Introduction

The SPIRE instrument will employ five bolometer arrays to detect radiation between 200 and 670 µm. In order to function correctly these arrays need the be cooled to 300 mK from the base temperature of the FIRST liquid helium cryostat of ~1.7-2 K. To achieve this a ^{3}He sorption cooler will be fitted to the SPIRE instrument. This will be provided by CEA-SBT, Grenoble and is similar in design to the one that flew on the Japanese IRTS experiment. The design of the cooler was presented at the SPIRE PDR in July 1999.*

The PDR review board highlighted the cooler sub-system as a potential single point failure for the SPIRE instrument and asked the instrument team to look at the possibilities for reducing the risk of total loss of instrument function. This note attempts to set out the constraints and options for the provision of cooler redundancy.

System Constraints

The major limitation on the provision of cooler redundancy is the extremely limited amount of space available. The 100x100x200mm envelope of the cooler can be accommodated – just – within the overall envelope of the instrument box. Fitting in a second cooler or a large increase in the envelope for the cooler will be very difficult to accommodate.

The second system constraint on the cooler is the thermal load on the liquid helium tank. The present design gives an average load of about 3 mW over the operational cycle. About 1 mW of this is the constant parasitic load and the other 2 mW comes from the recycling of the sorption pump. The SPIRE consortium is currently considering one of three options for the bolometer arrays – these have rather different thermal loads onto the liquid helium tank.

The total worst case thermal load from SPIRE into the helium tank is, including the cooler, about 10 mW for one of the detector options; the GSFC TES type. For another of the options, the JPL/Caltech spider web bolometers, the load comes entirely from the cooler and the structure parasitic load. Any increase in the load onto the helium bath has a direct effect on the mission lifetime and any increase must be strongly justified on the grounds of reliability, especially in the case where the cooler is the dominant load.

Other systems constraints such as wiring; mass; warm electronics etc are likely to be of second order difficulty compared to the envelope and thermal dissipation problems.

Options for redundancy

The possible options for providing a reliable cooler are described in this section. They range from two extremes – complete redundancy i.e. two separate coolers – to limited redundancy i.e. a single cooler as shown in the PDR with some extra components.

* The vu-graphs from the PDR presentation are available from the SPIRE project office on request if you don't have DMS access.

1. **Two coolers to all detectors:**
   In this option two complete cooler units would be fitted each of them connected to the thermal circuit that connects all five detector arrays. It is assumed that there would be no extra redundancy in the heat switches between the evaporator and the pump and the 2-K temperature stage. This option should provide insurance against any single random failure in any part of either cooler and still allow full operation of the instrument.

