SUBJECT: SPIRE CALIBRATION CRYOSTAT COOL DOWN ANALYSIS

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CONTENTS

1. Introduction

Scope: This study is concerned with the thermal behavior of Spire and the HOB during cool down in the Spire Calibration cryostat. A thermal model has been developed to allow the following to be investigated:

- Cool down behavior of the HOB Simulation plate and Spire cryogenic components,
- Steady-State gradients introduced in HOB Simulation plate,
- Gradients across the Level 2 cryostat filter,
- Optimisation of the Level 1 strap interface design.

This document defines the Spire Instrument integration within the Spire Calibration cryostat. As the model makes used of previously developed models, their accompanied document must be read in parallel with the appropriate documents.

2. Applicable Documents

ID	Title	Document Number
2.0	-	D. Simmons & M. Harman
2.1	Procurement Specification - SPIRE calibration cryostat - Issue 1	SPIRE-RAL-DOC-000582
2.2	Drawing 1 - HOB Preliminary Design	19-10-2001
2.3	Drawing 2 - Frame Rail Interface	26-10-2001
2.4	Drawing 3 - Foot Support	26-10-2001
2.5	Spire Geometric Model	Spire12.erg
2.6	Spire Cryogenic Interface thermal mathematical model - Issue 1	SPIRE-RAL-PRJ-000728
2.7	Calibration Cryostat Filter Model	SPIRE-RAL-NOT-000902
2.8	10K I.R Filter Mount	KG0710-130
2.9	Cold Calibration HOB Simulator Assembly	KGO710-100
2.10	Heat switches Definition – Email 27-11-2001	L. Duband
2.11	Material Properties II	K&K Associates
2.12	Spire GL links and Materials Properties	Excel Spreadsheet
2.13	PACS meeting 5-9-01spire.ppt – Email 17-9-01	M. Linder

Table 1 – References List

3. Model Overview

The overall thermal model consists of the following elements:

- The Spire FPU and the JFET Enclosures,
- The HOB Simulation plate on which Spire is mounted,
- The frame and rails supporting the HOB in the test cryostat via foot supports,
- The HERSCHEL cryostat main components such as the vacuum vessel, the LN2 shield, the Level2 heat shield and the helium tanks.

A simplified geometric model of Spire FPU, the JFET enclosures, the HOB, the rail supports, the 12K and 78K filters and the various Herschel cryostat vessels has been developed with Esarad to calculate radiative exchange factors for inclusion in the TMM. To limit the complexity of the geometric model, a separate one has been used to evaluate the radiative couplings between the detectors, their enclosures and Spire.

For the mathematical thermal model, the "Spire Cryogenic" ITMM01c [AD2.6] previously developed as been used to model Spire and its internal components. Radiative exchange factors have been added to this model since they have a significant impact at the higher temperatures experienced during cool down.

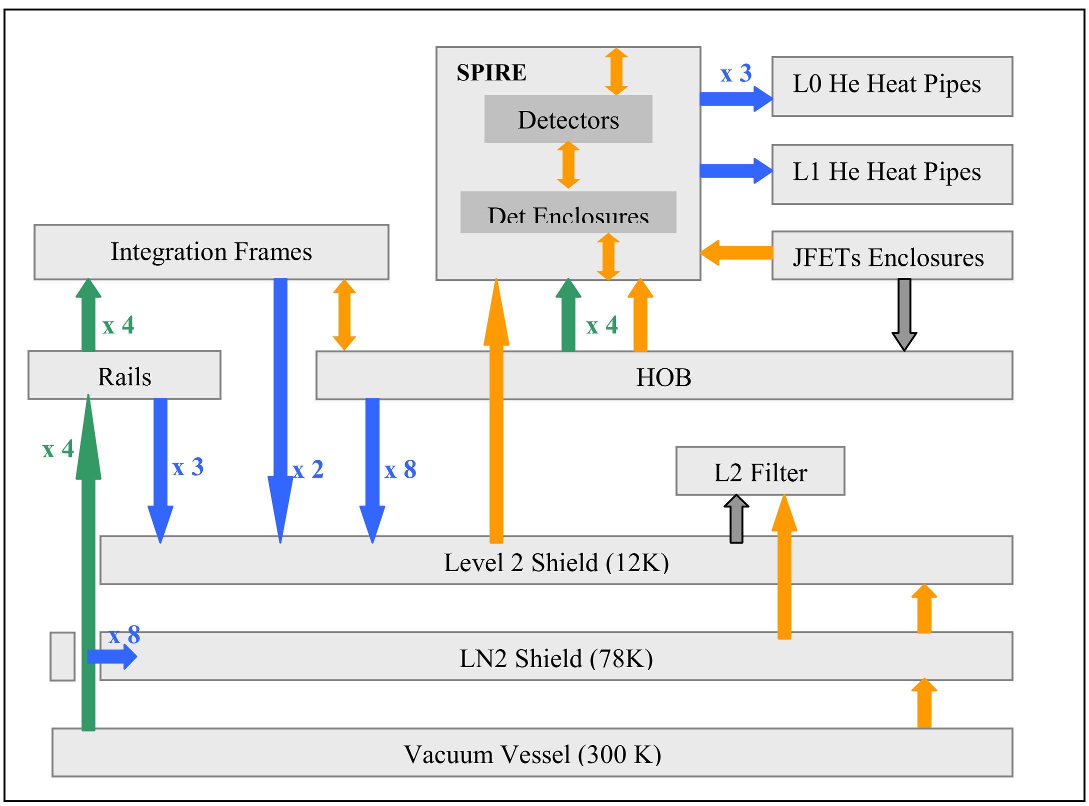
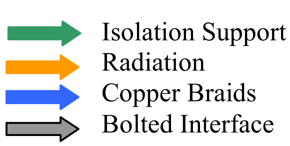


Figure 1 – Thermal Model Overview



4. Geometrical Mathematical Model

A geometric model spire22.erg has been developed with Esarad to simulate the radiation environment inside the cryostat. This model includes:

- The vacuum vessel,
- The LN2 shield, with emplacement for the 78K filter,
- The Level 2 heat shield, with emplacement for the 12K filter,
- The 10 K filter and its support,
- The 78 K filter and its support,
- The HOB support plate,
- The two rail supports,
- The Spire instrument, the spectrometer and photometer's JFET enclosures+.

An overview of main model components dimensions and their thermal optical properties is given in table 2.

Name	***Nodes***	***Main Dimensions (m)***	***Material***	***Emissivity***	***Ref***
Vacuum Vessel	8000	$\phi = 1.45$ L = 1.4	Stainless Steel 316L	0.14	*2.0*
LN2 Shield	7000	$\phi_{Ext} = 1.35$ $\phi_{Int} = 1.2$ L = 1.1	Aluminum	0.03	*2.0*
LN2 Shield Ends 1 LN2 Shield Ends 2	7010-7014 7020-7024	-	Aluminum	0.03	-
Support 78K Filter	500	$\phi = 0.298$	Aluminum	0.03	*2.8*
78K Filter	510	-	Polypropylene	0.1	*2.8*
Level 2 Heat Shield	2000-2004	$\phi_{Mean} = 1.124$ L = 1.0	Copper	0.05	*2.0*
L2 Heat Shield Ends 1 L2 Heat Shield Ends 2	2010-2014 2020-2024	-	Copper	0.05	-
Support 12K Filter	490	$\phi = 0.273$	Aluminum	0.03	*2.8*
12K Filter	430-450	-	Polypropylene	0.1	*2.8*
Front Rail Support	760-765	L = 0.9	Aluminum	0.03	*2.9*
Back Rail Support	770-775	L = 0.9	Aluminum	0.03	*2.9*
Hob Plate	1000-1009	0.99x0.9x0.019	Aluminum	0.03	*2.0*
Photometer Det. Spectrometer Det	120 130	-	Alochrome Alochrome	0.28 0.28	-
Photometer Det Enc Spectrometer Det Enc	100 110	-	Alochrome Alochrome	0.28 0.28	-
Spire Walls Shutter + Motor	30	- -	Alochrome Effective	0.28 0.06	- -
PH JFET Enclosure SP JFET Enclosure	10 20	0.088x0.104x271.5 0.088x0.104x90.5	Alochrome Alochrome	0.28 0.28	-

