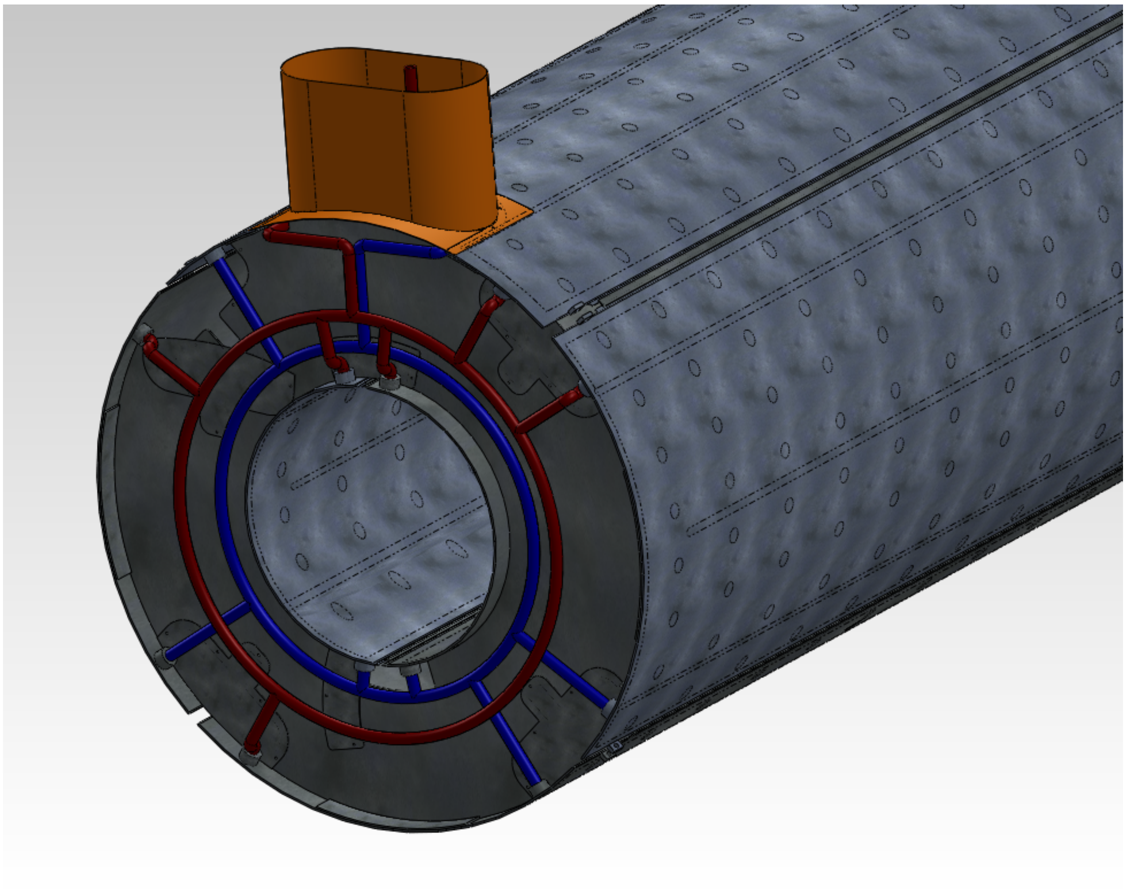
Text of the email, Frederick Forest, 28 October 2011

Blue is the incoming N2, red is the outcoming.
We have tried to put roughly the cold inlet at the bottom and the warm return at the top of each panel to help the flow (I don't remember whether it is pure thermo siphon or a forced flow under pressure)
Outer screen is made with 4 embossed panels, Inner screen is made with 2 embossed panels.
The end flanges are made with flat stainless steel disc 10 mm thick (or thinner or thicker according to your conduction calculations) welded with the embossed panel along the perimeter. It is simpler for the construction to not cool them with N2. I expect the conduction around the perimeter with the inner and outer embossed panels will be enough.



