4.1.6 Grill Model

The pressure loss characteristics of the grill were evaluated at air flow rates in the range of 0.25m/s to 1.5m/s and then applied to a porous surface representing the grill.

4.1.7 Normal conditions

In normal conditions the model was given the maximum contents heat load, stood upright on a solid flat surface, with an emissivity of 0.90, in 38°C still air and subjected to the insolation specified in TS-R-1.

4.1.8 Accident conditions

In the thermal test the model, in each orientation, was enclosed in an 800°C environment with an emissivity of 0.9, i.e. as in a furnace, but with a forced updraft of 8 m/s producing peak gas flow rates not less than 10 m/s around the package. This complied with the IAEA recommendations, TS-G-1.1. After thirty minutes the environment was replaced by normal conditions, i.e. still air at 38°C with full insolation, until temperatures in all critical areas had stopped rising.

4.2 BENCHMARKING

Once all external temperatures were in agreement with the test results the thermal contact resistance between the lead and stainless steel interfaces was adjusted until the mid-height cavity wall temperature was correct. The value obtained for the normal form model was 400 $W/m^2.°C$ when the external flask emissivity was set to 0.45. This was changed to 330 $W/m^2.°C$ when the Special Form study identified an emissivity of 0.55 as giving a better match with the measurements. The results are summarised as follows:

Measured and Modelled Temperatures [°C]				
Location	Measured	Modelled		
		R7110/1.1		R7410/1.1
		Prototype	Production Design	Revised Benchmark
Cavity wall (50mm below top)	151	152	153	152
Cavity wall (mid-height)	155 / 155 / 154	155	156	155
Cavity wall (50mm above base)	149	151	152	150
Closure flange (20mm below upper surface, 50mm from outer edge)	112 / 116	110	114	111
Drain point (centre of cylinder, outer surface)	83*1	101	101	97
Flask wall (mid-height, midway between fins)	112 / 111 / 112 / 113	119	120	116
Lifting fin (100mm from top edge, 75mm from outer edge)	49*2	65	67	64
Lifting fin (40mm from top edge, 55mm from outer edge)	55	57	60	55
Lifting fin (135mm from top edge, 35mm from outer edge)	61 / 59	66	68	65
Flask foot (top surface, 30mm from outer edge)	27 / 27	32	33	32
Jacket (top edge)	36 / 36	39	39	39

Measured and Modelled Temperatures [°C]				
Location	Measured	Modelled		
		R7110/1.1		R7410/1.1
		Prototype	Production Design	Revised Benchmark
Jacket (inner surface, 40mm from top edge)	43 / 40	45	46	46
Top shield (mid height vertical face)	35 / 36	42	39	38
Top shield (half way across horizontal face)	35 / 35	41	38	38
Top shield (top surface centre)	40	49	37	39
Ambient	21	21	21	21

Notes:
*1: These measurements have been ignored as they are obviously due to malfunctioning thermocouples.
*2: The drain plug head was not explicitly modelled as it has no safety significance. The nearest point was the flask surface which gave a higher calculated value due to the lack of a contact resistance.

In the contents model the emissivity of the stainless steel capsules was adjusted until their mid-height temperatures gave the best match. The value obtained was 0.60. The results are summarised as follows:

Measured and Modelled Source Temperatures [°C]		
Capsule	Measured	Modelled (R7110/1.1)
X	342 / 341 / 342	337
Y	311 / 312 / 312	332
Z	333 / 333 / 330	335

The results demonstrate good agreement with the test results and validate the models and input parameters for IAEA transport conditions modelling.

4.3 THERMAL PERFORMANCE OF THE PROTOTYPE VS THE PRODUCTION DESIGN

When the same internal heat load and contact resistance were applied to the production model all key temperatures remained essentially unchanged (the only significant area of difference being the surface of the top shield which had acquired an additional top plate and therefore ran a little cooler). This confirmed the changes made no significant difference to steady state thermal performance which allowed the contact resistance and capsule emissivity to be carried through without further benchmarking.