Table 2 – Geometric Model Description

+ *The previously developed Esarad model "spire12.erg" of the SPIRE FPU + JFETs has been used for this model. For the purpose of the study, the nodes of the model spire12.erg (with the exception of the JFET enclosure's nodes 10 and 20) have been merged into a unique node 30.*

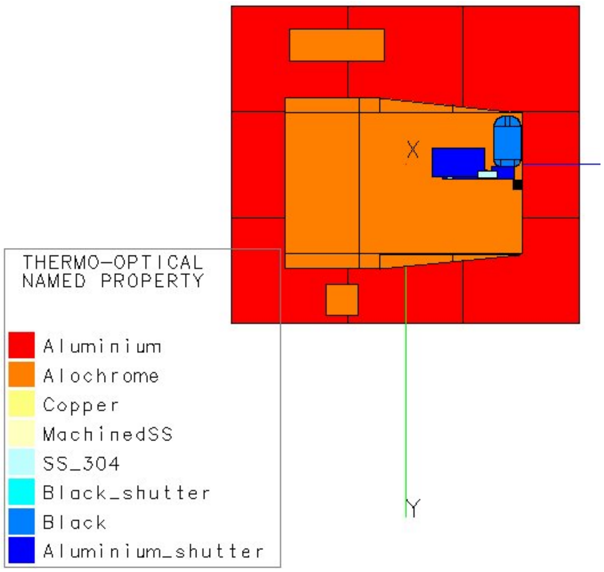


Figure 2 – Spire and HOB

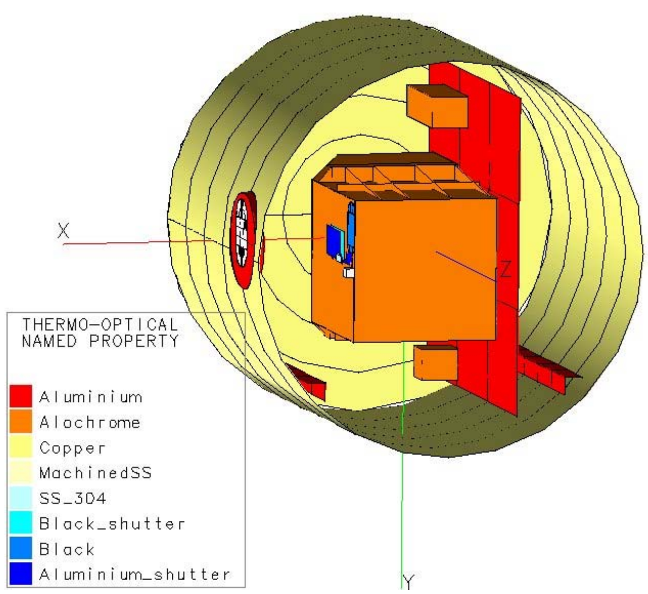


Figure 3 – Spire, HOB, 12K shield and filter support

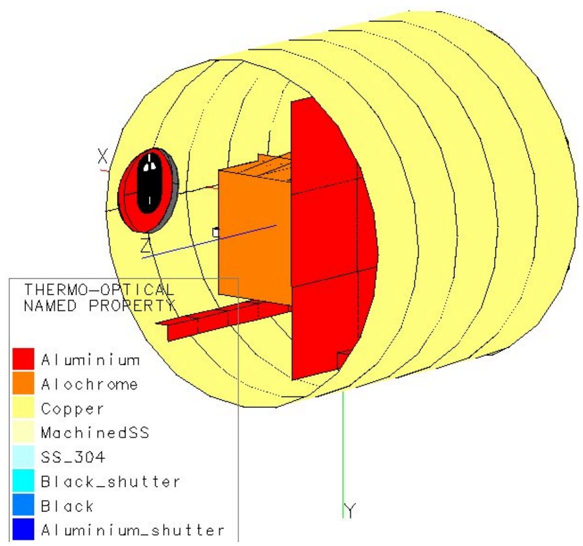


Figure 4 - Spire, the HOB and 12K shield

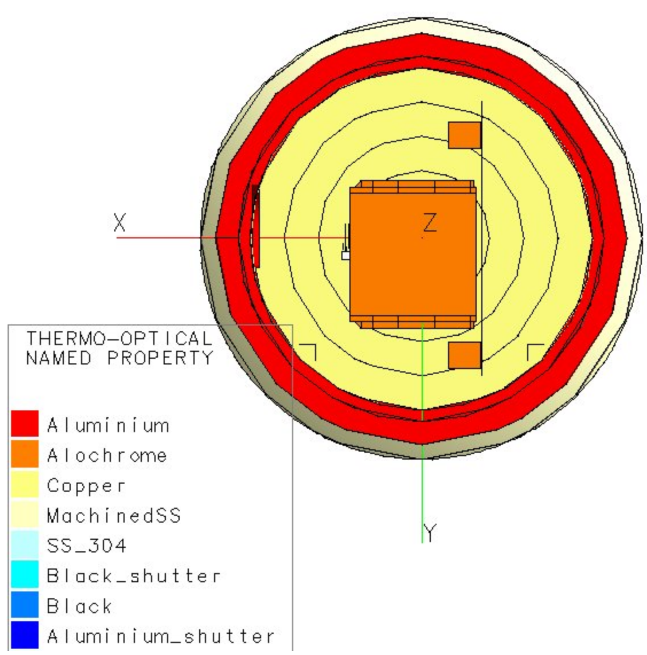


Figure 5 - Spire, HOB, 12K shield, LN2 shield and vacuum vessel

5. Thermal Mathematical Model

5.1 Nodal Breakdown

In addition to the nodes defined in the geometric model spire22.erg and in the "Spire Cryogenic" ITMM, the following elements have been added into the thermal mathematical model:

- Frame supporting the Hob plate inside the cryostat,
- Top ends of support feet.

For the purpose of the analysis, some nodes definitions in the "Spire Cryogenic" ITMM have been adapted for the new thermal model:

- The Spire strap interfaces and HOB nodes are now diffuse nodes,
- The HOB node has been discretised into 9 nodes,
- The Level 2 shield has been discretised into 15 nodes.

Tables 3 and 4 define the new and updated nodes of the mathematical thermal model.

Number	***Name***	***Temperature (K)***
8000	Vacuum Vessel	295
7000	78K shield	78
500	78K Filter Support	78
510	78K Filter	78
2000-2004	L2 Herschel Shield	12
11000	L1 Helium Tank	4.2
10000	LO Helium Tank	1.7

Table 3 - Boundary Nodes

Node Number	***Node Name***	***Material***	***Ref***
From 7010 to 7014	LN2 Shield side 1	Al 5083	-
From 7020 to 7024	LN2 Shield side 2	Al 5083	-
6000	L0 Strap Interface – Cooler Evap	Copper	*2.6*
5000	L0 Strap Interface – Cooler Pump	Copper	*2.6*
4000	L0 Strap Interface – Detectors Enc	Copper	*2.6*
3000	L1 strap Interface - FPU	Copper	*2.6*
From 2010 to 2014	L2 Shield side 1	OHFC	-
From 2020 to 2024	L2 Shield side 2	OHFC	-
From 1001 to 1009	Hob Simulation Plate	Al 5083	*2.0*
From 731 to 738	Front Frame Side 1	Al 6082T6	*2.2*
From 741 to 748	Front Frame Side 2	Al 6082T6	*2.2*
750	Front Frame Top	Al 6082T6	*2.2*
755	Front Frame Top 2	Al 6082T6	*2.2*
From 751 to 753	Front Frame Bottom	Al 6082T6	*2.2*
From 701 to 708	Rear Frame Side 1	Al 6082T6	*2.2*
From 711 to 718	Rear Frame Side 2	Al 6082T6	*2.2*
From 760 to 765	Front Rail Support	Al 6082T6	*2.0*
From 770 to 775	Back Rail Support	Al 6082T6	*2.0*
780,781,782,783	Top Foot Supports	SS304	*2.4*
From 430 to 450	12K Filter	Polypropylene	*2.8*
490	12K Filter Support	Aluminum	*2.8*

