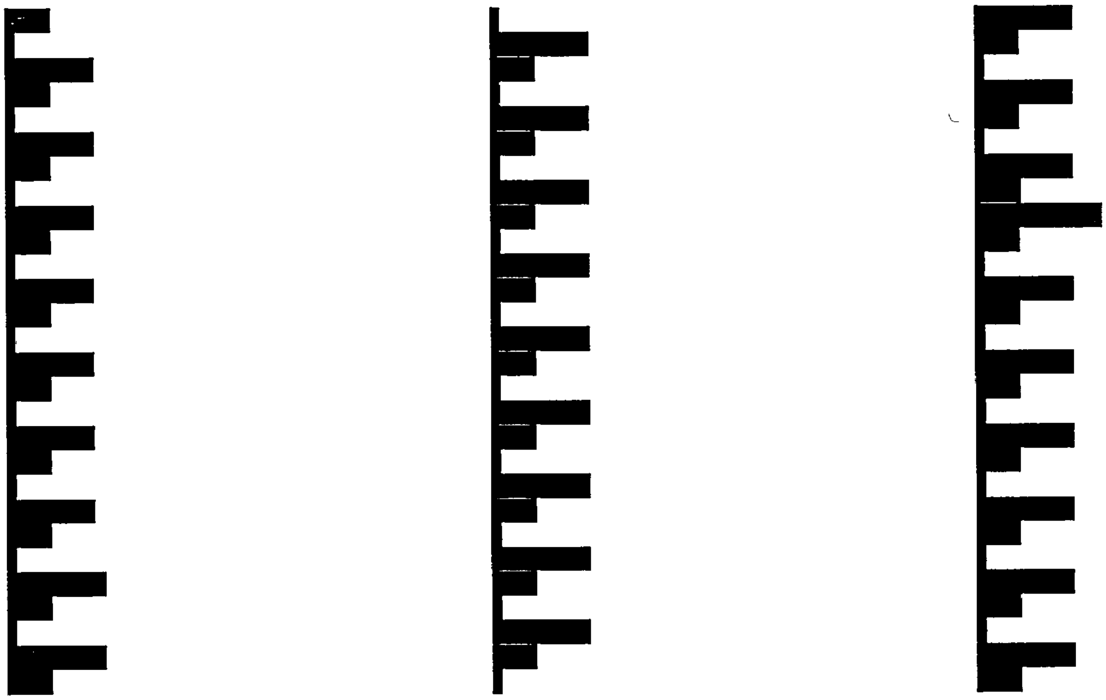
[redacted]

[redacted]

[redacted]

[redacted]

[redacted]



Appendix F
[redacted] Material Property Information

APPENDIX 3.7.2:

[redacted]

CHAPTER 4 – CONTAINMENT

This chapter identifies and discusses the package containment for the Normal Conditions of Transport (NCOT) and the Hypothetical Accident Conditions of Transport (HACOT).

4.1 CONTAINMENT BOUNDARY

The containment boundary is the welded 316L stainless steel double encapsulation of the radioactive contents (cesium-137). Refer to appendix 4.5.1 for detailed specifications and certificates.

4.1.1 CONTAINMENT VESSEL

The GC-40 is certified to transport C-161 Type 8 and C-440 source capsules that are classified as Special Form sealed sources. See appendix 4.5.1 for Special Form Certificates.

These source capsules are designed, tested and certified to meet:

1. ANSI Standard N542 designation ANSI 77 E65546 (Ref. [3]), and
2. Special Form

Copies of the certificates are attached in Appendix 4.5.1. Certificates of Performance to the stated standards are also attached in Appendix 4.5.1.

4.1.2 CONTAINMENT PENETRATION

There are no penetrations into the containment system.

4.1.3 SEALS AND WELDS

The welds of the containment system are identified in Appendix 4.5.1. The main design specifications as per ANSI Standard N542 are:

Pressure:	minimum 25kPa	maximum 70MPa	
Temperature:	minimum -40°C	maximum 800°C	
Vibration frequencies:	minimum 25 Hz	maximum 2000 Hz	duration 90 min

4.1.4 CLOSURE

The sealed sources provide double encapsulation of the radioactive material.

4.2 REQUIREMENTS FOR NORMAL CONDITIONS OF TRANSPORT

This section uses the applicable analysis and discussion from Chapter 2 to demonstrate that the integrity of the package containment system is maintained under the normal conditions of transport. Full scale testing has shown the sealed source to remain leak tight. (See Appendix 2.10.5).

4.2.1 RELEASE OF RADIOACTIVE MATERIAL

Chapter 2, section 2.6 of this report discusses the performance of the F-430 package when subjected to tests simulating the normal conditions of transport. With respect to the two Cesium-137 capsules in question, these normal conditions of transport are shown to be much less severe than the tests performed on the capsule certifying it as Special Form radioactive material and to ANSI Standard N542 designation ANSI 77 E65546. As both C-161 Type 8 and C-440 sealed sources are certified as Special Form, it is therefore concluded that no radioactive material will be released from the containment system as a result of normal conditions of transport.

A full-scale F-430 prototype packaging was subjected to nine drop tests. In the F-430 test packaging, the radioactive contents were simulated using a dummy, full-scale C-440 in a full-scale GC-40 (lower head) carrier. The dummy C-440 was subjected to a helium leak test before and after the drop tests. The leaktightness levels of 1 x 10^{-9} atm cc/sec was met. The test results are presented in Appendix 2.10.5.

4.2.2 PRESSURIZATION OF CONTAINMENT SYSTEM

The two Cesium-137 sources are certified to withstand pressures of up to 70MPa (10153psi).

Both the main and inner covers are equipped with neoprene gaskets, however, the transport cavity pressure is not expected to increase due to gasket mating surfaces not being perfectly flat (rolled and welded stainless steel sheet and angle – no machining).

Calculations for theoretical maximum capsule pressure were done in section 3.5.6.1 based on maximum source temperature during normal condition of transport. This value was only 5 psi which is well below the capsule maximum certified pressure. Therefore, containment boundary shall not be damaged by excessive pressure during normal conditions of transport.

4.3 CONTAINMENT REQUIREMENTS FOR HYPOTHETICAL ACCIDENT CONDITIONS

A full-scale F-430 test packaging was subjected to nine drop tests. Two normal 1.2m drops, three 9m free drops and four 1m pin drops.

In the cavity of the F-430 test packaging, the radioactive contents was simulated using dummy, full-scale C-440 capsule in a full-scale GC-40 source carrier with 500kg (40%) of extra weight.

The drop test results are presented in Chapter 2, Appendix 2.10.5.

The dummy C-440 was helium leak tested prior to and after the drop tests and remained leak tight.

In the hypothetical accident conditions of transport of F-430 loaded with 2kCi of cesium-137 in C-440 sealed sources, the transport cavity is not subjected to internal pressure as the two overpack covers are not pressure tight. The cavity wall is at 94°C and the source is 102°C (see Chapter 3, Section 3.5).

4.3.1 FISSION GAS PRODUCTS

This requirement is not applicable since the F-430 does not contain any fissile material.

4.3.2 RELEASE OF CONTENTS

Multiple full scale drop tests of the F-430/GC-40 showed no significant damage to the contained irradiator and no release of the contents from the shield.

4.4 REFERENCES FOR CHAPTER 4

[1] 10 CFR, Chapter 1, Part 71 - *Packaging and Transportation of Radioactive Material*, 1-1-91 Edition.

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

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

[4] 10 CFR, Chapter 1, Part 36 – *Licenses and Radiation Safety Requirements for Irradiators* 1-1-91 Edition.

4.5 APPENDICES

Appendix 4.5.1 Source capsule certificates and other supporting documentation.

APPENDIX 4.5.1:
Source Capsule Certificates and Other Supporting Documentation

Certification

Atomic Energy Control Board

Commission de contrôle de l'énergie atomique

SPECIAL FORM RADIOACTIVE MATERIAL CERTIFICATE NO. CDN/0011/S, (REV. 4)

30-A2-228-0

June 25, 1999

The Atomic Energy Control Board hereby certifies that the capsules, as described below, have been demonstrated to meet the regulatory requirements prescribed for special form radioactive material as defined in the Canadian *Transport Packaging of Radioactive Materials Regulations* and in the IAEA Regulations*, subject to the following limitations, terms and conditions.

CAPSULE IDENTIFICATION

MDS Nordion Inc. C-161 Type 8 Capsule and C-1000 Capsule

CAPSULE DESCRIPTION

The C-161 Type 8 Capsule, as shown on Nordion Drawing No. G120201-100 (Issue B), is a cylindrical, welded, 316L stainless steel, double-walled capsule. The dimensions of the capsule are 40 mm diameter by 43 mm long.

The C-1000 Capsule, as shown on Nordion Drawing No. G120201-102, (Issue B), is a cylindrical, welded, 316L stainless steel, double-walled capsule. The dimensions of the capsule are 12.7 mm diameter by 271.5 mm long.

Illustrations of the capsules are shown on attached Drawing Nos. C-161, Type 8 (Rev. 0) and C-1000, (Rev. 0).

AUTHORIZED RADIOACTIVE CONTENTS

The C-161 Type 8 Capsule is authorized to contain not more than 80 TBq (2160 Ci) of cesium-137 in 102g of cesium chloride. The C-1000 capsule is authorized to contain not more than 26.6 TBq (720 Ci) of cesium-137 in 34g of cesium chloride.

EXPIRY DATE

This certificate expires June 30, 2003.

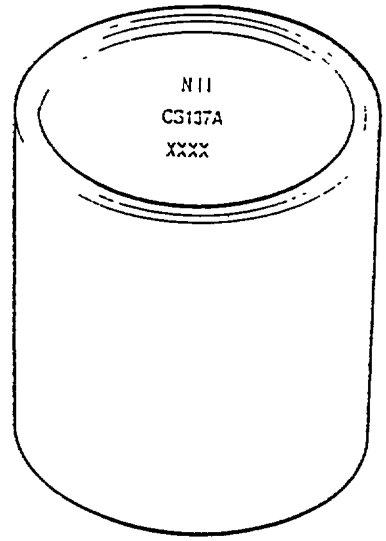
R. Thomas
Director
Materials Regulation Division

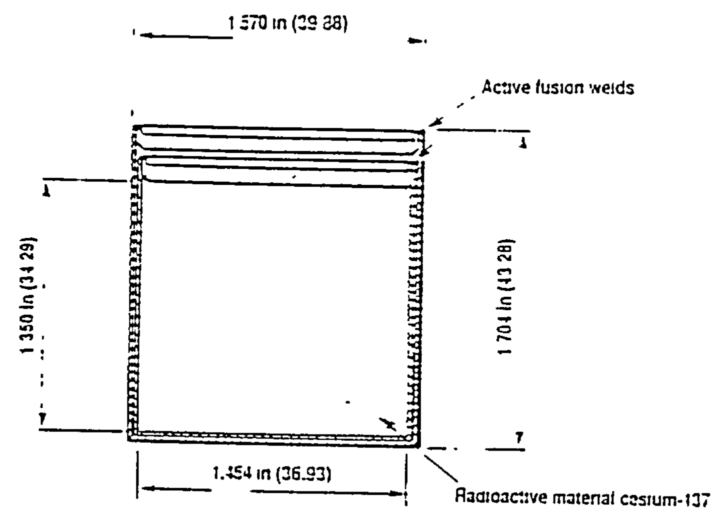
REFERENCE

* International Atomic Energy Agency Safety Series No. 6, Regulations for the Safe Transport of Radioactive Materials, 1973 Revised Edition (as amended).

NOTES

1. Revision 0: July 5, 1990. Original certificate.
2. Revision 1: June 4, 1991. C-1000 capsule added.
3. Revision 2: November 20, 1991. Capsule Description and Authorized Contents revised.
4. Revision 3: April 28, 1995. Certificate renewed.
5. Revision 4: June 25, 1999. Certificate renewed.





Notes

1. Material: stainless steel, Type 316L
2. Wall thickness: 0.020 in (0.53 mm)
3. Engraving on upper end cap - serial number
4. Conforms to I.A.E.A Special Form requirements under AECB Certificate No. CDN/0011/S
5. Dimensions in brackets are expressed in millimeters

NORDION INTERNATIONAL INC

447 March Road, P.O. Box 13500
Kanata, Ontario Canada, K2K 1X8
Tel:(613) 592-2790 • Fax:(613) 592-6937 • Telex: 053-4162

TITLE: C-161 Type 8 Casium-137 Sealed Source

REF DWG	G120201-100
DATE	1990 June
REVISED	
DRAWN	K.B.
CHECKED	[signature]
APPROVED	[signature]
No	C-161 Type 8
REV.	0
SHEET	of

CERTIFICATE

SEALED SOURCE
CLASSIFICATION DESIGNATION AND PERFORMANCE

Sealed sources are classified in accord with standards established by
THE AMERICAN NATIONAL STANDARDS INSTITUTE (ANSI) and
THE INTERNATIONAL ORGANIZATION FOR STANDARDIZATION (ISO)

CERTIFICATE NO: 71
DATE: Aug 12, 1991

CAPSULE MODEL: C-161 Type 8
CONTENTS: Cs Cl Pellets Nominal Wt. 103 g

DRWG. NO: G120201-100

CAPSULE MATERIAL: 316L Stainless Steel
OVERALL DIAMETER: 1.570"

ENCAPSULATION: Double
OVERALL LENGTH: 1.704"

ANSI CLASSIFICATION AND PERFORMANCE STANDARD (1) **ANSI 77 E65546**

CLASSIFIED PERFORMANCE STANDARD (2)

TEST	CLASS	METHOD	REMARKS
TEMPERATURE	6	Test	See Comments
EXTERNAL PRESSURE	5	Test	See Comments
IMPACT	5	Test	See Comments
VIBRATION	4	Test	See Comments
PUNCTURE	6	Test	See Comments

(1) See definition on reverse side
(2) See Table 1 "Performance Standards on reverse side
(3) American National Standard N542-1977 is a revision of ANSI N5.10-1968

COMMENTS:

Capsules were subjected to integrity Helium leak test after each test.