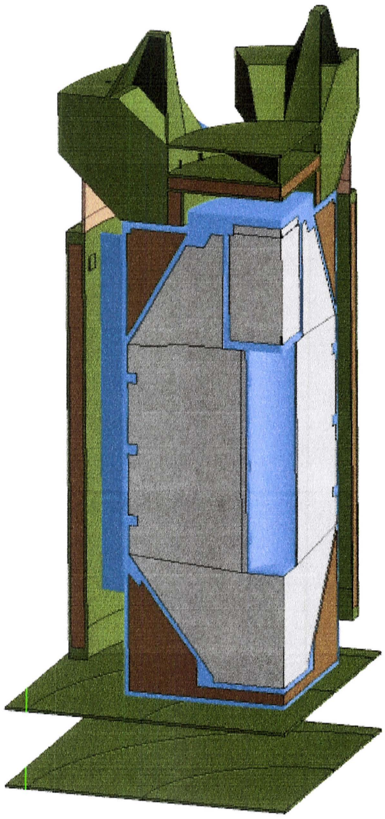

Figure 2: Prototype Thermal Model

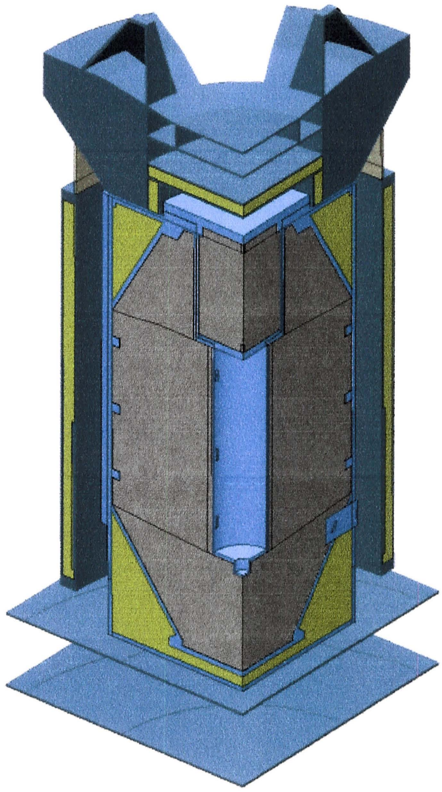

Figure 3: Modified Design Thermal Model

4.4 SENSITIVITY STUDY

The thermal analysis investigated the sensitivity of the design to various assumed values or attributes including those of its contents. The key design and modelling parameters are as follows:

- The emissivity of flask external surfaces.
- The emissivity of carbon steel surfaces.
- The thermal conductivity of the flask, jacket and top shield insulation.
- The number of capsules (total activity remaining constant) in the cavity.
- The gas in the cavity.
- The cavity gas pressure.

The reference case contents consisted of sixteen R2089 sources in a neon filled cavity at 1 atm. The emissivity of the flask external surfaces was 0.4, the emissivity of the carbon steel surfaces was 0.9 and the conductivity of the insulation was the manufacturer's stated value. The contents heat load was the maximum permitted and the environment was normal conditions in all cases except for the insulation conductivity which was also run in accident conditions. The results are summarised as follows:

Effect of Various Parameters on Normal Conditions Package Temperatures [^{o}C]						
Location	Reference Case	Emissivity of S/S		Emissivity of C/S		Ins cond $2*k_{ins}$
		0.20	0.60	0.80	0.98	
Cavity wall (mid-height)	178	184	176	179	178	178
Maximum lead temperature	168	175	166	169	169	168
Closure flange (20mm below upper surface, 50mm from outer edge)	136	142	133	137	137	136
Drain point (centre of cylinder, 80mm from outer surface)	138	144	135	139	138	137
Flask wall (mid-height, midway between fins)	139	146	137	141	140	139
Flask foot (top surface, 30mm from outer edge)	62	62	64	64	62	63
Top shield (top surface centre)	95	83	87	92	99	91
Ambient	38	38	38	38	38	38

Effect of Variation in Insulation Conductivity on Accident Condition Package Temperatures [^{o}C]		
Location	Reference Case	Conductivity Doubled
Cavity wall (mid-height)	271	278
Maximum lead temperature	268	271
Closure flange (20mm below upper surface, 50mm from outer edge)	253	258
Drain point (centre of cylinder, 80mm from outer surface)	224	231
Flask wall (mid-height, midway between fins)	254	264

Effect of Various Contents Parameters on Source Temperature [^{o}C]					
Reference Case	Number of Capsules		Cavity Gas		Pressure [atm]
16/neon/1 atm	12	18	Helium	Air	2
334	348	325	265	360	332

The sensitivity study demonstrated:

- Flask temperatures are not particularly sensitive to the stainless steel emissivity in normal conditions of transport though a lower value does give slightly higher results.
- Flask temperatures are not sensitive to the carbon steel emissivity or the insulation conductivity in normal conditions of transport.
- Flask temperatures are not particularly sensitive to the insulation conductivity in accident conditions though a higher value does give slightly higher results.
- Contents temperature is sensitive to capsule activity (the higher the activity the higher the temperature) and cavity gas (air being worse than either neon or helium) but is not sensitive to the gas pressure.