Table 4 - Diffuse Nodes

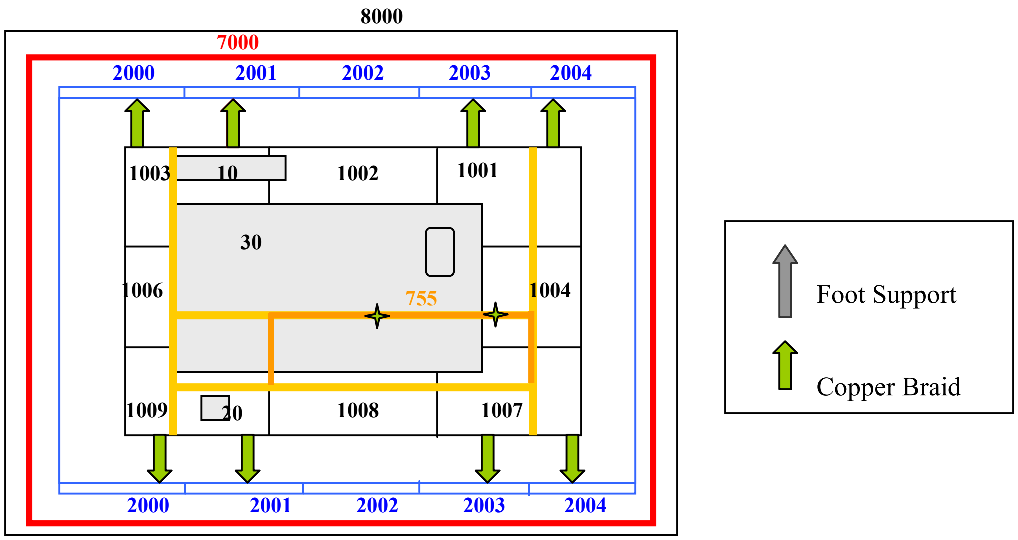


Figure 6 – Nodal Breakdown

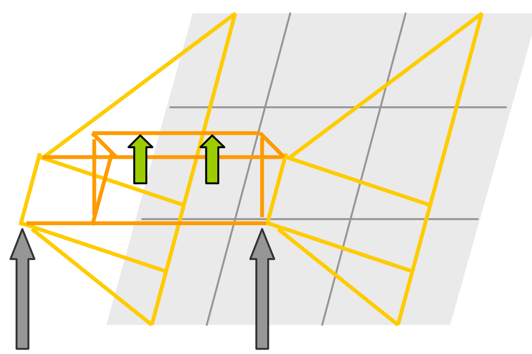


Figure 7 – Simplified Front Frame Geometry and foot support contacts

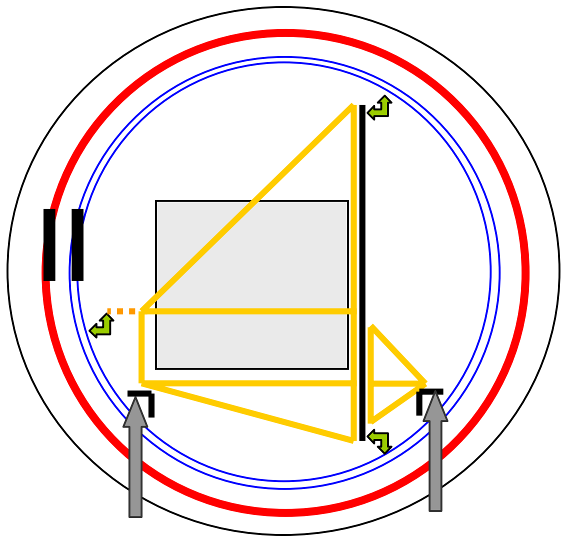


Figure 8 – 12 K Shield Copper Braids

5.2 Conductive Couplings

Tables 5 and 6 define the new and updated GL and GR of the mathematical thermal model.

1st Node	*2nd Node*	*Description*	*Material*	*X-Section (m^2)*	*Length (m)*	*Ref*
1003	10	PH JFET Bolted Interface	Al-Al	4 bolts	-	*2.6*
1009	20	SM JFET Bolted Interface	Al-Al	4 bolts	-	*2.6*
1003	30	FPU Support Feet	Stainless Steel	2.65E-5	0.04	*2.6*
1004	30	FPU Support Feet	Stainless Steel	2.65E-5	0.04	*2.6*
1006	30	FPU Support Feet	Stainless Steel	2.65E-5	0.04	*2.6*
1009	30	FPU Support Feet	Stainless Steel	2.65E-5	0.04	*2.6*
1007	40	RF Filter Harness	Stainless Steel	0.0000072222	0.2	*2.6*
8000	780	Vacuum Vessel - Top Foot Support	Geff [+]	-	-	*2.4*
8000	781	Vacuum Vessel - Top Foot Support	Geff [+]	-	-	*2.4*
8000	782	Vacuum Vessel - Top Foot Support	Geff [+]	-	-	*2.4*
8000	783	Vacuum Vessel - Top Foot Support	Geff [+]	-	-	*2.4*
771	780	Back Rail - Top Foot Support	Al-Al	1Bolt	-	*2.4*
774	781	Back Rail - Top Foot Support	Al-Al	1Bolt	-	*2.4*
761	782	Front Rail - Top Foot Support	Al-Al	1Bolt	-	*2.4*
764	783	Front Rail - Top Foot Support	Al-Al	1Bolt	-	*2.4*
775	704	Back Rail - Back Frame side 1	Al-SS-Al	-	-	*2.12*
770	714	Back Rail / Back Frame side 2	Al-SS-Al	-	-	*2.12*
765	737	Front Rail / Front Frame side 1	Al-SS-Al	-	-	*2.12*
760	747	Front Rail / Front Frame side 2	Al-SS-Al	-	-	*2.12*
1001	734	HOB – Front Frame Side 1	Al-Al	4 Bolts	-	*2.9*
1004	735	HOB – Front Frame Side 1	Al-Al	2 Bolts	-	*2.9*
1007	736	HOB – Front Frame Side 1	Al-Al	1 Bolt	-	*2.9*
1003	744	HOB – Front Frame Side 2	Al-Al	4 Bolts	-	*2.9*
1006	745	HOB – Front Frame Side 2	Al-Al	2 Bolts	-	*2.9*
1009	746	HOB – Front Frame Side 2	Al-Al	1 Bolt	-	*2.9*
1007	701	HOB – Back Frame Side 1	Al-Al	3 Bolts	-	*2.9*
1007	702	HOB – Back Frame Side 1	Al-Al	1 Bolt	-	*2.9*
1007	703	HOB – Back Frame Side 1	Al-Al	1 Bolt	-	*2.9*
1009	711	HOB – Back Frame Side 2	Al-Al	3 Bolts	-	*2.9*
1009	712	HOB – Back Frame Side 2	Al-Al	1 Bolt	-	*2.9*
1009	713	HOB – Back Frame Side 2	Al-Al	1 Bolt	-	*2.9*
1001	2004	HOB - 12 K Shield Strap	Copper	0.025 x 0.005	0.19	-
1001	2003	HOB - 12 K Shield Strap	Copper	0.025 x 0.005	0.19	-

[+] *To simplify the mathematical model, the foot supporting the Hob in the cryostat has been investigated separately (foot_support_g.erg and FootSupport.d) and its effect has then been integrated into the thermal model as an effective thermal link Geff between the vacuum vessel and the top of the foot support.*

1st Node	2nd Node	Description	Material	X-Section (m^2)	Length (m)	Ref
1003	2001	HOB - 12 K Shield Strap	Copper	0.025 x 0.005	0.19	-
1003	2000	HOB - 12 K Shield Strap	Copper	0.025 x 0.005	0.19	-
1007	2004	HOB - 12 K Shield Strap	Copper	0.025 x 0.005	0.19	-
1007	2003	HOB - 12 K Shield Strap	Copper	0.025 x 0.005	0.19	-
1009	2001	HOB - 12 K Shield Strap	Copper	0.025 x 0.005	0.19	-
1009	2000	HOB - 12 K Shield Strap	Copper	0.025 x 0.005	0.19	-
755	2003	Front Frame 2 - 12 K Shield Strap	Copper	0.025 x 0.005	0.19	-
755	2004	Front Frame 2 - 12 K Shield Strap	Copper	0.025 x 0.005	0.19	-
764	2001	Front Rail Support – 12K Shield Strap	Copper	0.025 x 0.005	0.37	-
764	761	Copper Bridge between front rail ends	Copper	0.025 x 0.005	0.37	-
771	2000	Back Rail Support – 12K Shield Strap	Copper	0.025 x 0.005	0.17	-
774	2004	Back Rail Support – 12K Shield Strap	Copper	0.025 x 0.005	0.17	-
3000	11000	L1 Strap Interface – L1 He pipe	Copper	0.025 x 0.005	0.05	-
4000	10000	L0 Strap Interface 1.7K Enc – L0 He pipe	Copper	0.025 x 0.005	0.05	-
5000	10000	L0 Strap Interface Cooler Pump – L0 He pipe	Copper	0.025 x 0.005	0.05	-
6000	10000	L0 Strap Interface Cooler Evap – L0 He pipe	Copper	0.025 x 0.005	0.05	-

