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Technical Memorandum

Thermal Performance of Transport Container Design No. 3750A

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Date	04/10/00	Date	30/10/00.

1. PURPOSE AND SCOPE

This document details the thermal performance of the key features of the 3750A design transport container under the various environmental conditions specified in Safety Series No.6 for Type B(U) packaging. The results, which are all worst-case temperatures at various points in and around the structure, are used to directly, to demonstrate the ability of the design to withstand the environmental conditions, and indirectly to provide reference data for documents that demonstrate other aspects of regulatory compliance.

2. INTRODUCTION

The 3750A consists of a finned stainless steel flask attached to a stainless steel pallet. The flask is enclosed within a well-braced, stainless steel cage also attached to the pallet.

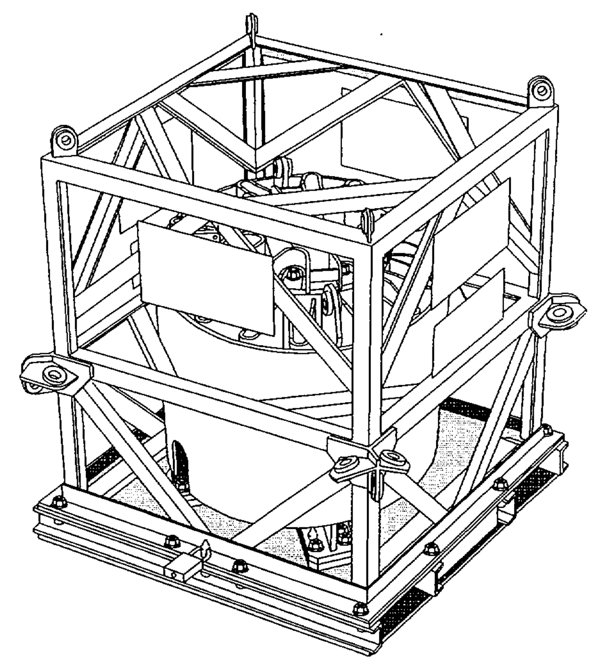

Figure 1: 3750A Assembly

All thermal modelling is based on benchmark test data obtained from 3750/01 loaded with 273 kCi ^{60}Co. Finite element analysis is used to analyses the temperature distribution in the flask and contents. Temperatures at various points outside the flask body are calculated in this document. The 3750A maximum design content of ^{60}Co is 340 kCi (12.6 PBq).

3. ANALYSIS

3.1 CRITERIA

- If any accessible surface of the cage or pallet exceeds 50°C under normal conditions of transport in the shade (Safety Series No.6, paras. 515 & 545) the shipment must be made under "Exclusive Use" conditions.
- No accessible surface shall exceed 85°C under normal conditions of transport in the shade (Safety Series No.6, para. 555).

- No stainless steel/depleted uranium interface shall exceed 950°C during or after the fire test with or without accident damage to the flask: Stainless steel can form a eutectic with uranium above 725°C. All stainless steel surfaces in contact with depleted uranium are therefore coated with a 125-micron copper barrier layer. The minimum copper eutectic is 950°C (Metals Reference Book).
- No source capsule shall exceed 800°C during the fire test with or without accident damage to the flask: The Special Form nature of the contents allows them to be considered as the containment system (Safety Series No.6, para. 531). Special Form testing is conducted at 800°C.

3.2 ASSUMPTIONS

- External flask temperatures may be linearly adjusted to compensate for the difference between the test ambient temperature (23.3°C) and the regulatory maximum (38°C). The difference in the thermal values for air over this range is typically about 5%, which is small enough to be ignored.
- External flask temperatures may be proportionally adjusted to compensate for the difference between the test heat load, i.e. the activity of its radioactive contents, and the design maximum. Heat flow from the flask to the environment is by convection. The flask is heavily finned to optimise heat dissipation. The fins are enclosed in a stainless steel jacket. The temperature of the jacket is little different from the ambient temperature. Minimal heat energy will escape as radiant energy, or by conduction. The controlling equation for convection is:

$$Q = A \times h \times dT$$

Where the temperature difference, dT, is directly proportional to the quantity of heat, Q, being transmitted.

3.3 OUTPUT DATA REQUIRED

There are four regulatory environments to be considered. Locations where the maximum temperature under one or more of these conditions is required are as follows:

Location	Equilibrium in the shade (@ 38°C)	Equilibrium in the sun (@ 38°C)	During and after a 30 min, 800°C fire test	
			Without accident damage	With accident damage
Cage mesh	T_{m1}	T_{m2}	T_{m3}	-
Cage lifting eyes	-	T_{e2}	-	-
Flask lifting eyes	T_{fe1}	-	-	-
Cage tie-down eyes	-	T_{td2}	-	-
Cage-to-pallet studs	-	T_{cp2}	-	-
Flask-to-pallet studs	-	T_{fp2}	-	-
Flask closure studs	T_{fc1}	T_{fc2}	-	-
Flask wall	T_{fw1}	T_{fw2}	T_{fw3}	T_{fw4}
Cavity wall	T_{w1}	T_{w2}	T_{w3}	T_{w4}
Capsule wall	T_{c1}	T_{c2}	T_{c3}	T_{c4}

3.4 STEADY STATE IN THE SHADE

3.4.1 Cage mesh

The mesh directly above the flask is the hottest accessible surface on the 3750A. The predicted mesh temperature, T_{ml}, on a 3750A loaded with 340 kCi ^{60}Co in an ambient of 38°C will be:

$$T_{ml} = \frac{C_2}{C_1} \times (T_1 - T_a) + 38$$

where

C_1 = test radioactive contents = 273 kCi (RTR 070).
C_2 = maximum radioactive contents = 340 kCi.
T_1 = measured mesh temperature = 34.5° (RTR 070).
T_a = measured ambient temperature = 23.3°C (RTR 070).

thus

$$T_{ml} = \frac{340}{273} \times (34.5 - 23.3) + 38 = 52°C$$

Note: The maximum content activity for a 50°C maximum surface temperature is:

$$C_2 = C_1 \frac{(50 - 38)}{(T_1 - T_a)}$$

$$= 273 \frac{(50 - 38)}{(34.5 - 23.3)} = 293 \text{ kCi } ^{60}Co$$

3.4.2 Flask lifting eyes

The eye temperature on a 3750A loaded with 351 kCi in an ambient of 38°C will be:

$$T_{fel} = \frac{C_2}{C_1} \times (T_1 - T_a) + 38$$

where

C_1 = test radioactive contents = 273 kCi (RTR 070).
C_2 = maximum radioactive contents = 340 kCi.
T_1 = mean measured eye temperature = 68.8°C (RTR 070).
T_a = measured ambient temperature = 23.3°C (RTR 070).

thus

$$T_{ml} = \frac{340}{273} \times (68.8 - 23.3) + 38 = 95°C$$

3.4.3 Flask closure studs

T_{fcl} = 112°C (MSA(00)R0483).

3.4.4 Flask wall

T_{fwl} = 166°C (MSA(00)R0483).

3.4.5 Flask cavity wall

T_{w1} = 250°C (MSA(00)R0483).

3.4.6 Capsule wall

T_{c1} = 538°C (MSA(00)R0483).

3.5 STEADY STATE IN THE SUN

Solar radiation levels are specified in Table 12, Safety Series No. 6 as follows:

Surface Type	Incident Heat Flux (W/m^2)
Flat horizontal facing upwards	800 (Hh)
Flat horizontal facing downwards	0
Other flat surfaces	200 (Hv)

3.5.1 Cage mesh

The temperature of the closure studs rises 13°C under insolation (MSA(00)R0483). Given a peak mesh temperature of 52°C in the shade it may be assumed the temperature rise will be no greater. Thus T_{m2} = 52 + 13 = 65°C.

3.5.2 Cage lifting eyes

The cage lifting eyes are set in vertical stainless steel plates. Heat is lost by convection and radiation. The formula balancing heat input against heat loss is as follows:

Qi = $h.dT + \varepsilon.\sigma(Kv^4\text{-}Ka^4)$

where

Qi = heat absorbed = Hv.α

where

α = total solar absorptivity
= 0.49 (316 st/st @ 100°F, Thermal Radiation Properties, p.251, Table 39)

thus

Qi = 200 x 0.49 = 98 W/m^2

h = convection coefficient for vertical surfaces = $0.95dT^{0.333}$ (Heat Transfer, Holman)

dT = temperature differential = Tv – Ta

where

Tv = surface temperature (°C) = T_{e2}

Ta = ambient temperature = 38°C

ε = total normal emissivity
= 0.28 (316 st/st, as received, Thermal Radiation Properties, Table 144)

σ = Stefan-Boltzmann constant = 5.67 x 10^{-8} W/m^2.°K

Kv = absolute surface temperature (°K)
Ka = absolute ambient temperature = 273 + 38 = 311°K

Substituting a surface temperature of 60°C (333°K) gives a total heat output, Qo, therefore:

$$Qo = 0.95(60 - 38)^{0.333} \times (60 - 38) + 0.28 \times 5.67 \times 10^{-8}(333^4 - 311^4)$$
$= 105\ W/m^2$ which is sufficiently close to Qi ($98\ W/m^2$) to be acceptable.

thus
T_{e2} = 60°C (this temperature will also apply to all other flat vertical surfaces).

3.5.3 Cage tie-down eyes

The cage tie-down eyes are set in near horizontal stainless steel plates. Heat is lost by convection and radiation. The formula balancing heat input against heat loss is as follows:

$$Qi = h.dT + \varepsilon.\sigma(Kh^4 - Ka^4)$$

where
Qi = heat absorbed = Hh.α

thus
Qi = 800 x 0.49 = 392 W/m^2
h = convection coefficient for horizontal surfaces facing upwards
= $1.43dT^{0.333}$ (Heat Transfer, Holman)

A surface temperature of 90°C (363°K) gives a total heat output therefore of:

$$1.43(90 - 38)^{0.333} \times (90 - 38) + 0.28 \times 5.67 \times 10^{-8}(363^4 - 311^4) = 404\ W/m^2$$

thus
T_{td2} = 90°C

Note: This temperature will also apply to all other external, upward facing, flat horizontal surfaces.

3.5.4 Cage-to-pallet studs

The studs are set in a flat, upward facing, stainless steel plate. T_{cp2} is taken as 90°C following the argument above.

3.5.5 Flask-to-pallet studs

The foot temperature on a 3750A loaded with 340 kCi in an ambient of 38°C will be:

$$T_{fp2} = \frac{C_2}{C_1} \times (T_1 - T_a) + 38$$

where
C_1 = test radioactive contents = 273 kCi (RTR 070).
C_2 = maximum radioactive contents = 340 kCi.

T_l = mean measured feet temperature = 31.5°C (RTR 070).
T_a = measured ambient temperature = 23.3°C (RTR 070).

thus

$$T_{ml} = \frac{340}{273} \times (31.5 - 23.3) + 38 = 48°C$$

3.5.6 Flask closure studs

T_{fc2} = 131°C (MSA(00)R0483).

3.5.7 Flask wall

T_{fw2} = 170°C (MSA(00)R0483).

3.5.8 Cavity wall

T_{w2} = 255°C (MSA(00)R0483).

3.5.9 Capsule wall

T_{c2} = 528°C (MSA(00)R0483).

3.6 DURING AND AFTER A 30 MINUTE, 800°C FIRE TEST (WITHOUT ACCIDENT DAMAGE)

3.6. Cage mesh

All external surfaces on the cage and pallet will reach a maximum temperature of 800°C during and after the fire test.

3.6.2 Flask wall

T_{fw3} = 415°C (MSA(00)R0483).

3.6.3 Cavity wall

T_{w3} = 420°C (MSA(00)R0483).

3.6.4 Capsule wall

T_{c3} = 587°C (MSA(00)R0483).

3.7 DURING AND AFTER A 30 MINUTE, 800°C FIRE TEST (WITH ACCIDENT DAMAGE)

3.7.1 Flask wall

T_{fw4} = 425°C (MSA(00)R0483).

The flask is little affected by the crush damage to some of the cooling fins. The report shows that the steady state temperatures are slightly elevated but, just as its ability to dissipate heat is downgraded, so its ability to accept heat in the fire is also degraded. The net effect is a relatively small increase in the peak temperature reached during the fire test.

3.7.2 Cavity wall

T_{w4} = 421°C (MSA(00)R0483).

The report shows that effect of the localised fin damage on the cavity wall temperature is not only minimal but also that the high coefficient of conductivity of the flask structure has distributed the temperature rise evenly around the cavity wall.

3.7.3 Capsule wall

T_{c4} = 588°C (MSA(00)R0483).

As might be expected the small rise in cavity wall temperature gives rise to a smaller rise in capsule temperatures.

3.8 RESULTS SUMMARY

With a maximum content activity of 340 kCi of ^{60}Co the thermal performance of the 3750A is as follows:

Location	Equilibrium in the shade (@ 38°C)	Equilibrium in the sun (@ 38°C)	During and after a 30 min, 800°C fire test	
			Without accident damage	With accident damage
Cage mesh	52	65	800	-
Cage lifting eyes	-	60	-	-
Flask lifting eyes	95	-	-	-
Cage tie-down eyes	-	90	-	-
Cage-to-pallet studs	-	90	-	-
Flask-to-pallet studs	-	48	-	-
Flask closure studs	116	131	-	-
Flask wall	164	170	415	425
Cavity wall	249	255	420	421
Capsule wall	526	528	587	588

4. Conclusions

4.1 Criteria

- The maximum temperature in the shade of any accessible surface exceeds 50°C but does not exceed 85°C.
- The maximum temperature of any stainless steel/depleted uranium interface during the fire test is 425°C. This is 525°C below the maximum acceptable temperature of 950°C.
- The maximum temperature reached by a source capsule during the fire test is 588°C. This is 212°C below the maximum acceptable temperature of 800°C.

4.2 Accuracy

- Steady state environments: The thermal modelling is based on data obtained from an 80% full load test. The results are representative and accurate.
- Transient environment (fire): The thermal modelling is based on the regulatory guidelines and recommendations detailed in Safety Series No 37. The results show that for each of the two criteria, the steel/uranium temperature and the capsule temperature, the remaining margin to failure exceeds the total temperature rise in the fire test by a minimum factor of 2.1 (see table below). This is sufficient to compensate for any lack of direct validation.

Location	Steady state in the sun (°C)	During and after fire test (°C)	Temperature rise (°C)	Design limit (°C)	Margin to limit (°C)	Safety factor
Flask wall	170	425	255	950	525	2.1
Cavity wall	255	421	166	950	529	3.2
Capsule wall	528	588	60	800	212	3.5

4.3 Overall

- The 3750A meets all of its thermal design criteria under Type B(U) regulatory environments, as defined in Safety Series No.6, with the maximum contents heat load and with the accumulative damage from mechanical testing modelled.
- The 3750A meets its thermal design criteria with adequate margins of safety.
- When loaded with more than 293 kCi ^{60}Co, the 3750A must be transported under "Exclusive Use" conditions.

5. REFERENCES

- Safety Series No.6: Regulations for the Safe Transport of Radioactive Material, 1985 Edition (As Amended 1990), IAEA, Vienna.
- Safety Series No. 37: Advisory Material for the IAEA Regulations for the Safe Transport of Radioactive Material (1985 Edition).
- Thermal Radiation Properties Survey, Second Edition, GG Gubareff, Honeywell Research Centre, Minneapolis, Minnesota.
- Metals Reference Book, CJ Smithells & EA Brandes, 5th Edition, Butterworths, London.
- Heat Transfer, Holman J P, 5th Edition, 1981, McGraw Hill Book Co. New York.
- MSA(00)R0483, Issue 1: Thermal analysis of the 3750A flask and contents, Mark Soper and Associates Ltd.
- RTR 070: Temperature survey for transport container 3750/01.

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Technical Memorandum

Shielding Performance of Transport Container Design No. 3750A

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1. Purpose and Scope

The purpose of this document is to characterise the basic shielding performance of the transport container design no. 3750A in order to calculate maximum dose levels and establish regulatory compliance.

The 3750A design consists of a finned stainless steel flask containing a depleted uranium shield mounted on a pallet. Access to the flask is prevented by means of a protective cage bolted onto the pallet.

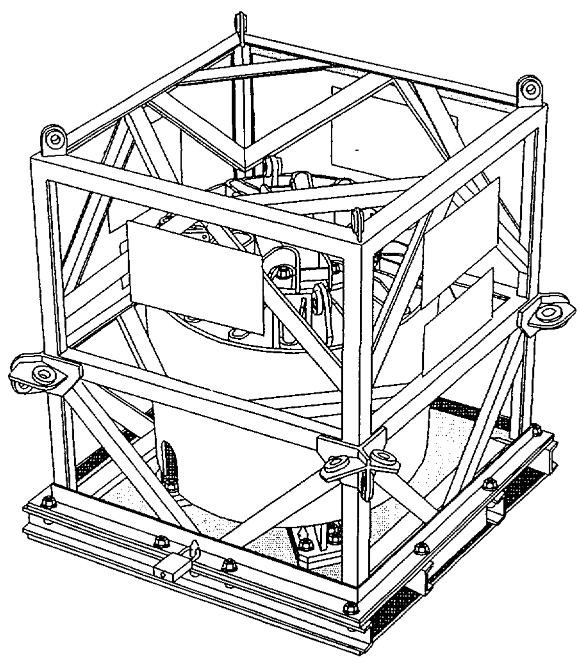

Figure 1: 3750A Assembly

The flask shielding is made up of cylindrical blocks of machined depleted uranium. The blocks in the body are mechanically interlocked, stacked vertically and, with the exception of the base block, are machined out in the core to provide the central cavity. The two lowermost blocks have a channel machined out between them to accept a stainless steel tube running from the base of the cavity to the flask outer shell that allows water to drain during pond operations.

2. Assessment

2.1 Criteria

- Radiation levels with the maximum contents shall not exceed 2.0 mSv/h on the outer surface or 100 μSv/h at one metre (para. 435, Safety Series No. 6).
- Radiation levels after Type A testing shall not increase by more than 20% (para. 537, Safety Series No. 6).
- Radiation levels after Type B testing shall not exceed 10 mSv/h (para. 542, Safety Series No.6).

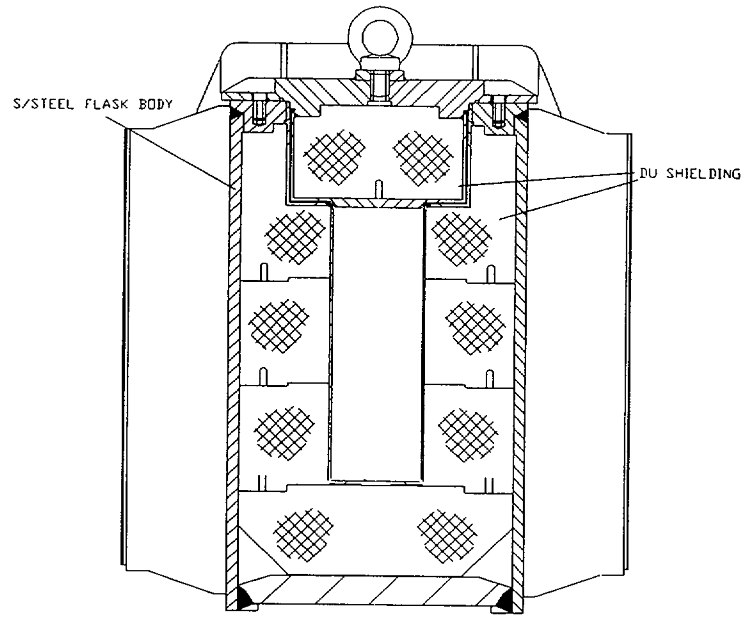

Figure 2: Flask cross-section

2.2 SHINE PATHS

- All adjoining faces on the blocks in the body have machined interlocking steps at the mid-point of their thickness.
- The topmost flask block is counterbored to take the closure plug creating two right angle bends in the radiation path. In addition the underside of the closure jacket has a projection of solid stainless steel that creates a third bend and shadows the horizontal path.
- The drainage channel is machined in a "J" profile in plan view.
- The uranium block lifting points are filled with threaded depleted uranium inserts.

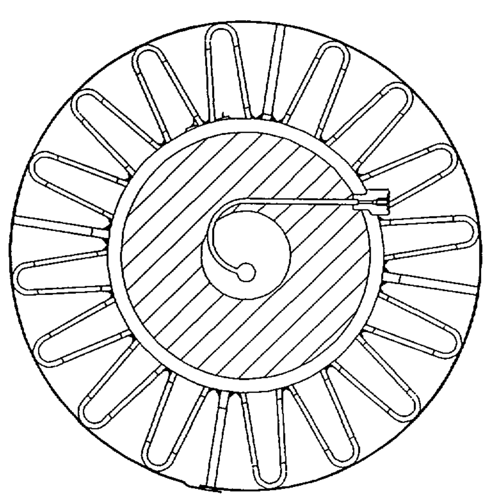

Figure 3: Horizontal flask section

2.3 MAXIMUM CONTENTS

The 3750A design is used to transport a maximum of 340 kCi (12.6 PBq) ^{60}Co or up to 150 kCi of ^{137}Cs. The latter is not significant from a shielding perspective.

2.4 CALCULATIONS

2.4.1 Radial radiation levels

The capsule array may be considered to behave as a line source positioned along the cavity centre-line.

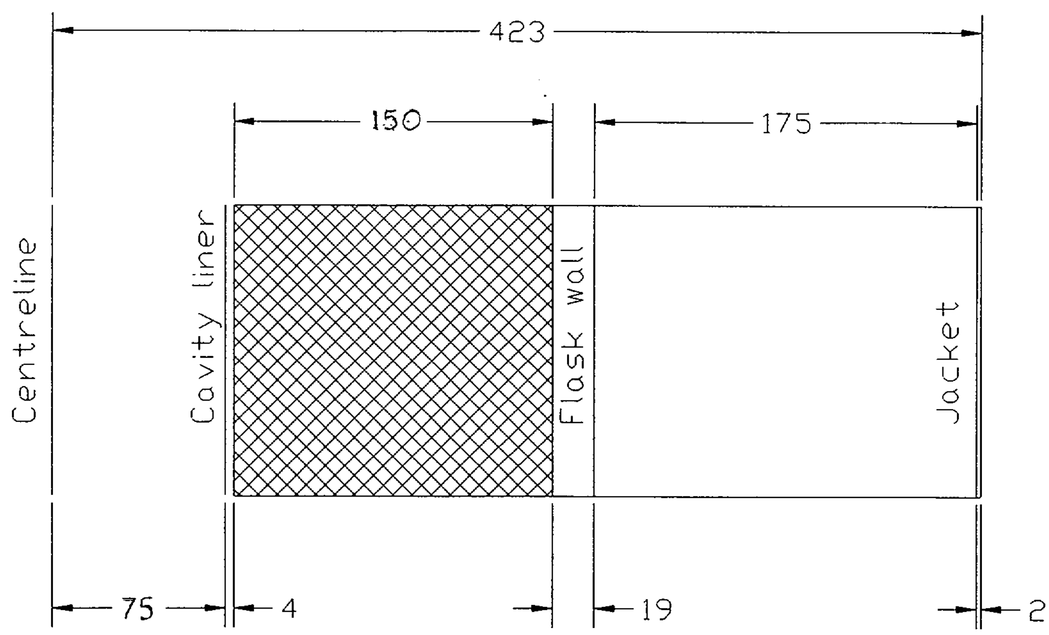

Figure 4: Details of radial shielding

The radiation level, E, from BS 4094:

$$E = \frac{\Gamma Q T}{d^2} \text{ R/h}$$

where,

Γ	= specific gamma ray constant = 1.32 R/Ci.h at 1m
Q	= source activity in curies
T	= transmission factor for shielding material
d	= distance of exposure point from point activity

From figure 3, the dose rate at the flask jacket surface, i.e. 0.426 m from the point source, is:

Q	$= 351 \times 10^3$ Ci
d	= 0.423 m

The transmission factor, T, is based on the shielding material and thickness where:
Thickness of depleted uranium = 15.0 cm
Total thickness of stainless steel = 2.5 cm ≈ 0.5 cm of depleted uranium.

Figure 2b(i) of BS 4094 does not extend beyond a thickness of 12 cm for uranium. Transmission factors for greater thicknesses are therefore obtained by extrapolation. The following derivation is used:

As the graph is straight line logarithmic it may be converted to an equation:

Original equation is of the form $y = Ae^{bx}$

Logarithmic equation is of the form $\log_e y = \log_e A + bx$

Taking 2 points from figure 2b(i) i.e. (0, 1) and (10, 10^{-5}) and substituting into logarithmic equation gives;

$\log_e 1 = \log_e A + 0 \quad \therefore A = 1$

$\log_e 10^{-5} = \log_e 1 + 10b \quad \therefore b = \dfrac{\log_e 10^{-5} - \log_e 1}{10} = -1.15129$

thus

$y = 1 \times e^{-1.15129x}$

Using this equation, when x = 15.5 cm, y = 1.77×10^{-8}.
Putting these values into the original equation gives the dose rate on the cage surface, i.e. 0.57m from the centreline:

$$E = \frac{1.32 \times 340 \times 10^3 \times 1.77 \times 10^{-8}}{0.57^2} = 0.024 \text{ R/h}$$

$= 240\ \mu$Sv/h

The dose rate at 1m from the cage, 1.57m from the centreline is:

$$E = \frac{1.32 \times 340 \times 10^3 \times 1.77 \times 10^{-8}}{1.57^2} = 0.0032 \text{ R/h}$$

$= 32\ \mu$Sv/h

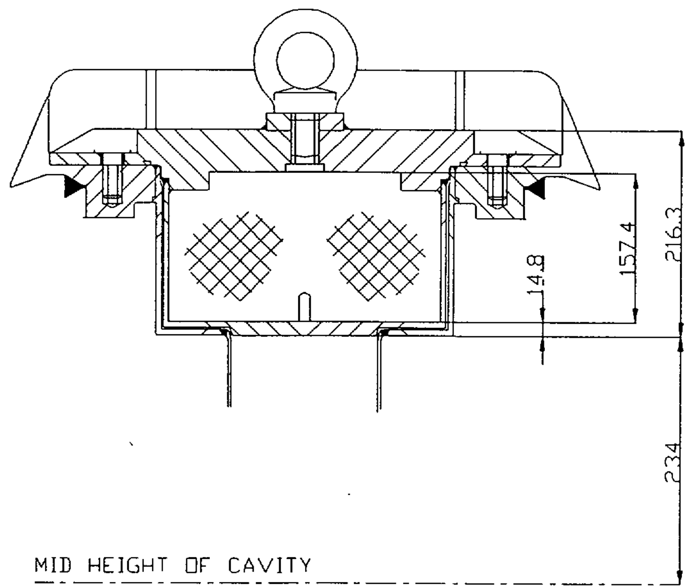

Figure 5: Detail of closure shielding

2.4.2 Vertical upwards radiation levels

Radiation levels at the top of the design can be found by considering the capsule array as a point source positioned at the geometrical centre of the source array. From figure 4, the dose rate on the flask closure, i.e. 0.45 m from the centre, is as follows;

$Q = 351 \times 10^3$
$d = 0.45$ m

The transmission factor is obtained from Fig. 2b(i), BS 4094 where:
Thickness of depleted uranium = 15.7 cm
Additional thickness of stainless steel = 1.48 + 2.93 cm = 4.4 cm ≈ 1.0 cm of depleted uranium.