It is hereby certified that the described sealed source meets the specified standard as prescribed in (3) American National Standard N542-1977 "Sealed Radioactive Sources, Classification". This standard complies with the classification and performance requirements of ISO 2919-1980(E).

Tested by J. Culbertson
Title Sr. Met. Technician
Date Aug 14, 1991

Authorized G.A. Burbidge
Title Manager, Package Engineering
Date Aug 14, 1991

NORDION INTERNATIONAL INC.

REFERENCES

(1) DEFINITION - CLASSIFICATION DESIGNATION:

The classification of a sealed source shall be designated by the code ANSI followed by two digits to indicate the year of approval of the American National Standard used to determine the classification followed by a letter and five digits.

The letter shall be either a C or an E. The letter C designates that the contained activity does not exceed the maximum levels established by ANSI. The letter E designates that the contained activity exceeds the maximum levels established by ANSI.

The first digit shall be the class number which describes the performance standards for temperature.

The second digit shall be the class number which describes the performance standards for external pressure

The third digit shall be the class number which describes the performance standards for impact.

The fourth digit shall be the class number which describes the performance standards for vibration.

The fifth digit shall be the class number which describes the performance standards for puncture.

(2) TABLE 1 - PERFORMANCE STANDARDS:

TEST	CLASS					
	1	2	3	4	5	6	X
Temperature	No Test	-40°C (20 min) +80°C (1h)	-40°C (20 min) +180°C (1h)	-40°C (20 min) +400°C (1h) and thermal shock 400°C to 20°C	-40°C (20 min) +600°C (1h) and thermal shock 600°C to 20°C	-40°C (20 min) +800°C (1h) and thermal shock 800°C to 20°C	Special Test
External Pressure	No Test	25 kN/m^2 abs. (3.6 lbf/in^2) to atmosphere	25 kN/m^2 abs. to 2 MN/m^2 (290 lbf/in^2) abs.	25 kN/m^2 abs. to 7 MN/m^2 (1015 lbf/in^2) abs.	25 kN/m^2 abs. to 70 MN/m^2 (10 153 lbf/in^2) abs.	25 kN/m^2 abs to 170 MN/m^2 (24 656 lbf/in^2) abs.	Special Test
Impact	No Test	50 g (1 8 oz) from 1 m (3.28 ft) and free drop ten times to a steel surface from 1.5 m (4 92 ft)	200 g (7 oz) from 1 m	2 kg (4 4 lb) from 1 m	5 kg (11 lb) from 1 m	20 kg (44 lb) from 1 m	Special Test
Vibration	No Test	30 min 25 to 500 Hz at 5 g peak amp.	30 min 25 to 50 Hz at 5 g peak amp. and 50 to 90 Hz at 0.635 mm amp. peak to peak and 90 to 500 Hz at 10 g	90 min 25 to 80 Hz at 1.5 mm amp. peak to peak and 80 to 2000 Hz at 20g	Not Used	Not Used	Special Test
Puncture	No Test	1 g (15.4 gr) from 1 m (3 28 ft)	10 g (154 gr) from 1 m	50 g (1.76 oz) from 1 m	300 g (10 6 oz) from 1 m	1 kg (2.2 lb) from 1 m	Special Test

SPECIAL FORM RADIOACTIVE MATERIAL TEST SUMMARY

The capsule model specified herein has been evaluated in accord with the International Atomic Energy Agency (I.A.E.A.) Safety Series No. 6, Regulations for the Safe Transport of Radioactive Materials, 1985 Edition, Section VI, paragraphs 604-613 and 618.

TEST SUMMARY NO: 22

DATE: Aug. 10, 1991

CAPSULE MODEL: C-161 Type 8

CONTENTS: Cs Cl Pellets
Nominal Wt. 103 g

DRWG NO: G120201-100

CAPSULE MATERIAL: 316L Stainless Steel

OVERALL DIAMETER: 1.570"

ENCAPSULATION: Double

OVERALL LENGTH: 1.704"

SPECIAL FORM REQUIREMENTS (1)

TEST	PASS	FAIL	METHOD	REMARKS
IMPACT (607)(618)	x		Test Comparison	See Comment 1
PERCUSSION (608)	x		Test Comparison	ANSI N542-1977, Class 6 Puncture Test performed
BENDING (609)	--		--	Test not required
HEAT (610)	x		Test Comparison	See Comment 2
LEACHING (612)(613)				

(1) See special form requirements on reverse side

COMMENTS: IAEA Safety Series #6:

1. Paragraph 611(a) excepts capsules from testing since they have been tested to Class 5 Impact as per ISO 2919-1980(E): test worksheet attached.

Also,

2. Paragraph 611(b) excepts capsules from testing since they have been tested to Class 6 Temperature as per ISO 2919-1980(E): test worksheet attached.

This summary verifies that the described capsule model meets the requirements of Special Form in accord with the I.A.E.A. Safety Series No. 6, Regulations for the Safe Transport of Radioactive Materials, 1985 Edition, Section VI, paragraphs 604-613 and 618.

Tested by	J. Culbertson	*Authorized*	G.A. Burbidge
Title	Sr. Met. Technician	*Title*	Manager, Package Engineering
Date	Aug. 14, 1991	*Date*	Aug. 14, 1991

NORDION INTERNATIONAL INC.

I.A.E.A. TESTS FOR SPECIAL FORM RADIOACTIVE MATERIAL

General

604. The tests which shall be performed on specimens that comprise or simulate **special form radioactive material** are the impact test, the percussion test, the bending test, and the heat test.

605. A different specimen may be used for each of the tests

606. After each test specified in paras 607-611, a leaching assessment or volumetric leakage test shall be performed on the specimen by a method no less sensitive than the methods given in para 612 for indispersible solid material and para 613 for encapsulated material.

Test methods

607. Impact test. The specimen shall drop onto the target from a height of 9 m. The target shall be as defined in para.618.

618. The target for the drop test specified in para 607 shall be a flat, horizontal surface of such a character that any increase in its resistance to displacement or deformation upon impact by the specimen would not significantly increase the damage to the specimen.

608. Percussion test. The specimen shall be placed on a sheet of lead which is supported by a smooth solid surface and struck by the flat face of a steel billet so as to produce an impact equivalent to that resulting from a free drop of 1 4 kg through 1 m. The flat face of the billet shall be 25 mm in diameter with the edges rounded off to a radius of (3 0 ± 0.3)mm. The lead, of hardness number 3.5 to 4 5 on the Vickers scale and not more than 25 mm thick, shall cover an area greater than that covered by the specimen. A fresh surface of lead shall be used for each impact. The billet shall strike the specimen so as to cause maximum damage

609. Bending test. The test shall apply only to long, slender sources with both a minimum length of 10 cm and a length to minimum width ratio of not less than 10 The specimen shall be rigidly clamped in a horizontal position so that one half of its length protrudes from the face of the clamp. The orientation of the specimen shall be such that the specimen will suffer maximum damage when its free end is struck by the flat face of a steel billet. The billet shall strike the specimen so as to produce an impact equivalent to that resulting from a free vertical drop of 1.4 kg through 1 m. The flat face of the billet shall be 25 mm in diameter with the edges rounded off to a radius of (3.0 ± 0.3)mm.

610. Heat test. The specimen shall be heated in air to a temperature of 800°C and held at that temperature for a period of 10 minutes and shall then be allowed to cool.

611. Specimens that comprise or simulate **radioactive material** enclosed in a sealed capsule may be excepted from:

(a) The tests prescribed in paras 607 and 608 provided they are alternatively subjected to the Class 4 impact test prescribed in the International Organization for Standardization document ISO 2919-1980(E), "Sealed radioactive sources - Classification",and

(b) The test prescribed in para 610 provided they are alternatively subjected to the Class 6 temperature test specified in the International Organization for Standardization document ISO 2919-1980(E),"Sealed radioactive sources - Classification".

Leaching and volumetric leakage assessment methods

612. For specimens which comprise or simulate indispersible solid material, a leaching assessment shall be performed as follows:

(a) The specimen shall be immersed for 7 days in water at ambient temperature. The volume of water to be used in the test shall be sufficient to ensure that at the end of the 7 day test period the free volume of the unabsorbed and unreacted water remaining shall be at least 10% of the volume of the solid test sample itself. The water shall have an initial pH of 6-8 and a maximum conductivity of 1 mS/m(10 μho/cm) at 20°C.

(b) The water with specimen shall then be heated to a temperature of (50 ± 5)°C and maintained at this temperature for 4 hours.

(c) The activity of the water shall then be determined.

(d) The specimen shall then be stored for at least 7 days in still air of relative humidity not less than 90% at 30°C.

(e) The specimen shall then be immersed in water of the same specification as in (a) above and the water with the specimen heated to (50 ± 5)°C and maintained at this temperature for 4 hours.

(f) The activity of the water shall then be detrmined

613. For specimens which comprise or simulate **radioactive material** enclosed in a sealed capsule, either a leaching assessment or a volumetric leakage assessment shall be performed as follows:

(a) The leaching assessment shall consist of the following steps:

(i) The specimen shall be immersed in water at ambient temperature The water shall have an initial pH of 6-8 with a maximum conductivity of 1 mS/m(10 μho/cm) at 20°C.

(ii) The water and specimen shall be heated to a temperature of (50 ± 5)°C and maintained at this temperature for 4 hours

(iii) The activity of the water shall then be determined.

(iv) The specimen shall then be stored for at least 7 days in still air at a temperature of not less than 30°C.

(v) The process in (i),(ii) and (iii) shall be repeated

(b) The alternative volumetric leakage assessment shall comprise any of the tests prescribed in the International Organization for Standardization document ISO/TR 4826-1979(E), "Sealed radioactive sources - Leak test methods", which are acceptable to the **competent authority.**

NORDION INTERNATIONAL INC.

447 March Road, P.O Box 13500, Kanata, Ontario, Canada K2K 1X8 Tel : (613) 592-2790 Telex: (053) 4162 Fax: (613) 592-6937
447 chemin March, C P. 13500, Kanata, Ontario, Canada K2K 1X8 Tél.: (613) 592-2790 Télex: (053) 4162 Fax: (613) 592-6937

Reference GB/366/S-85

Certificate Issue 6

Certificate of Approval
of
Design for Special Form Radioactive Material

Title	
Capsule Code R6100 (X2161) (C-440)	
Drawing Nos and Specification References	
Drawing List QS 6100 Issue 3 Dated 10 December 1999 Specification (X2161) MPW/GB/366/S-85 Dated 2 October 1992 (R6100) R6100 SFA Issue 4 Dated 10 December 1999	
Q A Programme Ref Reviss Services Quality Manual	
Radioactive Material	Maximum Activity
Caesium - 137	83.25 TBq

THIS IS TO CERTIFY that the Secretary of State for the Environment, Transport and the Regions being, for the purposes of the Regulations of the International Atomic Energy Agency, the Competent Authority of Great Britain in respect of inland surface transport and of the United Kingdom of Great Britain and Northern Ireland in respect of sea and air transport and the Department of the Environment for Northern Ireland being the Competent Authority of Northern Ireland in respect of inland surface transport, have approved the above mentioned Special Form Design. Radioactive material manufactured to the above-mentioned design qualifies as special form radioactive material and as such will meet the requirements of the regulations overleaf.

This Certificate of Approval applies only to the design as set out in the above named drawings and specifications submitted by Reviss Services

In the event of any alteration in the composition of the package, the package design or in any of the facts stated in the application for approval, this certificate will cease to have effect unless the Competent Authority is notified of the alteration and the Competent Authority confirms the certificate notwithstanding the alteration.

This Certificate Cancels all Previous Issues and is valid until 31 January 2003

COMPETENT AUTHORITY IDENTIFICATION MARK: GB/366/S-85

UNITED KINGDOM COMPETENT AUTHORITY FOR THE TRANSPORT
26 JAN 2000
OF RADIOACTIVE MATERIALS

Transport Radiological Adviser
Department of the Environment,
Transport and the Regions
76 Marsham Street
London SW1P 4DR

On behalf of the Secretary of State for the Environment, Transport and the Regions and the Department of the the Environment for Northern Ireland

TEST CERTIFICATE

R E V I S S

REVISS SERVICES Limited
6 Sycamore House
Chiltern Court
Asheridge Road
Chesham
Buckinghamshire
HP5 2PX
Tel. +44 (0)1494 777444
Fax +44 (0)1494 777440

Customer Order No
4219413

Sale ID Account
515 NORDION

Sold to: Nordion International Inc.
447 March Road
Kanata
Ontario
CANADA
K2K 1X8

Description:

Inactive Simulator

RSL6100 Inactive Simulator to specification number PS6100 issue 2.