Table 5 - GL Links

In addition to the GR couplings resulting form the Esarad model, the following GR links have been added:

1st Node	2nd Node	Description	Area		Emissivity		GR
			A1	A2	$\varepsilon 1$	$\varepsilon 2$	
100	30	PH Det Enc - Spire	0.443191	1.370225	0.28	0.28	0.0412283
120	30	PH Det - Spire	0.067154	1.370225	0.28	0.28	0.00644149
100	120	PH Det Enc - PH Det	0.443191	0.067154	0.28	0.28	0.00866974
110	30	SP Det Enc - Spire	0.170304	1.277006	0.28	0.28	0.174615
130	30	SP Det - Spire	0.044770	1.277006	0.28	0.28	0.00404592
110	130	SP Det Enc - SP Det	0.170304	0.044770	0.28	0.28	0.00518646

Table 6 - GR Links

6. Heat switches Couplings

Gas heat switches are used between the cooler pump, the evaporator and level 0. These heat switches are passively in the ON state as long as their temperature is above 16K. Below this temperature, the switches are in the OFF state but can be actively set to ON by applying heat to them.

When in the OFF state, the conductive link consists of:

- Conduction through support tube,
- Radiation between concentric tubes.

When in the ON state, the conductive link consists of:

- Conduction through support tube,
- Radiation between concentric tubes,
- And predominantly, conduction through Helium gas.

Description	*Link Description*				*Ref*
	X Section (m^2)	*Length (m)*	*Emissivity*	*Material*	
Gas Conduction	0.00061	0.0001	-	Helium3	*2.10*
Conduction through Support Tube	2.23053E-6	0.05	-	Titanium	*2.10*
Radiation Across Concentric Tubes	6.61934E-4	-	0.1	Copper	*2.10*

Table 7 – Heat Switches Thermal Links

7. Strap interface design

The L1 Strap interface of the calibration cryostat should be designed as to allow its temperature to be controlled within the range 4.2 - 5.5 K. The proposed design consists in adding a high impedance interface between the L1 Strap interface and the copper braid to the Helium Pipe as described in figure 9.

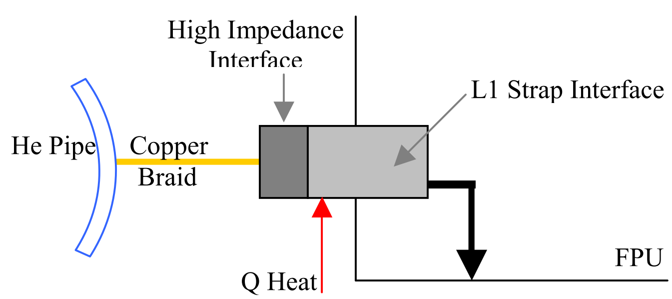
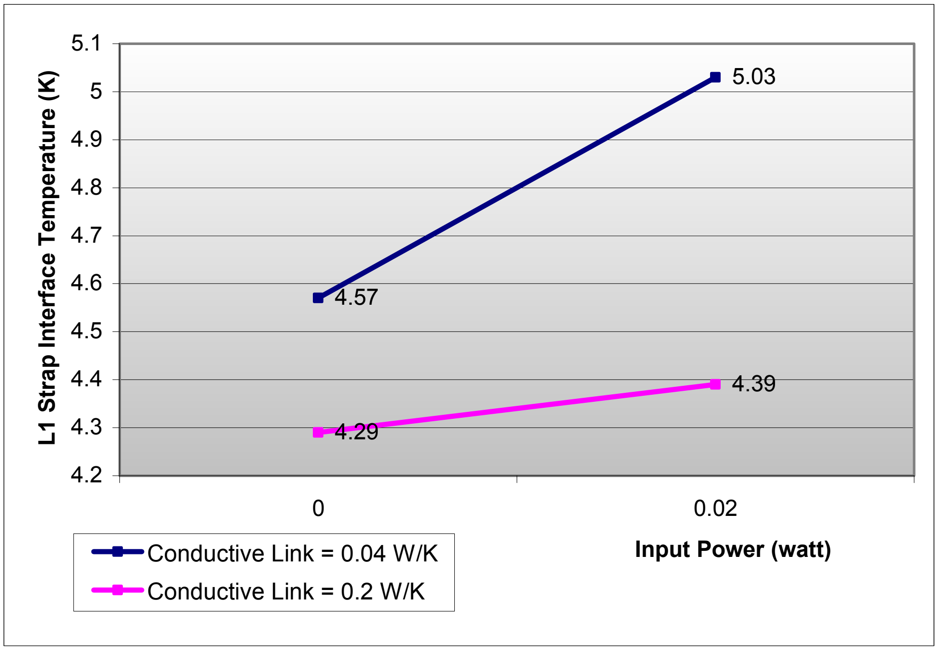


Figure 9 – L1 Strap Interface Design

During operation, this high impedance interface would reduce the amount of heat needed to increase the L1 interface's temperature, without shortening the cryostat's life. In the other hand, this impedance would increase the time required for the L1 interface and the FPU to cool down to 4.2 K. A trade-off study has therefore been performed for various conductive links from the L1 strap interface to the Helium Pipe [GL(3000,11000)] as well as for various power inputs to the L1 interface, as described in the graph 1.



Graph 1 – L1 Strap Interface Design Trade-off

In the first case, the 0.04 W/K conductive coupling between the L1 interface and the helium pipe consists on a copper braid [25 mm x 5 mm cross section with 50 mm in length] in series with a high conductance interface [60mm in diameter and 1 mm thick]. In the second case, the 0.2 W/K conductive coupling between the L1 interface and the helium pipe consists on a copper braid [12.5 mm x 5 mm cross section with 100 mm in length]. For both cases, the change in temperature of the L1 interface has been investigated for an input power of 0 and 20 mW.

<u>Note</u>: As the purpose of this study was to give a first insight of the temperatures that could be reached for a given impedance and input power, the coupling has been defined as simple constants and the capacitance of the interface [copper braid + high impedance] has not been included.

The results of the trade-off analysis have shown that:

- The lower the conductive link, the better the increase in temperature of the interface for a given amount of heat:
  For 20mW input power onto the L1 interface, a ΔT of 0.46 K can be achieved with a low conductive link of 0.04 while only $\Delta T = 0.1$ K is reached for an higher conductive link of 0.2.

However,

- The lower the conductive link, the more difficult it is for the interface to reach an operating temperature of 4.2 K:
  A conductive link of 0.2 allows the L1 interface to stabilize at 4.29K while the lower conductive link allows the L1 interface to stabilize at 4.57K only. In addition, a transient analysis also showed that for such a low conductive link, the L1 interface would require 83.3 hrs to cool down to 96.5K compare to 20 hrs without impedance.

8. Analysis Cases

8.1 Cool-down Simulation Description

For the cool down simulation, an initial temperature of 295 K has been assumed for any components of the model. The boundary nodes temperatures representing the Spire Calibration cryostat have then been cooled at a fixed rate of 20 K/hr until they reach their operating temperatures. The boundaries temperatures are then held constant for the remainder of the simulation.