As before, when $x = 16.7$, $y = 0.45 \times 10^{-8}$

Putting these values into the equation the dose rate on the top of the cage, 0.59m, from the centre is:

$$E = \frac{1.32 \times 340 \times 10^3 \times 0.45 \times 10^{-8}}{0.59^2} \qquad = 5.8 \times 10^{-3} \text{ R/h}$$

$$= 58 \ \mu\text{Sv/h}$$

The dose rate at 1m from the cage, 1.59m from the centre, is therefore:

$$E = \frac{1.32 \times 340 \times 10^3 \times 0.45 \times 10^{-8}}{1.59^2} \qquad = 0.80 \times 10^{-3} \text{ R/h}$$

$$= 8 \ \mu\text{Sv/h}$$

2.4.3 Vertical downwards radiation levels

As all the parameters affecting the shielding efficiency, i.e. shielding thickness and distances, are the same as on the top of the flask the radiation levels will be the same as before.

2.5 SUMMARY OF RESULTS

The table summarises the surface dose rates and the doserates at 1m. Alongside the calculated values are the results from a shielding survey on 3750/01 (RTR 067).

Surface	Radiation Level with 340 kCi ^{60}Co (μSv/h)			
	Cage/Pallet Surface		1m from Surface	
	Calculated	Measured	Calculated	Measured
Side	240	194	32	19.4
Top	58	126	8	9.7
Base	58	29	8	1.1
Regulatory limit	2,000		100	

2.6 RADIATION LEVELS FOLLOWING TYPE A AND TYPE B TESTING

A one third scale model of the 3750A design has been subjected to four complete sequences of Type A and Type B mechanical testing. Shielding surveys conducted before and after the mechanical testing (Test Report No. 1878) demonstrate that the shielding is unaffected by the tests.

3. CONCLUSIONS

- Calculations using BS 4094 and assuming a point source in the centre of the flask cavity give conservative but reasonably accurate results except where the shielding efficiency is affected by the necessary clearances around the flask closure.
- The 3750A transport flask shielding performance is in accordance with the design parameters and exhibits no evidence of radiation short paths or streaming.
- Shielding efficiency is well within regulatory limits and is unaffected by either Type A or Type B mechanical testing.

4. REFERENCES

- Safety Series No.6. "Regulations for the Safe Transport of Radioactive Material", 1985 Edition (As Amended 1990), IAEA, Vienna.
- BS 4094: Part 1, 1966. Data on shielding from ionising radiation.
- Test Report No. 1878: Packaging Design Group, Amersham International plc.
- RTR 067: Shielding survey on transport container 3750/01.

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Nuclide Heating

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1. Purpose and Scope

The purpose of this document is to define the decay heat output of a variety of nuclides for use in thermal calculations and analysis.

2. Introduction

When radiation is emitted by a decaying nucleus, energy is carried away by a combination of particles and electromagnetic radiation. When that radiation is absorbed, e.g. by shielding, its' energy is dissipated in the form of heat. The maximum amount of heating will occur when all of the energy of the radiation is absorbed. Any emitted neutrinos can be discounted, as they interact only weakly with matter and are not considered to contribute to heating effects.

3. Calculation of Nuclide Heating

In order to determine the total energy emitted by a decaying radioactive isotope, we must consider all possible decay routes that emit particles, except neutrinos, or photons. Browne *et* al[1] have published a table of experimental values for the average energy released, per disintegration, for a range of radioactive isotopes; they consider electromagnetic radiation, α-particles, electrons and positrons. Summing the average energies per disintegration, for all of these radiation types, gives the total average energy per disintegration that is available for conversion to heat.

Average energies emitted for a range of isotopes are listed in the Table of Radioactive Isotopes in units of keV. The total energy has been converted to power using the following relationships:

1 keV	=	1.60×10^{-16} J
1 W	=	1 Js^{-1}
1 Bq	=	1 disintegration per second
1Ci	=	3.7×10^{10} Bq

∴ Power	=	1.60×10^{-16} WBq^{-1}
	≡	0.160 $mWTBq^{-1}$
	≡	5.92×10^{-3} $mWCi^{-1}$

4. References

Table of Radioactive Isotopes, E Browne & R B Firestone (ed Virginia S Shirley), John Wiley & Sons, 1986.

Average Energies and Power Dissipation

Nuclide	Symbol	Half-Life	Average Energy Per Disintegration / keV					Power Dissipation	
			alpha	electron	positron	e.m.	Total	mW / Ci	mW / TBq
Actinium-227	^{227}Ac	21.77 yr	67.3	12.5		0.168	80	0.47	13
Americium-241	^{241}Am	432.7 yr	5480	30.4		28.7	5539	32.79	886
Americium-243	^{243}Am	7380 yr	5270			48.1	5318	31.48	851
Antimony-122	^{122}Sb	2.70 dy		566		434	1000	5.92	160
Antimony-124	^{124}Sb	60.20 dy		390		1850	2240	13.26	358
Bismuth-210	^{210}Bi	5.013 dy		389		0.45	389	2.31	62
Bismuth-214	^{214}Bi	19.9 min	1.43	662		1510	2173	12.87	348
Cadmium-109	^{109}Cd	1.267 yr		81.3		26	107	0.64	17
Caesium-134	^{134}Cs	2.062 yr		164		1550	1714	10.15	274
Caesium-137	^{137}Cs	30.0 yr		250		566	816	4.83	131
Californium-252	^{252}Cf	2.64 yr	5930	5.14		1.14	5936	35.14	950
Cobalt-56	^{56}Co	77.7 dy		3.6	120	3580	3704	21.93	593
Cobalt-57	^{57}Co	271.77 dy		17.6		125	143	0.84	23
Cobalt-58	^{58}Co	70.92 dy		3.6	30	977	1011	5.98	162
Cobalt-60	^{60}Co	5.271 yr		96		2500	2596	15.37	415
Curium-242	^{242}Cm	162.9 dy	6040	8.95		1.75	6051	35.82	968
Curium-244	^{244}Cm	18.11 yr	5800			1.6	5802	34.35	928
Europium-152	^{152}Eu	13.33 yr		127	8.70E-02	1160	1287	7.62	206
Europium-154	^{154}Eu	8.8 yr		279		1250	1529	9.05	245
Europium-155	^{155}Eu	4.96 yr		65		63	128	0.76	20
Europium-156	^{156}Eu	15.2 dy		425		1330	1755	10.39	281
Gadolinium-153	^{153}Gd	241.6 dy		39.9		102	142	0.84	23
Gold-198	^{198}Au	2.6935 dy		421		403	824	4.88	132
Hydrogen-3	^{3}H	12.3 yr		5.7		1.12E-04	6	0.03	1
Iodine-125	^{125}I	60.1 dy		17.9		42.4	60	0.36	10
Iodine-131	^{131}I	8.04 dy		192		382	574	3.40	92
Iridium-192	^{192}Ir	73.83 dy		216		813	1029	6.09	165
Iridium-194	^{194}Ir	19.15 hr		811		92	903	5.35	144
Iron-59	^{59}Fe	44.5 dy		118		1190	1308	7.74	209
Krypton-85	^{85}Kr	10.72 yr		251		2.4	253	1.50	41
Lead-201	^{201}Pb	9.33 hr		60.9	9.70E-02	760	821	4.86	131
Lead-210	^{210}Pb	22.3 yr		34.2		4.67	39	0.23	6
Lead-214	^{214}Pb	27 min		294		250	544	3.22	87
Molybdenum-99	^{99}Mo	2.7477 dy		408		273	681	4.03	109
Neptunium-237	^{237}Np	2.14E06 yr	4760	64		32.7	4857	28.75	777
Phosphorus-32	^{32}P	14.282 dy		695		1.18	696	4.12	111

Nuclide	Symbol	Half-Life	Average Energy Per Disintegration / keV					Power Dissipation	
			alpha	electron	positron	e.m.	Total	mW / Ci	mW / TBq
Plutonium-238	^{238}Pu	87.7 yr	5490	9.92		1.76	5502	32.57	880
Plutonium-239	^{239}Pu	2.411E+04 yr	5100			6.60E-02	5100	30.19	816
Plutonium-240	^{240}Pu	6.54E+03 yr	5160			2.86E-02	5160	30.55	826
Plutonium-241	^{241}Pu	14.4 yr	0.118	5.2		1.46E-03	5	0.03	1
Polonium-210	^{210}Po	138.376 dy	5300				5300	31.38	848
Polonium-214	^{214}Po	163.7 ms	7690			8.30E-02	7690	45.53	1230
Polonium-218	^{218}Po	3.11 min	6000				6000	35.52	960
Promethium-147	^{147}Pm	2.6234 yr		62		1.86E-02	62	0.37	10
Protactinium-231	^{231}Pa	3.28E+04 yr	4920	48		39.9	5008	29.65	801
Radium-226	^{226}Ra	1.60E+03 yr	4770	3.53		6.74	4780	28.30	765
Radon-222	^{222}Rn	3.825 dy	5490				5490	32.50	878
Samarium-151	^{151}Sm	90 yr		125		6.71E-02	125	0.74	20
Selenium-75	^{75}Se	119.77 dy		14.2		392	406	2.40	65
Silver-110m	^{110}Ag	249.76 dy		75.5		2740	2816	16.67	450
Sodium-24	^{24}Na	14.659 hr		554		4120	4674	27.67	748
Strontium-90	^{90}Sr	28.5 yr		196		0.124	196	1.16	31
Sulphur-35	^{35}S	87.5 dy		48.6		8.60E-03	49	0.29	8
Technetium-99m	^{99}Tc	6.006 hr		14.2		124	138	0.82	22
Tellurium-131m	^{131}Te	1.2 dy		52.3		1420	1472	8.72	236
Thorium-228	^{228}Th	1.913 yr	5400	20.1		3.4	5424	32.11	868
Thorium-230	^{230}Th	7.54E+04 yr	4660			0.371	4660	27.59	746
Thulium-170	^{170}Tm	128.6 dy		330		5.73	336	1.99	54
Tin-119m	^{119}Sn	293 dy		78.3		11.4	90	0.53	14
Tritium	See Hydrogen-3						0	0.00	0
Uranium-233	^{233}U	1.59E+05 yr	4810	5.5		1.29	4817	28.52	771
Uranium-235	^{235}U	7.04E+08 yr	4380	42		156	4578	27.10	732
Uranium-238	^{238}U	4.468E+09 yr	4190	9.5		1.3	4201	24.87	672
Ytterbium-169	^{169}Yb	32.022 dy		112		312	424	2.51	68

Test No.	RTR 067

3750A TRANSPORT CONTAINER SHIELDING TEST RECORD (Ref. OP 214)

OP 214 Issue	4	Cntr. Serial No.	3750/01
Test Plan/Issue	45/3750A/QP/05, issue 1.		
Package Monitor	DRG3 - 03	Serial No.	078
Contam. Monitor	-	Serial No.	-
Finger probe	DRG - 03 probe	Serial No.	078

Step	Description	Result or ✔
1	Measure background dose rate in area to be used for the test prior to moving container into the area.	(1) 1.08 μSv/h
2	Load 24 hole basket evenly with a total 115 - 230 kCi Co-60 in R2089 type capsules and record loading plan.	✔

Loading Plan

Activity ref. date: 07/07/2000

Posn. *	Source No	Content (kCi)	Posn.	Source No	Content (kCi)	Posn.	Source No.	Content (kCi)
1	12035EE	10.48	9	12036EE	10.49	17	12037EE	10.20
2	-	-	10	-	-	18	-	-
3	12032EE	10.32	11	12033EE	10.02	19	12039EE	10.88
4	-	-	12	-	0	20	-	-
5	12031EE	10.40	13	12044EE	10.90	21	12038EE	10.88
6	-	-	14	-	-	22	-	-
7	12034	10.02	15	12041EE	10.80	23	12053EE	10.46
8	-	-	16	-	-	24	-	-
TOTAL		41.22	TOTAL		42.21	TOTAL		42.42
						GRAND TOTAL(2)		125.85

* Counting clockwise from notch when viewed from above.

Step	Description	Result or ✔
3	Assemble flask onto pallet and replace cage.	✔
4	Using contamination monitor or package monitor scan entire flask surface, including underside, for any reading over 1,000 μSv/h. Check particularly in line with the drain plug and on a 300mm diameter on the top. If found record dose rate and position and continue only if safe to do so. If none found, record 'none'. Mark highest spots on the side, top and base for future reference.	NONE

Test No.	RTR 067

Vertical Scans

Step	Description						
5	Using package monitor scan vertically up the middle of each side of the cage in 100 mm steps from the pallet to the top moving clockwise around the flask, starting with drain point side.						
1st Side (drain point)		2nd Side		3rd Side		4th Side	
Height (mm)	Dose (μSv/h)	Height (mm)	Dose (μSv/h)	Height (mm)	Dose (μSv/h)	Height (mm)	Dose (μSv/h)
1100	10.8	1100	8.6	1100	7.2	1100	7.2
1000	40.3	1000	36.0	1000	28.8	1000	36.0
900	72.0	900	61.2	900	64.8	900	64.8
800	48.6	800	46.8	800	43.2	800	46.8
700	46.8	700	43.2	700	43.2	700	43.2
600	46.8	600	43.2	600	43.2	600	46.8
500	31.7	500	29.5	500	30.2	500	32.4
400	31.0	400	30.2	400	30.2	400	31.7
300	20.2	300	19.4	300	18.7	300	20.9
200	12.2	200	10.1	200	10.8	200	10.8
100	7.2	100	4.3	100	5.0	100	5.0
0	3.6	0	2.2	0	2.9	0	2.9
					Peak reading (3)		72.0

Horizontal Scan

Step	Description						
6	Identify the height at which the highest side dose is measured and using a package monitor scan each side horizontally from left to right in 200 mm steps at this height, starting with the drain point side.					Height above pallet	900 mm
1st Side (drain point)		2nd Side		3rd Side		4th Side	
Posn	Dose (μSv/h)	Posn	Dose (μSv/h)	Posn	Dose (μSv/h)	Posn	Dose (μSv/h)
0	18.0	0	25.2	0	28.8	0	28.8
200	46.8	200	39.6	200	46.8	200	46.8
400	61.2	400	43.2	400	54.0	400	54.0
600	72.0	600	61.2	600	64.8	600	64.8
800	39.6	800	39.6	800	32.4	800	39.6
1000	32.4	1000	28.8	1000	28.8	1000	28.8
					Peak reading (4)		72.0

Test No.	RTR 067

Top Surface Scan

Step	Description
7	Using the finger probe (maximum diameter 40 mm) scan the surface from the centre outwards in 20 & 100 mm steps towards the centre of each of the four sides in turn starting with the drain point side and moving clockwise. A package monitor may be used for the 100 mm steps.

1st Side (drain point)		2nd Side		3rd Side		4th Side	
Posn. *	Dose (μSv/h)	Posn.	Dose (μSv/h)	Posn.	Dose (μSv/h)	Posn.	Dose (μSv/h)
0	18.0	-	-	-	-	-	-
20	21.6	20	21.6	20	21.6	20	21.6
40	25.2	40	25.2	40	21.6	40	21.6
60	32.4	60	28.8	60	25.2	60	25.2
80	36.0	80	28.8	80	25.2	80	28.8
100	46.8	100	36.0	100	28.8	100	28.8
120	36.0	120	39.6	120	25.2	120	32.4
140	21.6	140	25.2	140	21.6	140	28.8
160	18.0	160	21.6	160	21.6	160	21.6
180	14.4	180	21.6	180	18.0	180	18.0
200	14.4	200	18.0	200	14.4	200	18.0
220	10.8	220	145.4	220	14.4	220	14.4
240	10.8	240	10.8	240	14.4	240	14.4
260	10.8	260	10.8	260	10.8	260	10.8
300	10.8	300	10.8	300	10.8	300	10.8
400	10.8	400	10.8	400	10.8	400	10.8
500	10.8	500	8.6	500	7.2	500	7.2

* distance from centre.

Peak reading (5)	46.8

Base Surface Scan

Step	Description
8	Using a package monitor scan the surface from the centre outwards in 100 mm steps towards the centre of each of the four sides in turn starting with the drain point side and moving clockwise..

1st Side (drain point)		2nd Side		3rd Side		4th Side	
Posn. *	Dose (μSv/h)	Posn.	Dose (μSv/h)	Posn.	Dose (μSv/h)	Posn.	Dose (μSv/h)
0	10.8	-	-	-	-	-	-
100	7.2	100	7.6	100	10.8	100	10.8
200	2.2	200	2.9	200	2.9	200	4.3
300	2.2	300	2.2	300	2.2	300	2.9
400	2.2	400	2.2	400	2.2	400	2.2
500	2.2	500	2.2	500	2.2	500	2.2

* distance from centre.

Peak reading (6)	10.8

Test No.	RTR 067

Special Areas Scan

Step	Description	Result
9	Use the finger probe to measure the peak dose rate directly in line with the drain point.	36.0 μSv/h
10	Use the finger probe to measure the peak dose rate on a 300 mm diameter in the centre of the top of the cage.	46.8 μSv/h
11	Carefully scan the entire surface of the container. Record any position having a dose rate greater than the maximum found in any of the surveys above.	NONE μSv/h
12	Maximum surface dose rate from (3), (4), (5) & (6)	(7) 72.0 μSv/h

Surface Dose Rate Sentencing

Step	Description	Result	
13	Subtract background (1) from maximum dose rate (7), multiply by 351 and divide by total test activity (2) in kCi.	197.8 μSv/h	
14	PASS if less than 2,000 μSv/h, FAIL if over.	PASS	~~FAIL~~

Transport Index Scan and Sentencing

Step	Description	Result	
15	Using a package monitor scan the container at a distance of one metre from the surface on the sides, top and base of the container. Record the maximum dose rate observed and its position. Pay particular attention to high dose areas identified in the previous surveys.	Top: 3.6 μSv/h Sides: 7.2 μSv/h Base: 0.4 μSv/h	
16	Subtract background from maximum dose rate above, multiply by 351 and divide by total test activity (kCi).	17.07 μSv/h	
17	PASS if less than 100 μSv/h, FAIL if over.	PASS	~~FAIL~~

Notes:

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22/11/00

Number of additional pages: ....-..........

Signed		Date	
Witnessed/Reviewed		Date	

Test No.	RTR 070

3750A TRANSPORT CONTAINER THERMAL SURVEY RECORD (Ref. OP 215)

OP 215 Issue	2	Cntr. Serial No.	3750/01

Step	Operation	Result or ✔
1	Prepare flask with thermocouples and identify as in table overleaf.	✔
2	Load basket evenly with at least 20 R2089 (nominal 8-12 kCi each) and record loading plan.	24 sources

Loading Plan					Activity ref. date	16/08/2000		
Posn. *	Source No.	Content (kCi)	Posn.	Source No.	Content (kCi)	Posn.	Source No.	Content (kCi)
1	TC	11.56	11	12175EE	11.28	21	12521EE	11.37
2	12178EE	11.09	12	12176EE	11.18	22	12216EE	11.11
3	12530EE	11.28	13	12173EE	11.00	23	12511EE	11.37
4	12215EE	11.66	14	12174EE	10.91	24	12523EE	11.82
5	12171EE	10.91	15	12532EE	11.74	25	-	-
6	12177EE	11.46	16	12217EE	11.30	26	-	-
7	12520EE	10.92	17	TC	11.74	27	-	-
8	12170EE	11.00	18	12524EE	11.37	28	-	-
9	TC	11.25	19	12522EE	11.73	29	-	-
10	12218EE	11.99	20	12512EE	11.83	30	-	-
	Total	112.56		Total	114.08		Total	45.67
							Grand Total	272.31

* Counting clockwise from notch when viewed from above.

Step	Operation	Result or ✔		
3	Load flask, replace closure (using spacers under lid to allow leads to exit flask) and replace flask on pallet.	✔		
4	Site container in a clear area not less than 2.4 m square, free from continuous drafts and with as constant an ambient temperature as possible.	✔		
5	Record time, date and air temperature	Time 18.30	Date 16/08/00	Air 23.6°C

Test No.	RTR 070

Thermocouple Details

Identity	Location	Thermocouple Type/Part No.
1a-b	Cavity base, 2 central positions.	K
2a-c	Cavity wall, mid-height, 3 positions, equi-spaced.	K
3a-b	Closure underside, 2 central positions.	K
4	Closure eyebolt under shoulder.	K
5a-b	Closure nuts under washer, 2 opposite positions.	K
6a-b	Flask lifting eyes, 2 opposite positions.	K
7a-d	Flask body cylindrical surface, 25mm from top, midway between V-fin welds, 4 positions, equi-spaced.	K
8a-d	Flask surface, mid-height, midway between V-fin welds, 4 positions, below previous positions.	K
9a-d	Flask surface, mid-height, on welds between adjacent V-fins, 4 positions, midway between lifting fins.	K
10a-d	Flask surface, 25 mm from base, midway between V-fin welds, 4 positions, below previous positions 7 & 8.	K
11	Flask drain plug.	K
12	Flask base, centre.	K
13	Flask maintenance plug.	K
14a-b	Flask feet welds, 2 opposite positions.	K
15a-d	Average air temperature exiting V-fins, 4 positions, equi-spaced.	K
16a-b	Highest cage mesh temperature above V-fins, 2 opposite positions.	K
17	Ambient air temperature.	K

Step	Operation	Result or ✔		
		Time	Date	Air
6	After a minimum of 12 hours equilibration: Record time, date and air temperature here and thermocouple temperatures below.	14.00	17/08/00	23.0°C
7	Leave container for one hour, ensuring air temperature does not change by more than 2°C, and record time, air temperature and thermocouple temperatures again.	15.00		23.3°C

Equilibration

Thermo-couple	Initial Readings (°C)				Aver-age	After 1hr (°C)				Aver-age	Change (±%)
	a	b	c	d		a	b	c	d		
2a-c	197.5	195.5	199.3		197.4	197.8	195.4	199.4		197.6	+0.10
8a-d	133.9	121.3	134.8	129.5	129.9	133.9	121.3	134.6	128.9	129.7	-0.15

Step	Operation	Result or ✔
8	Calculate average temperatures and percentage difference. Check differences are less than +0.25%.	0.15%
9	Record all temperature readings; again ensuring air temperature does not change by more than 2°C.	✔

Test No.	RTR 070

Results

Identity		°C	Identity		°C	Identity		°C	Identity		°C	Identity		°C
1	a	172.2	5	a	88.6	8	a	133.9	10	a	81.3	15	a	36.6
	b	174.0		b	88.8		b	121.3		b	78.2		b	40.0
~~2~~ 3	a	173.7					c	134.6		c	78.0		c	42.5
	b	174.5	6	a	69.2		d	128.9		d	76.4		d	38.5
~~3~~ 2	a	197.8		b	68.4	9	a	120	11		87.5	16	a	34.5
	b	195.7	7	a	101.2		b	124.5	12		97.7		b	31.5
	c	199.4		b	101.0		c	125.5	13		98.2	17		23.3
4		100.2		c	102.0		d	127.3	14	a	32.3			
				d	103.0					b	30.6			

Notes:

TC - 1: 7H4 + 8T3 (RSL 1700)
TC - 9: 9C4 + 9H0 (RSL 1700)
TC - 17: 9C6 + 7C1 (RSL 1700)

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Number of pages attached:.........

Signed		Date	
Witnessed/Reviewed		Date	

REVISS SERVICES

SUPPLY SPECIFICATION
STAINLESS STEEL FOR WELDING APPLICATIONS

Design Approval	D W Rogers [signature] (signature) date: 11/07/00
Management Approval	D A Coppell [signature] (signature) date: 18 July 2000
Quality System Approval	B S Patel [signature] (signature) date: 20 July 2000
Controlled file number	01

1.0 PURPOSE AND SCOPE

This specification defines a group of corrosion resistant materials suitable for general use in welded applications. The material group may be described as any weld-stabilised, austenitic (i.e. 300 series) stainless steel. Such materials have broadly similar strength, ductility and anti-corrosion properties that make them suitable for general application.

This specification provides guidance for manufacturers in material selection. It applies to the raw material forms of sheet, plate, strip, rod, bar, tube and pipe. It does not apply to proprietary items such as fasteners and mesh.