BSI / ISO Classification		Special Form Certificate No	Recommended Working Life
Actual E65546	Minimum E43434	GB/366/S-85	15 Years

Serial No:

A1271

Test pass dates:

Vacuum Bubble Test: 16 October 1998
To ISO 9978 1992(E) 6 2 1

Helium Pressurisation Test: 19 October 1998
To ISO 9978 1992(E) 6 1 2 Pass limit: 1 0 x 10^{-8} Pa m^3 s^{-1}

Wipe Test: 21 October 1998
To ISO 9978 1992(E) 5 3 1 Pass limit: <18 5Bq

(See overleaf for definition and description of tests

Notes:

Signed [signature]

Date 2 February 1999

Signature in this box signifies release of product for sale

TEST CERTIFICATE

REVISS

REVISS SERVICES Limited
6 Sycamore House
Chiltern Court
Asheridge Road
Chesham
Buckinghamshire
HP5 2PX
Tel: +44 (0)1494 777444
Fax: +44 (0)1494 777440

Customer Order No
4191393

Sale ID 383 | Account NORDION

Sold to: Nordion International Inc.
447 March Road
Kanata
Ontario
CANADA
K2K 1X8

Nuclide.
Caesium-137

Description.
RSL6100 To specification number PS6100 issue 1.

BSI / ISO Classification		Special Form Certificate No	Recommended Working Life
Actual E65546	Minimum E43434	GB/366/S-85	15 Years

Serial No:	Activity reference date	Air Kerma Rate	Content Activity
.1065	12 March 1998	1.146 µ Gy/sec at 1metre	1.850 kCi 68.5 TBq

Test pass dates:

Vacuum Bubble Test: 12 March 1998
To ISO 9978.1992(E) 6 2.1

Helium Pressurisation Test: 12 March 1998
To ISO 9978.1992(E) 6.1 2 Pass limit: 1 0 x 10^{-8} Pa m^3 .s^{-1}

Wipe Test: 13 March 1998
To ISO 9978·1992(E) 5 3.1 Pass limit: <18.5Bq

(See overleaf for definition and description of tests

Notes:
The measurement is made from the END of the source. The Cs134 content is less than 1.0% of the Cs137 content.

Signed [signature]

Date 30th March 1998

Signature in this box signifies release of product for sale

Third Angle Projection
This drawing conforms to BS 308

This drawing is the private and confidential property of Amersham International plc. and must not be loaned copied or reproduced without written permission.

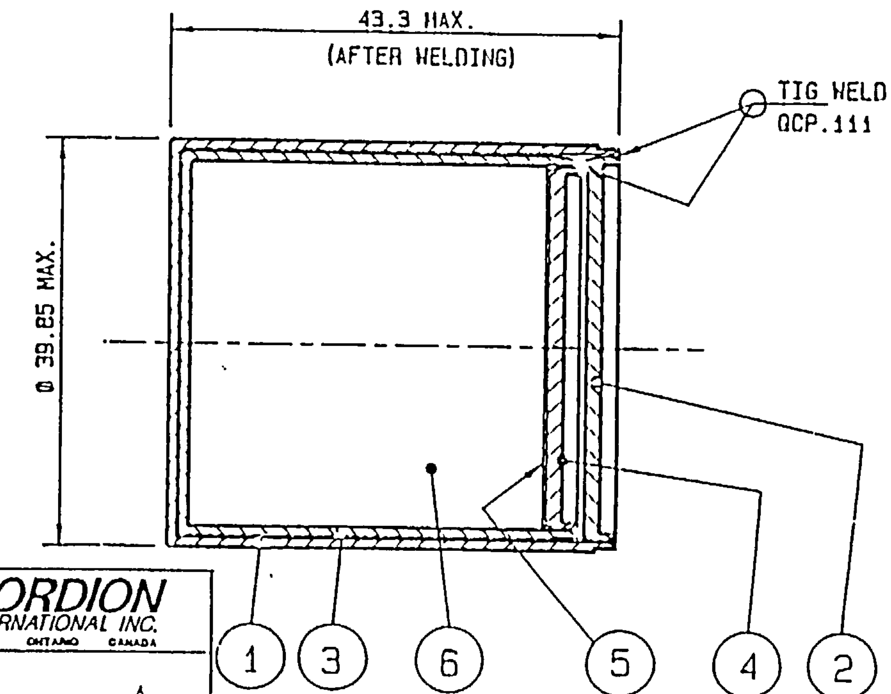
Item No	Drawing No	Description		No off
1	2A62545(G120201-112)ITEM.1	SHEATH BODY	STAIN.STL.	1
2	2A62545(G120201-112) ITEM.2	SHEATH LID	STAIN.STL.	1
3	2A62546(G120201-113) ITEM.1	CELL BODY	STAIN.STL.	1
4	2A62546(G120201-113) ITEM.2	CELL LID	STAIN.STL.	1
5	3A62597 (G120201-114)	SPACER	STAIN.STL.	1
6		ACTIVE MATERIAL		——

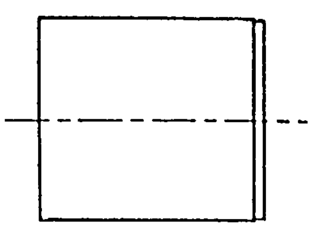
ENGRAVE TO QCP.114

NOT TO BE USED FOR MANUFACTURING PURPOSES

RE-DESIGNED VERSION OF NORDION CAPSULE C-161 TYPE.B (GC40) NORDION DR'G.No. G120201-100 ISS.B & G120201-101 ISS.A

THIS SOURCE DESIGN IS OWNED BY NORDIAN, FOR EXCLUSIVE NORDIAN SUPPLY ONLY.





ACTUAL SIZE

NORDION INTERNATIONAL INC. KANATA ONTARIO CANADA

ASSIGNED N. I. I. DRAWING NUMBER G120201-111 REV A

Material & Spec.	Tolerances	Surface Texture	Finish	Approval: This Drawing is not to be used for any purpose unless signed as approved
——	—— Unless stated	✓ —— Unless stated	—— Remove all burrs	

Issue	Mod. No.	Date	Drawn	Checked	QA approved
A		22-6-92	C.D.		

Title
ASSEMBLY OF CAPSULE X2161 (C-440)

Original Scale 2/1 Do not scale | Dims.in millimetres | Used on ——

Drg. 3A62547

CHAPTER 5 – SHIELDING EVALUATION

5.1 DISCUSSION AND RESULTS

F-430 overpack has been designed to transport shielded radioactive contents with maximum weight of 4300 lb (including internal frames and braces), which can generate up to [redacted]

The full-scale prototype overpack was built and tested with the lower head of GC-40 irradiator, which may contain up to 2kCi of cesium-137 [1] which generates up to [redacted].

The Special Form sealed source (1.57" diameter, 1.70" long) is stored in a cylindrical cavity inside a lead filled, source drawer (2.5" diameter, 19.2" long). This source drawer is placed inside a cylindrical housing, which is filled with lead (6" all around). With the drawer in the transport position, the dose-equivalent rates at any point on the external surface of either head have been measured to be less than 200mrem/h and on the surface of the F-430 container less than 10 mrem/hr. (The Cs-137 source activity was 1737Ci measured on April 21,1998. At the time of the survey, the source activity was 1687 Ci).

A cross-sectional view of the GC-40 unit is provided in Figure 5.1 A full-scale F-430/GC-40 packaging was subjected to nine drop tests using a lower head containing 1100lb of extra weight. With the exception of the extra weight of 500kg (1100 lb) the drop test specimen was built to the manufacturing specifications of a standard GC-40 lower head irradiator.

Radiation surveys were performed on one standard GC-40 (lower head) inside and outside the F-430 container before drop testing, and inside the container only after drop testing. The results are shown in Table 5.3.

The tested GC-40 was also surveyed before and after drop testing, inside and outside the F-430 overpack. See Table 5.1 and Table 5.2. In all cases the same source and source drawer were used. The locations of the field point measurements are given in Figure 5.2 and Figure 5.3. The details of all the measurements are given in F-430 Test Report (Appendix 2.10.5).

Radiation surveys on drop test specimen of GC-40 (with additional lead used as dummy weight) give indication of relative increase of radiation levels due to multiple drop testing. Also, the maximum readings were recorded on the source drawer covers, which are 90° away from the dummy weights.

The results show no significant increase in radiation levels. Neither the source capsule, nor the source drawer suffered any permanent noticeable damage. Both were free to slide out and remove without visible signs of damage.

In order to assess the effect of the supplemental lead weight on the results of the shielding tests, an unmodified unit was tested. The results show that this effect is insignificant as maximum radiation levels are at the front and back covers. The location of the supplemental weights did not improve the shielding in these areas.

Table 5.1: Radiation fields for F-430 (GC-40 with dummy weights)

Location	Surface Measurement (mR/h)		Field at 1 m from Surface (mR/h)	
	Pre-drop	Post-drop	Pre-drop	Post-drop
Top Surface	0.14	0.13	≤ 0.05	≤ 0.05
Bottom Surface	0.05	0.05	≤ 0.05	≤ 0.05
Right Side	0.08	0.06	≤ 0.05	≤ 0.05
Back Side	0.05	0.06	≤ 0.05	≤ 0.05

Table 5.2: Radiation fields for GC-40 (with dummy weights)

Field Point	Pre-drop (mR/h)		Post-drop (mR/h)	
	Surface	Field at 1m	Surface	Field at 1m
Front Source Drawer Cover	3.5	0.20	2.7	0.14
Rear Source Drawer Cover	7.0	0.34	7.0	0.15
Top Surface	0.30	0.20	0.30	0.12
Right Side	0.30	0.30	0.30	0.30

Table 5.3: Radiation fields for F-430 (GC-40 without dummy weights)

Location	Surface Measurement (mR/h)		Field at 1 m from Surface (mR/h)	
	Pre-drop	Post-drop	Pre-drop	Post-drop
Top Surface	0.30	0.40	≤ 0.20	≤ 0.20
Bottom Surface	0.05	0.05	≤ 0.20	≤ 0.20
Right Side	0.40	0.50	≤ 0.20	≤ 0.20
Back Side	0.30	0.40	≤ 0.20	≤ 0.20

Table 5.4: Radiation fields for GC-40 (without dummy weights)

Field Point	Pre-drop (mR/h)		Post-drop (mR/h)	
	Surface	Field at 1m	Surface	Field at 1m
Front Source Drawer Cover	2.2	0.20	-	-
Rear Source Drawer Cover	7.5	0.34	-	-
Inside Cone	160	0.40	-	-
Right Side	0.45	0.30	-	-

