Summary:
In this note I have brought together all the information we have on the requirements on the thermal straps from the SPIRE cooler to the helium tank and the interpretation of this by Astrium. I've also brought in the subsequent analysis of the impact of the conductance on the cooler performance by Anneso and her most recent evaluation of the strap as currently designed.

The short version of the problem is:
The recommendation by Lionel is that the strap conductance is ~100 mW/K TOTAL from the evaporator to the tank. Astrium will only guarantee 200 mW/K for their bit leaving the SPIRE part another 200 mW/K if we are to meet the recommended performance. This performance for the SPIRE part looks unlikely under any circumstances given the need for electrical isolation etc so we are taking a performance of 150 mW/K in the thermal model. The design as it stands appears to provide only ~30 mW/K due to the copper alone – not including any degradation to the performance from the electrical isolation. This is not acceptable because, as discussed by Lionel (see e-mail below), a poor conductance down this link will directly impact on the recycling efficiency of the cooler and, as shown by Anne-Sophie, lead to an increased load on the 300 mK stage. Both of these effects will lead to a reduced hold time for the cooler where we already have negative margin.

Possible solutions:
We now need to take action to greatly improve the thermal conduction of both the evaporator and pump straps if the instrument is to work correctly. One possibility is to use aluminium: even this doesn't quite get us to the recommended performance but it's much better than copper and leads to improved performance for the cooler. Using aluminium for the stiff part of the strap would seem to be a straightforward exchange (especially as this is the baseline for Astrium) – using aluminium for the flexible links is not so obvious.

The other difficult area is the electrical isolation – the proposed single sandwich again doesn't appear to be good enough based on published data and a better "multi-layer" design should be considered.

Cost and Schedule:
Doing anything to the design of instrument at this stage will clearly have an effect on the cost and the schedule – indeed it may now be too late for the STM. It would appear that this is an area that calls for a Project Team co-ordinated approach to come up with an optimised design for at least the CQM if not the STM instrument whilst minimising the impact as much as possible on cost and schedule across the project as a whole. It must be emphasised however that we cannot accept the design as it presently stands.

Specification for the Cooler Straps:
The original specification for the straps came from an e-mail from Lionel reproduced below (Appendix I). ESA released the IID-B on the 20th September 2000 with no reference to the actual value for the strap conductance. After much argy-bargy, the following sentence appears in the notorious ECR09 which we take as our requirement on the TOTAL conductance from the cooler interface to the helium tank.

> A thermal strap of 0.1W/K is recommended for the evaporator strap, and 0.05W/K for the pump strap. The detector strap must be also 0.05W/K for a tank at 1.7K.

However, and here's the rub, this was not translated into a specific requirement on either the Astrium or the SPIRE part of the strap.

An assumption was made in the thermal model on the A/L and interface conductance values. These assumptions are now shown to be optimistic because a) the interface point has moved and b) electrical isolation has now been introduced. Additionally Astrium have reported (at the interface meetings HP-ASPI-MN-2298) that achieving very much more than 150 mW/K on just their part of the connection will be difficult. The design goal is still to have 100 mW/K for the total strap but we must accept that we may not reach this and the thermal modelling will reflect this from now on.

Analysis of present design and possible improvements
Anne-Sophie has done an analysis of the strap conductance that we would have with the MSSL proposed design (see appendix II) – it is much lower than required and some attention must be paid to its design. Anne-Sophie has looked using pure aluminium of the same dimensions for both the "stiff" part of the strap and the flexible link (Appendix II *et seq.*). If the literature values are correct, this would appear to offer a good improvement over copper, however, the dimensions of the strap still need to be increased to meet the requirement.

The electrically isolating joint as proposed is for a single layer of stycast sandwiched between the high conductivity parts of the bolted interface. This too appears to give a lower conductance value than required given the information available from the literature. There may be new data from Cardiff but we don't seem to have it. A possible solution to the electrically isolating joint is to use a multi-layer construction which would dramatically increase the surface area of the joint without impacting on the fundamental design of the strap.