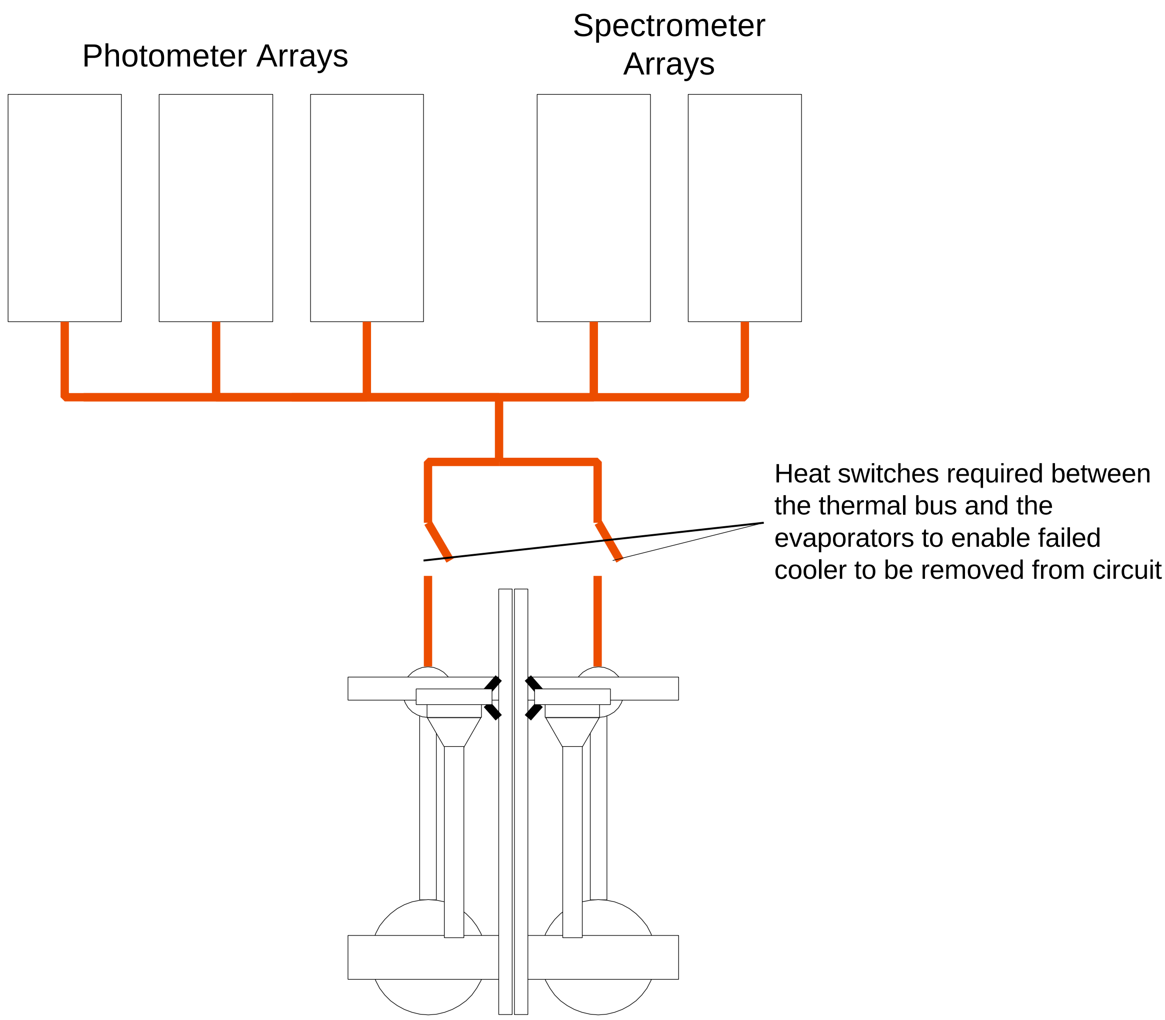

Figure 1: Option of two coolers in parallel for all five detector arrays

2. **Two coolers one for photometer one for spectrometer**
   Here the two sub-instruments each has its own cooler – again the assumption is that there would be no extra redundancy in the heat switches for the evaporator and pump in either of the coolers. This option would leave one or other of the sub-instruments operating in the event of a random failure in any part of either cooler.

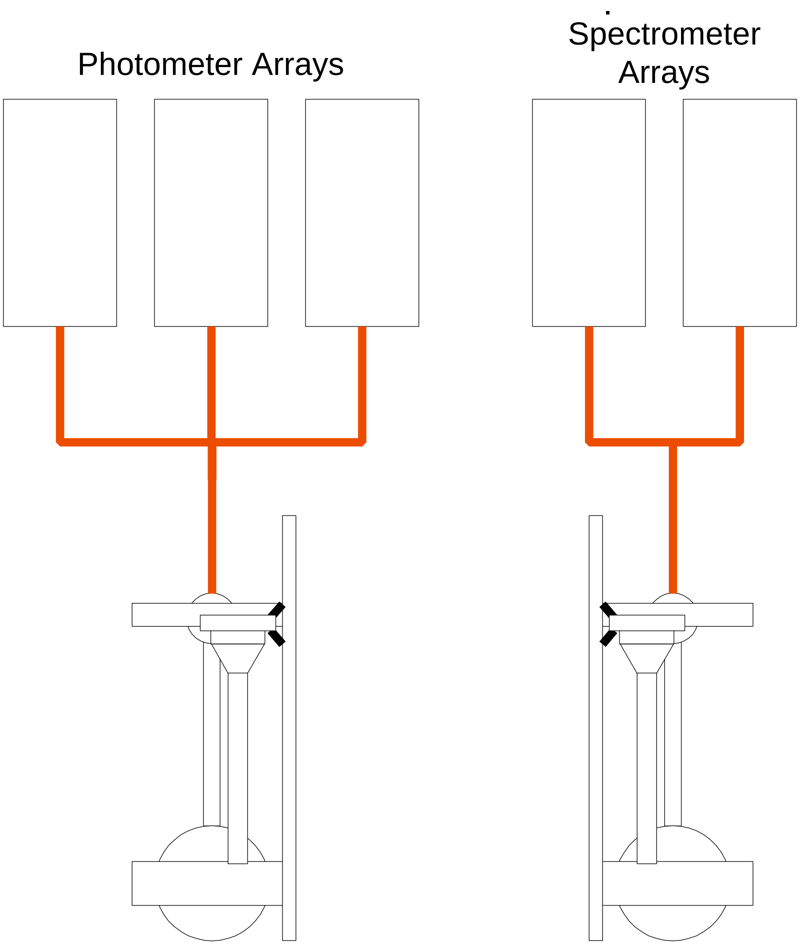

Figure 2: Option of one cooler for photometer arrays and one for the spectrometer arrays