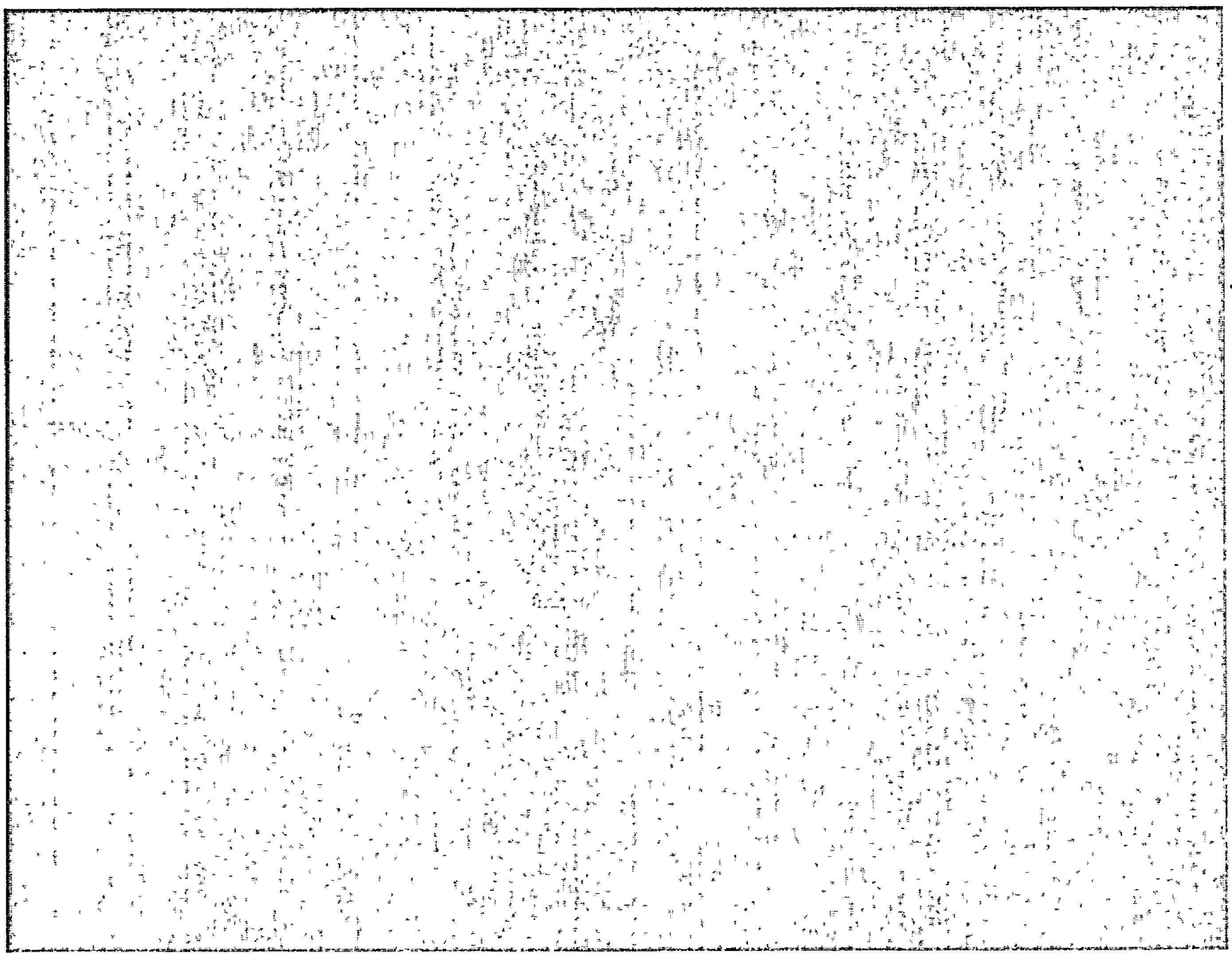


Figure 5.1: GC-40 Irradiator with dummy weights of 500kg

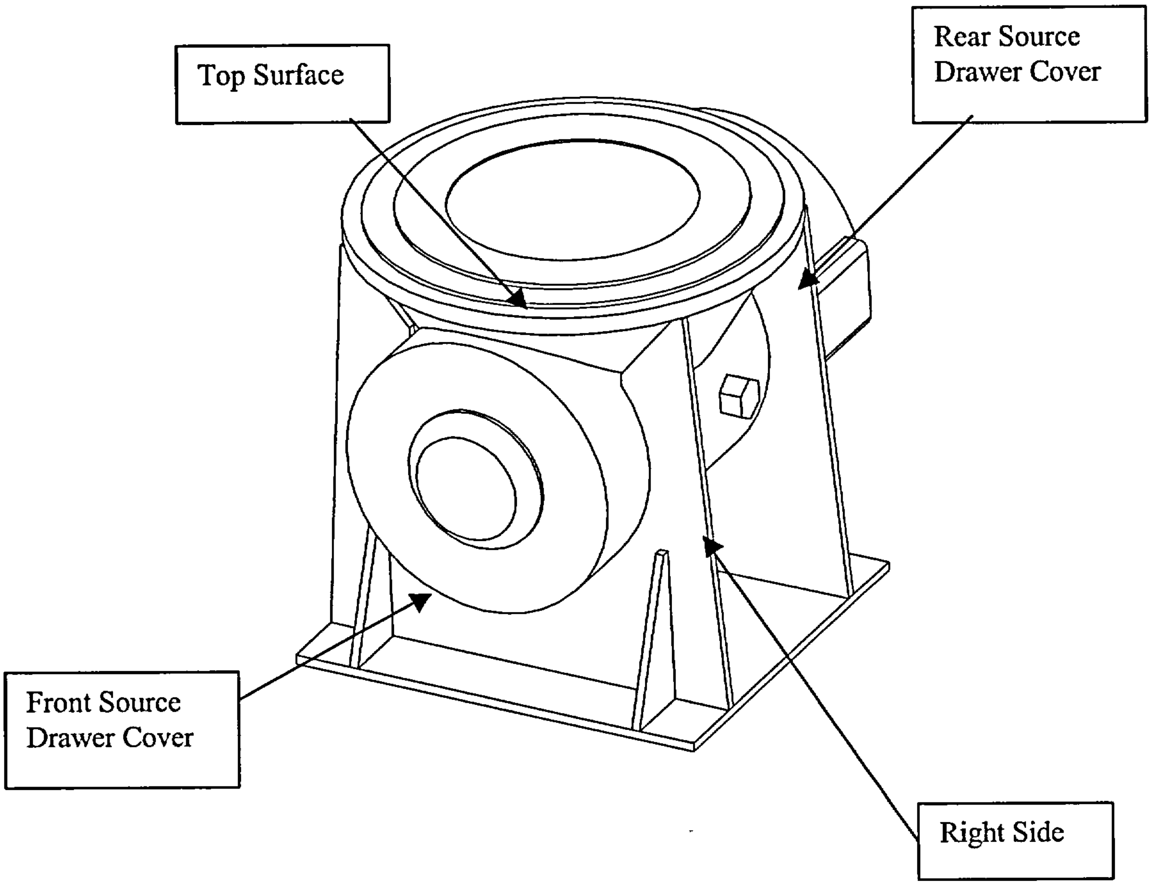


Figure 5.2: Radiation Survey Field Points, GC-40 Lower Head

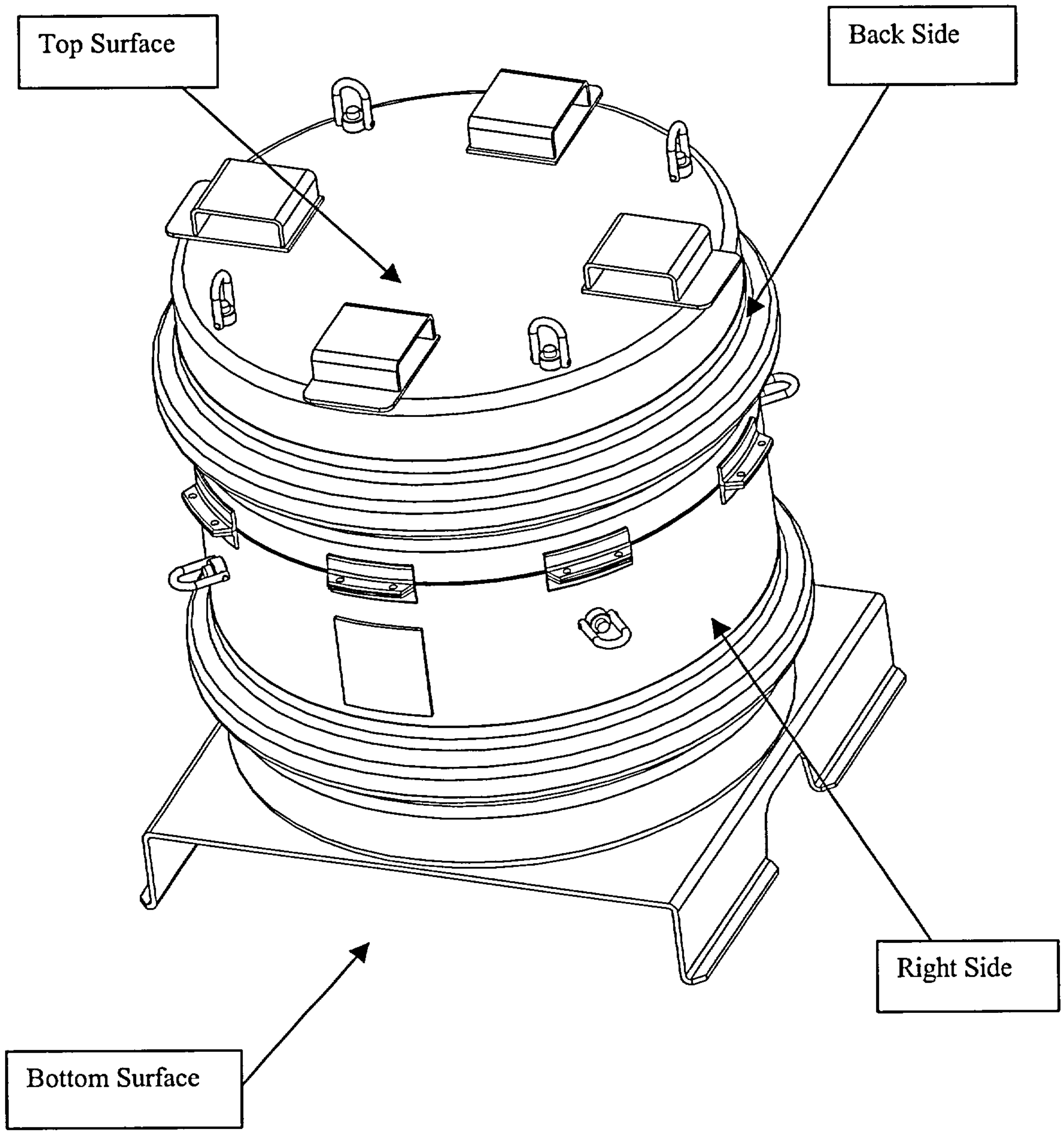


Figure 5.3:Radiation Survey Field Points, F-430

5.2 SOURCE SPECIFICATION

The GC-40 is certified to carry C-161 Type 8 and C-440 Special Form sealed sources.

C-161 Type 8 source capsule is authorized to contain not more than 2160 Ci of Cesium-137 in 102g of cesium chloride pellets. C-440 capsule is certified for a maximum of 2248 Ci of Cesium-137.

No modelling was used in the shielding evaluation. The Cs-137 energy spectrum is shown in Figure 5.4. (Reference is Browne, E., Firestone, R.B., *Tables of Radioactive Isotopes*, John Wiley and Sons, New York, 1986.)

Photons (^{137}Cs)

⟨γ⟩=566 *11* keV

γ_{mode}	γ(keV)	γ(%)† *
Ba L_ℓ	3.954	0.0144 *20*
Ba L_η	4.331	0.0064 *7*
Ba L_α	4.465	0.40 *5*
Ba L_β	4.944	0.37 *5*
Ba L_γ	5.620	0.049 *7*
Ba $K_{\alpha2}$'	31.817	2.05 *7*
Ba $K_{\alpha1}$	32.194	3.77 *14*
Ba $K_{\beta1}$'	36.357	1.04 *4*
Ba $K_{\beta2}$'	37.450	0.264 *10*
γ M4	661.660 *3*	85.21'

†0.08% uncert(syst)

* with ^{137}Ba(2.552 min) in equilib

Atomic Electrons (^{137}Cs)

⟨e⟩=61.9 *10* keV

e_{bin}(keV)	⟨e⟩(keV)	e(%)
5	0.199	3.8 *4*
6	0.147	2.6 *3*
25	0.0159	0.062 *6*
26	0.045	0.173 *18*
27	0.074	0.28 *3*
30	0.0166	0.055 *6*
31	0.047	0.152 *16*
32	0.0101	0.032 *3*
35	0.0051	0.0145 *15*
36	0.0027	0.0076 *8*
624	49.4	7.91 *16*
656	9.46	1.44 *3*
660	1.59	0.241 *5*
661	0.918	0.139 *3*
662	0.0279	0.00422 *9*

Continuous Radiation (^{137}Cs)

⟨β-⟩=188 keV;⟨IB⟩=0.124 keV

E_{bin}(keV)		⟨ ⟩(keV)	(%)
0 - 10	β-	0.170	3.42
	IB	0.0095	
10 - 20	β-	0.499	3.33
	IB	0.0087	0.061
20 - 40	β-	1.95	6.5
	IB	0.0155	0.054
40 - 100	β-	12.8	18.4
	IB	0.035	0.054
100 - 300	β-	94	48.8
	IB	0.045	0.029
300 - 600	β-	68	18.2
	IB	0.0089	0.0023
600 - 1175	β-	10.7	1.40
	IB	0.00137	0.00020

$^{137}_{55}Cs$(30.0 *2* yr)

Mode: β-

Δ: -86561 *6* keV

SpA: 87.0 Ci/g

Prod: fission

Figure 5. 4: Energy Spectrum for Cesium-137

5.3 MODEL SPECIFICATION

No models were used. Shielding evaluation was based on full-scale test results.

5.4 SHIELDING EVALUATION

Maximum deformation [redacted] Since the radiation fields were hardly measurable before and after the drop testing at this and all other locations, the effect of reduction in source-to-dose distance is negligible.

5.5 APPENDICES

There is no appendix in this chapter. For radiation survey results see Appendix 2.10.5 (F-430 Test Report).

CHAPTER 6 – CRITICALITY EVALUATION

The requirements of this chapter are not applicable since F-430 package is not intended to transport fissile materials.

CHAPTER 7 – OPERATING PROCEDURES

This chapter describes the operating procedures for the F430/GC40 package. The following operations are described:

1. Loading the GC40 into the F430 Overpack and preparation for shipment
2. Securing the F430/GC40 on road vehicles.
3. Unloading the F430/GC40
4. Preparing an Empty Packaging for Shipment.

7.1 COMPLIANCE AND RESPONSIBILITY

1. It is the responsibility of MDS Nordion to ensure that the radioactive material transport packaging is approved and maintained in compliance with the approval certificates.
2. It is the responsibility of MDS Nordion personnel or its qualified agent to ensure that the operations described by these procedures are followed and the F430/GC40 transport package is prepared for shipment in compliance with this procedure and any supplementary regulatory requirements.
3. In the case of a shipment from a customer site, it is the responsibility of the customer, in the role of the consignor, to approve the release of the F430/GC40 shipment.
4. It is the responsibility of the pertinent regulatory authority to enforce compliance as per the F430/GC40 transport package license.

7.2 PROCEDURES FOR PREPARING THE GC40 FOR SHIPMENT

There are three versions of the GC40: The original GC40, later version GC40E and the current version GC40E+. The differences are in the type of source motion drive and control. Once disassembled for shipment the three versions are the same for the purpose of loading inside the F430 overpack.

7.2.1 GC40 DISASSEMBLY (ONLY)

1. Conduct a radiation survey to confirm radiation levels are within regulatory limits.
2. Perform a routine wipe test on the unit to check for removable contamination. See section 7.3.1.1 for procedure and passing criteria.
3. Prominently display the NRC-3 Form or corresponding STATE NOTIFICATION (USA operations only).
4. Ensure both source drawers are in safe position and unplug the GC40 from the electrical supply.
5. Disassemble the unit.
6. Conduct a routine wipe test on the cylinder rod, air cylinder mounting flange and the end of the source drawer. See section 7.3.1.1 for procedure and passing criteria.
7. Check the source drawer retaining ring is tight.
8. Install the end shipping plate to the source head using the four 3/8 - 16UNC x 45mm long socket head screws provided.
9. Repeat steps #5 though step #8 on the lower source head.
10. Remove the upper bearing block secured by the four socket head screws from the upper source head.