The last critical area that requires design attention is the flexible link right at the end the strap. The cross section of this is presently much too small. A possible improvement may come from the use of aluminium or it might be that a different type of flexible link could be implemented in copper.

Appendix I
Lionel's e-mail
From: Lionel Duband [duband@drfmc.ceng.cea.fr]
Sent: 27 September 2000 13:13
To: Heys, SC (Sam)
Cc: bw@mssl.ucl.ac.uk; b.m.swinyard@rl.ac.uk
Subject: STRAPS

Bonjour again again,

This is what I wrote in June (e-mail 14/06/2000):

****
As for numbers, as a first approximation you can assume that on average for CSTR1 (evaporator + shunt strap) there will be 50 mW flowing. What we want for sure is that at the end of the condensation phase the temperature is as close as possible to T cryostat (1.8 K or less). Since I don't have the exact power dissipation profile, I would say with 50 mW the temperature should not raised more than 1 K (0.05 W/K conductance).

For CSTR2 (sorption pump) it is less critical. We could use a similar strap, but one with say 10 mW/K should do.

****

In the light of our recent measurements:

** CSTR1 - if you look at the temperature profile you see that at the end of the recycling phase there was still about 20 mW flowing to the cold plate. Of course we could have waited longer until the temperature of the evaporator dropped close to 1.8 K (and in this case the flowing power would obviously be less) but we wanted to show we could recycle in less than 2 hours.*
In any case for now to assume 20 mW and a T not in excess of 0.2 K seems reasonable. This turns into a conductance at 2 K of 100 mW/K (or 0.01 K/mW).
If one assume k = 5 T W/(cm.K) (they can probably do better) and 40 cm long, it corresponds to a 40 mm2 strap.

** CSTR2 - here we have more flexibility, however I think we do not want the temperature at the end of this strap to raise too high, since it will probably be close to the other one (conductive path), it will radiate, etc....*
So let's assume it will not go higher than say 8 or 10 K at the peak power.
Let's assume this peak is 400 mW, then we end up with about 50 mW/K.

Then there are all the contact conductance, so I suggest it is better to oversize a little bit the strap.

How does this sound ?.

Cheers

Lionel

Appendix II

SPIRE L0 Flexible Strap Design Analysis – Overview
19-12-02
Anne-Sophie Goizel

Current MSSL Design:

- L0 external straps cross section: 20 mm x 3 mm, copper
- L0 flexible straps cross section: 10 mm x 1 mm, copper

For information, the thermal conductivity of the copper used in the SPIRE DTMM for this analysis is about 700 W/m.K at 1.8K.

Assumptions: the two interfaces (cooler/flexible strap and flexible strap/external strap) have been assumed to be copper/copper as a starting point with a conductance of 0.144 W/K at 1.8K (ref – Cardiff University measurements). No electrical Insulation included as limited amount of data available in this area.

Description	Cross Section mm x mm	Length mm	Material Cond (W/m.K)	Interface Cond (W/K)	Sub-Total (W/K)
Cooler/Flexible	-	-	Cu/Cu	0.144	0.144
L0 Flexible	10 x 1	76	700	-	0.09
Flexible/External	-	-	Cu/Cu	0.144	0.144
L0 Evap External	20 x 3	322.5	700	-	0.13
				Total	0.031

Conductance description

Mode	Spectrometer	Photometer
Total Cooler (microW)	40.52	37.56

Cooler Loads

The overall 150 mW/K conductance for the L0 evaporator strap is not achieved with this design.

A same analysis has been done with the copper replaced by pure un-annealed aluminium – the straps have been defined with same dimensions as above. For information, the thermal conductivity of the aluminium used in the SPIRE DTMM for this analysis is about 5000 W/m.K at 1.8K.