The following briefly describes the cool down process used for the simulation:

- Cool down of the LN2 Shield, L2 Shield and He tanks (7000, 2000-2004, 11000 and 10000) at a 20 K/hr until the LN2 shield reaches 78 K,
- Keep all boundaries at 78K until the SOB reaches 85 K,
- Cool down the L2 shield and Helium tanks temperatures (2000-2004,11000,10000) at 20 K/hr, until the L2 shield reaches 12K,
- Keep the L2 shield temperature at 12K while the L1 and L0 He Tanks continue to cool down at 20K/hr,
- When 4.2 K is reached by the L1 He tank, stop cooling it and keep its temperature at 4.2K,
- Cool down the L0 He tank at 20 K/hr until it reaches 1.7K.

In addition, the heat switches are passively in the ON state from 295 to 20K. At this point, 2 mW are applied to actively keep them in the ON state. This is necessary in order that the highly isolated Level 0 stages and detectors continue to cool below 20K at a similar rate to the other L0 components. Once the detectors reach 2K, the heat switches are then switched to the OFF state (stop the 2 mW input).

The transient analysis was concerned with the period of time that is required for various components of the system to cool down at their final operating temperature. Appendices A3, A4 and A5 describe the cool down of various components (using a baseline definition: k braid = k foot = 1).

8.2 Steady state Analysis

Six different case studies have been carried out for the steady state analysis as described in table 8. The first three allowed to evaluate the impact of the Spire heat loads on the cryostat when Spire is ON. For these cases, the boundary temperature of the Level 2 Shield has been adapted as to match the Spire test temperatures *[Ref 2.13]*. These three cases have also been performed with a baseline temperature of 12K for the level 2 shield (results available if needed).
Three sensitivity studies have also been performed to give an insight of the importance of the conductive links between the HOB and the Level 2 shield (k braid) as well as between the vacuum vessel and the rail (k foot). For these three analyses, the Level 2 shield temperature was set to 12K as a baseline.
Finally, a simulation with the rail supports coupled to the 12K shield has been performed as to analyze the reduction in temperature gradients introduced by the foot support in the rails and frame structure. For this last study, two copper braids [25 mm x5 cross section with 170 mm length] were attached to the back rail near the foot support contact area and linked to the Level 2 shield in the provided emplacements. For the front rail, one copper braid [25 mm x 5 mm cross section with 370 mm length] was used to link one end of the rail to the emplacement provided on the level 2 shield and a copper bridge [25 mm x 5 mm with 370mm length] has been used to link the rail extremities.

	Baseline			**Sensitivity Studies**			
Power Mode	*Spire OFF*	*Photo ON*	*Spectro ON*	*Spire OFF*	*Spire OFF*	*Spire OFF*	*Spire OFF*
L2 Shield Temp K	**6.7**	**10.3**	**9.8**	12	12	12	12
kBraid	1	1	1	0.5	1.25	1	1
kfoot	1	1	1	1	1	1.5	1
Rail	-	-	-	-	-	-	Coupled to the 12K shield via copper braids
Power Dissipation							
PH JFET	0.0	49.5	0.0	0.0	0.0	0.0	0.0
SP JFET	0.0	0.0	14.1	0.0	0.0	0.0	0.0
BSM	0.0	4.0	1.0	0.0	0.0	0.0	0.0
SMECCm	0.0	0.0	2.4	0.0	0.0	0.0	0.0
PH Calib.	0.0	0.1	0.0	0.0	0.0	0.0	0.0
SP Calib.	0.0	0.0	2.0	0.0	0.0	0.0	0.0
Pump	0.0	1.02	1.02	0.0	0.0	0.0	0.0
Shunt	0.0	0.005	0.005	0.0	0.0	0.0	0.0
Pump HS	0.0	0.2	0.2	-	-	-	-
Ref	2.6	2.6	2.6	-	-	-	-

Table 8 – Steady State Cases

Appendix A1 provides the steady states temperatures of various components of the model for each of the cases stated in table 8. A description of the main heat fluxes path is also described in Appendix A2.

9. Assumptions and uncertainties

- 10 copper braids have been used for the coupling of the hob to the shield (Cross Section of 25 mm x 5 mm and path length of 190 mm).
- Spire copper strap interfaces to the Helium heat pipes assumed to have a cross section of 25 mm x 5 mm and path length of 50 mm.
- Simplified interface frame.
- HOB Simulation Plate dimensions: 990 mm x 900 mm x 19 mm.
- L2 shield assumed to be a perfect boundary but gradients could be present between vent pipes. This factor will be investigated in future analysis.
- All boundary nodes have been cool down at a fixed rate of 20 K/hr, and have been considered as stable once their specific boundary temperature has been reached.
- Constant values have been assumed for the polypropylene material of the filter (Cp = 2343 J/kg.K and k = 0.12552 W/m.K [AD2.11]).

10. Discussion and Conclusion

The steady states results have emphasized the following:

- A very slight increase in temperature in the HOB plate is introduced by the JFET boxes when in the ON state.

- Temperature gradient in the filter of maximum 0.5K (at the center of the filter) have been detected at this stage of the analysis, but the filter material properties need more accurate data.

- A maximum temperature gradient of 0.18 K is present in the HOB plate for the baseline study with the photometers detectors in ON state.

- A maximum gradient of 2.27K is present in the LN2 shield End plates.

- The main heat input in the HOB Simulation plate comes from the vacuum vessel (at 300K) via the foot supports, which also introduce important temperature gradient along the frames (from 12.38K to 17.7K). Coupling the back rail support to the 12K shield via 2 copper braids and the front rail support via a copper braid to the 12K shield and a copper bridge along the rail has shown to greatly reduce these gradients which are now within 2K of the L2 shield temperature, but also improved the HOB simulation plate cool down and gradients.

The previous transient cool down studies (where one was waiting for the HOB to reach 85K before continuing the cooling down) had shown the following:

- It takes about 26.5 hrs for the HOB Simulation plate to reach 12.6 K and 29.5 hrs stabilize at 12.19 K with 10 copper braids to the 12K shield,
- The SOB requires 29.5 hrs to cool down at 4.2K,
- The photometer detectors and their enclosure however, requires a much longer time (28 hrs) to cool down to 1.7K compare to the spectrometers detectors which need about 25 hrs.

The new transient cool down simulation (where the SOB temperature control the cooling down instead of the HOB temperature) had shown the following:

- It takes about 38 hrs for the HOB Simulation plate to reach 13 K and 40 hrs stabilize at 12 K with 10 copper braids to the 12K shield,
- The SOB requires 40.5 hrs to cool down at 4.2K,

- The photometer and spectrometer detectors both need about 39 hrs to cool down to 1.7K

As a simplified thermal model for the frame has been used, the additional frame inertia in the real system would improve the final steady state temperature within the HOB Simulation plate as well as the time required to cool it down. An increased coupling between the photometer and spectrometer detectors enclosures would improve the time to cool down the photometer.

In conclusion and bearing in mind that the primary requirement for the level 1 interface is to be at 4.2 K, it has been decided that a high conductive coupling between the interface and the helium pipes would be used in conjunction with heater already available to the Helium Pipe to control the L1 interface within a 4.2K - 4.5K range of temperatures.

The table 9 gives an indication of a good coupling and also the amount of power that would be required to achieve the specified range:

Coupling Description: - Copper braid of 30 mm x 5 mm with length of 70 mm - 10 cm^2 Copper-Apiezon-Copper of contact areas between the copper braid, the L1 interface and the helium pipe.		
Input power on L1 interface (mW)	***L1 interface Temperature (K)***	***SOB temperature (K)***
0	4.24	4.27
120	4.54	4.57

Table 9

Steady State Results for the Various Cases:

	Power Mode	OFF	Spectro	Photo	OFF	OFF	OFF	OFF
	L2 Shield Temperature (K)	6.7	9.8	10.3	12	12	12	12
	K braid	1	1	1	0.5	1.25	1	1
	k foot	1	1	1	1	1	1.5	1
	Rail	-	-	-	-	-	-	Rail Coupled to 12K Shield
	Result	Baseline1	Baseline2	Baseline3	Case1	Case2	Case3	Case4
NODE	LABEL	T (K)	T (K)	T (K)	T (K)	T (K)	T (K)	T (K)
10	PH_JFET_ENCLOSURE	6.79	9.87	11.21	12.1	12.02	12.06	11.98
20	SP_JFET_ENCLOSURE	6.99	10.27	10.48	12.28	12.12	12.22	12
30	FPU_OPTICAL_BENCH	4.21	4.24	4.24	4.25	4.24	4.25	4.24
40	RF_FILTER_BOXES	4.23	4.29	4.3	4.35	4.35	4.35	4.34
50	BSM	4.21	4.29	4.45	4.25	4.24	4.25	4.24
60	SMECm	4.21	4.36	4.24	4.25	4.24	4.25	4.24
70	PH_CALIB	4.21	4.29	4.46	4.25	4.24	4.25	4.24
80	SPEC_CALIB	4.21	25.57	4.24	4.25	4.24	4.25	4.24
90	SHUTTER	4.21	4.24	4.24	4.25	4.24	4.25	4.24
100	PH_DETECTOR_ENCLOSURE	1.72	1.72	1.72	1.72	1.72	1.72	1.72
110	SP_DETECTOR_ENCLOSURE	1.71	1.71	1.71	1.71	1.71	1.71	1.71
120	PH_DETECTORS	1.71	1.71	1.71	1.71	1.71	1.71	1.71
130	SP DETECTORS	1.71	1.71	1.71	1.71	1.71	1.71	1.71
160	COOLER_PUMP	1.7	1.72	1.72	1.7	1.7	1.7	1.7
170	COOLER_SHUNT	1.7	1.7	1.7	1.7	1.7	1.7	1.7
180	COOLER_EVAP	1.71	1.71	1.71	1.71	1.71	1.71	1.71
190	COOLER_PUMP_HS	1.7	1.72	1.72	1.7	1.7	1.7	1.7
200	COOLER_EVAP_HS	1.7	1.7	1.7	1.7	1.7	1.7	1.7
430	12 K filter	6.7	9.8	10.3	12	12	12	12
431	12 K filter	7.14	10.24	10.74	12.44	12.44	12.44	12.44
432	12 K filter	6.7	9.8	10.3	12	12	12	12
433	12 K filter	6.7	9.8	10.3	12	12	12	12
434	12 K filter	7.18	10.28	10.78	12.48	12.48	12.48	12.48
435	12 K filter	6.7	9.8	10.3	12	12	12	12
436	12 K filter	6.7	9.8	10.3	12	12	12	12
437	12 K filter	7.14	10.24	10.74	12.44	12.44	12.44	12.44
438	12 K filter	6.7	9.8	10.3	12	12	12	12
439	12 K filter	7.13	10.23	10.73	12.43	12.43	12.43	12.43
440	12 K filter	6.7	9.8	10.3	12	12	12	12
441	12 K filter	6.7	9.8	10.3	12	12	12	12
442	12 K filter	7.13	10.23	10.73	12.43	12.43	12.43	12.43
443	12 K filter	7	10.1	10.6	12.3	12.3	12.3	12.3
444	12 K filter	6.7	9.8	10.3	12	12	12	12
445	12 K filter	7	10.1	10.6	12.3	12.3	12.3	12.3
446	12 K filter	6.7	9.8	10.3	12	12	12	12
447	12 K filter	7.01	10.1	10.6	12.3	12.3	12.3	12.3

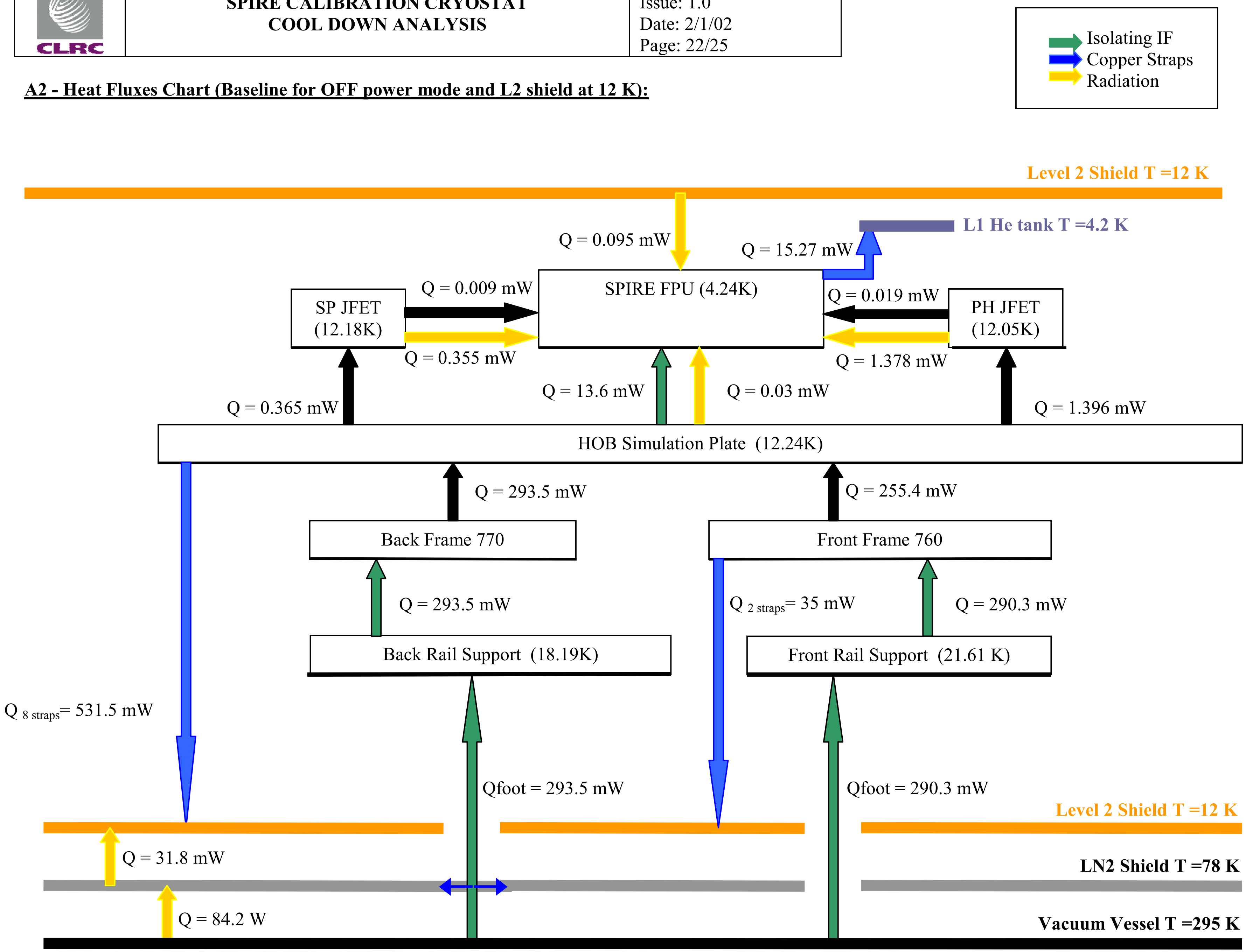
	Result	Baseline1	Baseline2	Baseline3	Case1	Case2	Case3	Case4
NODE	LABEL	T (K)	T (K)	T (K)	T (K)	T (K)	T (K)	T (K)
448	12 K filter	6.7	9.8	10.3	12	12	12	12
449	12 K filter	7	10.1	10.6	12.3	12.3	12.3	12.3
450	12 K filter	6.7	9.8	10.3	12	12	12	12
490	Filter Support	6.7	9.8	10.3	12	12	12	12
500	LN2 Filter Support	78	78	78	78	78	78	78
510	78 K filter	78	78	78	78	78	78	78
701	Rear Frame Side 1	9.62	11.86	12.24	13.77	13.63	14.37	12.02
706	Rear Frame Side 1	10.32	12.34	12.72	14.25	14.11	15.09	12.03
707	Rear Frame Side 1	10.59	12.61	12.99	14.52	14.38	15.49	12.03
708	Rear Frame Side 1	10.55	12.58	12.96	14.49	14.34	15.43	12.03
711	Rear Frame Side 2	9.62	11.87	12.24	13.77	13.63	14.37	12.02
712	Rear Frame Side 2	9.51	11.81	12.19	13.72	13.58	14.3	12.02
713	Rear Frame Side 2	9.51	11.81	12.19	13.72	13.58	14.3	12.02
714	Rear Frame Side 2	11.01	13.04	13.41	14.94	14.8	16.11	12.04
715	Rear Frame Side 2	10.32	12.35	12.72	14.25	14.11	15.09	12.03
716	Rear Frame Side 2	10.32	12.35	12.72	14.25	14.11	15.09	12.03
717	Rear Frame Side 2	10.59	12.62	12.99	14.52	14.38	15.49	12.03
718	Rear Frame Side 2	10.55	12.58	12.96	14.49	14.34	15.43	12.03
731	Front Frame Side 1	11.34	13.1	13.51	15.11	14.99	16.39	12.14
732	Front Frame Side 1	12.12	13.76	14.18	15.81	15.71	17.45	12.18
733	Front Frame Side 1	9.11	11.16	11.59	13.25	13.16	13.71	12.06
734	Front Frame Side 1	7.34	10.32	10.77	12.44	12.35	12.53	12.02
735	Front Frame Side 1	9.45	11.54	11.95	13.54	13.44	14.1	12.07
736	Front Frame Side 1	9.38	11.56	11.96	13.55	13.43	14.08	12.07
737	Front Frame Side 1	13.85	15.53	15.94	17.56	17.45	20	12.26
738	Front Frame Side 1	10.38	12	12.43	14.07	13.97	14.89	12.1
741	Front Frame Side 2	11.46	13.24	13.65	15.23	15.12	16.61	12.21
742	Front Frame Side 2	12.28	13.93	14.35	15.96	15.86	17.72	12.26
743	Front Frame Side 2	9.2	11.21	11.66	13.29	13.2	13.78	12.08
744	Front Frame Side 2	7.36	10.33	10.81	12.45	12.37	12.55	12.02
745	Front Frame Side 2	9.55	11.61	12.03	13.6	13.49	14.19	12.1
746	Front Frame Side 2	9.48	11.62	12.03	13.6	13.48	14.18	12.1
747	Front Frame Side 2	14.1	15.77	16.19	17.79	17.68	20.12	12.39
748	Front Frame Side 2	10.45	12.08	12.52	14.14	14.04	15.02	12.14
750	Front Frame Top	7.89	10.47	10.9	12.64	12.55	12.82	12.03
751	Front Frame Bottom	12.12	13.67	14.09	15.75	15.65	17.41	12.24
752	Front Frame Bottom	10.78	12.25	12.68	14.38	14.28	15.38	12.14
753	Front Frame Bottom	11.33	12.84	13.26	14.95	14.85	16.2	12.15
755	Front Frame Top2	6.83	9.91	10.39	12.16	12.06	12.11	12
760	Front Rail	21.43	22.24	22.5	23.48	23.42	27.34	13.23
761	Front Rail	21.95	22.75	23	23.99	23.92	28.1	13.36
762	Front Rail	21.94	22.74	23	23.98	23.92	28.09	13.22
763	Front Rail	21.94	22.74	22.99	23.98	23.91	28.09	13.08