2.0 REFERENCES

- SS 028: current issue: Quality assurance requirements for controlled purchases.
- BS 970: Part 3: 1991: Bright bars for general engineering purposes.
- BS 1449: Part 2: 1983: Specification for stainless and heat resisting steel plate, sheet and strip.
- BS 1501: Part 3: 1990: Specification for corrosion and heat resisting steels: plates, sheet and strip.
- BS 3605: Pt 1: 1991: Specification for seamless tubes.
- BS 3605: Pt 2: 1992: Specification for longitudinally welded tubes.
- BS EN ISO 3651-2: 1998: Ferritic, austenitic, and ferritic-austenitic (duplex) stainless steels. Corrosion tests in media containing sulfuric acid.

3.0 DEFINITIONS

- Purchaser : REVISS Services (UK) Ltd.
- Supplier or Manufacturer : Organisation named in the purchase order

4.0 QUALITY ASSURANCE

- General requirements are detailed in SS 028.
- See purchase order and any specifications referenced therein for any supplementary requirements.
- The Supplier is responsible for maintaining traceability back to the material cast or heat number.

5.0 GENERAL

- The purchase order takes precedence over the manufacturing drawing.
- The manufacturing drawing takes precedence over this specification.
- The manufacturing drawing will specify the principle dimension(s) and form of the raw material and any additional requirements.

6.0 SPECIFICATION

Section 6.1 tabulates acceptable UK material grades and their chemical and mechanical properties. The Manufacturer shall only use materials from one the three basic groups in any welded fabrication (thus low carbon steels may not be used with titanium-stabilised steels).

Equivalent grade materials complying with other national or international standards may be used. The tables in Sections 6.2 & 6.3 give examples of some equivalent national standards and grades.

6.1 PROPERTIES GUIDE (BS 970, 1449 & 1501)

	Composition (% maximum unless stated)									Strength (min MPa)		Elong-ation
Grade	C	Si	Mn	P	S	Cr	Mo	Ni	Others	Tens-ile	0.2% Strain	5.65√So (% min)*
Low Carbon												
304S11	0.03	1.00	2.00	0.045	0.030	19.0 17.0	-	12.0 9.0	-	480	185	40
316S11	0.03	1.00	2.00	0.045	0.030	18.5 16.5	3.0 2.0	14.0 11.0	-	490	190	40
316S13	0.03	1.00	2.00	0.045	0.030	18.5 16.5	3.0 2.5	14.5 11.5	-	490	190	40
Niobium Stabilised												
347S31	0.08	1.00	2.00	0.045	0.030	19.0 17.0	-	12.0 9.0	Nb 1.00 10C	510	205	35
Titanium Stabilised												
320S31	0.08	1.00	2.00	0.045	0.030	18.5 16.5	2.5 2.0	14.0 11.0	Ti 0.80 5C	510	210	40
320S33	0.08	1.00	2.00	0.045	0.030	18.5 16.5	3.0 2.5	14.5 11.5	Ti 0.80 5C	510	210	40
321S31	0.08	1.00	2.00	0.045	0.030	19.0 17.0	-	12.0 9.0	Ti 0.80 5C	510	200	35
325S31	0.12	1.00	2.00	0.045	0.035 0.015	19.0 17.0	-	11.0 8.0	Ti 0.90 5C	510	200	35

* or 50 mm gauge length (So = cross-sectional area thus length is equivalent to 5D on cylindrical test piece).

6.2 OTHER NATIONAL STANDARDS

This table details German and US equivalent standards.

Material Form	UK	German	USA
Sheet and Strip	BS 1449, Pt 1	DIN 17440/17441	ASTM A240
Plate	BS 1449 Pt 2, BS 1501 Pt 3	DIN 17440	ASTM A240
Rod and Bar	BS 970, Pt 3	-	ASTM A479
Tube	BS 3605	DIN 50049 3.1.B	ASTM A269, A213, A511.
Pipe	BS 3605	DIN 500493.1.B	ASTM A312, A376, A358, ASME SA 312

6.3 EQUIVALENT MATERIAL GRADES

UK grades and a selection of equivalent grades:

UK	French (AFNOR)	German (W.Nr)	Italian (UNI)	Japanese (JIS)	Swedish (SS)	USA (SAE)
304S11	Z2CrNi18.10	1.4306	X2CrNi 18 11	SCS19	2352	304L
316S11	Z2CND17.12	1.4404	X2CrNiMo1712	SCS16	2348	316L
316S13	Z6CND18-12-03	1.4435	X8CrNiMo1713	SCS16	2353	316L
347S31	Z6CNNb18.11	1.4550	X6CrNiNb1811 X8CrNiNb1811	SUS347	2338	347
320S31	Z8CNND17.12	1.4571			2350	
320S33	Z8CNND17.12	1.4573			2350	
321S31	Z6CNTD18.12	1.4541	X6CrNiTi1812	SUS321	2337	321

6.4 HEAT TREATMENT

All materials shall be supplied in the solution-annealed condition.

6.5 INTERGRANULAR CORROSION

All materials must be capable of passing the inter-granular corrosion test specified in BS EN ISO 3651-2, Method A, or equivalent.

6.6 ALTERNATIVE STANDARDS

Equivalent grades of austenitic stainless steel conforming to national standards not listed above may be used subject to written permission from the Purchaser. Mechanical properties shall conform to the following requirements and it shall capable of passing the intergranular corrosion test above:

Strength (min MPa)		Elongation
Tensile	0.2% Strain	5.65√So
480	173	40% min

7.0 RAW MATERIAL SIZES

The manufacturing drawing will state the stock material sizes in one system of units. The manufacturer may deviate from the specification in two instances:

Machined items:

When the primary dimension (thickness, width or diameter) is subsequently machined down the size may be taken as a guide only. The manufacturer may use any appropriate stock size.

Imperial/metric parity:

When the primary dimension is not subsequently machined and materials are not available in the unit system specified the Supplier may use the following equivalent sizes subject to first notifying the Purchaser and obtaining approval. The Supplier shall also ensure that dimensions of key features on mating components are adjusted appropriately to maintain design fits and clearances.

Imperial (ins)	1/8	3/16	¼	3/8	1/2	5/8	3/4	7/8	1.0	1.5	2.0
Metric (mm)	3	5	6	10	12	16	20	22	25	40	50

Imperial (swg)	22	20	18	16	14	12	10	8	6	4	2
Metric (mm)	0.75	1	1.25	1.5	2	2.5	3.5	4	5	6	7

8.0 DOCUMENTATION

The Supplier shall provide certified evidence from the manufacturer or from his own testing that a material's chemical composition and mechanical properties comply with its specification. All documentation shall reference the original cast or heat number.

CONTROLLED DOCUMENT

(when in red)

REVISS SERVICES

SUPPLY SPECIFICATION WELDING FOR TRANSPORT CONTAINERS	
Design Approval	D W Rogers D W Rogers (signature) date: 11/07/00
Management Approval	D A Coppell D A Coppell (signature) date: 13/7/2000
Quality System Approval	B S Patel Bhavlesh Patel (signature) date: 14/7/00.
Controlled file number	1

1.0 PURPOSE AND SCOPE

This document specifies the requirements for arc welding, resistance spot welding, brazing and soldering and the associated inspection processes used in the fabrication of transport containers for radioactive materials. It is not necessarily restricted to this application. It applies to both stainless and carbon steels. It does not cover the welding or joining of non-ferrous materials.

2.0 REFERENCES

- SS 028: current issue: Quality assurance requirements for controlled purchases.
- BS 499: Part 2C: 1980: Welding symbols.
- BS 1140: 1993: Specification for resistance spot welding of uncoated and coated low carbon steel.
- BS 1723: Part 1: 1986: Specification for brazing.
- BS 1723: Part 2: 1986: Guide to Brazing.
- BS 5500: 1997: Specification for unfired fusion welded pressure vessels.
- BS EN 287-1: 1992: Approval testing of welders for fusion welding. Steels.
- BS EN 288-2: 1992: Welding procedure specification for arc welding.
- BS EN 288-3: 1992: Welding procedure tests for the arc welding of steels.
- BS EN 571-1: 1997: Non-destructive testing. Penetrant testing. General principles.
- BS EN 875: 1995: Destructive tests on welds. Impact testing.
- BS EN 876: 1996: Destructive tests on welds. Longitudinal tensile test.
- BS EN 895: 1995: Destructive tests on welds. Transverse tensile test.
- BS EN 910: 1996: Destructive tests on welds. Bend testing.
- BS EN 1043-1: 1996: Destructive tests on welds. Hardness testing.
- BS EN 1043-2: 1997: Destructive tests on welds. Micro-hardness testing.
- BS EN 1320: 1997: Destructive tests on welds. Fracture testing.
- BS EN 1321: 1997: Destructive tests on welds. Macro- and microscopic examination
- BS EN 1435: 1997: Non-destructive examination of welds. Radiographic examination.
- BS EN 1712: 1997: Non-destructive examination of welds. Ultrasonic examination. Acceptance levels.
- BS EN 1714: 1998: Non-destructive examination of welds. Ultrasonic examination.
- BS EN 12517: 1998: Non-destructive examination of welds. Radiographic examination. Acceptance levels.
- BS EN 24063: 1992: Welding, brazing, soldering and braze welding of metals. Nomenclature of processes and reference numbers for symbolic representation on drawings.
- BS EN 25817: 1992: Arc-welded joints in steel. Quality levels for imperfections.
- ASME V: Boiler and pressure vessel code. Non-destructive examination.
- ASME IX: Boiler and pressure vessel code. Welding and brazing qualifications.

3.0 DEFINITIONS

- Purchaser : REVISS Services (UK) Ltd.
- Supplier : Organisation named in the purchase order
- Welder : Person performing a manual welding operation
- Operator : Person controlling a welding machine.

4.0 QUALITY ASSURANCE

- See SS 028 for general quality assurance and documentation requirements.
- See purchase order and any specifications referenced therein for any supplementary requirements.

5.0 GENERAL

- The purchase order takes precedence over the manufacturing drawing.
- The manufacturing drawing takes precedence over this specification.
- The manufacturing drawing specifies the weld form, size and, if necessary, the process, the inspection technique and any pre- or post-heat treatment.
- Welding, brazing and soldering terms and symbols comply with BS 499 and BS EN 24063. Any drawing using the current, 1999, issue of BS 499 will carry a note to that effect.
- Brazing and soldering procedures do not require procedure approval by the Purchaser.
- The Supplier is responsible for planning the order of operations to minimise distortion.

6.0 ARC WELDING

6.1 STANDARDS AND ALTERNATIVES

This specification follows the general principles and appropriate requirements of BS 5500. Other national or international pressure vessel standards may be considered technically equivalent, subject to approval by the Purchaser. As an example ASME IX (weld and welder approval) and ASME V (inspection) are acceptable. In any event the Supplier must be able to demonstrate a basic similarity in procedure and welder tests, methods of inspection and acceptance criteria. Weld procedure and welder qualification tests that may be required are BS EN 875 (impact), BS EN 876 (longitudinal tensile), BS EN 895 (transverse tensile), BS EN 910 (bend), BS EN 1043-1 & 2, (hardness), BS EN 1320 (fracture) and BS EN 1321 (macroscopic examination).

6.2 GENERAL

- All welding shall be performed in accordance with a welding procedure specification or other work instruction that conforms to BS EN 288-2. The only exception to this being for the welding of non-structural items such as source holders, mesh panels, labels etc.
- The Supplier may deviate from the drawing specification for weld preparation in order to comply with established welding procedures subject to Purchaser approval.
- All weld spatter shall be removed.
- Discolouration shall be removed from stainless steel fabrications. If discolouration is removed by chemical etching the surface must be cleaned of all residue following the manufacturer's instructions.

6.3 WELDING PROCEDURE APPROVAL

- Approval testing of welding procedures shall be conducted and recorded in accordance with BS EN 288-3 except for non-structural items.
- In addition, for butt welds in plate over 10 mm thick, a longitudinal tensile test should be conducted.
- Weld yield strength shall not be less than the specified minimum value for the parent metal. Elongation shall not be less than 80% of the specified minimum value for the parent metal.

6.4 WELDER APPROVAL

- Approval testing of welders shall be conducted and recorded in accordance with BS EN 287-1, except for non-structural items, where the supplier shall certify that the welder is competent and adequately trained.
- A welder who successfully welds all the test pieces for a weld procedure test need not be required to undertake the welder prolongation test for a subsequent period of six months.

6.5 CONSUMABLES

- Welding consumables shall be the same as those used in the weld qualification procedure except when alternative consumables are permitted within the grouping schemes specified in BS EN 288-3.
- The storing and handling of welding consumables shall be controlled in accordance with procedures written on the basis of the maker's information.
- Welding consumables and their packaging shall be marked in accordance with the welding standard.

6.6 ALIGNMENT

Joint, i.e. parent metal, alignment must comply with the welding procedure.

6.7 TACK WELDS

Tack welds may be incorporated into the weld only if permitted by the weld procedure.

6.8 TEMPORARY ATTACHMENTS

- Any temporary attachments or supports welded to the structure shall be of the same nominal chemical composition as the structure in that area.
- The location of such attachment welds shall be chosen, as far as is practicable, to avoid existing welds and areas to be subsequently welded.
- The welding process shall follow a welding procedure or be approved by the Purchaser.
- The weld area shall be dressed smooth after removal of the attachment.

6.9 HEAT TREATMENT

- Any pre-or post-weld heat treatment requirements will be specified on the manufacturing drawing.
- No welding is to take place if parent metal temperature is less than 0°C.

6.10 WELD PROFILE

- The weld profile will be specified on the manufacturing drawing.
- Any dressing or machining requirements will be specified on the manufacturing drawing.

6.11 INSPECTION

6.11.1 General

- Non-destructive testing of the parent materials or fusion faces prepared for welding is not required.
- The manufacturing drawing will specify the final inspection technique. Intermediate inspection such as for the root run shall be in accordance with the welding procedure.
- Inspection personnel for visual and dye penetrant inspection shall be certified by the Supplier to be trained to the required standard.

- Inspection personnel for ultrasound and radiography shall hold an appropriate certificate of competence from an independent inspection authority.

6.11.2 Visual Inspection

- All welds, with the exception of any surfaces that are subsequently machined, shall be visually inspected. Machined surfaces need only meet the dimensional and surface finish requirements specified on the manufacturing drawing.
- Acceptance criteria: Table 5.7 (3), BS 5500 or BS EN 25817 (quality level B, stringent) to the extent permitted by access.
- Excess reinforcement is acceptable provided overall dimensions are within tolerance.

6.11.3 Dye/liquid Penetrant Inspection

- To be carried out on the weld surface in its final condition, i.e. after any subsequent machining operation, in accordance with BS EN 571-1.
- Acceptance criteria: No indications permitted.

6.11.4 Radiographic Inspection

- To be carried out in accordance with BS EN 1435, Class B technique.
- Surfaces may be dressed only where weld surface ripples or irregularities will interfere with interpretation of the radiograph.
- Acceptance criteria: Table 5.7 (1), BS 5500 or BS EN 12517, Level 1.
- Where geometry or design make radiography impractical or unreliable the Supplier may prepare a coupon of the same geometry and materials and not less than the greater of 10% of the length of the production weld or 200 mm. The welder, or operator, shall weld the coupon at the same time as the production weld, run for run, without changing any machine settings. The coupon shall then be machined as necessary to allow a satisfactorily clear radiograph. The production weld may then be sentenced on the coupon results.

6.11.5 Ultrasound Inspection

- To be carried out in accordance with BS EN 1714, Level B.
- The condition of surfaces in contact with the probe must comply with the requirements of BS EN 1714.
- Acceptance criteria: Table 5.7 (2) BS 5500 or BS EN 1712, Level 2.
- Where geometry or design make ultrasound impractical or unreliable the Supplier may prepare a coupon of the same geometry and materials and not less than the greater of 10% of the length of the production weld or 200 mm. The welder, or operator, shall weld the coupon at the same time as the production weld, run for run, without changing any machine settings. The coupon shall then be machined as necessary to allow satisfactorily inspection. The production weld may then be sentenced on the coupon results.
- May be replaced with radiographic inspection.

6.12 REPAIRS

- Repair welds shall be carried out to an approved procedure and are subject to the same acceptance criteria as the original work.

6.13 TRACEABILITY MARKINGS

- All materials, other than those less than 6 mm thick or those used in non-structural fabrications, shall be permanently marked on an external surface, for instance by stamping, vibro-engraving or equivalent process, with the cast or heat number for that material.

- Welds in materials so marked shall be permanently marked in their vicinity with the welder's identity mark.
- Where possible a marking shall be sited on an unmachined external surface. If all external surfaces are machined the marking shall avoid areas of 0.8 µm surface finish and shall be only be deep enough to be legible. If there is no accessible external surface the marking may be omitted.
- Temporary markings shall be removed after manufacture but before any acceptance testing.

7.0 RESISTANCE SPOT WELDING

- Spot welding shall comply with the general principles of BS 1140.
- Welder/operator and inspector shall be certified by the Supplier to be trained to the required standard.
- The procedure shall be established using identical samples (materials, thicknesses, surface condition or coatings and number and size of welds).
- Weld samples shall be clearly identified with the procedure, issue status and date.
- Samples shall be tested destructively by splitting apart the joint with a hammer and chisel.
- A plug of metal from one side shall be retained on the other side of the joint.
- Prior to any production spot welding the welder shall check the machine settings by destructively testing a sample as above. No production spot welding may take place until the settings have been satisfactorily rechecked.
- After continuous production welding for a period of two hours, and subsequently every two hours, the welder shall check the machine settings by retesting a sample as above.

8.0 BRAZING AND SOLDERING

- Brazing shall comply with the general principles of BS 1723, Parts 1 & 2.
- The welder/operator and inspector shall be certified by the Supplier to be trained to the required standard.
- The Supplier shall be able to show that the consumables are suitable for the process and materials being joined.
- The storing and handling of welding consumables shall be controlled in accordance with procedures written on the basis of the maker's information.
- The brazing/soldering procedure shall be established using identical samples (materials, thicknesses and surface condition).
- The procedure shall include the removal of corrosive fluxes and cleaning agents.
- Samples shall be examined visually with a 2-4 times magnifying lens. The joint shall show no evidence of lack of flow or cracks in or around the joint.

SUPPLY SPECIFICATION
SURFACE FINISH REQUIREMENTS FOR TRANSPORT CONTAINERS

Design Approval	D W Rogers .... (signature) date: 21/10/99
Management Approval	D A Coppell .... (signature) date: 26 October 1999
Quality System Approval	B S Patel .... (signature) date: 26 October 1999
Controlled file number	01

1.0 PURPOSE AND SCOPE

This document specifies the surface coating or finish requirements (painting, galvanising, electroplating, clean and matt) of components for transport containers for radioactive materials. It is not necessarily restricted to this application.

2.0 REFERENCES

- SS 028: current issue: Quality assurance requirements for controlled materials.
- BS 4800: 1989 (1994): Schedule of paint colours for building purposes.
- BS EN 22063: 1994: Metallic and other inorganic coatings. Thermal spraying. Zinc, aluminium and their alloys.
- BS 1706: 1990 (1996): Method for specifying electroplated coatings of zinc and cadmium onto iron and steel.

3.0 DEFINITIONS

- Purchaser : REVISS Services (UK) Ltd.
- Supplier : Organisation named in the purchase order

4.0 QUALITY ASSURANCE

- See SS 028 for general quality assurance and documentation requirements.
- See purchase order and any specifications referenced therein for any supplementary requirements.

5.0 GENERAL

- The purchase order takes precedence over the manufacturing drawing.
- The manufacturing drawing takes precedence over this specification.
- The manufacturing drawing will specify the treatment, the applicable area and any special instructions.

6.0 PROTECTIVE COATINGS

6.1 PAINT

- Applies to only carbon steel surfaces. Prepare and apply all paint coatings in accordance with manufacturer's instructions.
- Prepare surface and zinc spray in accordance with BS EN 22063. Nominal thickness 0.1 mm.
- Apply one coat two-pack etch primer (98-SAP 3*).
- Apply one coat two-pack, high build, epoxy zinc phosphate primer (J 168*). Nominal thickness 75-100 microns.
- Apply one coat two-pack, high build, epoxy, micaceous iron oxide primer (Z 70075*). Nominal thickness 75-100 microns.
- Apply one coat two-pack polyurethane, full gloss top coat (AE 245. Nominal thickness 30-50 microns. Colour: Blue mink (BS 4800, ref 18-B-17).
- Repairs: Use two-pack polyurethane, full gloss, brushing top coat (B 25*). Nominal thickness 30-50 microns. Colour: Blue mink (BS 4800, ref 18-B-17).

* Trimite codes shown for convenience. Other manufacturers' paints complying with the generic descriptions are acceptable.

6.2 GALVANISING

- Applies to carbon steel surfaces.
- Prepare surface and hot dip galvanise in accordance with BS 729. Nominal thickness 0.1 mm.
- No drips or spikes permitted.

6.3 ZINC PLATING

Prepare surface, zinc electroplate and passivate in accordance with BS 1706, Zn-3.

7.0 STANDARD SURFACE FINISHES

Applies to corrosion resistant materials such as stainless steel, brass and lead:

7.1 CLEAN

Surfaces are to be wiped clean of all visible traces of lubricants, machining fluids, swarf, loose particles and dirt.

7.2 MATT

- Often used on stainless steel surfaces for glare control it may be achieved using bead blasting. Clean glass or plastic beads are necessary to avoid iron contamination and will avoid the surface becoming too rough.
- A matt finish may be achieved by mechanical or chemical means if not otherwise specified. Chemical techniques must include an appropriate cleansing procedure.
- The procedure and a sample of the finish must be submitted for approval by the Purchaser before application.

REVISS SERVICES

SUPPLY SPECIFICATION MARKING TECHNIQUES FOR TRANSPORT CONTAINERS	
Design Approval	D W Rogers DWRogers (signature) date: 21/10/99
Management Approval	D A Coppell DACoppell (signature) date: 26 October 1999
Quality System Approval	B S Patel Bhanubhai S Patel (signature) date: 26 October 1999
Controlled file number	01

1.0 PURPOSE AND SCOPE

This document specifies the requirements for the permanent marking (engraving, stamping, laser etching, vibro-engraving and paint marking) of components for transport containers for radioactive materials. It is not necessarily restricted to this application.

2.0 REFERENCES

SS 028: current issue: Quality assurance requirements for controlled materials.

3.0 DEFINITIONS

- Purchaser : REVISS Services (UK) Ltd.
- Supplier : Organisation named in the purchase order

4.0 QUALITY ASSURANCE

- See SS 028 for general quality assurance and documentation requirements.
- See purchase order and any specifications referenced therein for any supplementary requirements.

5.0 GENERAL

- The purchase order takes precedence over the manufacturing drawing.
- The manufacturing drawing takes precedence over this specification.
- The manufacturing drawing and/or associated supply specification will specify the content, size, position and marking technique.
- All text shall be in an upright, non-ornate (sans-serif) typeface. The capital letter height will be specified on the drawing or associated specification.
- All text and symbols must be faithfully reproduced. It is not permissible to change the case, omit, add or otherwise modify what is shown on the drawing or associated specification.
- Care should be observed in reading the drawing notes or associated specification. Variable text is usually shown as dashes or crosses with an instruction where to find the actual text (for instance "See purchase order for serial number").

6.0 MARKING TECHNIQUES

6.1 ENGRAVING

- Engraving is the machining of a U-shaped groove in the surface of a component.
- The groove width shall be 12-20% of the specified text height unless otherwise specified on the manufacturing drawing or specification.
- The groove depth shall be 0.10 - 0.30 mm.
- If "back-fill in black" is specified the Supplier shall use a waterproof paint or paint system recommended by the paint manufacturer for the base metal to ensure adequate adhesion.
- If a trefoil (the standard radiation warning symbol) is required and the drawing gives only the outer diameter the proportions defined in Figure 1 shall be used.
- Laser etching is an acceptable alternative to "engraving back-filled in black" when it is applied to stainless steel sheet.

6.2 LASER ETCHING

- Laser etching is the computer controlled oxidation of a stainless steel surface with a scanning laser.
- Line width shall be 12-20% of the specified text height unless otherwise specified on the manufacturing drawing or specification.
- If a trefoil (the standard radiation warning symbol) is required and the drawing gives only the outer diameter the proportions defined in Figure 1 shall be used.

6.3 STAMPING

- Stamping is the indentation of a surface one, character at a time, by the impact of a shaped punch tool.
- The minimum depth shall be determined by legibility. The maximum depth shall be 0.5mm.
- Engraving is an acceptable alternative technique.

6.4 VIBRO-ENGRAVING

- Vibro-engraving is the indentation of a surface using a hand tool with a vibrating hardened tip.
- Text shall be non-ornate and clearly legible to the naked eye.
- Engraving or stamping is an acceptable alternative technique..

6.5 MARKING

- Marking is the application of text using paint and a stencil.
- It may be applied to metallic or organic base materials.
- The Supplier shall use a waterproof paint or paint system recommended by the paint manufacturer for the base metal to ensure adequate adhesion.