3. **Single cooler with fully redundant heat switches and heaters**
   In this option a single cooler is used with two serial pairs of heat switches in parallel on both the evaporator and the pump. In this way a failure of any one heat switch in the ON configuration – leading to a thermal shunt between the 2-K stage and the detectors – could be isolated by having its pair in serial switched off. The cooler would then be operated using the parallel pair of switches. In addition a second heating element could be provided as insurance against random failure of the pump heater. This option gives protection against random failure in all cooler elements except a rupture of the pumping line or poisoning of the pump charcoal.

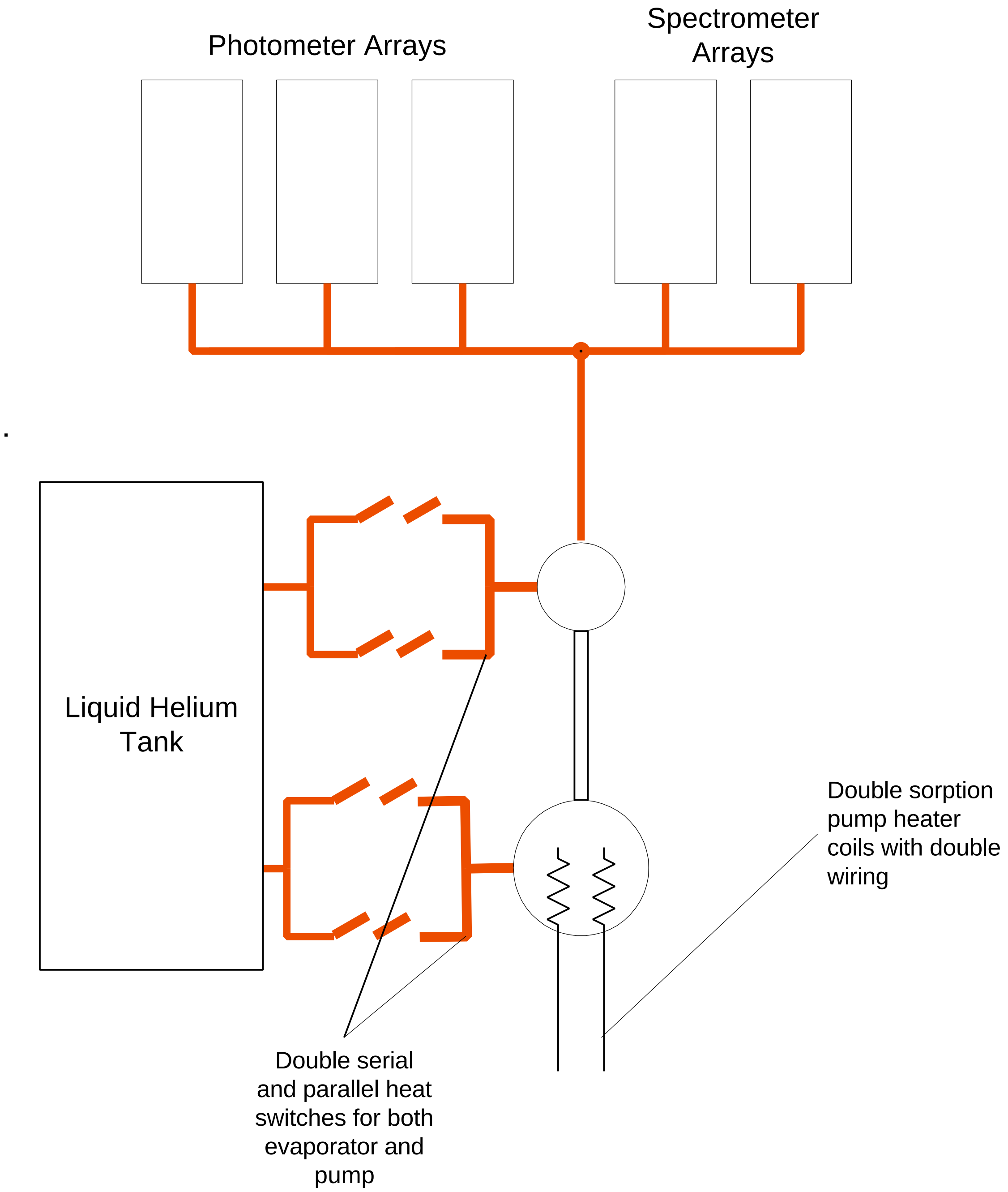

Figure 3: Option for fully redundant heat switches and pump heater elements

4. **Single cooler with partially redundant heat switches and fully redundant heater.**
   If we make the assumption that the failure of a heat switch can only occur by either a failure of the sorption pump or by the concentric shells touching with a weak thermal contact; then fully redundant serial pairs may not be necessary. In this option there are only parallel pairs of heat switches on the evaporator and pump and a double heating element in the pump. This protects against a random failure in any single heat switch if, and only if, the assumption stated here is correct. If a heat switch fails in such a way as to connect the evaporator to the 2-K stage the instrument is lost. If a heat switch fails connecting the pump to the 2-K stage, the instrument may still be able to function with reduced efficiency and increased thermal load on the liquid helium tank (*Lionel – comment?)*.