Description	Cross Section mm x mm	Length mm	Material Cond (W/m.K)	Interface Cond (W/K)	Sub-Total (W/K)
Cooler/Flexible	-	-	Cu/Al	0.144	0.144
L0 Flexible	10 x 1	76	5000	-	0.66
Flexible/External	-	-	Al/Al	0.144	0.144
L0 Evap External	20 x 3	322.5	5000	-	0.93
				Total	0.061

Conductance description

Mode	Spectrometer	Photometer
Total Cooler (microW)	39.17	36.43

Cooler Loads

The overall 150 mW/K conductance for the L0 evaporator strap is not achieved with this design but increasing the material conductivity saved between 1.1 and 1.3 microW on the total cooler load. Please note that identical interface conductance have been used for a comparison purpose. At this time of the analysis, it was not clear weather Al/Cu and Al/Al interfaces can achieve such a conductance at 1.8K.

Current SPIRE ITMM Design:

In this specific case, the L0 strap dimensions, material and interface conductances have been selected in order to meet the 150 mW/K requirement on the evaporator strap. They do not represent any physical design or baseline.

- L0 external straps cross section: 25 mm x 3 mm, aluminium
- L0 flexible straps cross section: 10 mm x 3 mm, aluminium
- Interface conductance: 0.4 W/K

Description	Cross Section mm x mm	Length mm	Material Cond (W/m.K)	Interface Cond (W/K)	Sub-Total (W/K)
Cooler/Flexible	-	-	Cu/Al	0.4	0.4
L0 Flexible	10 x 3	76	5000	-	1.97
Flexible/External	-	-	Al/Al	0.4	0.4
L0 Evap External	25 x 3	322.5	5000	-	1.16
				Total	~0.157

Conductance description

Mode	Spectrometer	Photometer
Total Cooler (microW)	38.2	35.65

Cooler Loads

The overall 150 mW/K conductance for the L0 evaporator strap is achieved with this design and between 1.9 and 2.3 microW have been saved on the total cooler load.
While changing the strap dimensions to the ones specified in the above table does not appear to be a major issue, the stated interface conductances are. In addition, the fact that those joints should also include an electrical insulation makes the matter even more complex.

For information, the following data has been used and stated previously as a starting point with regard to electrical insulating joint conductance:

Ref – ISO report on Electrically insulating joints

Copper/Epoxy/Copper – 2 mm thick Stycast 1266
~ 0.006 W/cm2.K at 1.8K, for 6 cm2 contacting area at L0 interfaces:
~ 0.035 W/K

Sensitivity Analysis on Spire Level 0 Straps
AS Goizel
09-10-02

This sensitivity analysis has been done with the current spire detailed thermal model (spir20ntrm.d) integrated into the Herschel reduce thermal model (eplmntrm.d).

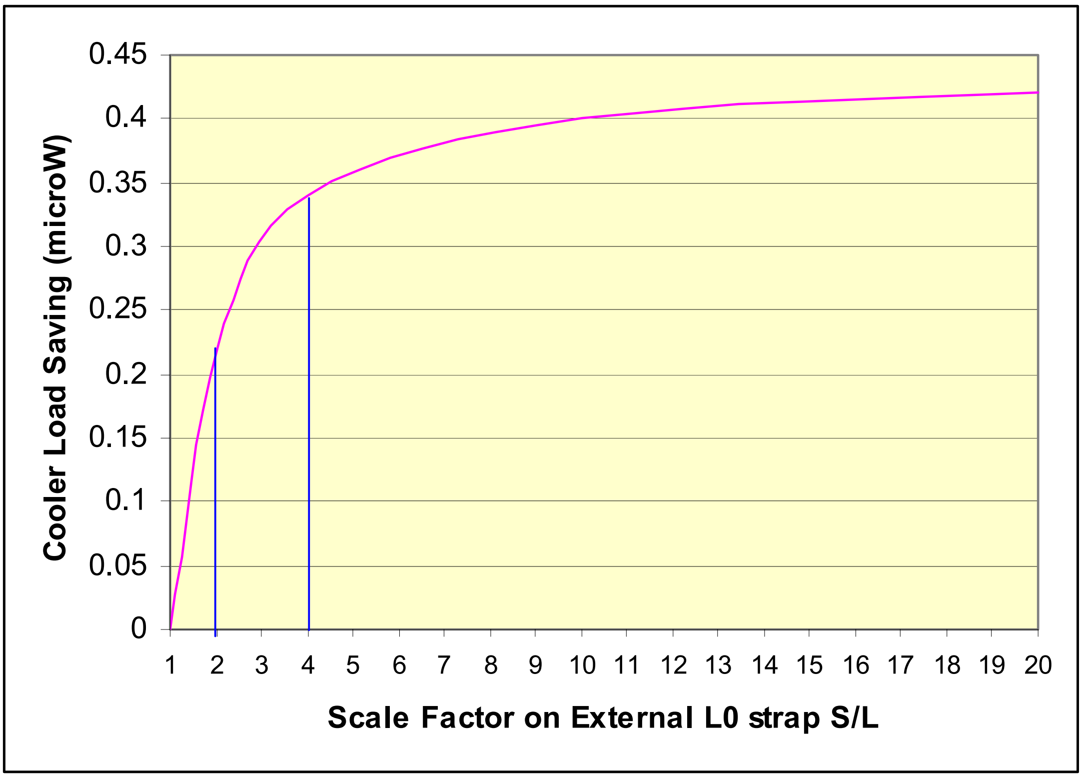
The total cooler load has been assessed for different scaling factor (from 2 to 20) on the following straps components S/L:

- Internal flexible copper straps (3 of them),
- Internal strap between the spectrometer enclosure and the photometer enclosure,
- L0 external straps to the interface (3 of them).

Each runs has been done with the Spire instrument running in Spectrometer mode, as this mode has now become the worst case in terms of total cooler load.

<u>Sensitivity Analysis on External L0 Strap A/L</u>

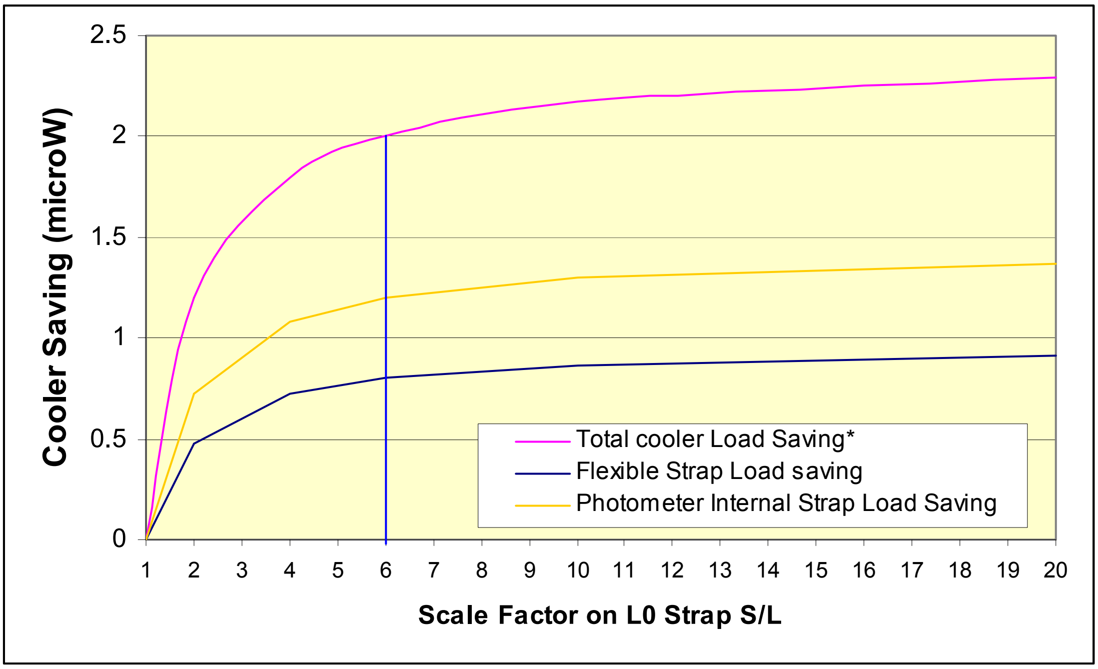
Initial Straps Cross section: 20 mm x 3 mm each, of varying length between 180 and 290 mm.