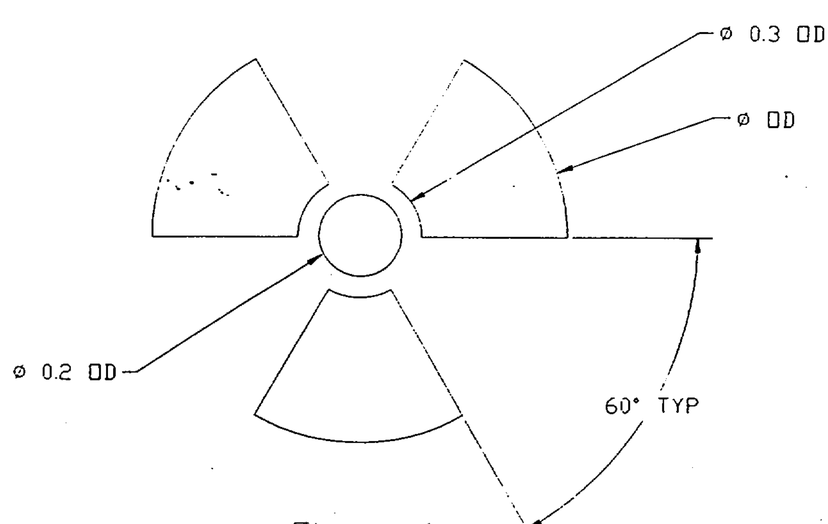

Figure 1
Trefoil Proportions

REVISS SERVICES

SUPPLY SPECIFICATION
URANIUM COMPONENTS FOR TRANSPORT CONTAINERS

Design Approval	D W Rogers [signature] (signature) date: 11/07/00
Management Approval	D A Coppell [signature] (signature) date: 14 July 2000
Quality System Approval	B S Patel [signature] (signature) date: 14 July 2000
Controlled file number	1

1.0 PURPOSE AND SCOPE

The purpose of this specification is to define the material, identification, inspection, storage, packaging, transport, quality assurance and documentation requirements for components used for gamma radiation shielding in transport containers, though it need not be restricted to this application. Such components usually take the form of solid discs or cylinders or hollow cylinders.

2.0 REFERENCES

- SS 024: Marking techniques for transport containers.
- SS 028: Quality assurance requirements for controlled purchases.
- Safety Series No. 6: Regulations for the Safe Transport of Radioactive Material, 1985 Edition (As Amended 1990), International Atomic Energy Agency, Vienna, 1990.
- ST-1: Regulations for the Safe Transport of Radioactive Material, 1996 Edition, International Atomic Energy Agency, Vienna, 1996.

3.0 DEFINITIONS

- Purchaser : REVISS Services (UK) Ltd.
- Supplier : Organisation named in the purchase order.

4.0 QUALITY ASSURANCE

The quality assurance requirements will be specified on the purchase order. For documentation requirements see Section 8.

5.0 SPECIFICATION

5.1 RULING SPECIFICATION

This material specification is used in conjunction with a purchase order and a detailed drawing. Where there is any conflict the purchase order takes precedence over the drawing and the drawing take precedence over this specification.

5.2 DIMENSIONS AND TOLERANCES AND SURFACE TEXTURE

Specified in the detailed drawing.

5.3 SURFACE TEXTURE

Specified in the detailed drawing. Setting out marks, identification markings and isolated surface defects such as minor indentations or casting imperfections outside the general drawing surface texture requirement are permitted provided there are no raised edges and the depth does not exceed 2% of the component thickness measured at right angles to the surface.

5.4 CHEMICAL COMPOSITION

Uranium content to be not less than 99%.

5.5 FISSILE CONTENT

Uranium U-235 content not to exceed 0.7%

5.6 DENSITY

Not less than 18.5 g/cc.

5.7 CASTING PROCEDURE

The Supplier must employ a procedure that ensures components are made of sound metal that meets the density requirement. This will depend on controlling the rate of cooling from the liquid to the solid and ensuring an adequate reservoir of liquid metal to fill the contraction volume. The design of the mould should take into account its thermal mass, its rate of cooling and the amount of excess material to be cast below, around and above the finished size. The process instructions should define all other equipment and materials used, the degree of preheat of the mould and the liquid uranium and all other significant machine settings or actions.

5.8 IDENTIFICATION

Markings

When specified on the detail drawing components shall be marked in accordance with SS 024 as follows:

(1)
(2) / (3) / (4)
(5)

where:
(1) is the purchase order number (e.g. RSL 12345).
(2) is the drawing number, and item number if applicable (e.g. P/1234/567 or P/1234/567/8).
(3) is the drawing issue (e.g. A).
(4) is the component manufacturing serial number starting at 01 (i.e. the first component manufactured to a particular drawing, issue and order number shall be marked 01, the second 02 etc.).
(5) is the measured weight rounded up to the nearest kg.

The marking process must be mechanical, for example engraving, marking with a hand tool (vibro-engraving) or stamping. The minimum text height is 2 mm. Any raised edges created by the marking process must be removed.

Manufacturers markings

The Supplier may add his own markings underneath the identity markings using the same process.

5.9 CLEANLINESS

After machining all surfaces must be wiped clean to remove fluids and loose particles.

6.0 INSPECTION AND TESTING

6.1 DIMENSIONS, SURFACE TEXTURE AND IDENTIFICATION

100% on all components.

6.2 CHEMICAL COMPOSITION

Analyse percentage content of all elements present above 0.1% in each cast.

6.3 FISSILE CONTENT

U-235 content of each cast to be measured.

6.4 DENSITY

Calculate density from the dimensions and weight of a coupon taken from each cast. The coupon volume must not be less than 10 cm^3. It must be taken from directly over the centre of a solid component or over the middle of the wall thickness of a hollow component. Where more than one component is made from a single cast the measurements may be made from a coupon at the top. The density of components weighing less than 10 kg may be calculated from measurements made on the component in the finished or part-machined condition.

7.0. STORAGE AND TRANSPORT

7.1 STORAGE

Components must be protected from moisture. This may be achieved for example by wrapping the components in plastic sheet or metal foil, in an airtight container such as a metal box with a sealed lid and enclosing a porous bag containing dry silica gel.

7.2 TRANSPORT

Regulations

It is the Supplier's responsibility to ensure that packaging complies with all relevant national and international transport regulations. Guidance may be found in the current version of Safety Series No. 6, or ST-1 if applicable, or from your local authorities.

Moisture

Packaging must protect components from moisture for a minimum of one year from despatch (see Storage above).

Mechanical protection

Packaging must protect the contents from normal handling conditions. Components must be adequately restrained and cushioned. Where more than one component is packed in the same package they must be adequately restrained and cushioned from each other.

Handling

Components with handling features such as eyebolt holes must be packed with these features uppermost. It is the Supplier's responsibility to agree package handling features with freight agent and consignee if the package weight exceeds 50 kg.

Weight

It is the Supplier's responsibility to agree the maximum package weight with freight agent and consignee.

Labelling

The Supplier must label each package in accordance with the requirements of the national and international regulations (if necessary). Component identification markings must be included on the package labelling.

8.0 DOCUMENTATION

The Supplier must supply the following documentation with each component:

- A certificate of conformance detailing:
    - the order number and amendment number.
    - the drawing number and issue.
    - this specification and issue.
    - the component identity marking (if applicable).
- A record of dimensional measurements.
- A certificate of chemical analysis.
- A certificate of U-235 content.
- The calculated density.
- The measured weight.

Any or all of these documents may be combined in one document. Batches of components that are not individually identified may be provided with one certificate covering the batch providing it has been made from one cast.

REVISS SERVICES

SUPPLY SPECIFICATION **LOW CARBON STAINLESS STEELS**	
Design Approval	D W Rogers D W Rogers (signature) date: 11/07/00
Management Approval	D A Coppell DA Coppell (signature) date: 18/7/2000
Quality System Approval	B S Patel Bhailal S Patel (signature) date: 20/7/2000
Controlled file number	01

1.0 PURPOSE AND SCOPE

This purpose of this document is to define the essential physical and chemical properties of the group of materials generally known as low carbon, austenitic stainless steels. It also provides guidance for manufacturers in the selection and use of these materials. It applies only to the raw material forms of sheet, plate, strip, rod, bar, tube and pipe. It does not apply to proprietary items such as fasteners and mesh.

2.0 REFERENCES

- SS 028: current issue: Quality assurance requirements for controlled purchases.
- BS 970: Part 3: 1991: Bright bars for general engineering purposes.
- BS 1449: Part 2: 1983: Specification for stainless and heat resisting steel plate, sheet and strip.
- BS 1501: Part 3: 1990: Specification for corrosion and heat resisting steels: plates, sheet and strip.
- BS 3605: Pt 1: 1991: Specification for seamless tubes.
- BS 3605: Pt 2: 1992: Specification for longitudinally welded tubes.
- BS EN ISO 3651-2: 1998: Ferritic, austenitic, and ferritic-austenitic (duplex) stainless steels. Corrosion tests in media containing sulphuric acid.

3.0 DEFINITIONS

- Purchaser : REVISS Services (UK) Ltd.
- Supplier or Manufacturer : Organisation named in the purchase order.

4.0 QUALITY ASSURANCE

- General requirements are detailed in SS 028.
- See purchase order and any specifications referenced therein for any supplementary requirements.

5.0 GENERAL

- The purchase order takes precedence over the manufacturing drawing.
- The manufacturing drawing takes precedence over this specification.
- The manufacturing drawing will specify the principle dimension(s) and form of the raw material and any additional requirements.

6.0 SPECIFICATION

6.1 STANDARDS

The table lists acceptable UK standards and a selection of German and US equivalents current at the time of writing:

Material Form	UK	German	USA
Sheet and Strip	BS 1449, Pt 1	DIN 17440 DIN 17441	ASTM A240
Plate	BS 1449, Pt 2	DIN 17440	ASTM A240

Material Form	UK	German	USA
	BS 1501, Pt 3		
Rod and Bar	BS 970, Pt 3	-	ASTM A479
Tube	BS 3605	DIN 50049 3.1.B	ASTM A269 ASTM A213 ASTM A511
Pipe	BS 3605	DIN 500493.1.B	ASTM A312 ASTM A376 ASTM A358 ASME SA312

6.2 MATERIAL GRADES

The table lists acceptable UK grades and a selection of equivalent grades current at the time of writing:

UK (BS 970)	French (AFNOR)	German (WNr)	Italian	Japanese (JIS)	Swedish (SIS)	USA (SAE)
304S11	Z2CN18.10	1.4306	X2CrNi 18 11	SUS304L	14 23 52	304L
316S11 316S13	Z2CND17.12	1.4404 1.4435	X2CrNiMo 17 12	SUS316L	14 23 53 14 23 48	316L

6.3 INTERGRANULAR CORROSION

All materials must be capable of passing the intergranular corrosion test specified in BS EN ISO 3651-2, Method A, or equivalent.

6.4 OTHER STANDARDS AND GRADES

Materials conforming to other equivalent national or international standards may be used subject to written permission from the Purchaser. Such materials shall meet the following chemical and mechanical requirements and the intergranular corrosion test specified above:

6.4.1 304L

Composition (% maximum unless stated)								Strength (min MPa)		Elongation
C	Si	Mn	P	S	Cr	Mo	Ni	Tensile	0.2% Strain	$5.65\sqrt{So}$*
0.030	1.00	2.00	0.045	0.030	20.0 17.0	-	13.0 8.0	480	173	40% min

* or 50 mm gauge length (So = cross-sectional area, thus length is equivalent to 5D on cylindrical test piece).

6.4.2 316L

Composition (% maximum unless stated)								Strength (min MPa)		Elongation
C	Si	Mn	P	S	Cr	Mo	Ni	Tensile	0.2% Strain	5.65√So*
0.030	1.00	2.00	0.045	0.030	18.5 16.5	3.0 2.0	15.0 10.0	480	173	40% min

7.0 RAW MATERIAL SIZES

The manufacturing drawing will state the stock material sizes in one system of units. The manufacturer may deviate from the specification in two instances:

Machined items:

Where the primary dimension (thickness, width or diameter) is subsequently machined down the size may be taken as a guide only. The manufacturer may use any appropriate stock size.

Imperial/metric parity:

Where the item is not machined, and materials are not available in the unit system specified, the manufacturer may use the following equivalent sizes. It is the manufacturer's responsibility to ensure that all mating dimensions are adjusted so that fits and clearances are maintained.

Imperial (inch)	1/8	3/16	1/4	3/8	1/2	5/8	3/4	7/8	1.0	1.5	2.0
Metric (mm)	3	5	6	10	12	16	20	22	25	40	50

Imperial (swg)	22	20	18	16	14	12	10	8	6	4	2
Metric (mm)	0.75	1	1.25	1.5	2	2.5	3.5	4	5	6	7

8.0 DOCUMENTATION

The Supplier shall provide certified evidence from the manufacturer or from his own testing that the chemical composition and mechanical properties meet this specification or one of the equivalents cited previously. All documentation shall reference the original cast or heat number.

CONTROLLED DOCUMENT
(when in red)

REVISS SERVICES

SUPPLY SPECIFICATION **COPPER SPRAYING FOR TRANSPORT CONTAINERS**	
Design Approval	D W Rogers D W Rogers .... (signature) date: 19/07/00
Management Approval	D A Coppell D A Coppell .... (signature) date: 18 July 2000
Quality System Approval	B S Patel Bhaoli S Patel .... (signature) date: 20 July 2000
Controlled file number 01	

1.0 PURPOSE AND SCOPE

This document specifies the quality assurance, procedural, validation, inspection and test requirements for copper spraying when applied to components for transport containers for radioactive materials. It applies to thermal copper spraying, either by flame or plasma technique, onto stainless steel. It is not necessarily restricted to this application.

2.0 REFERENCES

SS 028: current issue: Quality assurance requirements for controlled materials.

3.0 DEFINITIONS

- Purchaser : REVISS Services (UK) Ltd.
- Supplier : Organisation named in the purchase order.

4.0 QUALITY ASSURANCE

- See SS 028 for general quality assurance and documentation requirements.
- See purchase order and any specifications referenced therein for any supplementary requirements.
- The Supplier is responsible for reviewing all manufacturing drawings and specifications and agreement with Purchaser.

5.0 GENERAL

- The purchase order takes precedence over the manufacturing drawing.
- The purchase order will specify the component identity and/or the drawing, issue and item numbers as applicable and any special instructions.
- The manufacturing drawing takes precedence over this specification.
- The manufacturing drawing will specify this document, the copper thickness and tolerance, the area to be sprayed and any special instructions.
- The Supplier is responsible for planning the spraying operation to ensure best control of coating thickness.

6.0 PROCEDURE

6.1 VALIDATION AND APPROVAL

- The Supplier shall work to a procedure agreed in writing by the Purchaser prior to spraying.
- The coating procedure shall be validated by testing for adhesion and thermal performance (see Section 7).

6.2 CONTENTS

The procedure shall include the following processes and requirements:

- The training and competence requirements for the operator.

- Preliminary visual and dimensional examination of components.
- Removal of surface contamination such as oils and greases and protection of surfaces from further contamination.
- Method of surface preparation including equipment and materials used. Adequate precautions shall be taken to remove oil and moisture from compressed air.
- Method of masking. Materials shall not burn, run or contaminate adjacent surfaces or coating.
- Maximum interval between surface preparation and coating application. Unless otherwise agreed this shall not exceed twenty-four hours.
- Minimum component temperature. If pre-heating is required the method shall avoid contamination, local overheating or distortion.
- Copper grade: Not less than 98% purity.
- Equipment settings. The equipment manufacturer's instructions with regard to feed rates, spraying distances, gas and air pressures and flow rates shall be followed.
- Spray dust. Care shall be taken to avoid entrapment of spraying dust in the coating (less accessible areas such as corners or re-entrants should be sprayed first).
- Minimum pistol angle to surface. Wherever possible the pistol shall be held at right angles to the surface to be coated. In any event it shall not be held at less than 45°.
- Shafts and cylindrical surfaces. Wherever possible such surfaces shall be rotated and the pistol traversed to ensure coating is deposited in thin, even layers.

7.0 TESTING

7.1 ADHESION (VALIDATION AND PRODUCTION):

Using a cutting tool with a hard point cut a lattice of scratches on the coated face of a coupon. The lines shall cut through the coating, shall be spaced a nominal distance of 3 mm apart and shall cover an area not less than 15 mm square. The coating shall be visually examined and shall be free from lifting edges, cracking, flaking or other failure of the adhesive bond.

7.2 THERMAL (VALIDATION):

- A coupon shall be heated to not less than 300°C for not less than 200 hours in a vacuum or inert gas atmosphere. After cooling it shall pass the scratch test.
- A coupon shall be heated to not less than 800°C for not less than 30 minutes in a vacuum or inert gas atmosphere. After cooling it shall be visually examined and shall be free from lifting edges, cracking, flaking or other failure of the adhesive bond.

8.0 COUPONS

8.1 VALIDATION COUPONS

- The coupon shall be flat, not less than 20 x 20 mm, not less than 10 mm thick and manufactured from austenitic stainless steel plate.

- Each coupon shall be permanently marked on the reverse with the procedure identity and issue status and the parent material specification.
- Each coupon shall be prepared and coated to the same thickness as the production coating, following the same procedure and with the pistol held at the maximum angle to vertical that would be used in production.
- Validation coupons shall be scratch and thermal tested for adhesion (see Section 7).

8.2 PRODUCTION COUPONS

- A production coupon shall be prepared for each component.
- The coupon shall be:
  - flat, not less than 20 x 20 mm,
  - not thicker than the thinnest coated part of the component to which it relates,
  - as close as practicable to the thickness of the coated part of the component to which it relates (though note that, for components > 5mm thick a 5mm thick coupon is acceptable)
  - manufactured from the same material grade as the component to which it relates
- Each coupon shall be permanently marked on the reverse with the Purchaser's order number and its date or revision number and the component identity or its drawing, issue and item number as applicable.
- The coupon shall be prepared and coated at the same time as the production coating to the same thickness, following the same procedure and with the pistol held at the maximum angle to vertical used in production.
- Production coupons shall be scratch tested for adhesion (see Section 7.1).
- In the event of a fail result the component associated with the coupon shall be clearly marked "QC Fail" or equivalent until such time as it can be stripped, recoated, re-inspected and cleared.

8.3 SUPPLY

All production coupons shall be supplied to the Purchaser with the finished components.

9.0 INSPECTION

- Exposed coating edges shall be visually examined for lifting.
- The thickness shall be verified by direct measurement or by before and after measurements. Where the geometry makes measurement impractical or imprecise the Supplier may use a coupon sprayed alongside the component, at the same time, by the same operator with the same machine settings.
- Uncoated surfaces shall be visually inspected for freedom from over-spray.
- In the event of a fail result the component shall be clearly marked "QC Fail" or equivalent until such time as it can be reworked, re-inspected and cleared.

10.0 MACHINING

If mechanical working is required after coating in order to meet dimensional requirements it shall be carried out by a method that avoids local heating or unnecessary drag that might disrupt the bond.

11.0 DOCUMENTATION

The Supplier shall provide a certificate of conformity detailing:

- The Purchaser's order number and its date or revision status.
- The component identity and/or its drawing and issue and item number, as applicable.
- The specified coating and thickness applied to each component.
- A certificate of chemical analysis for the copper.
- A record of visual inspection results.
- The measurements taken to confirm coating thickness and final dimensions.
- This specification and its issue status.
- The Supplier's procedure identity and issue status.

REVISS SERVICES

SUPPLY SPECIFICATION
STAINLESS STEELS FOR NON-WELDED APPLICATIONS

Design Approval	D W Rogers D W Rogers .... (signature) date: 11/07/00
Management Approval	D A Coppell D A Coppell .... (signature) date: 18 July 2000
Quality System Approval	B S Patel B Bhanubhai Patel .... (signature) date: 20 July 2000
Controlled file number	01

1.0 PURPOSE AND SCOPE

Austenitic stainless steels have broadly similar strength, ductility and anti-corrosion properties that make them suitable for general application. The purpose of this specification is to define the physical and chemical properties of this group of materials. Not all of them are suitable for welding; therefore this specification should only be used for non-welded applications.

This specification provides guidance for manufacturers in material selection. It applies to the raw material forms of sheet, plate, strip, rod, bar, tube and pipe. It does not apply to proprietary items such as fasteners and mesh.

2.0 REFERENCES

- SS 028: current issue: Quality assurance requirements for controlled purchases.
- BS 970: Part 3: 1991: Bright bars for general engineering purposes.
- BS 1449: Part 2: 1983: Specification for stainless and heat resisting steel plate, sheet and strip.
- BS 1501: Part 3: 1990: Specification for corrosion and heat resisting steels: plates, sheet and strip.
- BS 3605: Pt 1: 1991: Specification for seamless tubes.
- BS 3605: Pt 2: 1992: Specification for longitudinally welded tubes.
- BS EN ISO 3651-2: 1998: Ferritic, austenitic, and ferritic-austenitic (duplex) stainless steels. Corrosion tests in media containing sulfuric acid.

3.0 DEFINITIONS

- Purchaser : REVISS Services (UK) Ltd.
- Supplier or Manufacturer : Organisation named in the purchase order.

4.0 QUALITY ASSURANCE

- General requirements are detailed in SS 028.
- See purchase order and any specifications referenced therein for any supplementary requirements.

5.0 GENERAL

- The purchase order takes precedence over the manufacturing drawing.
- The manufacturing drawing takes precedence over this specification.

6.0 SPECIFICATION

The Supplier may use any of the material grades listed in the tables in this section. The first table gives examples of the range of material grades and properties available under UK standards. The following tables give examples of equivalent national standards and grades.

6.1 PROPERTIES GUIDE (BS 970, 1449 & 1501)

	Composition (% maximum unless stated)									Strength (min MPa)		Elong-ation
Grade	C	Si	Mn	P	S	Cr	Mo	Ni	Others	Tens-ile	0.2% Strain	5.65√So * (%min)
302S31	0.12	1.00	2.00	0.045	0.030	19.0 17.0	-	10.0 8.0	-	510	190	40
303S31	0.12	1.00	2.00	0.060	0.035 0.015	19.0 17.0	1.0	10.0 8.0	-	510	190	40
303S42	0.12	1.00	2.00	0.060		19.0 17.0	1.0	10.0 8.0	Se0.35 0.15	510	190	40
304S11	0.03	1.00	2.00	0.045	0.030	19.0 17.0	-	12.0 9.0	-	480	185	40
304S15	0.06	1.00	2.00	0.045	0.030	19.0 17.5	-	11.0 8.0	-	480	195	40
304S31	0.07	1.00	2.00	0.045	0.030	19.0 17.0	-	11.0 8.0	-	490	195	40
310S31	0.15	1.50	2.00	0.045	0.030	26.0 24.0	-	22.0 19.0	Ti 0.80 5C	510	205	40
316S11	0.03	1.00	2.00	0.045	0.030	18.5 16.5	3.0 2.0	14.0 11.0	-	490	190	40
316S13	0.03	1.00	2.00	0.045	0.030	18.5 16.5	3.0 2.5	14.5 11.5	-	490	190	40
316S31	0.07	1.00	2.00	0.045	0.030	18.5 16.5	2.5 2.0	13.5 10.5	-	510	205	40
316S33	0.07	1.00	2.00	0.045	0.030	18.5 16.5	3.0 2.5	14.0 11.0	-	510	205	40
320S31	0.08	1.00	2.00	0.045	0.030	18.5 16.5	2.5 2.0	14.0 11.0	Ti 0.80 5C	510	210	35
320S33	0.08	1.00	2.00	0.045	0.030	18.5 16.5	3.0 2.5	14.5 11.5	Ti 0.80 5C	510	210	40
321S31	0.08	1.00	2.00	0.045	0.030	19.0 17.0	-	12.0 9.0	Ti 0.80 5C	510	200	35
325S31	0.12	1.00	2.00	0.045	0.035 0.015	19.0 17.0	-	11.0 8.0	Ti 0.90 5C	510	200	35
347S31	0.08	1.00	2.00	0.045	0.030	19.0 17.0	-	12.0 9.0	Nb 1.00 10C	510	205	35

* or 50 mm gauge length (So = cross-sectional area thus length is equivalent to 5D on cylindrical test piece).

6.2 OTHER NATIONAL STANDARDS

This table details German and US equivalent standards.

Material Form	UK	German	USA
Sheet and Strip	BS 1449, Pt 1	DIN 17440/17441	ASTM A240
Plate	BS 1449 Pt 2, BS 1501 Pt 3	DIN 17440	ASTM A240
Rod and Bar	BS 970, Pt 3	-	ASTM A479
Tube	BS 3605	DIN 50049 3.1.B	ASTM A269, A213, A511.
Pipe	BS 3605	DIN 500493.1.B	ASTM A312, A376, A358, ASME SA 312

6.3 EQUIVALENT MATERIAL GRADES

UK grades and a selection of equivalent grades:

UK	French (AFNOR)	German (W.Nr)	Italian (UNI)	Japanese (JIS)	Swedish (SS)	USA (SAE)
304S11	Z2CrNi18.10	1.4306	X2CrNi 18 11	SCS19	2352	304L
304S15 304S16	Z6CN18.09	1.4301	X5CrNi 18 10	SUS304	2333	304
304S31				SUS302	2332	302
316S11	Z2CND17.12	1.4404	X2CrNiMo1712	SCS16	2348	316L
316S13	Z6CND18-12-03	1.4435	X8CrNiMo1713	SCS16	2353	316L
316S31	Z6CND17.11	1.4401	X8CrNiMo1713	SUS316	2343	316
316S33	Z6CND17.11	1.4436	X8CrNiMo1713	SUS316	2347	316
347S31	Z6CNNb18.11	1.4550	X6CrNiNb1811 X8CrNiNb1811	SUS347	2338	347
320S31	Z8CNND17.12	1.4571			2350	
320S33	Z8CNND17.12	1.4573			2350	
321S31	Z6CNTD18.12	1.4541	X6CrNiTi1812	SUS321	2337	321

6.4 INTERGRANULAR CORROSION

All materials must be capable of passing the inter-granular corrosion test specified in BS EN ISO 3651-2, Method A, or equivalent.

6.5 ALTERNATIVE STANDARDS

Equivalent grades of austenitic stainless steel conforming to national standards not listed above may be used subject to written permission from the Purchaser. Mechanical properties shall conform to the following requirements and it shall be capable of passing the intergranular corrosion test above:

Strength (min MPa)		Elongation
Tensile	0.2% Strain	$5.65\sqrt{So}$
480	173	40% min

7.0 RAW MATERIAL SIZES

The manufacturing drawing will state the stock material sizes in one system of units. The manufacturer may deviate from the specification in two instances:

Machined items:

When the primary dimension (thickness, width or diameter) is subsequently machined down the size may be taken as a guide only. The manufacturer may use any appropriate stock size.