11. Conduct a routine wipe test on the upper bearing block, the upper interlock guide and the source drawer retaining ring. See section 7.3.1.1 for procedure and passing criteria.
12. Unscrew the upper source drawer retaining ring and insert the tube spacer over the interlock bar into the source drawer bore. This tube retains the source in the safe position during shipment.
13. Install the end shipping plate on the upper source head using the four 3/8 - 16 UNC x 45mm inch socket head screws provided.
14. Repeat steps #10 through #13 on the lower source.
15. Disconnect the heads and using a suitable forklift truck or crane, rated at 1361kg or 3000lb., lift the upper source head clear of the fixed shield and sample chamber assembly.
16. Screw the two 3/8 x 16 UNC eye bolts provided into diagonally exposing holes of fixed shield and sample chamber assembly. Using a sling, rated in access of 272kg. (600lb), lift the assembly clear of the lower source head and set it down on blocks of sufficient height to clear the hinge pin. Remove sample chamber assembly from lower head
17. Proceed to preparation for shipment as described in section 7.3.

7.2.2 GC40E DISASSEMBLY (ONLY)

1. Conduct a radiation survey to confirm radiation levels are within regulatory limits.
2. Perform a routine wipe test of the unit to check for removable contamination. See section 7.3.1.1 for procedure and passing criteria.
3. Prominently display the NRC-3 FORM or corresponding State Notification (USA Operations only).
4. Ensure the sources are in the safe position and then unplug the GC-40 from the electrical supply.
5. Disassemble the unit.
6. Unscrew the ball screw from the end of the source drawer.
7. Conduct a wipe test on the retaining ring, the exposed end of the source drawer assembly, and the source drawer drive assembly and check for non-fixed contamination. See section 7.3.1.1 for procedure and passing criteria.
8. Check to ensure the retaining ring is tight.
9. Install the end shipping plate to the upper source head using four 3/8-16 UNC x 45mm long socket head screws provided.
10. Repeat steps #5 through #9 on the lower source head.
11. Remove the upper bearing block secured by the four socket head screws from the upper source head.
12. Conduct a routine wipe test on the upper bearing block, the upper interlock guide and the source drawer retaining ring. See section 7.3.1.1 for procedure and passing criteria.
13. Unscrew the upper source drawer retaining ring and insert the tube spacer over the interlock bar into the source drawer bore. This tube retains the source in the safe position during shipment.
14. Install the end shipping plate on the upper source head using the four 3/8 - 16 UNC x 45mm inch socket head screws provided.

15. Repeat steps #11 through #14 on the lower source.
16. Disconnect the heads and using a suitable fork lift truck or crane, rated at 1361kg (3000lb), lift the upper source head clear of the fixed shield and sample chamber assembly.
17. Screw the two 3/8 x 16 UNC eye bolts provided into diagonally exposing holes of fixed shield and sample chamber assembly. Using a sling, rated in access of 272kg (600lb), lift the assembly clear of the lower source head and set it down on blocks of sufficient height to clear the hinge pin. Remove sample chamber assembly from lower head
18. Proceed to preparation for shipment as described in section 7.3.

7.2.3 GC40E+ DISASSEMBLY (ONLY)

1. Conduct a radiation survey of the unit to confirm radiation levels are within regulatory limits.
2. Perform a routine wipe test of the unit to check for removable contamination. See section 7.3.1.1 for procedure and passing criteria.
3. Prominently display the NRC-3 FORM or corresponding State Notification (USA Operations only).
4. Ensure the sources are in the safe position and then unplug the unit from the AC power outlet.
5. Disassemble the unit.
6. Unscrew the ball screw from the end of the source drawer.
7. Conduct a wipe test on the retaining ring, the exposed end of the source drawer assembly, and the source drawer drive assembly for non-fixed contamination. See section 7.3.1.1 for procedure and passing criteria.
8. Check to ensure the retaining ring is tight.
9. Install the end shipping plate to the upper source head using the four 3/8-16 UNC x 45mm long socket head screws provided.
10. Repeat steps #5 through #9 on the lower source head.
11. Remove the upper bearing block secured by the four socket head screws from the upper source head.
12. Conduct a routine wipe test on the upper bearing block, the upper interlock guide and the source drawer retaining ring. See section 7.3.1.1 for procedure and passing criteria.
13. Unscrew the upper source drawer retaining ring and insert the tube spacer over the interlock bar into the source drawer bore. This tube retains the source in the safe position during shipment.
14. Install the end shipping plate on the upper source head using the four 3/8 - 16 UNC x 45mm inch socket head screws provided.
15. Repeat steps #11 through #14 on the lower source.
16. Disconnect the heads, and using a suitable fork lift truck or crane, rated at 1361 kg (3000lb), lift the upper source head clear of the fixed shield and sample chamber assembly.
17. Screw the two 3/8 - 16UNC eye bolts provided into diagonally exposing holes of fixed shield and sample chamber assembly. Using a sling, rated in access of 272kg, (600lb) lift the assembly clear of the lower source head and set it down on blocks of sufficient height to clear the hinge pin. Remove sample chamber assembly from lower head.
18. Proceed to preparation for shipment as described in section 7.3.

7.3 LOADING THE GC40 INTO THE F430 AND PREPARING THE PACKAGE FOR SHIPMENT

The F430 overpack is designed to carry the upper or lower head of GC40 irradiator. Two F430 overpacks are required for the shipment of one complete GC40 irradiator. The packaging arrangement is shown in Figure 7.1.

To prepare the GC40, GC40E and GC40E+ in the F430 overpack, some special tools and equipment are necessary. A 15/16" socket is required to remove or install bolts securing the two overpack covers. To lift the GC40 lower head with its brace, two 5.5m long nylon endless slings, 1134kg minimum lift capacity each are required. Slings should choke the body of the GC40 lower head at the front and back (see Figure 7.2), and should be left in place inside the overpack.

7.3.1 LOADING PROCEDURE

1. Determine the level of non-fixed radioactive contamination by wiping an area on the external surface of the upper and lower head assemblies.

   The level of non-fixed contamination shall be determined by wiping an area of 300 cm^2 of the external surface by hand with a dry filter paper or a wad of dry cotton wool or any other material of this nature. The maximum permissible level of removable contamination on the wipe is 0.4 Bq/cm^2 (10^{-5} $\mu Ci/cm^2$).

2. Ensure that the following steps are carried out on both the upper and lower heads of the GC40, GC40E or GC40E+.

   a) Insert the drawer shipping spacer in the source tube.

   b) Screw the locking rings into the source tube at both ends of the respective heads.

   c) Install the drawer shipping plate at both ends using four 3/8 - 16UNC x 45mm long SAE J429 Grade 8 socket head screws or the approved equivalent. Torque each screw to 20 to 22 Nm. (180 to 200 in-lb).

3. Place internal steel brace over each head of GC40.

4. Put the internal fixing brace on the lower head, sling around both ends of the lower head cylinder, and place the lower head into the transport cavity of the container together with the brace (Figure 7.2). Position the lower head in the overpack body so as to align two corners of the square base of the GC40 against the protective pads at the bottom of the cavity. Leave slings inside the overpack and ship them with the unit.

5. Close cavity with internal cover and secure cover with sixteen 5/8" bolts (torque bolts to 81 +/- 13 Nm [60 +/- 10 ft-lb]).

6. Close the container with the main cover and secure it with sixteen 5/8" bolts (torque bolts to 81 +/- 13 Nm [60 +/- 10 ft-lb]).

7. Check the radiation fields on the external surface of the overpack and at 1m, to determine which of the Radioactive I or II or III Category labels is appropriate (see). The maximum field at the surface of the package must be less than 200 mrem/h. The maximum field 1m from the surface of the package must be less than 10 mrem/h

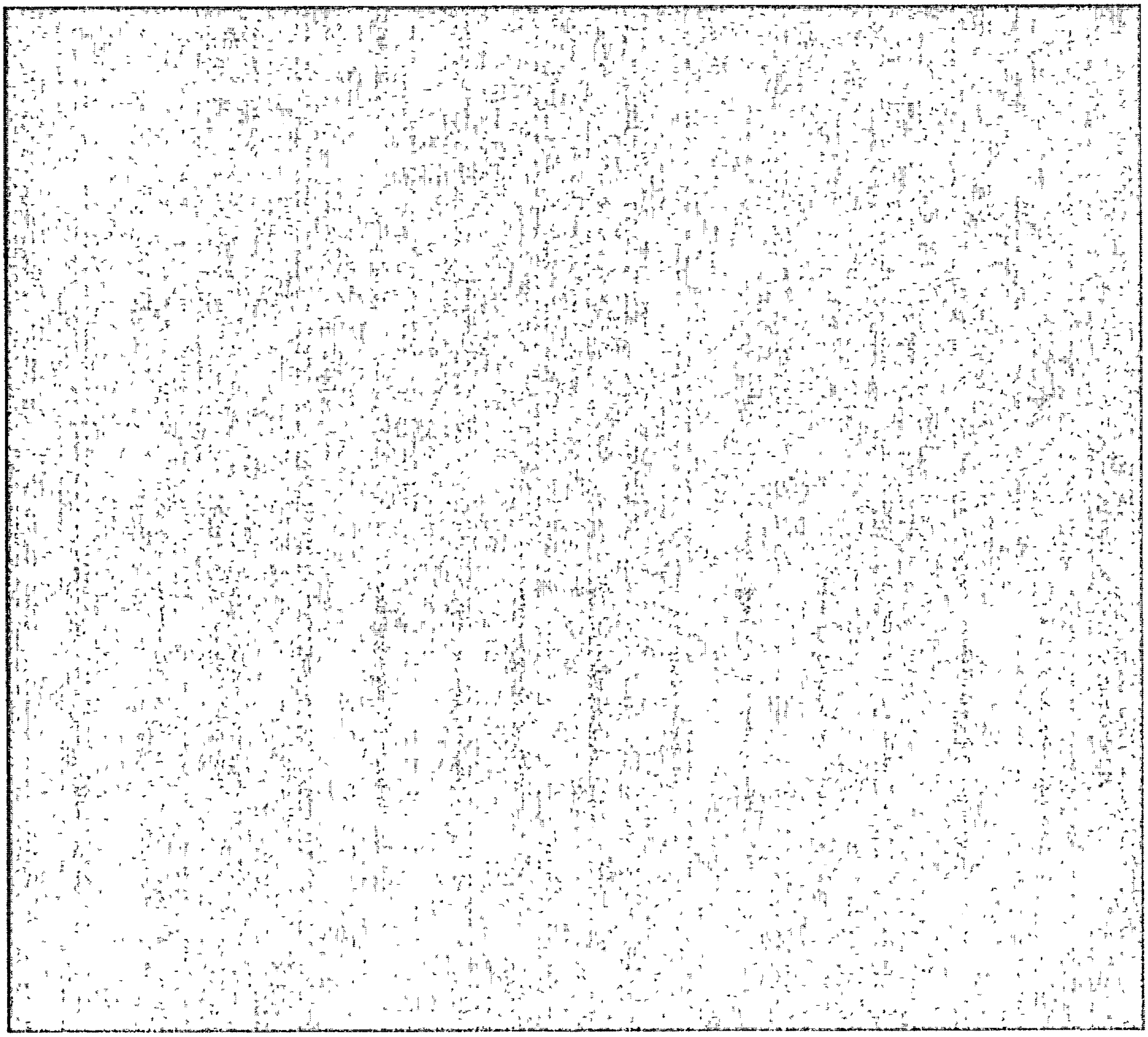


Figure 7.1: F-430/GC-40, Main Components

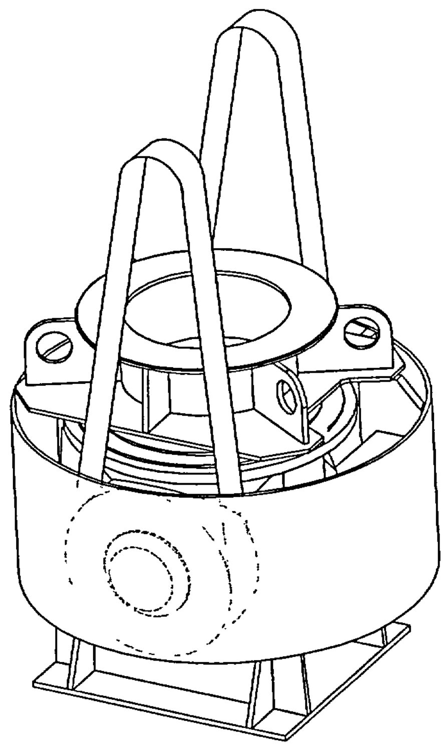


Figure 7.2: Slinging GC-40 Lower Head With Fixing Brace

8. Perform a routine wipe test on the unit to check for removable contamination. See section 7.3.1.1 for procedure and passing criteria.

   <u>Ensure that the Identification Plates and Radiation Caution Plates are securely affixed to two opposite sides of the F-430. Replace if necessary.</u>

9. Affix the following labels on the label backing plates provided on the two opposite sides of the overpack.

   a) Appropriate Radioactive I (white) label, Radioactive II (yellow) label, or Radioactive III (yellow) label

Note: The Radioactive Category label depends on the measured radiation fields. The requirements are summarized in Table 7.1. Information regarding the radioactive contents (number of Curies) and the Transport Index (TI) must be added to the Radioactive Category label. The TI is the highest reading obtained in mrem/h at 1 metre from any external surface of the package.

   b) 'Ship To' labels. Check off the bottom block on the label and fill in the required information.

   c) UN2916 label. This label must be printed with both the "UN2916" marking and the proper shipping name "Radioactive Material, Type B(U) Package". Note: This label must be affixed next to the Radioactive category label.

LOADING THE UPPER HEAD

10. Screw the lifting eyebolt into the top of the upper head and lower the upper head (with internal brace on top of it) into the transport cavity of the second F430 overpack and place it on top of the wooden base. Leave the lifting eyebolt inside the upper head.

11. Close cavity with internal cover and secure cover with sixteen 5/8" bolts (torque bolts to 81 +/- 13 Nm [60 +/- 10 ft-lb]).