As shown in the graph above, doubling the conductance of the external L0 strap would allow a 0.225 microW saving on the total cooler load, while an applied factor of 4 would save ~ 0.4 microW.

Sensitivity Analysis on L0 internal Strap A/L

Initial flexible straps S/L (SOB Cover to Spec Enclosure):
10 mm2 and 76 mm in length each (3 straps)
Initial photometer internal strap S/L (Spec Enclosure to Phot Enclosure):
9 mm2 and 198 mm in length.



** When the scaling factor is applied to both the flexible strap and the internal photometer enclosure strap at the same time.*

The blue curve describes the impact of changing the L0 internal flexible straps S/L on the total cooler load. The same analysis has been done on the internal strap connecting the spectrometer enclosure to the photometer enclosure, as shown by the yellow curve.

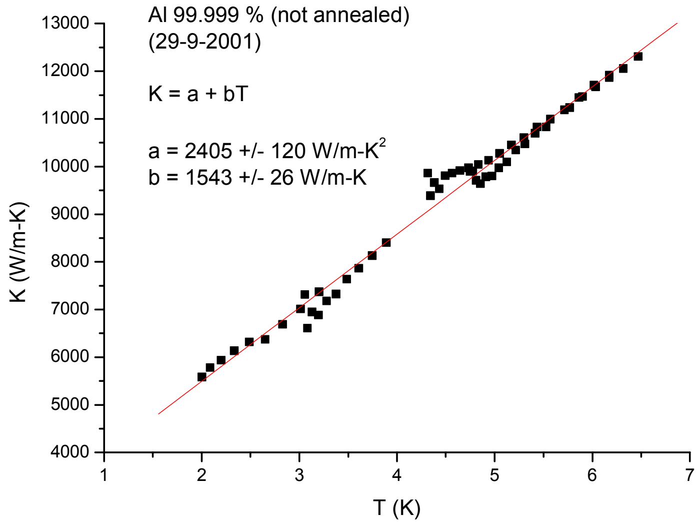
From this graph we can see that for an identical applied scale factor, the change in photometer strap has more impact on the cooler load saving than the change in flexible strap.

If a scaling factor of 6 is applied at both the flexible and the photometer straps at the same time, a 2 microW total cooler load saving can be reached of which,

- ~ 40% of the heat load saving comes from the reduction in Spectrometer and Photometer L0 Enclosure temperatures caused by the higher conductance flexible strap,
- ~ 60% comes from the reduction in Photometer L0 Enclosure temperature caused by the higher conductance photometer strap.

Increasing the conductivity of the internal strap material could be a solution to reduce the total cooler load, if changing the strap dimensions does not appear feasible. However the conductivity of the copper used in this analysis is between 700 and 800 W/mK in the 1.8K and 2K range, which is already relatively high. Higher purity annealed copper with, for example, RRR of 2000 can have a thermal conductivity as high as 5000 W/mK @ 2K, but this is unlikely to be achieved in practice.

An alternative solution is a change to pure, unannealed aluminum, where a purity of >99.999% appears to give superior conductivity to annealed copper of the same purity over the temperature range of interest. The graph below gives an indication of the thermal conductivity of Pure Aluminium in the 2 K temperature range:



Thermal conductivity (W/m-K) of Aluminium (99.999% pure) based on measurements SRON. (Reference: Martin Linder email on 10-10-02).

The table below gives an indication of the current thermal conductivity of the L0 copper strap:

Average Temperature (K)	***High Purity Copper (W/mK)***	***L0 Straps***
1.83 K	700	Flexible Copper Strap
1.9 K	730	Internal Photometer Strap

Current L0 Straps Thermal Conductivity

Taking into account that with a better conductance the average temperatures of the strap will slightly reduce, it is safe to use a thermal conductivity of Aluminium of about 5000 W/mK for comparison purpose.

If the use of such Aluminium is possible for the L0 straps, then without modifying the current strap dimensions:

- A 6.8 factor increase in Photometer internal strap conductance could be achieved,
- A 7.1 factor in flexible straps conductance could be achieved.

As a result, changing the L0 strap material for un-annealed Pure Aluminium would allow a 2 microW saving in total cooler load.