Imperial/metric parity:

Where the item is not machined, and materials are not available in the unit system specified, the manufacturer may use the following equivalent sizes. It is the manufacturer's responsibility to ensure that all mating dimensions are adjusted so that fits and clearances are maintained.

Imperial (inch)	1/8	3/16	¼	3/8	1/2	5/8	3/4	7/8	1.0	1.5	2.0
Metric (mm)	3	5	6	10	12	16	20	22	25	40	50

Imperial (swg)	22	20	18	16	14	12	10	8	6	4	2
Metric (mm)	0.75	1	1.25	1.5	2	2.5	3.5	4	5	6	7

8.0 DOCUMENTATION

The Supplier shall provide certified evidence from the manufacturer or from his own testing that a material's chemical composition and mechanical properties comply with its specification. All documentation shall reference the original cast or heat number.

3750A THERMAL ANALYSIS

FLASK AND CONTENTS

MSA(00)R0483 Issue A

4th October 2000

B.M.H. Soper

This work was carried out for Reviss Services (UK) Ltd. under Purchase Order No. RSL01683

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SUMMARY

This report describes a thermal analysis of a fully loaded type 3750A Transport Flask and its contents. The cases considered were the steady state, insolation and fire accident conditions laid down by the International Atomic Energy Agency. The effect on thermal performance of mechanical damage to the cooling fins was also considered..

The analysis used both 2D and axisymmetric finite element models. These models allowed the detail of the cooling mechanisms as well as the end effects to be taken into consideration. The first stage of the analysis was to benchmark and tune these models against measured temperature data at part load conditions. The models were then applied to the full load case.

Calculated temperatures are presented for steady state, steady state plus insolation and the fire transient cases, with and without mechanical damage. It is shown that mechanical damage has little effect on the temperatures within the flask.

CONTENTS

1. INTRODUCTION

This report describes thermal analysis of the type 3750A transport flask and its contents. The payload considered was 30 type R2089 capsules containing cobalt 60. The total activity of the contents was 340kCi (12.6PBq).

Finite element analysis included calculation of the temperature distribution through the flask for the loading conditions required by the IAEA Regulations for the Safe Transport of Radioactive Materials (References 1 and 2).

The cases considered were:

- Benchmarking of the models against steady state temperature measurements on a flask at part load, 272 kCi (10.1 PBq).

- The steady state temperature distribution due to full load self-heat with an ambient temperature of 38°C.

- The steady state temperature distribution due to full load self-heat with insolation at the heat fluxes specified in Reference 1.

- Following the case above, the highest temperatures to be reached at selected locations in the flask, during or following a 30 minute hydrocarbon fire.

In addition, the effect of mechanical damage to a proportion of the fins has been considered both under normal and accident operating conditions.

The report provides a model of the thermal perfomance of the flask. The basis of the finite element models and the assumptions made are also presented.

2. DESCRIPTION OF THE FLASK

The design of the 3750A Flask is shown in Figure 1. The flask is mounted on a pallet and is surrounded by a protective cage, as shown in Figure 2. The flask itself is cylindrical in form and has 16 'V' shaped fins welded to its outer surface. A jacket shrouds the tips of the fins.

The internal components can be seen in Figure 3, which is a vertical section through the flask.

The capsules are held in a basket in the central cavity. For the load case under consideration, the 30 capsules are equispaced on a 133mm PCD.

The flask body comprises an outer stainless steel vessel, which houses the depleted uranium shield. A stainless steel liner separates the shield from the cavity. A feature of the design is that the manufacturing tolerances are small and this_results in narrow gaps between the shield and the stainless steel. The backfill gas for the body is helium. The closure is also fabricated from stainless steel and has its own depleted uranium shield. The backfill gas for the closure is argon.

3. METHODOLOGY

3.1 Modelling basis

The approach used in this work was a combination of axisymmetric and two-dimensional models. The axisymmetric model allows the end effects to be considered, whilst the 2D horizontal section allows the effect of the cooling fins and jacket to be assessed.

The main departure from axisymmetry is the fins on the external surface of the flask. To allow results from the 2D models to be transferred to the axisymmetric model, a simplified model in which the fins and jacket had been removed was used. The boundary conditions on the outside surface of the simplified model were modified until a similar transient performance to the 2D model was achieved.

For both modelling approaches, sufficient detail was included to allow adequate representation of the heat transfer processes. Figures 4 to 6 show details of the finite element models used for these calculations.

3.2 Benchmarking of Models Against Measured Data

The models were benchmarked against steady state temperature data. The measurements had been made on a flask loaded with 24 capsules having a total activity of 272 kCi (10.1PBq). Reference 3 gives the steady state temperature distribution through the flask and Reference 4 gives the temperatures for the capsules.

For the axisymmetric model the heat absorption rates and heat transfer coefficients on the flask external surfaces were tuned to provide the best agreement between the calculated and measured temperature distributions. Similarly, for the 2D section at flask mid height, the heat transfer coefficient on the external surfaces was tuned to achieve the best agreement between the measured and calculated temperature distributions.

3.3 Use of Models for Full Load Steady State Case

The heat absorption rates and heat transfer coefficients determined in the benchmarking work were used in the calculations for the full load case. The heat input was increased to account for the increase in total activity within the flask and the ambient temperature was increased to 38°C (Reference 1, para 728).

To account for the increase in air temperature as it rises through the fin enclosures, the measured temperature rise (Reference 3) was factored to account for the increase in heat load. The height of the flask outer wall was considered as three regions, each with a different value of bulk temperature.

3.4 Treatment of Insolation

The addition of a radiative heat flux heat flux of 400 W/m^2 (Reference 1, Table XI) to the external surface of the jacket of the 2D mid height section allowed the effect of insolation on the steady state temperature distribution to be established.

To determine the appropriate boundary condition for the axisymmetric model to re-create this temperature distribution, the 2D model without fins was used. This value of heat flux was then applied to the axisymmetric model in addition to the 800 W/m^2 on the top surface.

3.5 30 Minute Hydrocarbon Fire

For the hydrocarbon fire the ambient temperature was raised to 800°C (Ref. 2, para. A-628.17) and a surface absorptivity of 0.9 was used (Ref. 2, para. A-628.19). The heat transfer coefficient applied to the fin enclosures and base was 10.5 W/m^2K (Appendix 2). The heat transfer coefficient applied to the outside surface of the jacket and to the closure was 18.2 W/m^2K, which corresponds to a flame velocity of 10 m/s (Ref. 2, para. A-628.20 and Appendix 2). Radiation from the fire to the external surface of the jacket, with an emissivity of 0.9 (Ref. 2, para. A-628.18) was permitted. For the fin enclosures it was assumed that there was no direct radiation between the fire and the fins but radiation between the surfaces bounding the fin enclosures was included in the full 2D model.

3.6 Capsule Temperatures

The capsules were not considered in the finite element models but were treated in the following manner. The ring of 30 capsules was replaced by an equivalent tubular source and heat transfer between this source and the cavity wall, by both convection and radiation, was considered. The basis of the calculation is given in Appendix 1. This procedure was used to establish the proportion of heat generated within the cavity by absorption within the capsules themselves. This was done by comparing calculated capsule temperatures with measured data (Reference 4).

For full load operation it was assumed that the same proportion of the heat load would be generated within the capsules.

For the benchmarking work the cavity was treated as air filled but for the full load operation it was assumed that argon was used as the back fill gas. Argon will lead to the highest capsule temperatures of the potential back fill gases.

3.7 Accuracy

In general, the values presented in this report are quoted to 3 significant figures. Where undue loss of accuracy would result from this practice, eg the dimensions of narrow gas gaps, the accuracy has been increased accordingly. For readability, the embedded mathematics in the appendices is displayed to a higher accuracy.

4. FINITE ELEMENT MODELS

All of the models described in the following sections were built and run using the ANSYS computer program (Version 5.0A).

4.1 Description of the Models Used

4.1.1 2D Horizontal Section at Mid Height

The 2D horizontal cross-section at mid height finite element models is shown in Figure 4. Use of symmetry allowed the model to be simplified to one quadrant of the flask. All of the components that affect heat transfer have been included in the model. The tips of the 'V' fins come close to the jacket but are not connected to it, so there is no conduction path between these two components.

The self-heat load is input as a heat load per unit volume in both the liner and the first 12 mm of the depleted uranium shield (Section 4.2.2.1).

4.1.2 2D No Fin Horizontal Cross Section

The horizontal cross-section, described in 4.1 above, was modified by removing the jacket and fins and is shown in Figure 5.

The self-heat load is input as a heat load per unit volume in both the liner and the first 12 mm of the depleted uranium shield (Section 4.2.2.1).

Heat fluxes applied to the curved external surface emulate the thermal performance of the cooling fins and jacket.

4.1.3 Axisymmetric Model

The axisymmetric model is shown in Figure 6 and represents half of a vertical section through the flask. This model allows the thermal performance of the base and the closure to be included in the analysis.

4.2 Modelling Considerations

4.2.1 Treatment of Narrow Gas Filled Gaps

To improve the shape of the elements used to model the narrow gas gaps the minimum gap used was 1 mm. Where the actual gas gap was less than this value the thermal conductivity of the gas was increased to preserve the correct ratio of thermal conductivity to gap width. Also the density of the gas was reduced to maintain the correct thermal capacity. From the temperature dependent properties of helium, given in Appendix 3, the factors applied were 10 for the liner to depleted uranium gap and 1.43 for the depleted uranium to body gap.

4.2.2 Assumptions Used in the Modelling

4.2.2.1 Heat input

Heat is generated when gamma radiation is absorbed by materials. The heat produced by absorbtion in the capsules was not modelled in detail but was accounted for in the heat input to the flask. For both the 2D and axisymmetric models, heat was input on a 'per unit volume' basis to the stainless steel liner and the depleted uranium shield. For cobalt 60 the half thickness for gamma radiation in depleted uranium is 6 mm (Reference 5). In the models it was assumed that all of the heat input occurs within the liner and the first 12 mm of the shield.

For the axisymmetric model the proportions of heat flowing radially and axially were in the ratios of the surface areas of the cavity. The largest proportion was the radial heat flow, 15% of which was added to the stainless steel liner and the remainder to the first 12mm of the depleted uranium shield.

For the 2D mid height section the radial heat flow was the same as for the axisymmetric model and therefore took account of the heat lost from the top and bottom of the flask.

4.2.2.2 Heat Transfer Coefficients

The values of heat transfer coefficient used in the calculations were determined from the benchmarking work against measured data.

Appendix 2 calculates typical values of heat transfer coefficient, based upon recognised heat transfer correlations, to demonstrate that the values used do not deviate greatly from normally accepted values.

4.2.2.3 Treatment of Finned Surfaces

The flask design makes extensive use of finned surfaces, e.g. the fins on the closure and the base of the flask. In these cases the appropriate heat transfer coefficients, calculated in Appendix 2, have been enhanced to take account of the additional surface area.

4.2.2.4 Cage

The complete package has a protective cage surrounding the flask. The effect on this cage on the thermal performance of the package is expected to be negligible and it has not been included in the models.

4.3 Geometrical Data

The finite element models have been based upon the following drawings of the flask:

Component	Drawing	Issue
Body Assy.	P3750A/002	B
Closure Assy.	P3750A/003	B
Closure Shield	P3750A/008	B
Base Shield	P3750A/009	B
Lower Shield	P3750A/010	B
Middle Shield	P3750A/011	B
Upper Shield	P3750A/012	B
Jacket	P3750A/013	B

Table 1 Summary of Flask Drawings Used to Build Models

The geometrical data for the capsules was taken from the following drawings:

Component	Drawing	Issue
Assembly of Capsule R2089	GA20890	D
Body for Capsule R2089	D020894	B

Table 2 Summary of Capsule Data Used to Build Models

4.4 Material Data

The design material properties used in the analyses were temperature dependent. Appendix 3 gives details of the values used in the analyses.

4.5 Load data

4.5.1 Heat Generation

The internal heat generation was assumed to occur in the first 12 mm of the shield and at the stainless steel liner. Details of the calculation can be found in Appendix 4.

For the axisymmetric model, it was assumed initially that the distribution of heat absorbed in the body, base and closure were in proportion to the surface areas of the internal cavity.

For the purposes of achieving the closest match between measured and predicted temperatures, factors were introduced to allow the proportion of heat absorbed in the ends of the flask to be varied.

4.5.2 Insolation

For the 2D horizontal model with fins, a heat flux of 400 W/m^2 was applied to the outer surface of the jacket for a period of 12 hours.

The 2D No fin model showed that a heat flux of 50 W/m^2 for 12 hours on the curved outer surface was needed to re-create the temperature distribution produced from the full 2D model.

For the axisymmetric model, the 50 W/m^2 on the outer surface of the flask was used in conjunction with a heat flux of 800 W/m^2 on the closure outer surface.

4.5.3 Heat Transfer Coefficients

The values of heat transfer coefficient used in the analyses were determined from the benchmarking work, described in Section 3.2.

4.5.4 Radiative Heat Transfer

For the steady state case, the value of absorptivity used for all surfaces was 0.8 (Reference 2, para. A-628.19). During the Fire, the flame emissivity was 0.9 (Reference 2 para. A-628.18).

For the capsule model the values of emissivity used for the steady state were based upon Reference 15 and were 0.31 and 0.3 for the capsule surface and cavity wall respectively. For the fire case these values were increased to 0.35 and 0.32 respectively.

5. RESULTS

5.1 Model Validation Against Measured Temperature Data

The finite element models were used to predict the temperature distribution through the flask for the test conditions applicable to Test No. RTR070 (Reference 3).

5.1.1 Axisymmetric model

Using the values of heat transfer coefficient given in Appendix 2 as a starting point, the values on the flask outer surface, closure and base were adjusted to achieve the closest match between the measured and calculated temperature distributions. The proportions of heat generated within the flask body, closure and base were also varied as part of the process. The main criterion was to optimise the model to obtain the correct maximum temperature, i.e. on the cavity wall at mid height.

The best agreement was obtained with heat transfer coefficients of 27.8 W/m^2K on the outer surface, 12 W/m^2K on the closure and 3 W/m^2K on the base. In addition, the heat flow distribution was 5.3% to the closure, 5.3% to the base and the remaining 89.4% to the flask body. The resulting temperatures are summarised in Table 3 below:

Location	Temperature (°C)	
	Predicted	Measured[1]
Mid-height cavity wall	197	197
Cavity base centre	171	173
Closure underside centre	171	174
Closure top centre	112	100
Closure studs	103	89
flask wall top	106	102
Flask wall mid-height	141	127
Flask wall base	87	79
Base centre	133	98
Base maintenance plug	111	98

Table 3 Comparison between measured and predicted data

5.1.2 2D Mid Height Cross Section

The loading conditions for the model corresponded with the mid height conditions for the axisymmetric model. The radial heat flowed was reduced by the same proportion as the axisymmetric model to allow for heat lost to the ends of the flask. This model allowed the detail of the heat transfer process through the fins and jacket to be included. The heat transfer coefficient in the fin enclosures and on the jacket were adjusted to achieve the best fit between measured and predicted data. Table 4 compares measured and predicted temperature data.

Location	Temperature (°C)	
	Predicted	Measured[2]
Mid-height cavity wall	197	197
Flask wall mid-height mid way between 'V' fin welds	136	130
Flask wall mid-height on welds between 'V' fins	129	124

Table 4 Comparison between measured and predicted data

The results given in Table 4 were achieved when the heat transfer coefficient was set to 9.7 W/m^2K.

[1] The values given are the average of all measurements at that location.
[2] The values given are the average of all measurements at that location.

5.1.3 Capsule Temperatures

The capsule temperature calculation procedure, given in Appendix 1, was used to determine the proportion of the total heat load generated within the capsules. Based upon mid height cavity wall and capsule temperatures of 197°C and 460°C[3] respectively (References 3 and 4) it was found that the proportion of heat generated within the capsules was 15%. This was based upon emissivities for the capsule and cavity wall of 0.31 and 0.3 respectively (Reference 15).

5.2 Full Load Operation

The model validation work, described in Section 5.1, provided confidence in the model results for a total contents activity of 272.3 kCi.

5.2.1 2D Mid Height Cross Section

For this case the internal heat generation was increased in proportion to the increased total activity in the flask. The rise in temperature of the air passing through the fin enclosures was also increased by the same ratio to give a mid height figure of 48.1°C and the ambient temperature was set to 38°C. The resulting temperatures are shown in Table 5 for both the steady state case and following 12 hours of insolation.

Location	Temperature (°C)	
	Steady State	Plus 12 Hours Insolation
Mid-height cavity wall	249	251
Flask wall mid-height mid way between 'V' fin welds	167	169
Flask wall mid-height on welds between 'V' fins	175	177

Table 5 Predicted Temperatures for Steady State and Addition of 12 hours Insolation

5.2.2 Axisymmetric Model

The loading on the axisymmetric model was also adjusted to take account of the change in internal heat generation and the change in external boundary conditions. The results for this model are shown in Tables 6 for the steady-state and 12 hours insolation cases.

[3] Average value of all measurements taken.

Location	Temperature (°C)	
	Steady State	Plus 12 hours Insolation
Mid-height capsule surface	526	528
Mid-height cavity wall	249	255
Flask wall mid-height	164	170
Cavity base centre	219	223
Closure underside centre	223	243
Closure studs	116	131
Base maintenance plug	126	130

Table 6 Calculated Temperatures for Steady State and Addition of 12 hours Insolation

5.3 Accident Conditions

Starting from the steady state plus 12 hours of insolation condition, the flask was subjected to a 30 minute, all engulfing hydrocarbon fire. The computation was continued, following extinguishment of the fire, until the temperature at all points in the flask was falling. During the cooling down period, the heat transfer coefficients on the outside of the flask were progressively returned to the steady-state condition.

5.3.1 Undamaged Flask

Three finite element models were used for this work, which is described more fully in the following sections:

5.3.1.1 2D Mid Height Cross Section

The temperatures at selected points in the flask during this transient are shown in Figure 7.

5.3.1.2 2D No Fin Horizontal Cross Section

From the full 2D model transient results, the heat flux at the flask wall was determined at a number of times during the transient. This heat flux time history was then modified and applied to the No fin model to reproduce the flask temperature distribution at each time step.

Figure 8 compares the temperature time histories for the cavity wall at mid height for the models with and without cooling fins. It can be seen that, the maximum discrepancy for the No fin model was +6°C.

5.3.1.3 Axisymmetric Model

The modified heat fluxes, described in the above section, were applied to the asymmetric model to cover the fire condition.

Table 7 summarises the maximum temperatures reached at selected locations during the transient

Location	Temperature (°C)
Mid-height capsule surface	587
Mid-height cavity wall	420
Flask wall mid-height	415
Cavity base centre	434
Closure underside centre	398
Base maintenance plug	578

Table 7 Calculated Maximum Temperatures for the Undamaged Flask During and After a 30 Minute Hydrocarbon Fire

5.3.2 Damaged Flask

The effect of damage to the fins on the thermal performance of the flask during a hydrocarbon fire has been modelled. Figures 9 and 10 show the extent of damage to the flask following a drop test.

An adaptation of the 2D model with fins was used for this work and is shown in Figure 11. It was assumed that the damage extended the full height of the fins. Rather than attempt to model the damage to the fins in detail, the heat transfer coefficients for convection were modified locally to reflect the reduction in cross sectional area of the fin channels as this would directly affect their ability to convect heat to and from the flask. Figure 11 indicates the damage locations by number for cross reference with the values of heat transfer coefficient given in Table 8.

Table 8 shows the modified values of heat transfer coefficient used in the analyses.

Position	Original flow area (mm^2)	Damaged flow area (mm^2)	Ratio	Heat Transfer Coefficient (W/m^2K)	
				Steady state	Fire
1	9549	3258	0.341	3.31	3.58
2	6741	2048	0.304	2.95	3.19
3	9549	1265	0.132	1.29	1.39
4	6741	6075	0.901	8.74	9.46
5	8433	2825	0.335	3.25	3.52

Table 8 Heat Transfer Coefficients Used for Damaged Flask Model

Based on these modified heat transfer coefficients the calculated temperatures from the steady state and fire transient cases are given in Table 9 below: All values given are the maxima.

Location	Temperature (°C)	
	Steady State	Fire + Cool Down Transient
Mid-height capsule surface	531	588
Mid-height cavity wall	263	421
Flask wall mid-height	198	425

Table 9 Calculated Temperatures for Steady State and Fire Transient

6. CONCLUSIONS

The principal results of the thermal analyses are summarised in Table 10 below:

Location	Steady State with 38°C Ambient	Steady State + Insolation	Previous Cases + 30 minute hydrocarbon Fire + Cool Down	As Previous Column but with Flask Damage
Flask Closure Studs	116	131	-	-
Flask Wall at Mid Height	164	170	415	425
Cavity Wall at Mid Height	249	255	420	421
Capsule Wall at Mid Height	526	528	587	588

Table 10 Summary of Calculated Temperatures (°C)

These results show that the mechanical damage considered had little effect on the temperatures within the flask.

7. REFERENCES

1. IAEA Safety Series 6, 'Regulations for the Safe Transport of Radioactive Materials', 1985 Edition (as amended 1990), International Atomic Energy Agency, Vienna, 1999.

2. IAEA Safety Series 37, 'Advisory Material for the IAEA Regulations for the Safe Transport of Radioactive Materials (1985 Edition), 3rd Edition, International Atomic Energy Agency, Vienna, 1987.

3. Reviss Services, 3750A Transport Container Thermal Survey Record, Test No. RTR070, August 2000.

4. Reviss Services, 3750A Transport Container Contents Survey Record, Test No. RTR073, August 2000.

5. BS 4094, Part 1, 1966, Data on Shielding from Gamma Radiation.

6. Reviss Services, 'Nuclide Heating', Technical Memorandum RTM 025 Iss. 1, 2000.

7. MacGreggor,R.K. and Emery, A.P., 'Free Convection through Vertical Plane Layers: Moderate and High Prandtl Number Fluids', J. Heat Transfer, 91, 391, 1969.

8. Churchill, S.W. and Chu, H.H.S., 'Correlating Equations for Laminar and Turbulent Free Convection from a Vertical Plate', Int. J. Heat & Mass Transfer, 18, 1323, 1975.

9. Goldstein, R.J., Sparrow, E.M. and Jones, D.C., 'Natural Convection Mass Transfer Adjacent to Horizontal Plates', Int. J. Heat & Mass Transfer, 16, 1025, 1973.

10. Lloyd, J.R. and Moran, W.R., 'Natural Convection Adjacent to Horizontal Surfaces of Various Planforms', ASME Paper 74-WA/HT-66, 1974.

11. Commercial Uranium Fact Sheet, BNFL.

12. Data Sheets in SI Units, Issued by Research Reactors Division, Harwell, AEA Technology.

13. ANSYS User's Manual for Revision 5.0, Vols. I - IV.

14. ANSYS Verification Manual for Revision 5.0.

15. Gubereff, Janssen and Torborg, 'Thermal Radiation Properties Survey', Honeywell Research Centre, Minneapolis, 2nd Edition, 1960.