12. Close the container with the main cover and secure it with sixteen 5/8" bolts (torque bolts to 81 +/- 13 Nm [60 +/- 10 ft-lb]).

13. Check the radiation fields on the external surface of the overpack and at 1m, to determine which of the Radioactive I or II or III Category labels is appropriate (see Table 7.1). The maximum field at the surface of the package must be less than 200 mrem/h. The maximum field 1m from the surface of the package must be less than 10 mrem/h.

14. Perform a routine wipe test on the unit to check for removable contamination. See section 7.3.1.1 for procedure and passing criteria.

Note: Ensure that the Identification Plates and Radiation Caution Plates are securely affixed to two opposite sides of the F-430. Replace if necessary.

15. Affix the following labels on the label backing plates (2) provided on the two opposite sides of the overpack.

    a) Appropriate Radioactive I (white) label, or Radioactive II (yellow) label, or radioactive III (yellow) label as applicable.

Note: The Radioactive Category label depends on the measured radiation fields. The requirements are summarized in Table 7.1. *Information regarding the radioactive contents (number of Curies) and the Transport Index (TI) must be added to the Radioactive Category label. The TI is the highest reading obtained in mrem/h at 1m from any external surface of the package.*

    b) 'Ship To' labels. Check off the bottom block on the label and fill in the following information: RADIOACTIVE MATERIAL, SPECIAL FORM, N.O.S. (CESIUM 137).

    c) UN2916 label. This label must be printed with both the "UN2916" marking and the proper shipping name "Radioactive Material, Type B(U) Package". Note: This label must be affixed next to the Radioactive category label.

Table 7.1: Package Label Requirements

Label	Radiation Level at External Surface of Package	Transport Index (T.I.)[1]	Radiation Level at External Surface of Vehicle
Radioactive I (white)	≤ 5.0 μ Sv/h (0.5 mrem/h)	-	-
Radioactive II (yellow)	>5.0 μ Sv/h (0.5 mrem/h) ≤ 500 μ Sv/h (50 mrem/h)	≤1.0	
Radioactive III (yellow)	>500 μ Sv/h (0.5 mrem/h) ≤ 2,000 μ Sv/h (200 mrem/h)	> 1 and ≤10.0	

[1] T.I. - Radiation level in microsieverts per hour at 1m from the external surface of the package divided by 10 (mrem/h at 1 m).

7.4 INSTRUCTIONS FOR SECURING THE PACKAGE ON ROAD VEHICLES

7.4.1 SECURING THE PACKAGE ON THE VEHICLE

1. The F430/GC40 transport package must be positioned on the vehicle such that it is facing direction of travel, i.e. the skid legs are parallel to the direction of travel. Chocks should be used at the base of the feet. These should be firmly fastened to the bed of the vehicle.
2. Bracing, if applicable, shall be in accordance with local and national regulations.
3. If the package is tied down (rather than braced) the tie-down collar must be fitted on the F-430. One-inch shackles with load binders or turnbuckles and minimum 3/8-inch chains shall be used. The angle of the chain to the vertical should be between 40 and 50 degrees.
4. Tension the chains equally, to the point that each one is taut, with all visible sag removed.

The appropriate reference documents may be supplied to the carrier by the shipper, if not already in their possession. Other guidelines and regulations may apply in other jurisdictions.

7.4.2 ADDITIONAL INSTRUCTIONS

1. Any additional instructions with respect to the shipment as per Competent Authority Certificates of Compliance must be observed.
2. All applicable documents must be provided to the carrier or his agent.
3. Attach Radioactive Placards to the vehicle. Transport vehicles and freight containers carrying radioactive material transport packages must display placards in accordance with the applicable transport regulations. In case of road transport within North America, the trailer of the transport vehicle must display placards on both sides, and front and rear, indicating that it carries radioactive materials.

   In Canada, the transport vehicle must be placarded on all four sides when Radioactive I (white), or Radioactive II (yellow), or Radioactive III (yellow) packages are transported.

   In USA, the transport vehicle must be placarded on all four sides only when Radioactive III (yellow) labelled packages are transported.

7.5 PROCEDURES FOR UNLOADING THE F430/GC40 PACKAGE

7.5.1 RECEIPT OF F430/GC40 TRANSPORT PACKAGE

1. Visually inspect the F430/GC40 transport package for damage and deterioration. Damage and deterioration, if any, are designated as either superficial or integrity-related. Immediately contact MDS Nordion's Package Engineering regarding any damage or deterioration that may affect the integrity of the package.
2. Check and verify that the tamper-proof seal is intact. If the tamper-proof seal is not intact, contact the RSO at the customer's site or MDS Nordion for further disposition.
3. Ensure that any damage or deterioration is properly documented.

4. Check all external surfaces on the package for contamination. See section 7.3.1.1 for procedure and passing criteria.
5. Perform a radiation survey of the assembled package. Radiation levels shall not exceed those specified in Table 7.1.
6. Remove any loose dirt from the exterior surfaces as required.

7.5.2 UNLOADING THE GC40 FROM THE F430

1. Move the F430 Overpack to a location accessible by overhead crane, using a 4-legged lifting sling rated to at least 4500kg (10000lb). Note that the maximum weight of the transport package is 3200kg or approximately 7000lb.
2. Remove 16 screws retaining the F430 main cover and using the same lifting slings as in step 1 remove the F430 Lid set it in a safe place.
3. Perform a routine wipe test of the internal cover to check for removable contamination. See section 7.3.1.1 for procedure and passing criteria.
4. Remove 16 screws retaining the F430 inner cover, remove the cover and set it in a safe place.
5. Using the slings inside the transport cavity choke the body of the GC40 lower head at the front and back (see Figure 7.2), and lift the GC40 lower head with its brace on top. Set the GC40 on a skid, and remove the fixing brace and lifting slings.
6. Perform a radiation survey of the GC40. Radiation levels should not exceed 2 mSv/h (200 mrem/h) on accessible surfaces of the GC40 or 0.1 mSv/h (10 mrem/h) at any point one meter from the surface of the GC40. If the radiation fields exceed these limits, contact MDS Nordion immediately.
7. Put the internal fixing brace inside the F430, close both covers and move F430 to storage.

7.6 PREPARATION OF AN EMPTY PACKAGE FOR TRANSPORT

7.6.1 OPERATIONS ON THE EMPTY F430 OVERPACK

1. After the overpack is empty and on the trailer truck or in the designated staging area, monitor around the overpack to confirm that it is empty.
2. Check all external surfaces on the overpack for contamination. See section 7.3.1.1 for procedure and passing criteria.
3. Secure both lids with 5/8" bolts. Torque Main Cover bolts to 81+/-13 Nm (60+/-10 ft-lb)
4. If the shipment originates in the USA, cover the "Radiation Caution" plates with "EMPTY" labels. For shipments originating from other countries, cover the "Radiation Caution" but do not attach "EMPTY" labels.
5. Remove the Category labels and the UN number labels.
6. Affix address labels on two opposite sides of the container.
7. The F430 overpack is now ready for EMPTY shipment.

7.6.2 INSTRUCTIONS FOR SECURING THE EMPTY F430 ON ROAD VEHICLES

1. The F430/GC40 transport package must be positioned on the vehicle such that it is facing direction of travel. i.e. the skid legs must be parallel with the direction of travel. Chocks should be used at the base of the feet. These should be firmly fastened to the bed of the vehicle.
2. Bracing, if applicable, shall be in accordance with local and national Regulations.
3. If the package is tied down (rather than braced), one-inch shackles with load binders or turnbuckles and minimum 3/8-inch chains shall be used. The angle of the chain to the vertical should be between 40 and 50 degrees.
4. Tension the chains equally, to the point that each one is taut, with all visible sag removed.
5. The appropriate reference documents may be supplied to the carrier by the shipper, if not already in their possession. Other guidelines and regulations may apply in other jurisdictions.

7.6.3 ADDITIONAL INSTRUCTIONS

1. Any other additional instructions with respect to the shipment as per the applicable Certificates of Compliance shall be applicable.
2. Appropriate documents shall be provided to the carrier or his agent.

CHAPTER 8 – ACCEPTANCE TESTS AND MAINTENANCE PROGRAM

This chapter discusses the acceptance test and maintenance program used on the F430/GC40 transport package, in compliance with the applicable subsections of 10 CFR Part 71. MDS Nordion has a quality assurance program in place governing all aspects of the F430/GC40 overpack (design, manufacturing, testing, use, inspection and maintenance etc.

8.1 ACCEPTANCE TESTS

All inspections and tests of the F430 overpack, prior to its first use, are an integral part of the manufacturing process. The manufacturing process and its quality assurance requirements are established in a technical specification that is maintained by MDS Nordion in accordance with its Transport Package Quality Plan (refer to Appendix 9.3.1).

8.1.1 INSPECTION

The package is visually and dimensionally inspected for any non-conformance in materials or fabrication using applicable codes, standards and drawings. In particular it is ensured that:

1. The dimensions are in accordance with the engineering drawings
2. The overpack components fit together properly
3. all fasteners are in place and properly installed.

8.1.2 STRUCTURAL AND PRESSURE TESTS

Inspections and tests to ensure the structural integrity of the F430/GC40 package are an integral part of the manufacturing and quality assurance program. All critical materials, components, welding supplies, fasteners etc. are subject to the quality program. All critical components and subassemblies are inspected to engineering drawings and/or specifications at key points in the manufacturing process.

Should an inspection or test fail to meet the prescribed criteria, corrective action shall be in accordance with the Quality Plan for Transport Packages.

No pressure testing is required for the F430 overpack.

8.1.3 LEAK TESTS

There are no leak tests specified for the F430. Containment is provided by sealed sources which are leak tested during manufacturing and periodically leak tested in service.

8.1.4 COMPONENT TESTS

8.1.4.1 Valves, Rupture Discs, and Fluid Transfer Devices

This section is not applicable since there are no valves, rupture discs or fluid transfer devices on the F430/GC40 package.

8.1.4.2 Gaskets

The F430 overpack and its components undergo inspection prior to each shipment from MDS Nordion, Kanata, Ontario, Canada. The gasket is visually examined for defects. The seal surfaces are visually examined for nicks or damage.

A new gasket may be installed on the F430 during the regular or annual inspection and maintenance.

8.1.4.3 Miscellaneous

[redacted]

[redacted]

8.1.5 TESTS FOR SHIELDING INTEGRITY

The F430 Overpack provides principally crush and fire protection. Shielding is provided by the GC40. The GC40 is subjected to a thorough radiation survey as part of manufacturing. The acceptance criteria are as follows:

When installed in the laboratory configuration,

1. the average radiation fields on the external surface of the GC40 shall not exceed 20 mrem/h.
2. the maximum radiation fields on the external surface of the GC40 shall not exceed 100 mrem/h.
3. the average radiation fields at 1 m from any accessible external surface of the GC40 shall not exceed 2 mrem/h.
4. the maximum radiation fields at 1 m from any accessible external surface of the GC40 shall not exceed 10 mrem/h.

When prepared for shipment,

5. the maximum radiation fields on the external surface of the GC40 shall not exceed 200 mrem/h.
6. the maximum radiation fields at 1 m from any accessible external surface of the GC40 shall not exceed 10 mrem/h.

There are no neutron sources in the F430/GC40 package.

8.1.6 THERMAL ACCEPTANCE TESTS

Thermal acceptance testing is not required for each F430, since the internal heat generation in the GC40 is low (100Watts) and the thermal gradients are low. The properties of the polyurethane foam are verified during manufacturing as described previously.

8.2 MAINTENANCE PROGRAM

This section describes the maintenance program used to ensure the continued performance of the F430 overpack. The F430 package is inspected prior to each loading. The inspection and maintenance is carried out as per the MDS Nordion Transport Package Quality Plan (Appendix 9.3.1).

8.2.1 STRUCTURAL AND PRESSURE TESTS

Prior to shipment of the package, all critical components are visually inspected to ensure that they are undamaged and continue to meet the requirements of the applicable engineering drawings and specifications.

No pressure testing is required for the F430 overpack.

8.2.2 LEAK TESTS

No leak testing is required for the F430 overpack.

8.2.3 SUBSYSTEM MAINTENANCE

The inner brace and plywood base inside the transport cavity are subjected to regular visual inspections. If these inspections reveal damage such as significant dents or weld cracks, the components are repaired in accordance with the same standards that were used for manufacturing.

The plywood base from the bottom of the transport cavity is removed and the cavity is cleaned out of any loose dirt. Worn, cracked or wet plywood layers are replaced each time before loading.

On an annual basis, all components are weighed. The weight of each component may not change from its original weight by more than –1% or +3%. Any components that are painted as part of a maintenance activity shall be weighed before and after painting.

On an annual basis, the screws on all hoist rings shall be re-tightened to the specified torque.

8.2.4 VALVES, RUPTURE DISCS, AND GASKETS ON THE CONTAINMENT VESSEL

The F430/GC40 container undergoes inspection and maintenance prior to each shipment from MDS Nordion, Kanata, Ontario, Canada. The gaskets are visually examined for defects. The seal surfaces are visually examined for nicks or damage. New gaskets may be installed on the F430 during the regular or annual inspection and maintenance.

8.2.5 SHIELDING

Radiation surveys are performed on the GC40 and the F430/GC40 prior to every shipment. The acceptance criteria are as follows:

1. the maximum radiation fields on the external surface of the F430/GC40 shall not exceed 200 mrem/h, and
2. the maximum radiation fields at 1 m from any accessible external surface of the F430/GC40 shall not exceed 10 mrem/h.

8.2.6 THERMAL

No thermal testing is required on the F430 overpack.