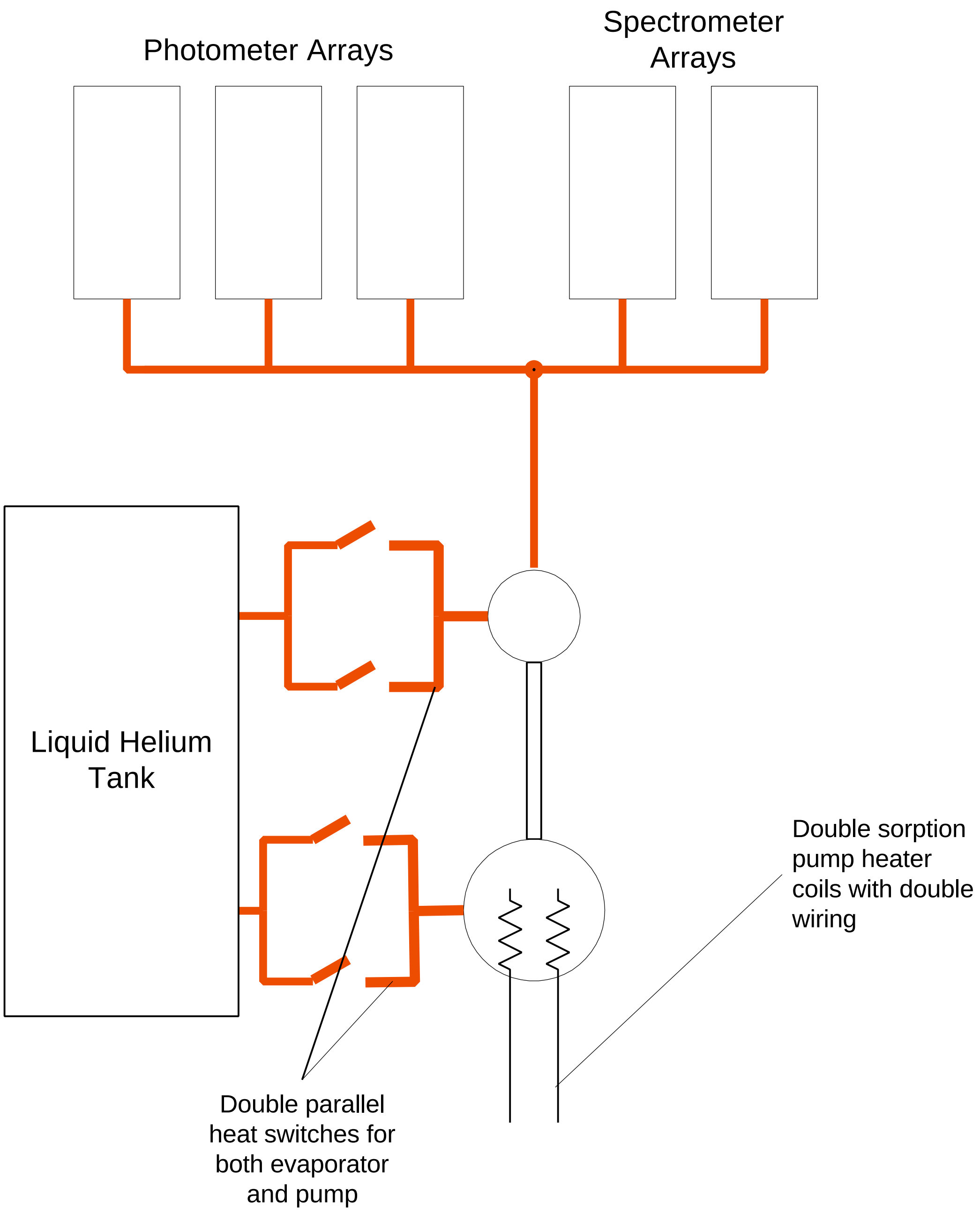

Figure 4: Option for partially redundant heat switches and fully redundant pump heating elements.

5. Single cooler with redundant heating elements and single heat switches

This is essentially the cooler as presented at the PDR with the addition of an extra heating element in the pump. In the event of a failure of either heat switch sorption pump all instrument operation is lost. If there is a