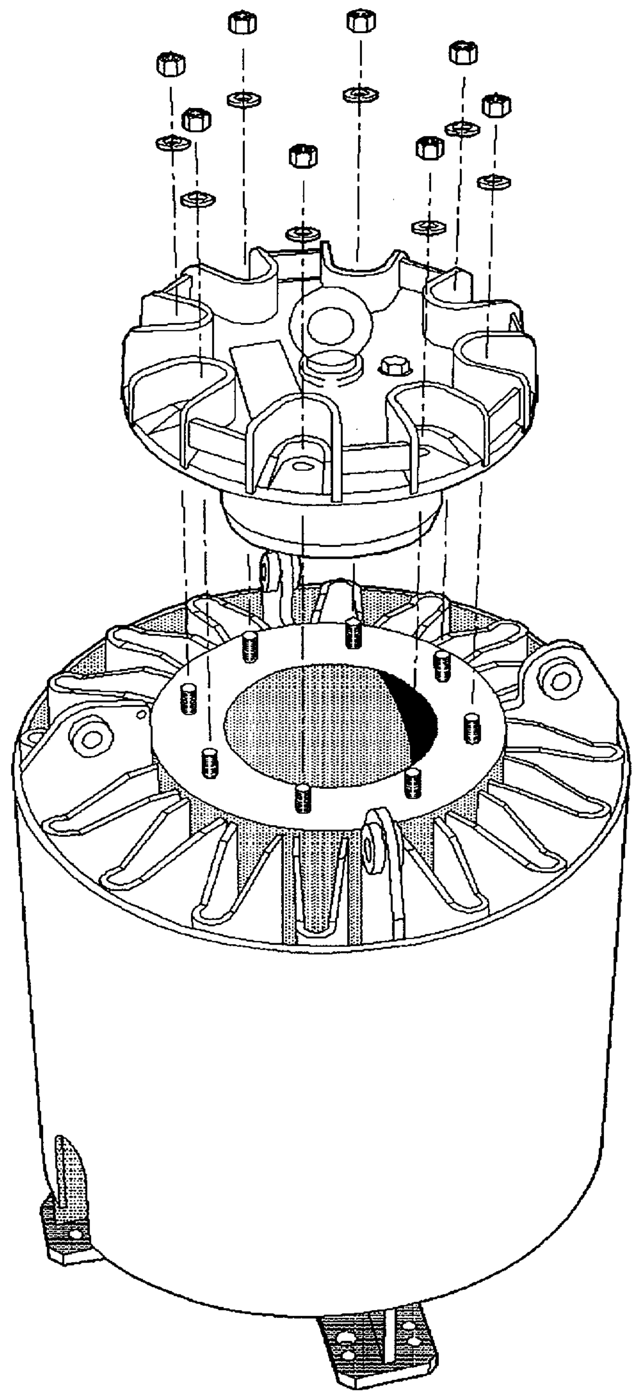


Figure 1 Type 3750A Transport Flask and Closure

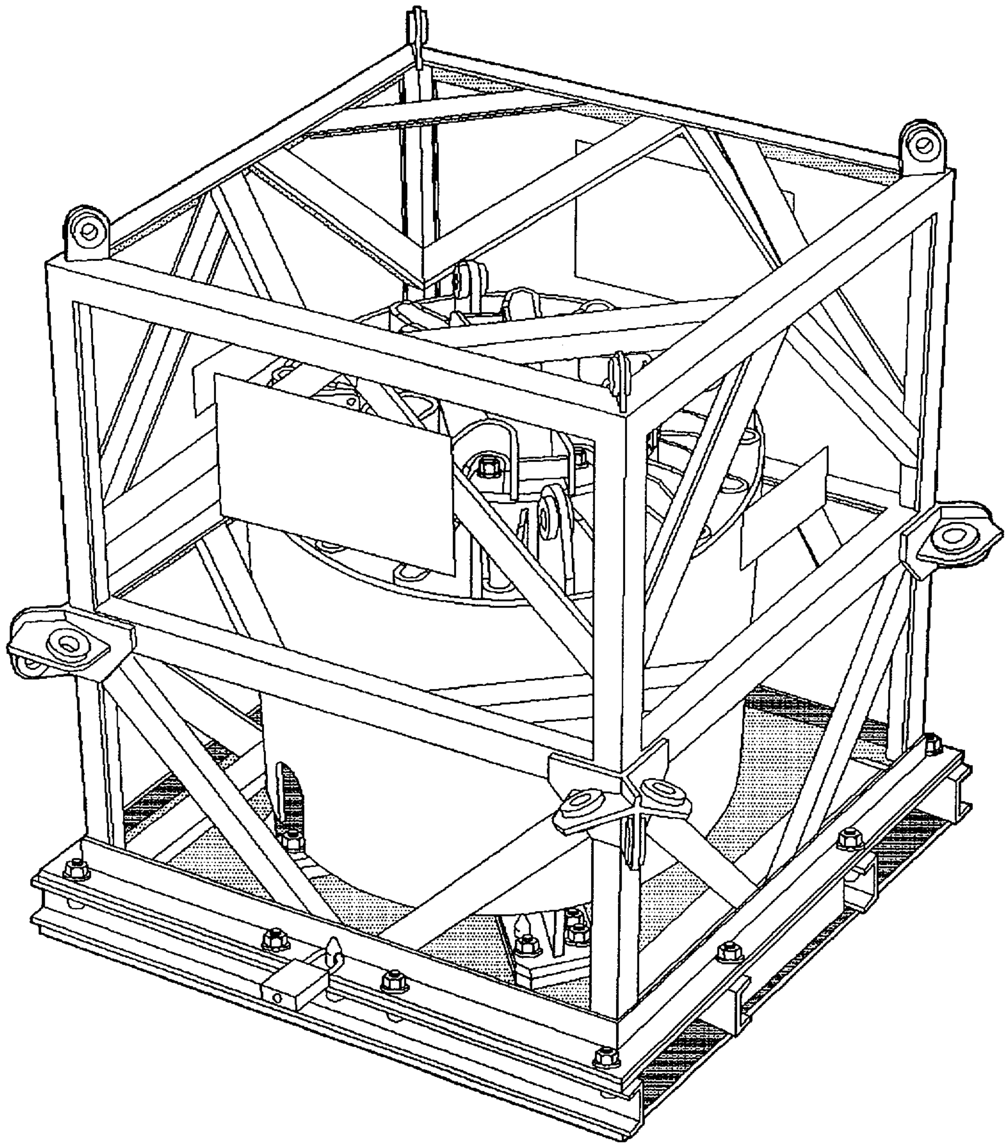


Figure 2 Type 3750A Transport Flask with Pallet and Cage

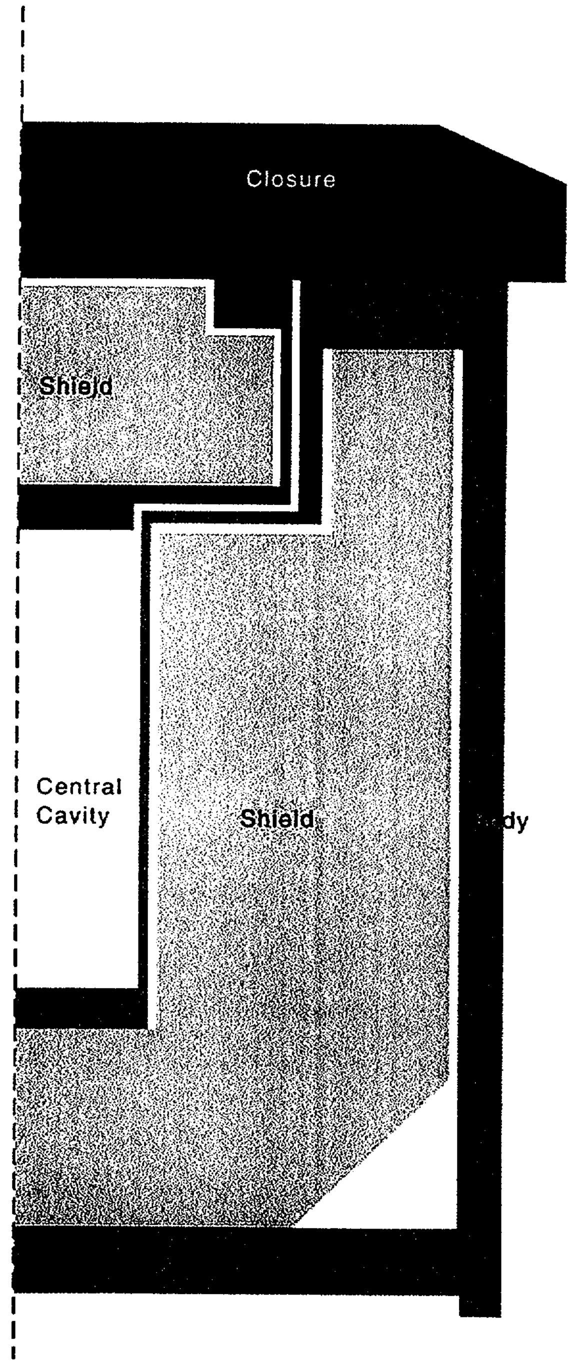


Figure 3 Vertical Section Through Type 3750A Transport Flask

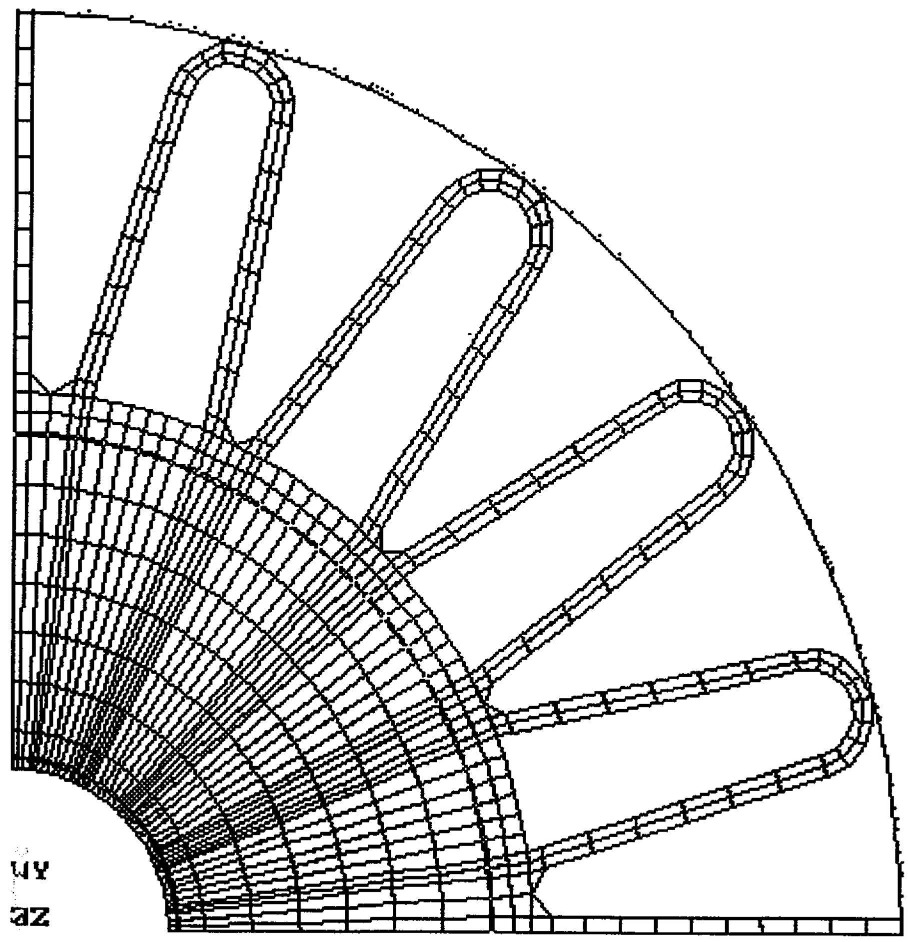


Figure 4 2D Horizontal Section at Mid Height

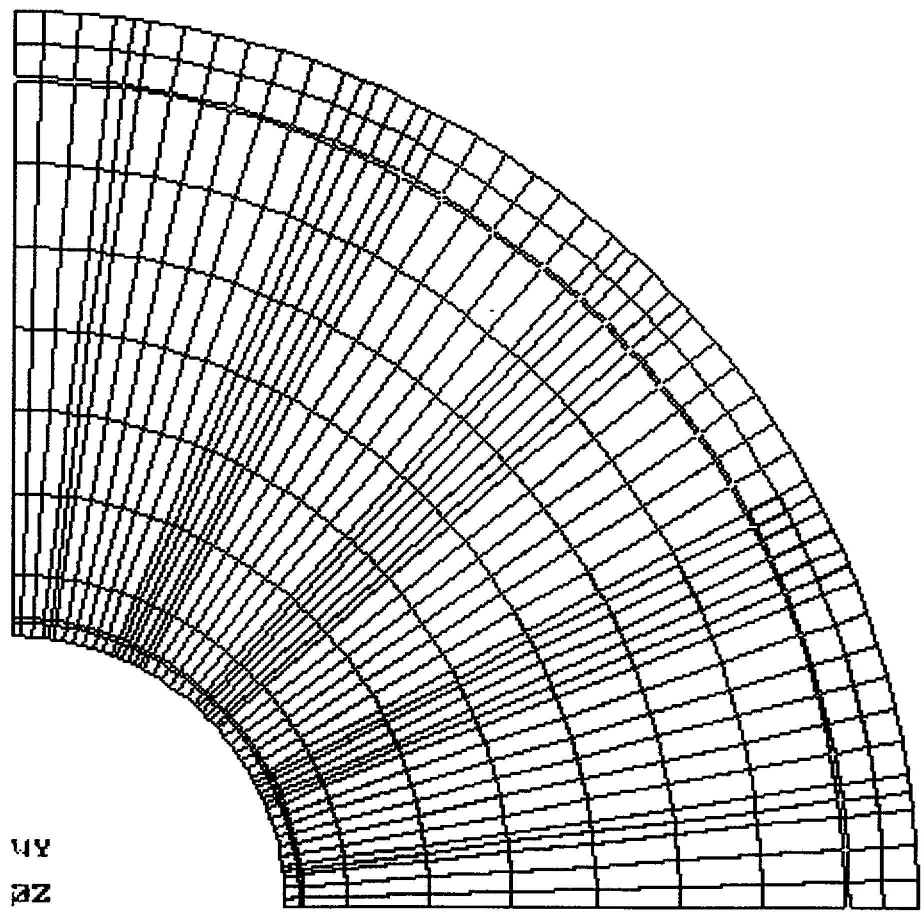


Figure 5 2D No Fin Horizontal Section at Mid Height

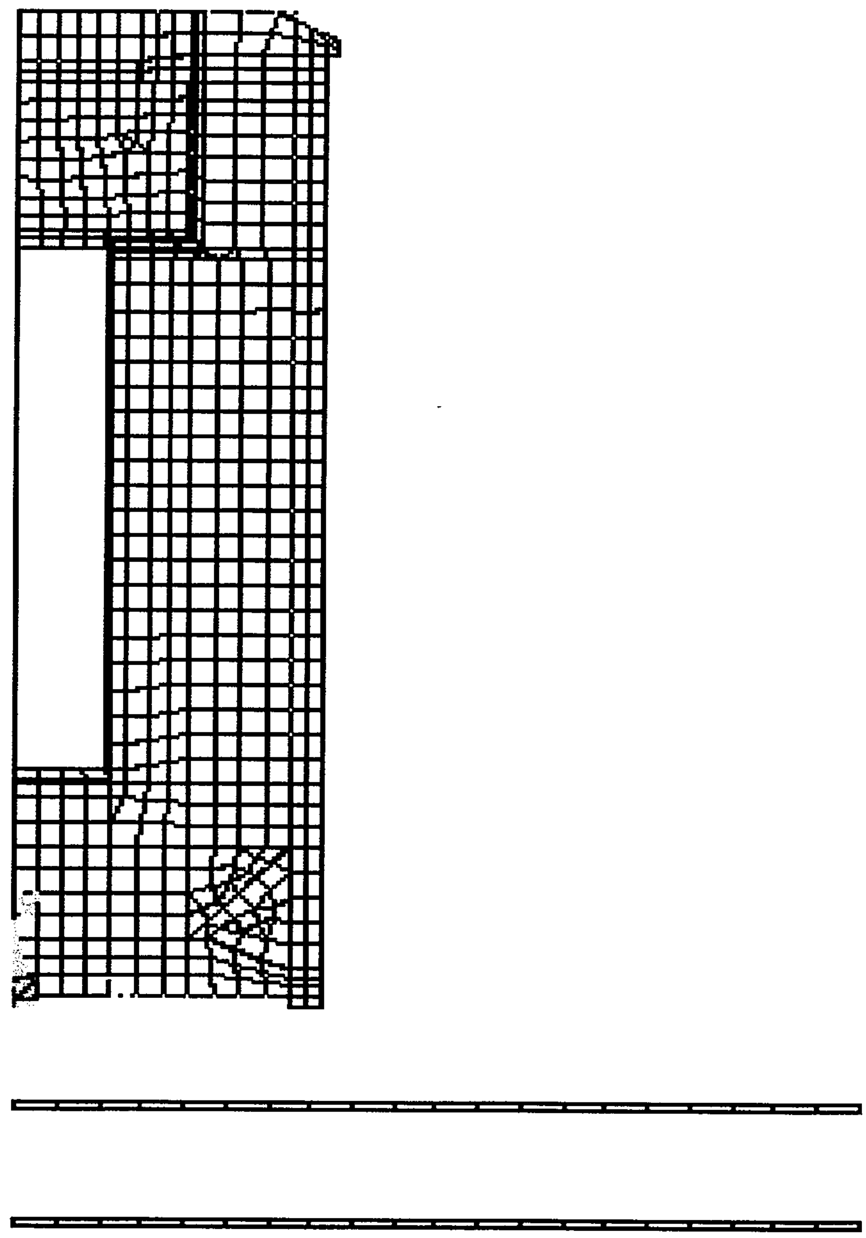


Figure 6 Axisymmetric Model of 3750A Flask

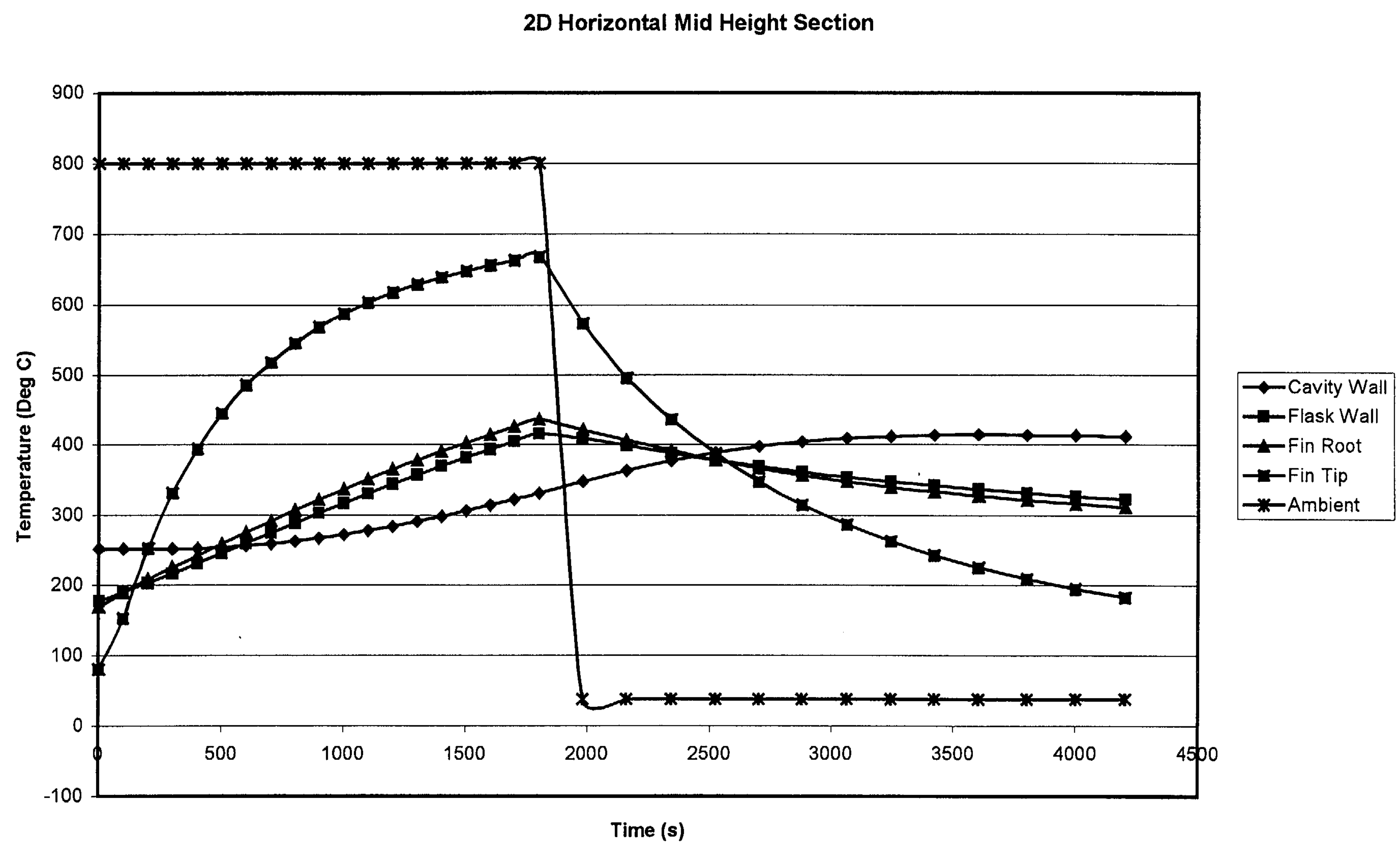


Figure 7 Thermal Transient During and After 30 Minute Hydrocarbon Fire

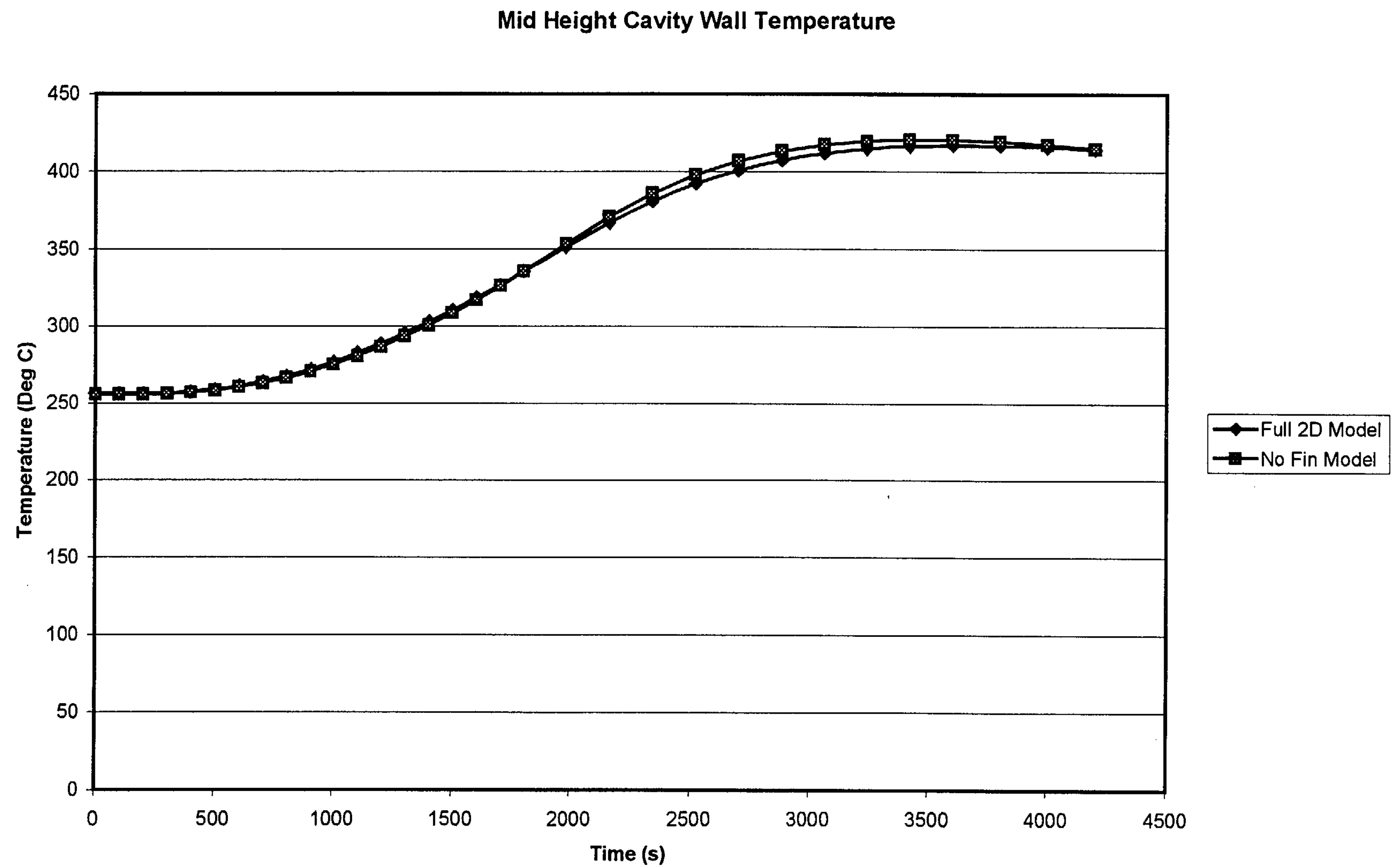


Figure 8 Comparison of Calculated Transients for Full 2D and No Fin Models

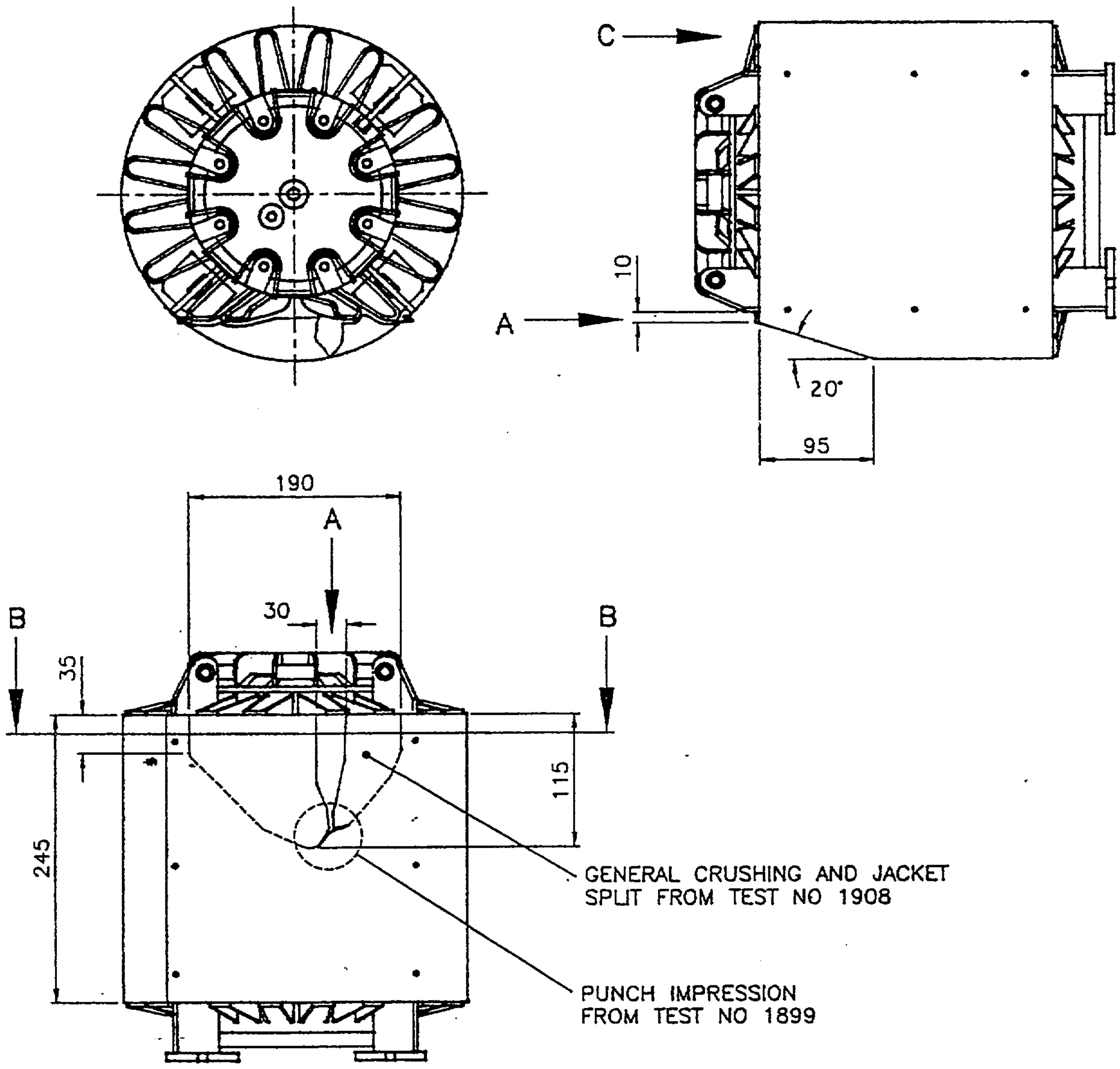
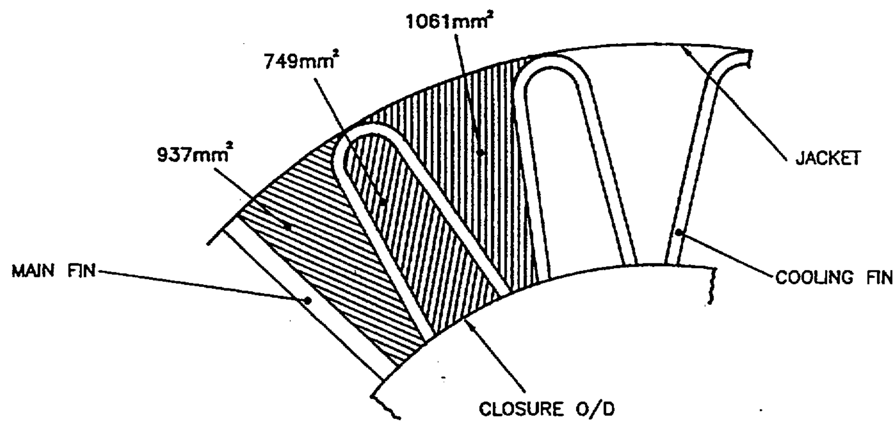


Figure 9 Damage to 3750A Flask



SCRAP VIEW ON ARROW C.
SCALE 1:1. CROSS SECTIONAL AREA AROUND UNDAMAGED FINS. CLOSURE DETAILS, FLASK FEET AND LIFTING POINTS OMITTED FOR CLARITY.