CHAPTER 9 – QUALITY ASSURANCE

This section describes the Quality Program in place at MDS Nordion International Inc., Kanata, Ontario, Canada, as it applies to the F-430 Transport Package. MDS Nordion International Inc. has an ISO9001 registered quality assurance program in place governing all aspects of the Transport Packaging (design, manufacturing, testing, use, inspection and maintenance etc.), and is approved by USNRC; (Quality Assurance Program Approval No. 0703, Docket No. 71-0703, dated June 24, 1992).

9.1 MDS NORDION QUALITY ASSURANCE PROGRAM

The Quality Assurance Program at MDS Nordion is as per MDS Nordion document IN/QA 0224 Z000 "RADIOACTIVE MATERIAL TRANSPORT PACKAGE QUALITY PLAN", attached in Appendix 9.3.1. The technical specification for the F-430 overpack is included in appendix 9.2.

9.2 MANUFACTURING OF THE F-430 PROTOTYPE

Manufacture:	Start Date:	May 1999.
	Completion Date:	August 1999.
Manufacturer:		Hewitt (Brockville) Ltd.
Purchase Order:		4213919
QA Program:		ISO 9002:1994
Certificate No.:		SGS International Certification Services Canada Certificate No. 181/96

9.3 APPENDICES

This section contains the following appendices.

Appendix 9.3.1 MDS Nordion Transport Package Quality Plan

Appendix 9.3.2 F430 Overpack Technical Specification

APPENDIX 9.3.1:
MDS Nordion Transport Package Quality Plan

IN/QA 0224 Z000 (4)

Radioactive Material Transport Package Quality Plan

Signatures

Prepared by: M Krzaniak, Manager Package Engineering Date: 00/06/28

Reviewed by: A. Warbick Cerone, Director, Regulatory Affairs Date: 00/06/28

Approved by: R. McGregor, Director, Quality Assurance, Nuclear Medicine Date: 00/06/28

Approved by: R. Kachaniwsky, Director, Quality Assurance, Industrial Irradiation and Therapy Systems Date: 00-06-28

Document History

Date	Version	Comments	Prepared by	Reviewed by	Approved by
92 Jun	A	Original Issue	See	Validation	Sheet
95 May	B	DCN A0221-D-01A			
96-12-09	3	DCN A0955 D-01A	M. Krzaniak	R. McKinnon K. Sibbert I. Trevena J. Corley	G. Malkoske
	4	DCN A1807-D-01A			

1. PURPOSE

This Quality Plan describes the activities associated with the design, fabrication, assembly, testing, maintenance, repair, modification, and use of MDS Nordion radioactive material (RAM) transport packaging. It identifies the activities, responsibilities, and action necessary to ensure that a transport package meets all regulatory, customer, and internal Quality Assurance Program requirements.

2. SCOPE

This plan is applicable to all MDS Nordion Transport Packages.

3. APPLICABLE DOCUMENTS

1. MDS Nordion Specification QSF 00, Industrial Irradiation Quality Manual
2. MDS Nordion SOP #5.00 –QA-00, Therapy Systems Quality Assurance Manual
3. MDS Nordion Specification QAM 00, Nuclear Medicine Quality Manual
4. IAEA Safety Standards, Safety Series No. 6 Regulations for the Safe Transport of Radioactive Material 1985 Edition (As Amended 1990)
5. IAEA Safety Guides, Safety Series No. 37 Advisory Material for the IAEA Regulations for the Safe Transport of Radioactive Material (1985 Edition, As Amended 1990)
6. IAEA Safety Standard ST-1, Regulations for the Safe Transport of Radioactive Material, 1996 Edition
7. US-NRC Regulation 10 CFR 71 Packaging of Radioactive Material for Transportation and Transportation of Radioactive Materials under Certain Conditions
8. Packaging and Transport of Nuclear Substances Regulations, Canadian Nuclear Safety Commission, May 31, 2000
9. International Standard ISO 9001-94 Quality Systems Model for quality assurance in design/development, production, installation and servicing
10. MDS Nordion Specification IN/OP 0352 Z000, Procedure for Design Control and Configuration Management

4. PROCEDURE

4.1 Management Responsibility

4.1.1 Quality Policy

The MDS Nordion Quality Policy is maintained in the divisional Quality Manuals [1,2,3] and is approved by senior management. It is the responsibility of all applicable staff, at all levels, to be aware of and understand the Quality Policy and supporting procedures.

This Quality Plan is used to ensure that the specified requirements of transport packaging for radioactive material comply with pertinent regulatory requirements. This Plan defines the standard operating practices that affect radioactive material transport package quality. It establishes a documented system of management controls that provide confidence in the quality of all associated work activities.

4.1.2 Organization

Responsibility and Authority

Senior management responsibilities are described in references 1,2 and 3. Responsibility assignments for other functions involved in quality related activities for transport packages are described below:

Director, Quality Assurance

The authority for the administration of the Divisional Quality Assurance Programs is delegated to the Divisional Directors of Quality Assurance, who report to the Vice-President, Quality and Regulatory Affairs.

Director, Regulatory Affairs

The Director, Regulatory Affairs reports to the Vice-President Quality and Regulatory Affairs The Director is responsible for the identification of regulatory requirements and coordinates the communications between MDS Nordion and the competent authorities.

Manager, Package Engineering

The Manager, Package Engineering reports to the Vice President, Engineering and Technology. The Manager is responsible for the design, specification and testing of radioactive material packages and ongoing technical support. The Manager is responsible for verifying that all regulatory submissions for RAM transport package certification are accurate and complete.

Project Engineer

The Project Engineer reports to the Manager, Package Engineering, and is responsible for design projects from inception to completion. This includes the preparation or review of design documentation, the preparation of specifications for manufacturing, and design qualification testing.

4.1.3 Management Review

Procedures for management review of the quality system are described in the Divisional Quality Assurance Manuals. [1,2,3]

4.2 Quality Plan and Quality Systems

The Divisional Quality Systems are described in the Divisional Quality Assurance Manuals [1,2,3] Requirements specific to transport packages are defined in this Quality Plan.

4.3 Contract Review

Authority for selection of transport packaging is through the operating divisions. Proposed uses of transport packaging which may not meet the specified requirements are referred to the Manager, Package Engineering for review. Each nonstandard application is reviewed for its capability to meet the standard, code, and regulatory requirements. For Type B packages, regulatory approval is obtained before use of any unapproved packaging combinations.

4.4 Design Control

4.4.1 Design Planning and Activity Assignment

Written plans are prepared for design and verification activities for each new or modified RAM package design at project initiation The Manager, Package Engineering assigns the project to qualified personnel equipped with the resources necessary to prepare a fully compliant design.

4.4.2 Design Input

The Project Engineer verifies design input requirements for adequate identification and documentation. Design input verification involves, but is not limited to:

a) performance and functional criteria, including operational requirements,

b) applicable codes and standards,

Notwithstanding national codes, standards and regulations, the standard for the design of a radioactive transport package is reference [4]. However, the project leader shall consider reference [6] when defining input requirements.

c) regulatory requirements, including applicable Package Design Approval or Special Form Radioactive Material Certificates,

d) environmental conditions,

e) documentation, training, maintenance and inspection plans,

f) the need for Special Form Material Certification for the sealed source if initial evaluation of radioactive material transport packaging/device or sealed source/packaging combinations indicate a need,

g) where applicable, the results of contract review.

Incomplete, ambiguous, or conflicting requirements are resolved by the Project Engineer with the responsibility for drawing up the requirements.

4.4 3 Design Output

Design output is documented and expressed in terms of requirements, calculations, tests, and analysis. The design output shall:

a) meet the design input specification,

b) show design analysis in sufficient detail to allow verification of the adequacy of the design and conformity to appropriate regulatory requirements whether or not these have been stated in the Design Plan,

c) include a Safety Analysis Report (SAR) in suitable detail to meet requirements of regulatory guidelines. The extent of the analysis and testing chosen must be sufficient to prove the validity of the design,

All new RAM transport package designs must be evaluated to the applicable requirements. For Type B designs, the evaluation is part of a safety analysis report submitted to the competent authority. No Type B packaging design can be used before the evaluation is complete and a license has been issued. The Project Engineer is responsible for preparing an application for each new or modified Type B RAM transport package design.

d) include engineering drawings and operating procedures,

e) include a Technical Specification for Type B packages,

Safety Analysis Report

The application for certification of a Type B radioactive material transport package includes at least the following:

a) package description detailing radioactive contents, containment system, shielding, and operational features,

b) structural evaluation including but not limited to:

   1. structural design
      - design criteria referencing requirements for packages as in IAEA Safety Series No. 6
      - mechanical properties of structural materials
      - weights and centres of gravity
   2. general requirements for packages such as:
      - lifting devices
      - closure methods
      - tiedown devices
      - external pressure
      - chemical and galvanic reactions
   3. conditions of transport

c) thermal evaluation,

d) accident analysis, based on IAEA or national competent authority regulatory requirements,

e) overview drawing,

f) preparation for shipment and inspection and maintenance procedures ,

g) Special Form evaluation, as applicable,

h) test results, and/or engineering justification.

Technical Specification

The Technical Specification is an integral part of the design documentation for a Type B package. It establishes the overall technical requirements for manufacture, assembly, inspection, test and delivery for each model of transport packaging. The Specification defines:

a) applicable engineering drawings,

b) applicable standards,

   Notwithstanding national codes, standards, and regulations, the standard for design of a radioactive material transport package is: IAEA Safety Standards, Safety Series No. 6 Regulations for the Safe Transport of Radioactive Material 1985 Edition (As Amended 1990),

c) MDS Nordion specifications and procedures,

d) quality program standards and codes required for manufacture. The manufacturer's quality program is normally subject to International Standard ISO 9002 or CSA CAN3-Z299.2-85: The code requirement for welding and welder qualification is normally ASME BPV Code Section IX,

e) where applicable, requirements for welding, fitting and machining, surface finish and cleanliness, lead pouring and bonding, and painting,

f) nonconformance and corrective action,

g) inspection requirements,

h) tests for welds, mechanical operation, lead bonding, radiation shielding, and leakage testing,

i) requirements for supplier history file.

4 4.4 Design Verification and Review

Designs and associated documents are verified and/or reviewed to ensure that they meet specified design requirements. Design verification is performed by qualified staff by conducting testing or by comparison to similar designs. The Manager, Package Engineering determines the extent of verification and review required. This decision is based on complexity, novelty, degree of standardization, and safety implications. The Design Plan identifies the verification and review requirements. All verification and review activities are documented. The nature of the verification process must conform to applicable codes and standards. The process involves:

a) qualification testing or comparison review according to applicable IAEA standards and competent regulatory authority regulations. Requirements, procedures, data, assumptions, and results are documented and filed. Results are evaluated against specified acceptance criteria. The conclusions of the tests or comparisons are recorded and filed in the design history files,

b) design review by qualified persons other than those who executed the design. The reviews determine if the design methods are appropriate and correctly applied. The reviewers verify that the assumptions and simplifications used are justifiable, and the design interfaces are properly addressed. Reviews are conducted before design release. They are documented, and include decisions.

4.4 5 Design Changes

A design change system is used for the control of drawings and supporting documentation. All changes to the design of RAM transport packages are reviewed and approved by the Manager, Package Engineering, the Director, Regulatory Affairs, Director, Quality Assurance; and where required, the representatives from the affected operating divisions. The Project Leader documents the change description, the reasons for it, and the implications. The method and extent of the design verification are dependent upon the extent and nature of the changes. The Project Leader identifies the necessary recipients of the revised design documents.

4.5 Document and Data Control

Documents and data that relate to the needs of the Quality Plan are controlled according to established procedures. [1]

4.6 Purchasing

Documented policies and procedures are maintained to ensure that the purchased RAM transport packaging, components, materials, and services conform to specified requirements.

Suppliers are selected based on their ability to meet the quality requirements. Measures are in place, through purchasing and QA policies and procedures, for the evaluation, selection and approval of suppliers. It is the responsibility of the Manager, Package Engineering to ensure that the purchasing documents clearly describe the material required. The key document for the information necessary is the purchase requisition, which references technical requirements such as the technical specification, drawings etc.

Each order for a transport packaging requires certain control activities and records, specifically:

a) purchase requisitions for transport packages are reviewed by Quality Assurance for adherence to the quality assurance procedures, and requirements,

b) selected suppliers are on an approved vendors list,

c) suppliers' Inspection and Test Plans are reviewed and approved by Package Engineering,

d) Incoming inspection is performed according to the Inspection and Test Plan,

e) requests for disposition of nonconformances must be submitted to the purchasing department in writing. Disposition is decided by the Manager, Package Engineering, or designate, and the Quality Engineer.

4.7 Control of Customer Supplied Product

Transport packaging supplied by customers is used in accordance with design and licensing documentation. As a minimum requirement, the customer is required to provide:

a) copies of relevant transport certificates, including certification of Special Form Radioactive Material Approval Certificates, if applicable,

b) Operating Procedures.

4.8 Product Identification and Traceability

Each Type B package is identified with a model number and a unique serial number.

4.9 Process Control

This quality element does not apply to transport packages in use. During manufacture, special processes are qualified by the manufacturer.

4.10 Inspection and Testing

Inspection Plans are written for inspections performed during the life cycle of RAM transport packaging. These plans outline the type of inspection or testing to be undertaken. For each returnable RAM transport packaging type, an inspection and maintenance plan is prepared. The plans include, as applicable:

a) new packaging first-off inspection and acceptance requirements,

b) periodic inspections after shipment, and before reuse,

c) annual inspection and maintenance,

d) inspection and maintenance checklists,

e) instructions for special tests such as: leak testing, pressure tests, shielding tests, etc.,

f) quality records to be kept.