failure of the evaporator heat switch with a large thermal conductance the instrument is also lost. One could imagine a variation on this design that would offer more protection if it were possible to have two separate sorption pumps on each heat switch.

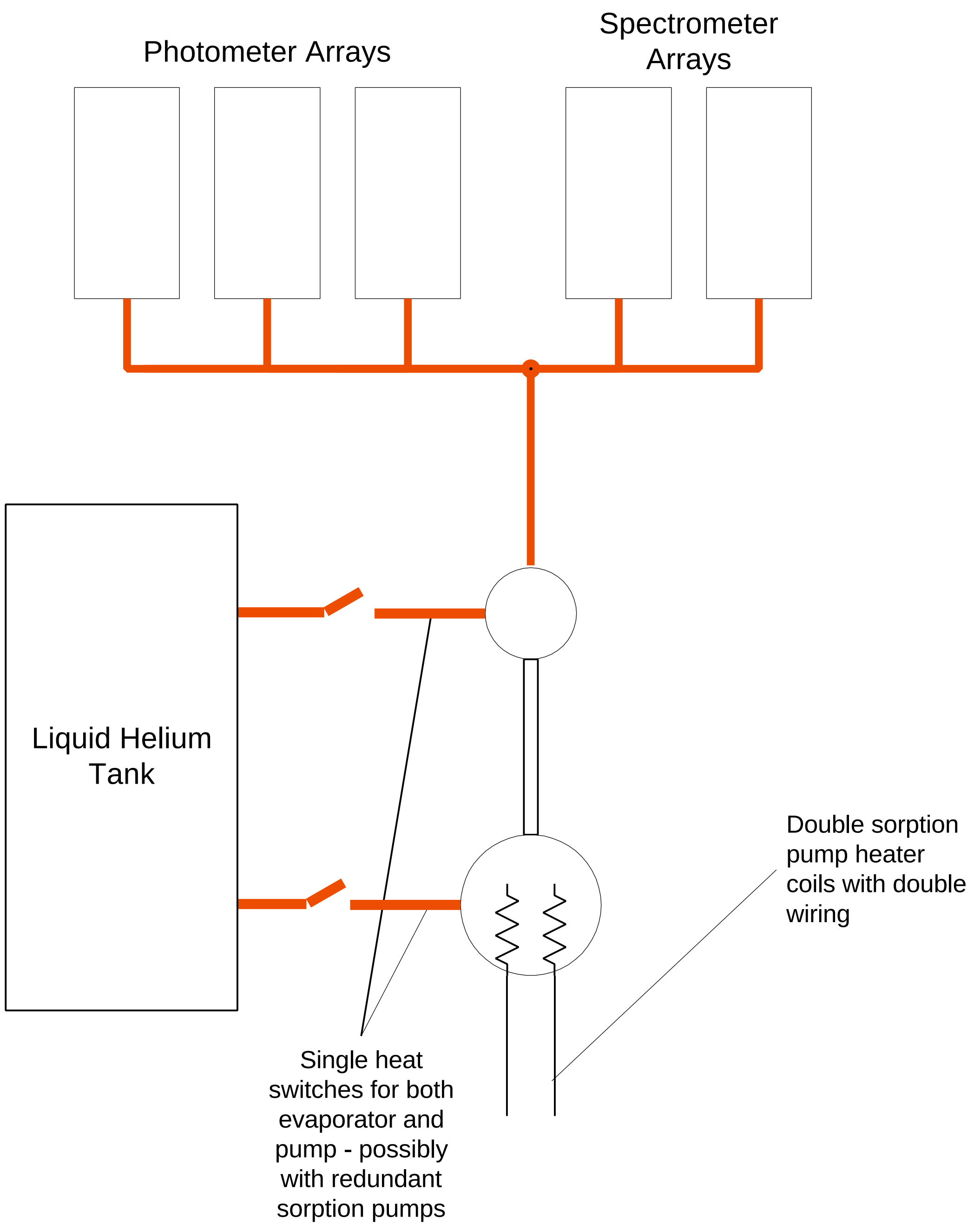

Figure 5: Option for present baseline with redundant pump heating elements and possibly redundant sorption pumps on the single heat switches.