	Result	Baseline1	Baseline2	Baseline3	Case1	Case2	Case3	Case4
NODE	**LABEL**	**T (K)**	**T (K)**	**T (K)**	**T (K)**	**T (K)**	**T (K)**	**T (K)**
764	Front Rail	21.93	22.73	22.98	23.97	23.91	28.08	12.93
765	Front Rail	21.41	22.21	22.46	23.45	23.39	27.32	12.85
770	Back Rail	20.26	21.06	21.2	21.8	21.75	24.91	12.2
771	Back Rail	20.78	21.57	21.72	22.32	22.26	25.67	12.22
772	Back Rail	20.78	21.57	21.72	22.32	22.26	25.67	12.22
773	Back Rail	20.78	21.57	21.72	22.32	22.26	25.67	12.22
774	Back Rail	20.78	21.57	21.72	22.32	22.26	25.67	12.22
775	Back Rail	20.26	21.06	21.2	21.8	21.75	24.91	12.2
780	Top Support Back	24.7	25.34	25.46	25.96	25.91	28.8	19.13
781	Top Support Back	24.7	25.34	25.46	25.96	25.91	28.8	19.13
782	Top Support Front	25.65	26.31	26.53	27.36	27.3	30.93	19.83
783	Top Support Front	25.64	26.3	26.51	27.34	27.29	30.91	19.56
1001	Hob Plate	6.8	9.88	10.37	12.12	12.04	12.08	12
1002	Hob Plate	6.87	9.93	10.42	12.17	12.07	12.14	12
1003	Hob Plate	6.8	9.88	10.4	12.12	12.04	12.08	12
1004	Hob Plate	7.07	10.05	10.52	12.29	12.17	12.28	12
1005	Hob Plate	6.99	10.01	10.49	12.25	12.13	12.23	12
1006	Hob Plate	7.07	10.06	10.54	12.29	12.17	12.29	12
1007	Hob Plate	6.99	10.01	10.48	12.29	12.12	12.23	12
1008	Hob Plate	6.99	10.01	10.48	12.27	12.13	12.23	12
1009	Hob Plate	6.99	10.02	10.48	12.29	12.12	12.23	12
2000	Inner 12K Shield	6.7	9.8	10.3	12	12	12	12
2001	Inner 12K Shield	6.7	9.8	10.3	12	12	12	12
2002	Inner 12K Shield	6.7	9.8	10.3	12	12	12	12
2003	Inner 12K Shield	6.7	9.8	10.3	12	12	12	12
2004	Inner 12K Shield	6.7	9.8	10.3	12	12	12	12
2010	Inner 12 K Shield Side 1	6.7	9.8	10.3	12	12	12	12
2011	Inner 12 K Shield Side 1	6.7	9.8	10.3	12	12	12	12
2012	Inner 12 K Shield Side 1	6.7	9.8	10.3	12	12	12	12
2013	Inner 12 K Shield Side 1	6.7	9.8	10.3	12	12	12	12
2014	Inner 12 K Shield Side 1	6.7	9.8	10.3	12	12	12	12
2020	Inner 12 K Shield Side 2	6.7	9.8	10.3	12	12	12	12
2021	Inner 12 K Shield Side 2	6.7	9.8	10.3	12	12	12	12
2022	Inner 12 K Shield Side 2	6.7	9.8	10.3	12	12	12	12
2023	Inner 12 K Shield Side 2	6.7	9.8	10.3	12	12	12	12
2024	Inner 12 K Shield Side 2	6.7	9.8	10.3	12	12	12	12
3000	L1_IF_FPU	4.2	4.21	4.22	4.22	4.22	4.22	4.22
4000	L0_IF_Enclosures	1.7	1.7	1.7	1.7	1.7	1.7	1.7
5000	L0_IF_Pump	1.7	1.71	1.71	1.7	1.7	1.7	1.7
6000	L0_IF_Evaporator	1.7	1.7	1.7	1.7	1.7	1.7	1.7
7000	LN2 Shield	78	78	78	78	78	78	78
7010	LN2 Shield Side 1	80.95	80.95	80.95	80.95	80.95	80.95	80.95
7011	LN2 Shield Side 1	80.77	80.77	80.77	80.77	80.77	80.77	80.77
7012	LN2 Shield Side 1	80.34	80.34	80.34	80.34	80.34	80.34	80.34