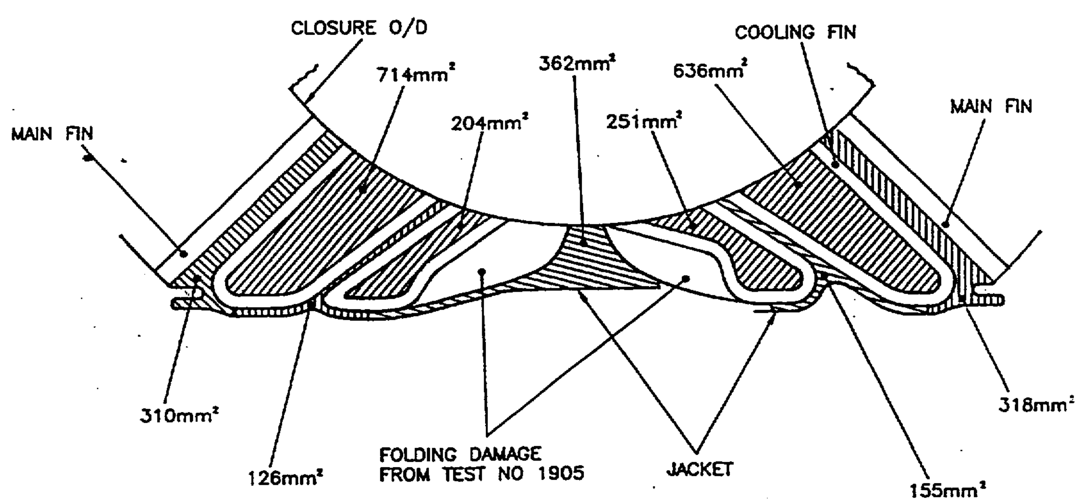


Figure 10 Detail of Damage to 3750A Flask Fins

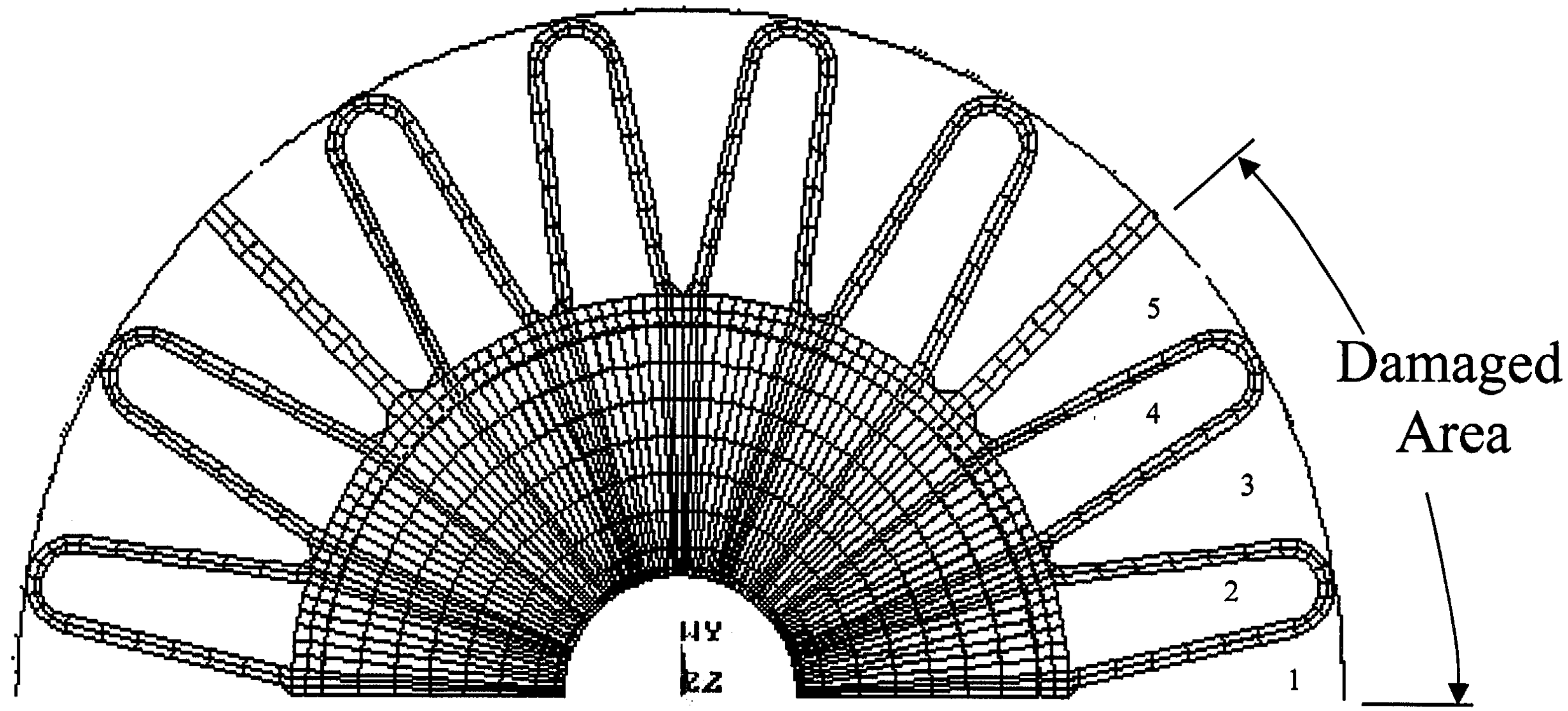


Figure 11 Model Used for Damage Case

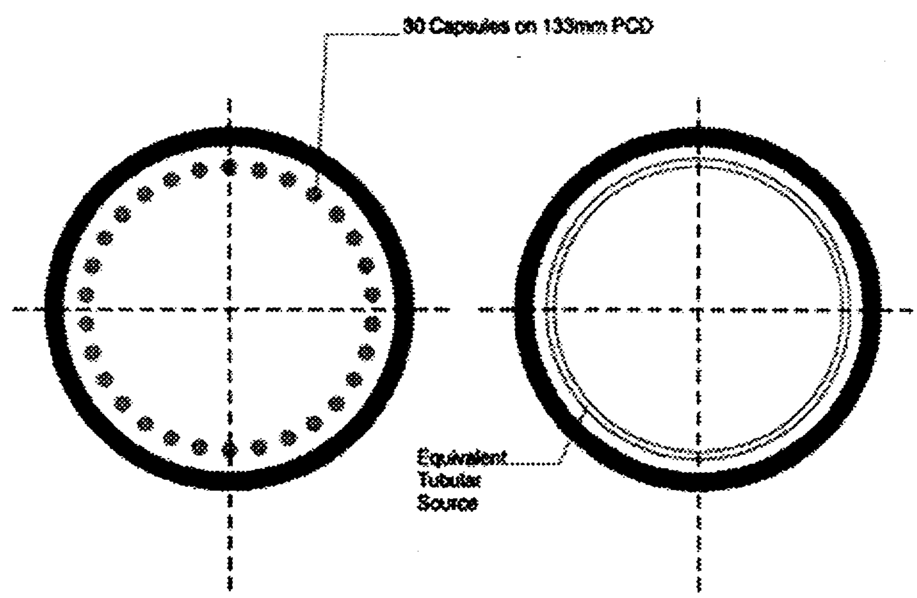
APPENDIX 1

ESTIMATION OF CAPSULE TEMPERATURES

This appendix describes the methods used to determine capsule temperature.

A1.1 Basis of Calculation Procedure

The heat transfer between the capsules and the cavity wall will be by both convection and radiation. Each capsule can radiate heat to the other capsules and to the cavity wall making the problem complex. To simplify the calculation, the ring of 30 capsules has been modelled as an equivalent tubular heat source as shown below. Heat is transferred from the outer surface of the tubular source to the cavity wall by both radiation and natural convection.



A1.2 The Modelling Procedure

The following example illustrates the method:

Total acivity of sources	$P := 340$	kCi	
Power dissipation for cobalt 60 (Reference 6)	$PD := 15.37$	W/kCi	
Total heat load	$Q_{tot} := P \cdot PD$	$Q_{tot} = 5.226 \cdot 10^3$	watt

Proportion of heat generated within capsules $\phi := 15$ %

$Q_{caps} := P \cdot PD \cdot \frac{\phi}{100}$ $Q_{caps} = 784$ watts

Number of capsules $N := 30$

Diameter of capsules $d_{cap} := 9.685 \cdot mm$

Cross sectional area of capsules $A_{cap} := \frac{N \cdot \pi \cdot d_{cap}^{2}}{4}$ $A_{cap} = 2 \cdot 10^{3} \cdot mm^{2}$

PCD of ring $PCD := 133 \cdot mm$

Thickness of equivalent area annulus $t_{an} := \frac{A_{cap}}{\pi \cdot PCD}$ $t_{an} = 5 \cdot mm$

Outer diameter of equivalent annulus $D_{an} := PCD + t_{an}$ $D_{an} = 138 \cdot mm$

Inner diameter of equivalent annulus $d_{an} := PCD - t_{an}$ $d_{an} = 128 \cdot mm$

Heat Transfer Calculation

Consider the steady state condition for the load case of interest.

Maximum cavity wall temperature $T_{cw} := 249.7 \cdot K$

Convective Heat Transfer

From the dimensions of the equivalent tubular source, calculated above, the annular cavity between the ring of sources and the cavity can be seen to be narrow.

For high aspect ratio vertical cavities, MacGreggor and Emery (Reference 7) have proposed the following correlation.

Nusselt Number $Nu := 0.046 \cdot Ra_{L}^{\frac{1}{3}}$

where Ra_{L} is the Rayleigh Number based on the cavity width.

Rayleigh Number is the product of the Grashof and Prandtl numbers. Both of these numbers are calculated from the fluid properties which are temperature dependent. An iterative approach is therefore needed in which the starting capsule temperature is assumed.

From a starting capsule temperature of 100 deg C higher than the cavity wall temperature increase this temperature until the heat flow across the cavity equals the capsule heat load. Assume the gas in the cavity is argon (worst case):

Starting capsule temperature $T_{cap} := T_{cw} + 276 \cdot K$ $\quad T_{cap} = 526 \cdot K$

Evaluate fluid properties at mean temperature

$$T_f := \frac{T_{cw} + T_{cap}}{2} \qquad T_f = 388 \cdot K$$

The properties of argon at this temperature are as follows:

Density $\rho := 0.735 \cdot \frac{kg}{m^3}$

Specific heat $c_p := 520.6 \cdot \frac{joule}{kg \cdot K}$

Absolute viscosity $\mu := 4.13 \cdot 10^{-5} \cdot \frac{kg}{m \cdot sec}$

Thermal conductivity $k := 0.033 \cdot \frac{watt}{m \cdot K}$

Absolute film temperature $T_{fabs} := T_f + 273 \cdot K$

Coefficient of volume expansion $\beta := \frac{1}{T_{fabs}}$

Kinematic viscosity $\nu := \frac{\mu}{\rho}$ $\quad \nu = 6 \cdot 10^{-5} \cdot \frac{m^2}{sec}$

Cavity diameter $D_{cav} := 150 \cdot mm$

Cavity width $L := \frac{D_{cav} - D_{an}}{2}$

Grashof Number $Gr_L := \frac{g \cdot \beta \cdot (T_{cap} - T_{cw}) \cdot L^3}{\nu^2}$

Prandtl Number $Pr := \frac{\mu \cdot c_p}{k}$

Rayleigh Number $Ra_L := Gr_L \cdot Pr$

Nusselt Number $Nu_L := 0.046 \cdot Ra_L^{\frac{1}{3}}$

Heat transfer coefficient $h := \frac{Nu_L \cdot k}{L}$ $h = 1 \cdot \frac{watt}{m^2 \cdot K}$

Mean diameter of annulus $D_{av} := \frac{D_{an} + d_{an}}{2}$

Height of cavity $H_{cav} := 475.4 \cdot mm$

Convective heat flow $Q_{conv} := h \cdot \pi \cdot D_{av} \cdot H_{cav} \cdot (T_{cap} - T_{cw})$ $Q_{conv} = 79 \cdot watt$

Radiatve Heat Transfer

Length of capsule $L_{cap} := 451.6 \cdot mm$

Surface area of source $S_s := \pi \cdot D_{an} \cdot L_{cap}$

Surface area of cavity $S_{cav} := \pi \cdot D_{cav} \cdot H_{cav}$

Emissivity of source $\varepsilon_s := 0.31$

Emissivity of cavity $\varepsilon_{cav} := 0.3$

Stefan Boltzmann Constant $\sigma := 5.67 \cdot 10^{-8} \cdot \frac{watt}{m^2 \cdot K^4}$

Absolute source temperature $T_{capabs} := T_{cap} + 273 \cdot K$

Absolute cavity temperature $T_{cwabs} := T_{cw} + 273 \cdot K$

Radiative heat flow $Q_{rad} := \sigma \cdot S_s \cdot \left[\frac{1}{\left[\frac{1}{\varepsilon_s} + \frac{S_s}{S_{cav}} \cdot \left(\frac{1}{\varepsilon_{cav}} - 1 \right) \right]} \right] \cdot \left(T_{capabs}^4 - T_{cwabs}^4 \right)$

$Q_{rad} = 702 \cdot watt$

Total heat flow rate $Q_{tot} := Q_{conv} + Q_{rad}$ $Q_{tot} = 780 \cdot watt$

which corresponds to the required heat load of 783.9 watts indicating that the capsule temperature is 526 deg C.

APPENDIX 2

CALCULATION OF HEAT TRANSFER COEFFICIENTS

A2.1 INTRODUCTION

This Appendix details the derivation of the heat transfer coefficients used in the analyses for both steady state and accident conditions.

A2.2 ESTIMATION OF HEAT TRANSFER COEFFICIENTS

A2.2.1 Flask Vertical Surfaces

Under steady-state operating conditions the heat transfer coefficient for the flask external surface, the fin surfaces and the jacket surfaces were calculated as shown below:

The following calculation relates to the RTR070 Test Case (Reference 3).

Ambient temperature $T_a := 23.3 \cdot K$

Surface temperature at mid height $T_s := 128 \cdot K$

Evaluate fluid properties at film temperature

$$T_f := \frac{T_a + T_s}{2} \qquad T_f = 75.65 \cdot K$$

For air at this temperature

Density $\rho := 1.01 \cdot \frac{kg}{m^3}$

Specific heat $c_p := 1009 \cdot \frac{joule}{kg \cdot K}$

Absolute viscosity $\mu := 2.1 \cdot 10^{-5} \cdot \frac{kg}{m \cdot sec}$

Thermal conductivity $k := 0.0299 \cdot \frac{watt}{m \cdot K}$

Absolute film temperature	$T_{fabs} := T_f + 273 K$	
Coefiicient of volume expansion	$\beta := \frac{1}{T_{fabs}}$	$\beta = 0.003 \cdot K^{-1}$
Kinematic viscosity	$\nu := \frac{\mu}{\rho}$	$\nu = 2.079 \cdot 10^{-5} \cdot \frac{m^2}{sec}$
Height of plate	$L := 0.873 m$	
Grashof Number	$Gr_L := \frac{g \cdot \beta \cdot (T_s - T_a) \cdot L^3}{\nu^2}$	$Gr_L = 4.532 \cdot 10^9$
Prandtl Number	$Pr := \frac{\mu \cdot c_p}{k}$	
Rayleigh Number	$Ra_L := Gr_L \cdot Pr$	

Churchill and Chu (Reference 8) have proposed the following correlation which is valid for a wide range of Rayleigh Numbers.

Nusselt Number

$$Nu_L := \left[0.825 + \left[\frac{0.387 Ra_L^{0.16667}}{\left[1 + \left(\frac{0.492}{Pr} \right)^{0.5625} \right]^{0.2963}} \right] \right]^2$$

Heat transfer coefficient	$h := \frac{Nu_L \cdot k}{L}$	$h = 6.045 \cdot \frac{watt}{m^2 \cdot K}$

The external surface area of the axisymmetric model is significantly less than the actual surface area provided by the fins. To account for this effect the heat transfer coefficient was enhanced as follows:

Flask diameter	$D := 498 mm$	
Flask height	$H := 873 mm$	
Surface area of curved surface	$S_{cs} := \pi \cdot D \cdot H$	$S_{cs} = 1.366 \cdot m^2$
Fin surface area	$S_f := 0.37 m \cdot 0.795 m \cdot 16 \cdot 2$	$S_f = 9.413 \cdot m^2$

Assuming a fin efficiency of 50%

Effective fin surface area $S_{fe} := \frac{S_f}{2}$ $S_{fe} = 4.706 \cdot m^2$

The fin attachment areas are effectively 'lost' from the outer curved surface of the flask.

Correction factor for surface area $\phi := 1 - \frac{32 \cdot (9.525 + 12) + 4 \cdot (15.875 + 24)}{\pi \cdot 498}$

$\phi = 0.458$

Effective surface area of flask $S_{fle} := \phi \cdot S_{cs}$ $S_{fle} = 0.625 \cdot m^2$

Area correction factor $f_{ac} := \frac{S_{fe} + S_{fle}}{S_{cs}}$ $f_{ac} = 3.904$

Area corrected heat transfer coefficient

$h_{ac} := f_{ac} \cdot h$ $h_{ac} = 23.599 \cdot \frac{watt}{m^2 \cdot K}$

which was the initial value of heat transfer coefficient applied to the external surface of the axisymmetric model.

During the fire typical flame velocities will be 5 - 10 m/s.

For flow over a plane surface IAEA Safety Series 37 (Reference 2, para. A-628.20) quotes

$$Nu_L := 0.036 Re^{0.8} \cdot Pr^{\frac{1}{3}}$$

For air at a temperature of 800 degress C.

Density $\rho := 0.325 \frac{kg}{m^3}$

Specific heat $c_p := 1156 \frac{joule}{kg \cdot K}$

Absolute viscosity $\mu := 4.51 \cdot 10^{-5} \cdot \frac{kg}{m \cdot sec}$

Thermal conductivity	$k := 0.0708 \frac{watt}{m \cdot K}$	
Prandtl Number	$Pr := \frac{\mu \cdot c_p}{k}$	$Pr = 0.736$
Flow velocity	$V := 5 \cdot \frac{m}{sec}$	
Reynolds Number	$Re := \frac{\rho \cdot V \cdot H}{\mu}$	$Re = 3.146 \cdot 10^4$
Nusselt Number	$Nu_L := 0.036 Re^{0.8} \cdot Pr^{\frac{1}{3}}$	
Heat transfer coefficient	$h := Nu_L \cdot \frac{k}{H}$	$h = 10.451 \frac{watt}{m^2 \cdot K}$

and this is the value used inside the fin enclosures during the fire.

On the outside of the jacket the full fire conditions exist and a velocity of 10 m/s was assumed (Reference 2, para. A-628.20). In this case:

Flow velocity	$V := 10 \cdot \frac{m}{sec}$	
Reynolds Number	$Re := \frac{\rho \cdot V \cdot H}{\mu}$	$Re = 6.291 \cdot 10^4$
Nusselt Number	$Nu_L := 0.036 Re^{0.8} \cdot Pr^{\frac{1}{3}}$	
Heat transfer coefficient	$h := Nu_L \cdot \frac{k}{H}$	$h = 18.197 \frac{watt}{m^2 \cdot K}$

and this is the value used on the external surfaces during the fire.

Closure

The following calculation relates to the RTR070 Test Case (Reference 3).

Ambient temperature	$T_a := 23.3K$
Surface temperature at mid height	$T_s := 128K$

Evaluate fluid properties at film temperature

$T_f := \frac{T_a + T_s}{2}$ $\qquad$ $T_f = 75.65 \cdot K$

For air at this temperature

Density	$\rho := 1.01 \cdot \frac{kg}{m^3}$	
Specific heat	$c_p := 1009 \frac{joule}{kg \cdot K}$	
Absolute viscosity	$\mu := 2.1 \cdot 10^{-5} \cdot \frac{kg}{m \cdot sec}$	
Thermal conductivity	$k := 0.0299 \frac{watt}{m \cdot K}$	
Absolute film temperature	$T_{fabs} := T_f + 273K$	
Coefficient of volume expansion	$\beta := \frac{1}{T_{fabs}}$	$\beta = 0.003 \cdot K^{-1}$
Kinematic viscosity	$\nu := \frac{\mu}{\rho}$	$\nu = 2.079 \cdot 10^{-5} \cdot \frac{m^2}{sec}$
Diameterof flask	$d := 0.498m$	
Plane area of closure	$A_c := \frac{\pi \cdot d^2}{4}$	
Perimeterof closure	$P := \pi \cdot d$	
Characteristic length	$D := \frac{A_c}{P}$	$D = 0.125 \cdot m$
Grashof Number	$Gr_D := \frac{g \cdot \beta \cdot (T_s - T_a) \cdot D^3}{\nu^2}$	$Gr_D = 1.319 \cdot 10^7$
Prandtl Number	$Pr := \frac{\mu \cdot c_p}{k}$	
Rayleigh Number	$Ra_D := Gr_D \cdot Pr$	$Ra_D = 9.316 \cdot 10^6$

Goldstein, Sparrow and Jones (Reference 9) have proposed the following correlation for upward facing circular plates in the turbulent regime.

Nusselt Number $Nu_D := 0.15 \cdot Ra_D^{\frac{1}{3}}$

Heat transfer coefficient $h := \frac{k \cdot Nu_D}{D}$ $h = 7.58 \cdot \frac{watt}{m^2 \cdot K}$

The external surface area of the closure in the axisymmetric model is less than the actual surface area due to the presence of fins on the closure. To account for this effect the heat transfer coefficient was enhanced as follows:

Plane area of closure $A_c := \frac{\pi \cdot d^2}{4}$

Fin surface area $S_{fc} := 0.26 \cdot m \cdot 0.06 \cdot m \cdot 8 \cdot 2$ $S_{fc} = 0.25 \cdot m^2$

Approximate area of bridge pieces $S_b := 2 \cdot 0.4 \cdot m \cdot \pi \cdot 0.45 \cdot 0.04 \cdot m$ $S_b = 0.045 \cdot length^2$

Fin surface area $S_{ftot} := S_{fc} + S_b$ $S_{ftot} = 0.295 \cdot m^2$

Assuming a fin efficiency of 50% and 10% of plane closure area 'lost' through attachments.

Effective fin surface area $S_{fce} := \frac{S_{ftot}}{2}$ $S_{fce} = 0.147 \cdot m^2$

Area correction factor $f_{ac} := \frac{0.9 \cdot A_c + S_{fce}}{A_c}$ $f_{ac} = 1.657$

Area corrected heat transfer coefficient

$h_{ac} := f_{ac} \cdot h$ $h_{ac} = 12.559 \cdot \frac{watt}{m^2 \cdot K}$

which was the initial value of heat transfer coefficient applied to the closure surface of the axisymmetric model.

In the fire, the top surface of the closure will be exposed to the fire and the value of heat transfer coefficient calculated above, 18.2 W/m^2K was applied to this surface.

Base

The following calculation relates to the RTR070 Test Case (Reference 3).

Using the properties of air evaluated for the closure.

Lloyd and Moran (Reference 10) have proposed the following correlation for the underside of heated circular plates.