Procedures for ongoing inspection and maintenance are normally prepared by the project engineer, and require review by the division responsible for the implementation of the inspection and maintenance procedure and the approval of the Manager, Package Engineering

4.10.1 Package Qualification

Type B RAM packaging and components are inspected to the established quality level and in accordance with the Technical Specification. Inspection and testing during manufacture are carried out by a qualified supplier using the Inspection and Test Plan approved by the Project Engineer. Supplier Manufacturing, Inspection and Test Plans are retained with the Unit History File.

Confirmation testing and/or review of supplier generated records to specific requirements is carried out at MDS Nordion prior to final acceptance of the RAM package. As a minimum requirement, a radiation survey must be performed prior to release for shipment. Documentation of the results is maintained in the unit manufacturing history file.

4.10.2 Inspection and Maintenance

In use packaging is periodically inspected to the appropriate Inspection and Maintenance Procedure by the applicable operating division.

4.11 Control of Inspection, Measuring and Test Equipment

Procedures for the control of Inspection, Measuring and Test Equipment are described in the Divisional Quality Assurance Manuals. [1,2,3]

4.12 Inspection and Test Status

During manufacture, the inspection and test status of packagings is maintained in accordance with the qualified supplier's procedures. Systems are in place to ensure that the inspection and test status of all packagings is maintained.

4.13 Control of Nonconforming Product

Following the procedures in the relevant Quality Manual, disposition of nonconforming material is reviewed and the activity recorded. The system requires that the disposition of nonconformances be requested in writing. [1]

4.14 Corrective and Preventive Action

Documented procedures are in place for implementing corrective and preventive action. [1,2,3]

4.15 Handling, Storage, Packaging, Preservation and Delivery

The Project Engineer identifies, in the Technical Specification for Type B packages , the requirements for handling and storing by MDS Nordion's suppliers.

All RAM transport packages are prepared for shipment in accordance with Preparation for Shipment procedures. These procedures provide instructions to ensure the units are prepared for shipment in accordance with the requirements of the package Safety Analysis Report and include requirements for contamination testing, radiation surveys and labeling.

Documented procedures are in place to receive transport packages.

4.16 Control of Quality Records

Manufacturing History File

Records are maintained to show that the specified quality requirements were met, and the quality system is operating correctly. Pertinent supplier quality records are an element of these data The nature of the quality records is identified in the manufacturing plans. These records are maintained as a Unit History File for each Type B radioactive material transport packaging purchase. As a minimum, the following records are prepared by the supplier to form a Manufacturing History File:

a) Table of Contents,

b) Copies of Purchase Orders and all amendments, if applicable,

c) Supplier History File for components used, including, but not limited to:
   - MDS Nordion QA Release Form,
   - Inspection and Test Plans,
   - completed inspection records,
   - list of drawings and specifications with current revisions in effect at the time of manufacturing and the serial numbers of the units supplied,
   - copies of Deviation Disposition Requests (DDRs),
   - Certified Material Test Reports, Certificates of Compliance or similar ,
   - Certified Non-destructive Examination (NDE) reports,
   - Welders' qualification certificates,
   - radiation survey data.

d) Reference to Manufacturing Plan used,

e) Release for Shipment forms,

f) Records are maintained in secured areas with limited access The retention period for these records is the life of the packaging + 15 years.

Service History

- Service history is maintained for each transport package design. This includes inspection and maintenance records and design history.

Details of retention periods for specific records are detailed in the Quality Records procedure in the relevant Quality Manual. [1,2,3]

4.17 Quality Audits

Internal quality system audits are planned and performed in accordance with the Division Quality Assurance Manuals. [1,2,3]

4.18 Training

Training requirements are defined for all key roles affecting safety of RAM transport. Actual training is tracked against requirements including technical knowledge, control of process, specific skills and general theory in quality issues, safety, and company policies.

Detailed instruction for the carrying out of training is provided in each Division's administrative procedures. The significant requirements are summarized below:

a) all personnel involved in the transport of radioactive material receive training in radiation safety and transport regulations,

b) specific qualification, training, and certification requirements are determined on an individual basis by line management. This determination is based on: the type of work, potential effect on quality, and the applicability of codes, standards or regulations,

c) the line managers are responsible, with Human Resources, for maintaining records of staff selection, qualification, certification, and training. They also provide for the necessary training, and evaluate needs during staff performance reviews.

4.19 Servicing

Routine inspection and maintenance to transport packages is discussed in section 4.10.

4.20 Statistical Techniques

This quality element does not apply to transport packages.

APPENDIX 9.3.2:
F430 Overpack Technical Specification

1. SCOPE

This specification establishes the technical requirements for the manufacture, assembly, inspection, and delivery of the F-430 overpack.

2. DESCRIPTION

The F-430 is an overpack designed primarily to transport MDS Nordion's Gammacell 40.

The F-430 is a welded stainless steel structure of a cylindrical shape. The walls are filled with energy absorbing and insulating material. There are four hoist rings and forklift pockets on top of the overpack for overhead lifting and four hoist rings on the side of the packages for tie-down during transport.

3. APPLICABLE DRAWINGS

The applicable issues of all drawings and specifications are listed in the Production List submitted at the time of tendering documents. In the event that certain requirements or data on the drawings conflict with the requirements of this specification, the governing requirements shall be at the discretion of MDS Nordion.

4. APPLICABLE STANDARDS

The standards referenced herein form an integral part of this specification. If there is any conflict between this specification and the listed documents, MDS Nordion must be contacted for a disposition on the overriding requirement.

5. REQUIREMENTS

The overpack shall be fabricated, assembled, inspected, and prepared for delivery by the Vendor as specified herein. Final acceptance of the packaging shall be dependent upon passing all tests and checks specified in Section 6 of this specification. The Vendor shall maintain a close liaison with MDS Nordion, or our authorized representative, throughout all phases of the work.

5.1 QUALITY PROGRAM

The vendor's quality program is subject to ISO 9002 or an equivalent approved by MDS Nordion.

5.2 STORAGE AND HANDLING OF MATERIALS AND COMPONENTS

Storage and handling of all materials and processed subassemblies shall be carried out in a manner that ensures their positive identification during manufacture and assembly. The requirements of ISO 9002-94 clause 4.15 shall apply.

The materials identification requirements are detailed in Section 6-3 of this specification.

5.3 MANUFACTURING PROCEDURES

5.3.1 Workmanship

Workmanship shall be of high quality in accordance with practice pertinent to the manufacture of steel structures. The packaging is subject to MDS Nordion's quality surveillance.

5.3.2 Manufacturing Control Plan and Special Process Procedures

A Manufacturing Control Plan and special process procedures shall be prepared by the Vendor according to the requirements of ISO 9002 and this specification. Special process procedures shall be submitted for MDS Nordion's approval. One approved copy will be returned to the Vendor for inclusion in the Unit History File (see section 6.5).

5.3.3 Welding

Welding shall be according to ASME BPV Code Section IX or CSA W59.

Welding electrodes, flux, and other materials to be used shall be certified to the applicable specifications.

Welding procedures, based on standards other than those specified above, must be submitted for approval.

Welders, who shall perform welding for this contract, and who are qualified to standards other than those specified above, must submit their qualifications for approval.

Unless approved by MDS Nordion, local heating shall not be used for any purpose whatsoever. Excessive force shall not be used for fit-up or in closing the work.

5.3.4 Fitting and Machining

As a minimum requirement, the dimensions and tolerances called for on the drawings shall be met. All surface finishes shall be in accordance with the finish noted on the drawings and shall be compatible with associated dimensional tolerances and fits.

5.3.5 Surface Finish and Cleanliness

All welded surfaces shall be smooth and shall merge smoothly into the parent metal. All gouges, scratches, or other marks shall be removed. All scale, oxide, weld spatter, oil, chips, and other foreign material shall be completely removed from all exposed parts. All surfaces that cannot be cleaned after complete fabrication and assembly shall be free of all foreign material prior to assembly.

All components shall be protected and covered to prevent damage, corrosion, and the ingress of foreign material. The packaging shall be supplied with all surfaces suitably protected against corrosion during shipment and storage at an indoor, unheated site. The methods of protection for all stages shall be subject to MDS Nordion's approval. All components shall be clearly marked with their part numbers.

5.3.6 Painting Carbon Steel Surfaces

After complete assembly and fabrication, all dirt, salt, oil, grease, chemical deposits and other surface contaminants shall be removed in accordance with the paint manufacturer's instructions. The cleaning method shall be considered to be a special process.

The paint and primer used shall be approved by MDS Nordion. Paint and primer shall be applied in accordance with the manufacturer's instructions and the engineering drawings. The Vendor shall allow at least 12 hours of drying time prior to handling and 48 hours of drying time prior to delivery. Allow at least 7 days before exposing to water.

5.4 [redacted]

5.4.1 [redacted]

[redacted]

Table 5.1: [redacted]

[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]

Table 5.2: [redacted]

[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]

5.4.2 [redacted]

[redacted]

5.4.3 [redacted]

[redacted]

5.4.4 [redacted]

[redacted]

5.4.5 [redacted]

[redacted]

6. INSPECTION, TESTS, AND DOCUMENTATION

The Vendor shall provide all the testing and inspection services and facilities except where otherwise specified. The inspection work shall be under the control of a competent chief inspector, whose prime responsibility is inspection and who is independent of production.

The Vendor shall prepare a detailed Inspection and Test Plan, including Inspection Check Sheets and Inspection Procedures according to the requirements of ISO 9002-94 and this specification. The Inspection and Test Plan must include hold points for customer inspection as negotiated with MDS Nordion.

The Inspection and Test Plan including Inspection Check Sheets and Inspection Procedures shall be submitted for MDS Nordion's approval. One approved copy will be returned to the Vendor for inclusion in the Unit History File.

Inspection by MDS Nordion, or our authorized representative, shall not in any way relieve the Vendor of any of the inspection duties called for herein.

MDS Nordion shall have the right to specify additional inspection or testing. Such inspection and testing shall be at the expense of MDS Nordion.

The Vendor shall maintain records of all inspections and tests that shall be available for review by MDS Nordion or our authorized representative.

6.1 NONCONFORMANCE AND CORRECTIVE ACTION

If any part, component or assembly fails to meet a design, an inspection or test requirement specified herein, the Vendor shall notify MDS Nordion according to the requirements of the MDS Nordion's Quality Assurance Manual.

The Vendor must obtain written permission from MDS Nordion before any remedial action is taken.

If remedial action, including associated redesign, is likely to affect the results of tests or work previously completed, appropriate re-inspection and testing shall be carried out. The repair, rework, and Quality Control procedures necessary to ensure a satisfactory repair shall be subject to MDS Nordion's approval.

Full documentation of any of the above shall be maintained so that nonconformance can be evaluated and corrected.

6.2 RE-INSPECTION

At the request of MDS Nordion, the Vendor shall re-inspect any component or material. The defects so revealed shall be cause for rejection of the component, or alternatively, for repair and subsequent re-inspection. All costs of re-inspection shall be borne by the Vendor. If no unacceptable defects are revealed, re-inspection requested by MDS Nordion shall be at MDS Nordion's expense.

6.3 MATERIALS AND COMPONENT INSPECTION

6.3.1 Raw Material

Materials and components used in the construction and assembly of the packaging and its associated equipment shall be as specified on the applicable drawings. If materials, or components are to be substituted, then the substitution must be approved by MDS Nordion. Where proprietary parts or materials are specified, it is the Vendor's responsibility to ensure that they conform to the standards given in the manufacturer's specifications.

Certification of materials by the Vendor is required in the form of Certified Material Test Reports (CMTR's) or Mill Certificates. This documentation shall be included in the History File described in Section 6.5 of this specification.

6.3.2 Purchased Mechanical Components

All purchased components shall be as specified on the engineering drawings. Proof shall be in the form of permanent markings, (such as model or part numbers) or statements of compliance by the supplier.

6.4 MECHANICAL TEST

The packaging and all attachments, and associated equipment, shall be inspected by the Vendor at all stages of manufacture and assembly to verify that the dimensions, fit, alignment, and surface finish are in accordance with the requirements shown on the applicable drawings. The reference temperature for dimensions shall be 20°C (68°F). The inspection shall also verify that the workmanship and cleanliness are in accordance with the requirements of this specification.

The critical dimensions of the F-430 overpack shall be checked by the vendor.

The weight of the completed overpack and any removable components shall be measured and recorded by vendor.

6.5 DOCUMENTATION RECORDS

The Vendor shall prepare and maintain records that shall be available to MDS Nordion during the period of manufacture. These shall be compiled as the work proceeds, into a bound 8 1/2 x 11 inch (or the equivalent metric size) History File that shall be turned over to MDS Nordion with the Quality Assurance Release Form.

The History File shall contain the following:

1. Table of Contents
2. Release Form No. QAP-SF-06 (MDS Nordion Quality Assurance Manual).
3. List of approved Manufacturing Control Plan, Special Process Procedures, Inspection Procedures, and Inspection and Test Plan including Inspection Check Sheets.
4. Completed Inspection and Test Check Sheets and Reports (critical dimensions, weights, etc.)
5. Copy of the Production List and a list of any additional Drawings or Specifications with the revisions in effect at the time of manufacture.
6. Copies of all original Deviation Disposition Requests (DDR's) signed by MDS Nordion's Engineering Department, on MDS Nordion Form No. QAP-AP-2F.
7. Certified Material Test Reports (CMTR's), or Mill Certificates.
8. Certified NDE Reports, etc., and personnel qualifications, where applicable.
9. Any other documents requested by MDS Nordion in the contract documents.