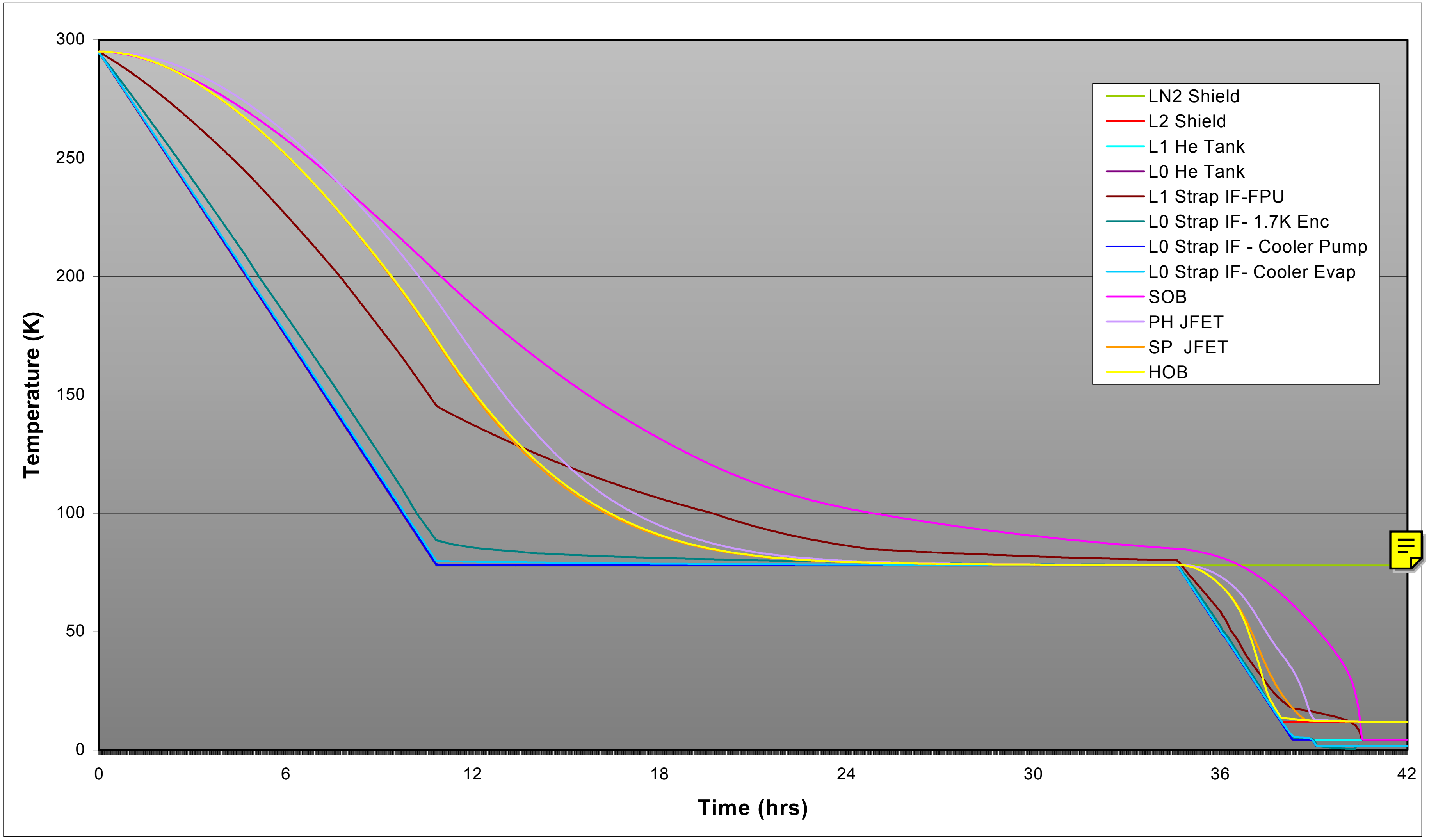
	Result	Baseline1	Baseline2	Baseline3	Case1	Case2	Case3	Case4
NODE	LABEL	T (K)	T (K)	T (K)	T (K)	T (K)	T (K)	T (K)
7013	LN2 Shield Side 1	79.64	79.64	79.64	79.64	79.64	79.64	79.64
7014	LN2 Shield Side 1	78.68	78.68	78.68	78.68	78.68	78.68	78.68
7020	LN2 Shield Side 2	80.95	80.95	80.95	80.95	80.95	80.95	80.95
7021	LN2 Shield Side 2	80.77	80.77	80.77	80.77	80.77	80.77	80.77
7022	LN2 Shield Side 2	80.33	80.33	80.33	80.33	80.33	80.33	80.33
7023	LN2 Shield Side 2	79.64	79.64	79.64	79.64	79.64	79.64	79.64
7024	LN2 Shield Side 2	78.68	78.68	78.68	78.68	78.68	78.68	78.68
8000	Vacuum Vessel	295	295	295	295	295	295	295
10000	L0 Helium Tank	1.7	1.7	1.7	1.7	1.7	1.7	1.7
11000	L1 Helium Tank	4.2	4.2	4.2	4.2	4.2	4.2	4.2
99998	INACTIVE_NODE	0	0	0	0	0	0	0
99999	DEEP_SPACE_NODE	-270	-270	-270	-270	-270	-270	-270

Table 10 – Steady State Temperatures

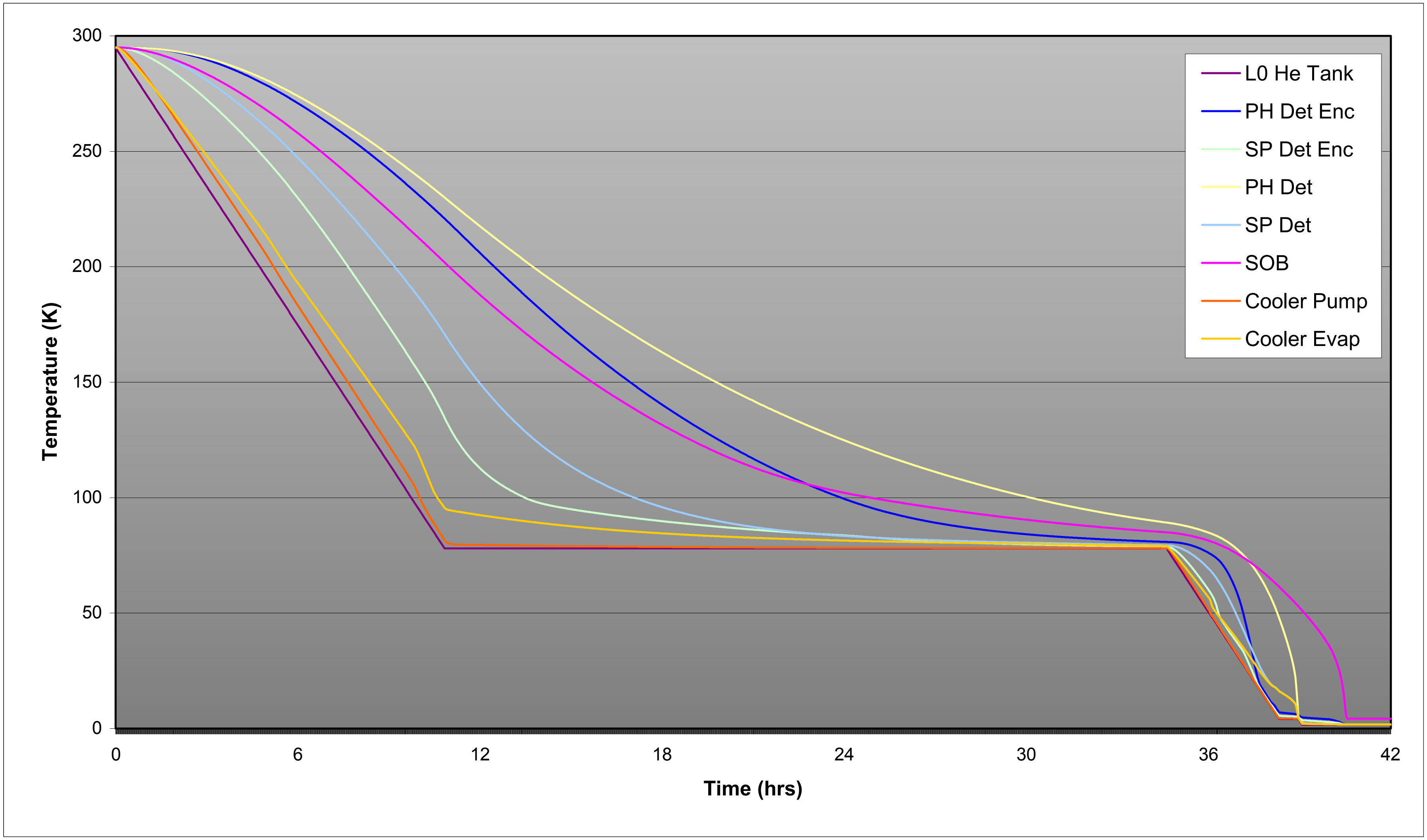
A2 - Heat Fluxes Chart (Baseline for OFF power mode and L2 shield at 12 K):



A3 - Transient Results (Baseline for OFF power mode and L2 shield at 12 K):



A4 - Transient Results (Baseline for OFF power mode and L2 shield at 12 K):



A5 – Shields End Plates Transient Results (Baseline for OFF power mode and L2 shield at 12 K):