6. **Single cooler with double pump chamber**
   Another variation on all the single cooler options would be to have a second complete pump unit on a single pumping line to the evaporator. This, in addition to insuring against failure of the heater element, would be presumed to give protection against poisoning of the charcoal in one or other of the pumps. I'm not sure that this assumption is valid as, without invoking the use of a vacuum valve, they would share the same gas. Therefore any contamination would likely end up in both pumps.

Assessment of the options

Here I give an assessment of the advantages and disadvantages of each of the options in terms of how well in insures against loss of the instrument and its impact on the system with respect to the current baseline. I have weighted the various items according to difficulty for the overall instrument design and impact on the overall reliability of the instrument. In doing the weighting I have considered that the most likely **random** failure modes, and therefore the ones that will attract higher scores if the option gives good redundancy, are (in order):

– Loss of pump heater element
– Loss of heat switch sorption pump heater element
– Launch failure of heat switch causing low thermal conductance across switch
– Launch failure of heat switch causing high thermal conductance across switch
– Poisoning of pump charcoal
– Rupture of pressure system
– Mechanical failure in Kevlar support system

Table 1 gives an assessment of the relative merits of the various options. For the systems issues a negative score has been given to each option in a range according to the adjudged severity of the systems impact of that option. For the risk reduction a single positive value is allocated to the option if it removes the perceived risk. These values are weighted between 1 and 10 depending on the estimated likelihood of the failure occurring. An additional score is given for the two cooler option 1 as it is the only one that will, potentially, remove the risk of any failure in the instrument operation for a single random failure in the cooler. This is mainly to differentiate this option from option 2.

Discussion

Estimation and interpretation of risk is, naturally, highly uncertain and this exercise is no different. However, it does show that using two coolers does not necessarily provide a total solution to our problem. This would be especially true if the true weight of "completely impossible" were given to the issue of accommodating a whole second cooler into the instrument. Adding a complete second pump also doesn't appear to offer very much advantage over doubling up the heating element in a single pump.

What is the choice between the other options? If it were possible to have redundant sorption pumps on the heat switches, my choice would be option 5 as this will have least impact on the system. If not then option 4 is the next best. Whatever else a much more thorough study on the likely failure modes of the heat switches would be extremely useful. Note that none of these options protects against a design fault in the cooler components. The only way around this would be, for instance, different heater technology for the redundant pump heating elements and a different heat switch technology for the redundant heat switches. I don't know whether this is feasible.

	Score or Range	Option 1: Two coolers all detectors	Option 2: Two coolers phot/spec	Option 3: Single cooler Full Red. HS/Heater	Option 4: Single Cooler Part. Red. HS Red Heater	Option 5: Single Cooler No red. HS Red. Heater	Option 6: Option 3-5 with red. pump Add to score
Systems Issues							
Accommodation	-10 to 0	-10	-10	-5	-3	0	-7
Thermal load	-5 to 0	-5	-3	-1	0	0	-1
Complexity	-5 to 0	-5	-3	-3	-1	0	-3
Risk Insurance		0					
Pump Heater	10	10	10	10	10	10	-
HS Sorption Pump	7	7	7	7	7	0 (7)[1]	-
HS fails on - low conductance	5	5	5	5	5	0	-
HS fails on - high conductance	3	3	3	3	0	0	-
Pump poisoning	2	2	2	0	0	0	0 (2)[2]
Pressure vessel rupture	1	1	1	0	0	0	-
Failure of Kevlar support	1	1	1	0	0	0	-
Partial instrument loss	3	3	0	0	0	0	-
Total Score	**34 (max)**	**12**	**13**	**16**	**18**	**10 (17)**	**-11 (-9)**

Table 1: Assessment of relative merits of the cooler redundancy options.

[1] If redundant sorption pump heaters can be fitted then this option gets full score.
[2] If it can be shown that the redundant pump protects against poisoning then this option gets full score.