Nusselt Number $Nu_D := 0.27 \cdot Ra_D^{\frac{1}{4}}$

Heat transfer coefficient $h := \frac{k \cdot Nu_D}{D}$ $h = 3.582 \cdot \frac{watt}{m^2 \cdot K}$

The external surface area of the base in the axisymmetric model is less than the actual surface area due to the presence of fins on the base. To account for this effect the heat transfer coefficient was enhanced as follows:

Plane area of base $A_b := \frac{\pi \cdot d^2}{4}$

Fin surface area $S_{fb} := 4 \cdot 0.37 \cdot m \cdot 0.0325 \cdot m + 8 \cdot 0.15 \cdot m \cdot 0.0325 \cdot m$

$S_{fb} = 0.087 \cdot length^2$

Assuming a fin efficiency of 50% and 5% of plane base area 'lost' through attachments.

Effective fin surface area $S_{fbe} := \frac{S_{fb}}{2}$ $S_{fbe} = 0.044 \cdot m^2$

Area correction factor $f_{ac} := \frac{0.95 \cdot A_b + S_{fbe}}{A_b}$ $f_{ac} = 1.174$

Area corrected heat transfer coefficient $h_{ac} := f_{ac} \cdot h$ $h_{ac} = 4.204 \cdot \frac{watt}{m^2 \cdot K}$

which was the initial value of heat transfer coefficient applied to the base surface of the axisymmetric model.

In the fire, the lower surface of the base will be exposed to the fire and the value of heat transfer coefficient calculated above, 10.5 W/m ^{2}K was applied to this surface.

APPENDIX 3

MATERIAL PROPERTIES USED IN THE ANALYSES

A3.1 Austenitic Stainless Steel (Reference 6)

Density: 8000 kg/m^3

Temperature °C	Specific Heat J/kgK	Thermal Conductivity W/mK
0	440	13.0
100	475	14.6
200	500	16.4
300	550	18.0
400	591	19.2
500	655	21.1
600	720	22.5
700	800	24.0
800	880	25.0

Table 11 Properties of Austenitic Stainless Steel

A3.2 Uranium (Reference 11)

Density: 18780 kg/m^3

Temperature °C	Specific Heat J/kgK	Thermal Conductivity W/mK
0	115	28.0
100	120	28.9
200	130	29.8
300	142	30.7
400	158	31.6
500	170	32.5
600	187	33.4
700	200	34.2
800	215	35.0

Table 12 Properties of Uranium

A3.3 Helium (Reference 12)

Temperature °C	Density kg/m^3	Specific Heat J/kgK	Thermal Conductivity W/mK
0	0.175	5195	0.145
100	0.128	5195	0.180
200	0.101	5195	0.213
300	0.084	5195	0.244
400	0.072	5195	0.273
500	0.063	5195	0.302
600	0.055	5195	0.330
700	0.050	5195	0.355
800	0.041	5195	0.380

Table 13 Properties of Helium

A3.4 Argon (Reference 12)

Temperature °C	Density kg/m^3	Specific Heat J/kgK	Thermal Conductivity W/mK
0	1.840	521.8	0.0164
100	1.300	521.1	0.0211
200	1.025	520.8	0.0253
300	0.825	520.7	0.0291
400	0.725	520.6	0.0326
500	0.630	520.5	0.0359
600	0.555	520.5	0.0390
700	0.498	520.5	0.0420
800	0.452	520.4	0.0447

Table 14 Properties of Argon

A3.5 Air (Reference 12)

Temperature °C	Density kg/m^3	Specific Heat J/kgK	Thermal Conductivity W/mK
0	1.290	1005	0.0241
100	0.945	1011	0.0318
200	0.745	1025	0.0386
300	0.615	1045	0.0450
400	0.525	1069	0.0508
500	0.505	1092	0.0561
600	0.405	1115	0.0614
700	0.364	1137	0.0664
800	0.330	1156	0.0710

Table 15 Properties of Air

APPENDIX 4

CALCULATION OF HEAT GENERATION RATES

The internal heat generation used in the finite element models was input on a heat per unit volume basis. For the case of interest, ie a total flask activity of 340 kCi, the calculation of these inputs for the axisymmetric model was as follows:

Total activity	$P := 340$ kCi	
For cobalt 60 (Reference 6)	$Diss := 15.37$ W/kCi	
Total heat load	$Q_{tot} := P \cdot Diss$	$Q_{tot} = 5.226 \cdot 10^3$ watt
Cavity radius	$r := 0.075 \cdot m$	
Cavity length	$L := 0.4754 m$	
End surface area	$A_{end} := \pi \cdot r^2$	$A_{end} = 0.018 \cdot m^2$
Curved surface area	$A_{cyl} := 2 \cdot \pi \cdot r \cdot L$	$A_{cyl} = 0.224 \cdot length^2$
Proportion of heat to each end	$pf_{end} := \frac{A_{end}}{\left(A_{cyl} + 2 \cdot A_{end}\right)} \cdot 100$	$pf_{end} = 6.813$
Tuning factors	$\phi_{top} := 1$	$\phi_{base} := 1$
	$Q_{top} := \frac{pf_{end} \cdot \phi_{top}}{100} \cdot Q_{tot}$	$Q_{top} = 356.046$ watt
	$Q_{base} := \frac{pf_{end} \cdot \phi_{base}}{100} \cdot Q_{tot}$	$Q_{base} = 356.046$ watt
Heat load to body	$Q_{radial} := Q_{tot} - Q_{top} - Q_{base}$	
	$Q_{radial} = 4.514 \cdot 10^3$ watt	

Radial direction

Percentage of heat load to steel liner	$pf_{radliner} := 15$
	$Q_{radliner} := \frac{pf_{radliner}}{100} \cdot Q_{radial}$ $\quad Q_{radliner} = 677.056$ watt
Inside diameter of liner	$d_{liner} := 150 \cdot mm$
Out side diameter of liner	$D_{liner} := 158 \cdot mm$
Effective length of liner	$L_{effliner} := 469 \cdot mm$
Effective volume of liner	$V_{effradliner} := \frac{\pi}{4} \cdot \left(D_{liner}^{2} - d_{liner}^{2}\right) \cdot L_{effliner}$
Heat load per unit volume to liner	$Q_{pervradliner} := \frac{Q_{radliner}}{V_{effradliner}}$
	$Q_{pervradliner} = 7.46 \cdot 10^{5} \cdot m^{-3}$
Percentage of heat load to shielding	$pf_{radshield} := 100 - pf_{radliner}$
	$Q_{radshield} := \frac{pf_{radshield}}{100} \cdot Q_{radial}$
	$Q_{radshield} = 3.837 \cdot 10^{3}$ watt
Inside diameter of shielding	$d_{shield} := 160 \cdot mm$
Out side diameter of liner	$D_{shield} := d_{shield} + 24 \cdot mm$
Effective length of liner	$L_{effshield} := 469 \cdot mm$
Effective volume of liner	$V_{effradshield} := \frac{\pi}{4} \cdot \left(D_{shield}^{2} - d_{shield}^{2}\right) \cdot L_{effshield}$
Heat load per unit volume to shielding	$Q_{pervradshield} := \frac{Q_{radshield}}{V_{effradshield}}$
	$Q_{pervradshield} = 1.262 \cdot 10^{6} \cdot m^{-3}$

Base

Diameter of liner	$D_{baslin} := 154 \cdot mm$
Thickness of liner	$t_{baslin} := 10 \cdot mm$
Effective volume of liner	$V_{baslin} := \frac{\pi}{4} \cdot D_{baslin}^{2} \cdot t_{baslin}$
	$V_{baslin} = 1.863 \cdot 10^{-4} \cdot m^{3}$
Percentage of heat load to steel liner	$pf_{baslin} := 15$
	$Q_{baslin} := \frac{pf_{baslin}}{100} \cdot Q_{base}$ $Q_{baslin} = 53.407$ watt
Heat load per unit volume to liner	$Q_{pervbaslin} := \frac{Q_{baslin}}{V_{baslin}}$
	$Q_{pervbaslin} = 2.867 \cdot 10^{5} \cdot m^{-3}$
Diameter of shield	$D_{basshield} := 160 \cdot mm$
Thickness of shield	$t_{bashield} := 12 \cdot mm$
Effective volume of shield	$V_{basshield} := \frac{\pi}{4} \cdot D_{basshield}^{2} \cdot t_{bashield}$
	$V_{basshield} = 2.413 \cdot 10^{-4} \cdot m^{3}$
Percentage of heat load to shield	$pf_{basshield} := 100 - pf_{baslin}$
	$Q_{basshield} := \frac{pf_{basshield}}{100} \cdot Q_{base}$ $Q_{basshield} = 302.639$ watt
Heat load per unit volume to shielding	$Q_{pervbasshield} := \frac{Q_{basshield}}{V_{basshield}}$
	$Q_{pervbasshield} = 1.254 \cdot 10^{6} \cdot m^{-3}$

Closure

Diameter of liner	$D_{toplin} := 150 \cdot mm$
Thickness of liner	$t_{toplin} := 7 \cdot mm$
Effective volume of liner	$V_{toplin} := \frac{\pi}{4} \cdot D_{toplin}^{2} \cdot t_{toplin}$
	$V_{toplin} = 1.237 \cdot 10^{-4} \cdot m^{3}$
Percentage of heat load to steel liner	$pf_{toplin} := 15$
	$Q_{toplin} := \frac{pf_{toplin}}{100} \cdot Q_{top}$ $Q_{toplin} = 53.407$ watt
Heat load per unit volume to liner	$Q_{pervtoplin} := \frac{Q_{toplin}}{V_{toplin}}$
	$Q_{pervtoplin} = 4.317 \cdot 10^{5} \cdot m^{-3}$
Diameter of shield	$D_{topshield} := 150 \cdot mm$
Thickness of shield	$t_{tophield} := 12 \cdot mm$
Effective volume of shield	$V_{topshield} := \frac{\pi}{4} \cdot D_{topshield}^{2} \cdot t_{tophield}$
	$V_{topshield} = 2.121 \cdot 10^{-4} \cdot m^{3}$
Percentage of heat load to shield	$pf_{topshield} := 100 - pf_{toplin}$
	$Q_{topshield} := \frac{pf_{topshield}}{100} \cdot Q_{top}$ $Q_{topshield} = 302.639$ watt
Heat load per unit volume to shielding	$Q_{pervtopshield} := \frac{Q_{topshield}}{V_{topshield}}$
	$Q_{pervtopshield} = 1.427 \cdot 10^{6} \cdot m^{-3}$

For the 2D sections the heat inputs were the same as for the radial direction for the axisymmetric model.

APPENDIX 5

THE ANSYS FINITE ELEMENT PROGRAM

A5.1 The Program

The ANSYS program is one of the world's major finite element engineering analysis packages. Developed in the USA, the program has a 30 year history and a proven track record.

Currently at level 5 the program is well-documented (Reference 13). The suppliers provide a high-level of technical support for their products and operate a quality procedure that alerts users to any problems that have been encountered.

ANSYS Inc. is accredited to ISO 9001 and has developed quality assured software, as a formal process since the 1970s. For each release, a set of more than 10000 tests is conducted to verify the validity and reliability of the software. To allow the program to be verified, ANSYS supply a set of standard problems for which analytical solutions exist (Reference 14).

The author has used the ANSYS program since 1988 on a wide range of thermal and structural applications. He has undertaken a large number of steady-state and transient thermal analyses for transport packages for radioactive materials.

A5.2 Treatment of Thermal Radiation

The ANSYS program provides three ways of handling radiation as follows:

a ***Radiation link 31*** - this element provides a convenient way of modelling radiation between parallel surfaces that are in close proximity with each other, eg narrow gaps.

b ***Surface elements*** - these elements are suitable for radiation between a surface and its surroundings. They are therefore suitable for radiation to and from external surfaces.

c ***Radiation superelements*** - these elements are intended for complex radiation problems between multiple surfaces. A special-purpose macro, AUX12, is used to define the radiating surfaces and the method of view factor calculation._These matrices are then read into the model as superelements. This approach was used for radiation in the fin enclosures.

Report

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Report

Thermal effect of transporting Cobalt Flasks in a linear array

T Richardson

November 1998

AEA TECHNOLOGY
ENERGY

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Executive Summary

Cobalt flasks generate heat and are cooled by convection. Their performance is usually modelled and tested individually. However, when flasks are transported or stored they may often be grouped in linear arrays. This report describes how this situation was modelled using finite elements in order to determine if this method of transporting the flasks has any significant effect on the temperatures of the flasks. Two typical types of flask have been considered, a stainless steel flask with a depleted uranium shield and a thin steel external jacket round the fins, and a stainless steel, lead shielded flask with a thick, insulated thermal shield surrounding the fins.

Contents

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1 Introduction

Cobalt flasks generate heat and are cooled by convection. Their performance is usually modelled and tested individually. However, when flasks are transported or stored they may often be grouped in linear arrays. This report describes how this situation was modelled using finite elements in order to determine if this method of transporting the flasks has any significant effect on the temperatures of the flasks. Two typical types of flask have been considered, a stainless steel flask with a depleted uranium shield and a thin steel external jacket round the fins and a stainless steel, lead shielded flask with a thick, insulated thermal shield surrounding the fins.

The finite element model consists of a horizontal cross-section through the mid-height of two flasks with their centres an appropriate distance apart. Advantage is taken of the symmetry of the flasks to reduce the model to a quarter of each flask. The applied boundary conditions mean that the model represents an infinite linear array of flasks.

2 Finite Element Model

In order to examine the effect of transporting flasks as a linear array two flasks for which models of single flasks had previously been made were selected. The flasks selected were a 3750A flask which has V-shaped fins surrounded by a thin steel jacket (Ref 1) and a new design of lead lined flask which has straight fins surrounded by an insulated thermal shield (Ref 2). These flasks were taken to be representative of flasks of similar construction.

Previous thermal assessments of these flasks (Refs 1 and 2) have shown that the maximum steady state temperatures occur on a horizontal cross-section through the flasks at mid-height. Advantage is taken of the symmetry to model a quarter of each flask. To complete the finite element mesh a mirror image of the quarter flask is added in both cases, the flask centres being 1.4 metres apart (Figures 1 and 2). The spacing gives a clearance of 150 mm between flasks which would be the typical minimum.

The heat generated by the contents of the flasks is modelled as a heat flux through the wall of the central cavity, the value of the flux being determined by assuming a uniform distribution of heat over all surfaces of the cavity. Between the fins heat is assumed to be lost to ambient temperature by convection. Heat is transferred between the outer surface of the flask, the inner surface of the jacket and the fin surfaces for each such region. In the case of the flask with V-shaped fins there is a similar transfer of heat between the flask surface and the inner surface of the fins.

The ends of the fins are not in contact with the inner surface of the jacket and it is assumed there is no transfer of heat by conduction. Radiation is the only means by which heat is transferred between the body of the flask and the jacket. Heat is assumed to be lost from the outer surface of the jacket to the ambient conditions by both convection and radiation. In addition heat is transferred by radiation between the two outer jacket surfaces in the model.

All other surfaces are assumed to be adiabatic. This implies that the model represents an infinite linear array of flasks and that any differences in temperature due to such an array will be conservative relative to the situation where a limited number of flasks are transported in such an array.

3 Results

3.1 FLASK WITH THIN STEEL JACKET

Figure 3 shows the increase in temperature on the outside surface of the jacket as a result of the flasks being transported as a linear array i.e. the calculated temperature from the current model minus the corresponding temperature for a single flask. The plot starts at the point where the flasks are closest together and the distance is measured round the circumference of the jacket. There is a variation in the temperature of the jacket caused by the proximity of parts of the jacket to the tips of the fins. These positions correspond to the bigger temperatures. The maximum temperature increase caused by the second flask is ~ 2.5 °C. The effect of the second flask on the temperatures at other positions within the flask is negligible.

3.2 FLASK WITH INSULATED THERMAL SHIELD

In the case of the flask with an insulated thermal shield surrounding the fins there is little or no variation in temperature round the outside of the jacket. Because this implies that there is little or no temperature difference between positions on the outside surface of the jackets of the two flasks in the model there is correspondingly little transfer of heat by radiation between the flasks. The effect on the temperature distribution of arranging this type of flask in a linear array is therefore negligible.

4 Conclusions

1. Transporting flasks with the fins surrounded by a thin metal jacket in a linear array results in a small increase in the temperature of the jacket (~2.5 °C) due to the variation in the jacket temperature close to the fin tips. The effect on other temperatures is negligible.

2. Transporting flasks with the fins surrounded by a thick, insulated thermal shield in a linear array has negligible effect on the flask temperatures because three is very little variation in temperature on the outer surface of the thermal shield.

5 References

1. T Richardson. Thermal Assessment of an Amersham International 3750A Transport Flask. SPD/D(95) 390 Issue 3, July 1998

2. T Richardson, S Yellowlees and P Boydell. Thermal Assessment of a New Design of Lead Shielded Transport Flask, August 1998

ABAQUS

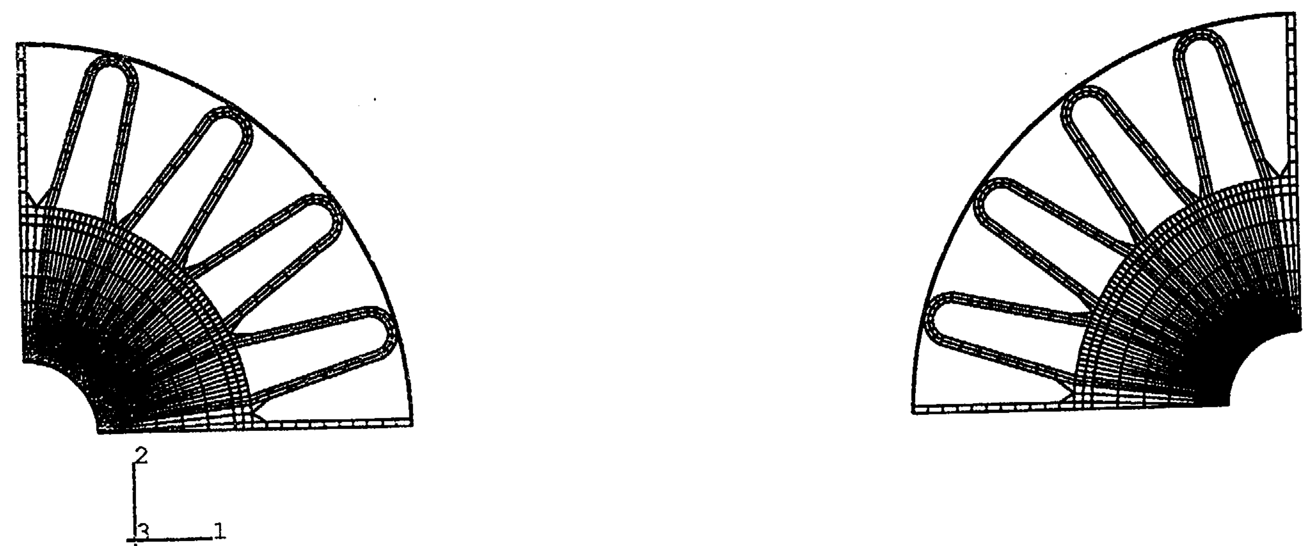

Figure 1 Flasks with V-shaped fins and thin steel jacket

ABAQUS

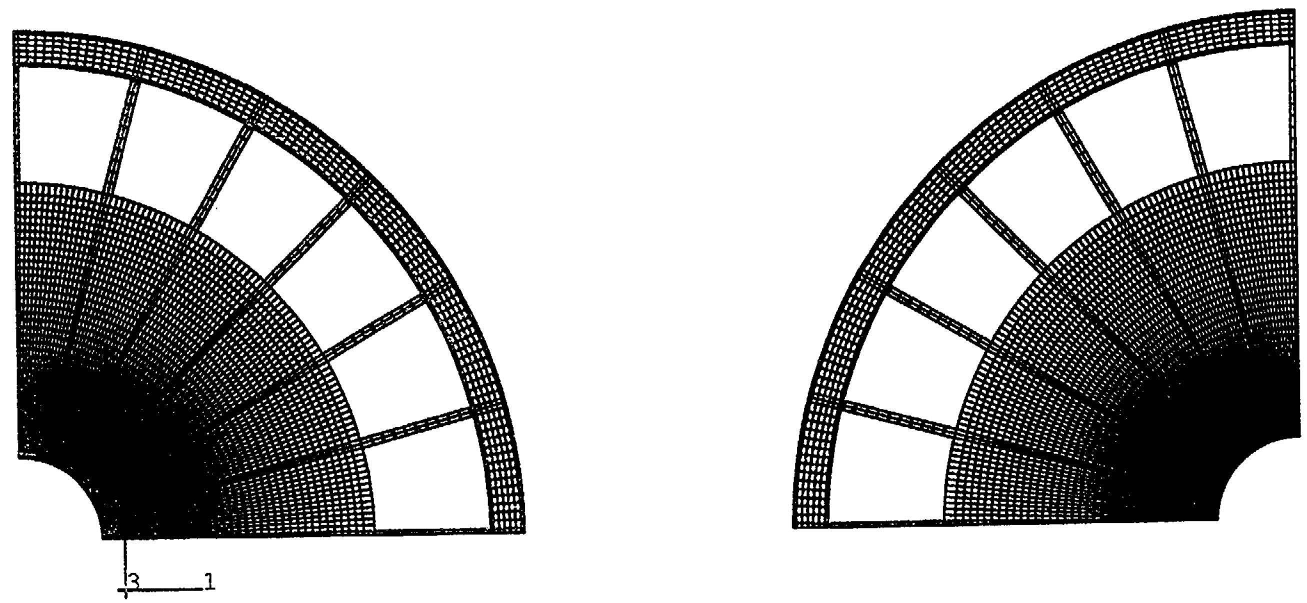

Figure 2 Flasks with straight fins and a thick insulated jacket

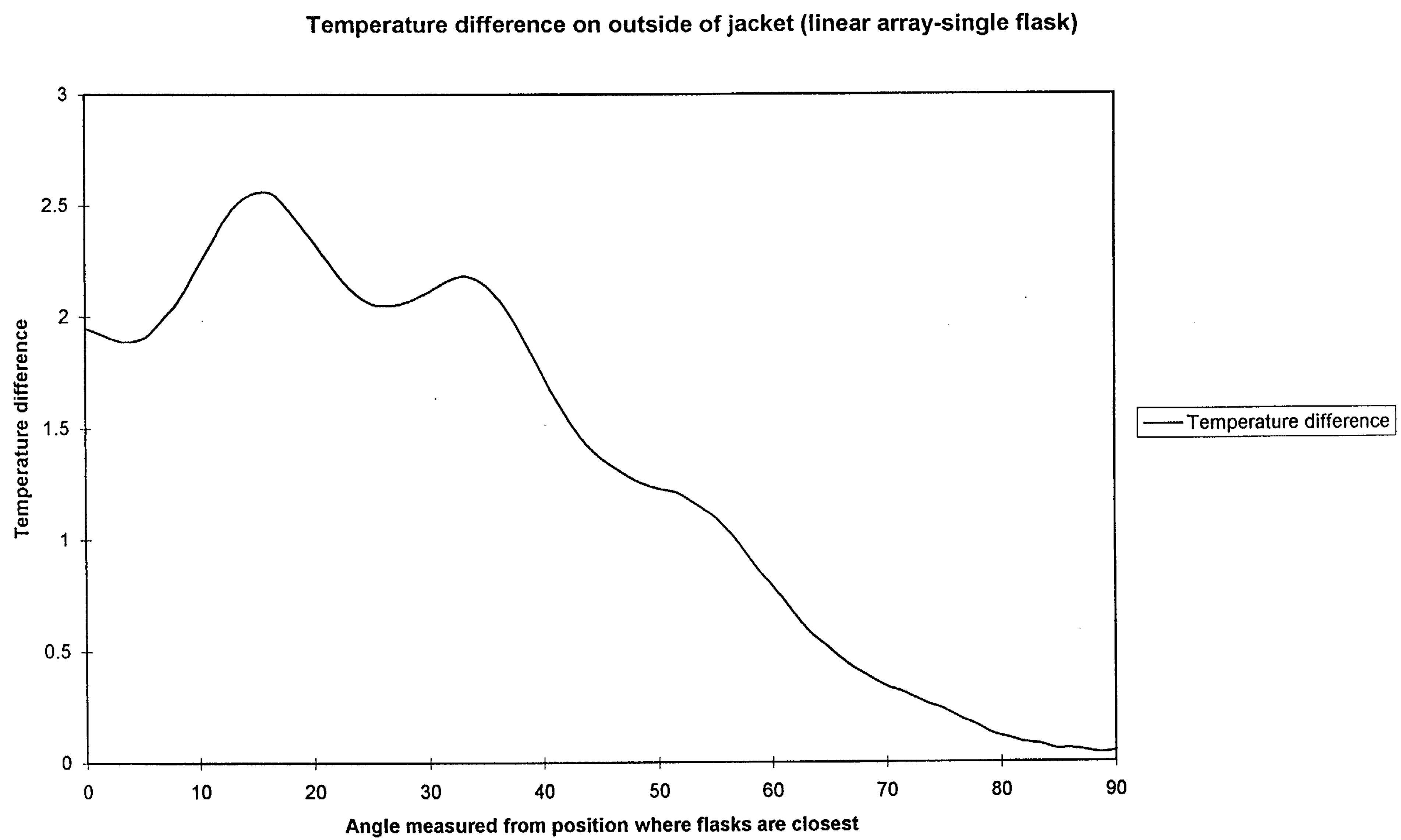
Temperature difference on outside of jacket (linear array-single flask)
Temperature difference
3
2.5
2
1.5
1
0.5
0
0
10
20
30
40
50
60
70
80
90
Angle measured from position where flasks are closest
Temperature difference

Figure 3