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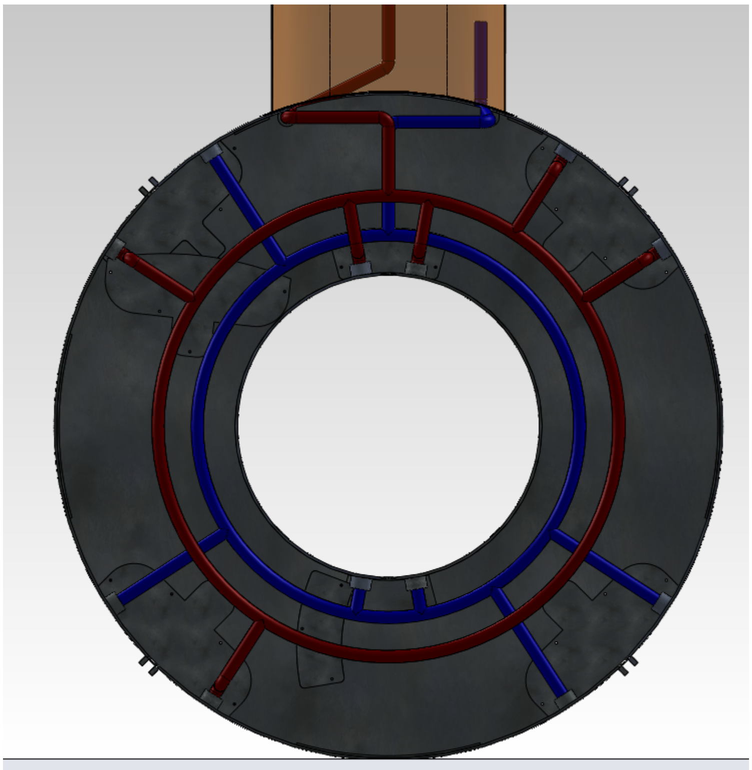

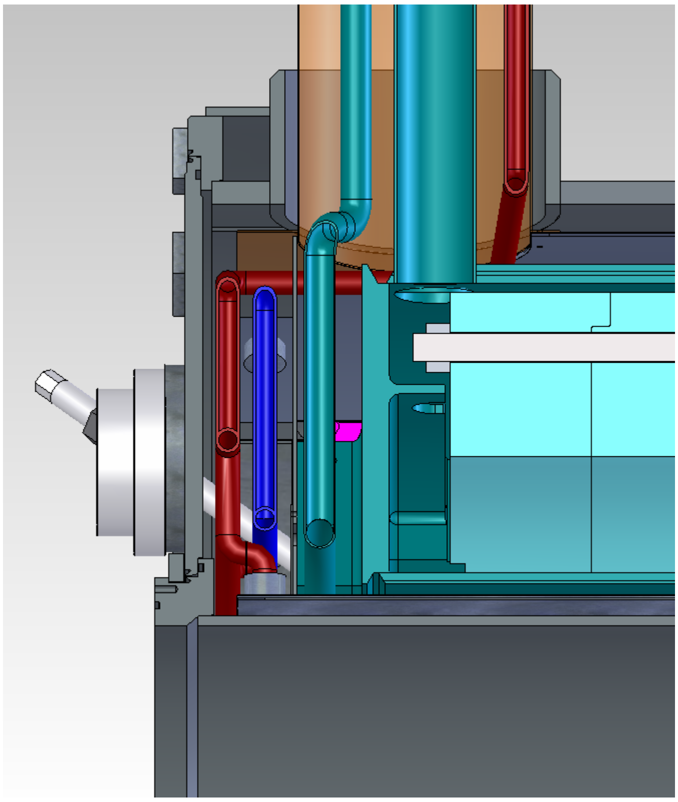

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TEMPERATURE RISE ACROSS THE END PIECE

Consider conduction across a plane with a uniform heat flux q

Material thickness t

Thermal conductivity k

Distance from the cooled edges is L

The peak temperature rise ΔT is on the line which is mid-way between the two cooled edges.

$$\Delta T = \frac{q \cdot L^2}{8 \cdot t \cdot k}$$

For the radiation screen q will have a value of about 1.2 W / m².

The thermal conductivity of stainless steel at 80 K is 8.116 W / m.K

The material thickness is 5 mm.

The outer diameter is 1 450 mm and the inner diameter 655 mm. Therefore the distance L is 397.5 mm. (Strictly this equation is a simplification for rectangular plates but it is sufficiently accurate for this analysis.)

$$\Delta T = \frac{q \times 0.3975^2 \text{ m}^2}{8 \times 0.005 \text{ m} \times 8.12 \text{ W/m.K}}$$

$$\Delta T = q \times 0.4865 \text{ K/W.m}^{-2}$$

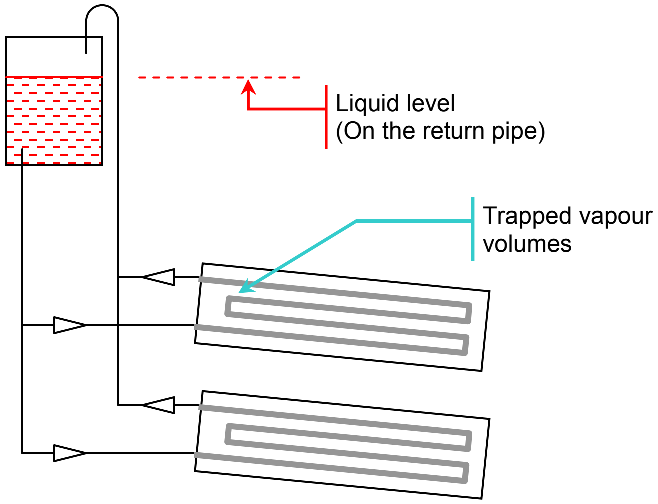
Therefore calculating ΔT for a range of heat fluxes:

At	q = 0.8 W / m²	then	ΔT = 0.4 K
At	q = 1.2 W / m²	then	ΔT = 0.6 K
At	q = 3.0 W / m²	then	ΔT = 1.5 K

1. Therefore the temperature rise on the end plate will be acceptable.
2. The edge connections must be checked that these do not introduce a temperature rise.
3. Point loads e.g. due to the supports should be linked to the embossed panels which are cooled by liquid nitrogen. If they are linked to the end plates then the temperature rise due to the heat load should be calculated.

FLOW CONFIGURATION

The distribution of the flow during cooldown and steady state operation is a concern. A simplified schematic of the system is shown below.



The return pipe opens above the liquid level in the reservoir. There will be a matching liquid level in the return pipe. Therefore the return will be vapour: the vapour bubbles will be generated on the radiation screen and then rise through the liquid to return to the reservoir. However high points on the screen will create trapped volumes of vapour.

Recommendations for review:

- ~ The seams in the panels to create flow channels are removed or modified – see the discussion below;
- ~ The liquid supply is at the low point;
- ~ The vapour return is at the high point.

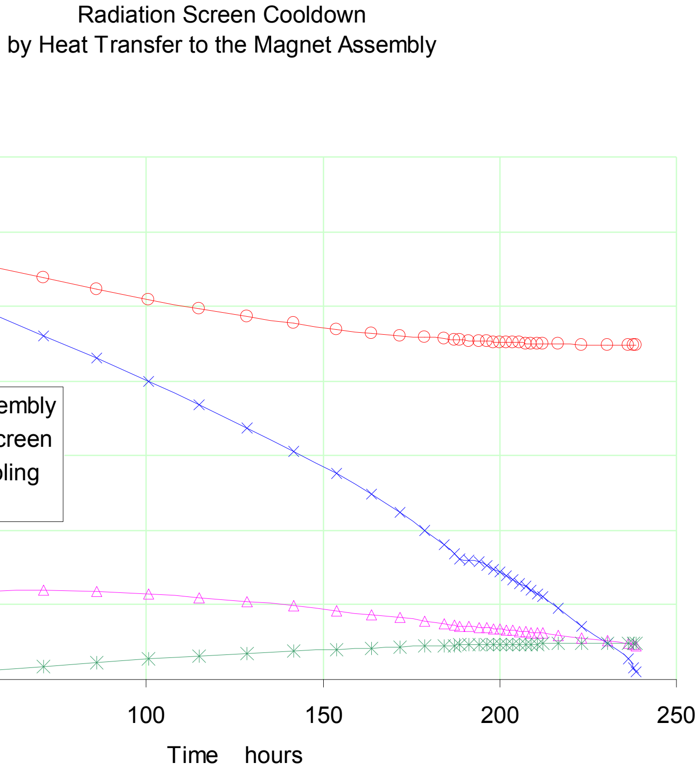
In addition:

- ~ The chimney is cooled by the return pipe;
- ~ The feed pipe is insulated from the chimney – nothing complicated but it is supported on GRP (Glass Reinforced Plastic) spacers.

The discussion which follows assumes that the connection of the return pipe to the reservoir and cannot be changed without incurring expense.

If there are no flow paths on the radiation screen panels then the cooldown is more difficult because of the potential problem of channeling. This can occur with parallel flow paths where one panel becomes colder, has a lower pressure drop, takes proportionately more flow and cools progressively faster than the other panels causing excessive thermal stresses and distortion.

One possibility is that the cooldown uses radiation cooling from the magnet assembly with no liquid nitrogen cooling on the radiation screen. The chart below shows an estimate of the cooling by radiation heat transfer between the radiation screen and the magnet assembly as the magnet assembly cools. The red line (circles) is the radiation screen temperature, the blue line (crosses) is the magnet assembly temperature, the green line (asterix) is the heat load to the radiation screen and the magenta line (triangles) is the radiant cooling between the radiation screen and the magnet assembly. The net power available to cool the screen is the difference between the purple line and the green line.



The radiation screen will equilibrate at about 220 K which is still too warm to continue the cooling with liquid nitrogen without a danger that thermal stresses will cause distortion and damage to the screen.

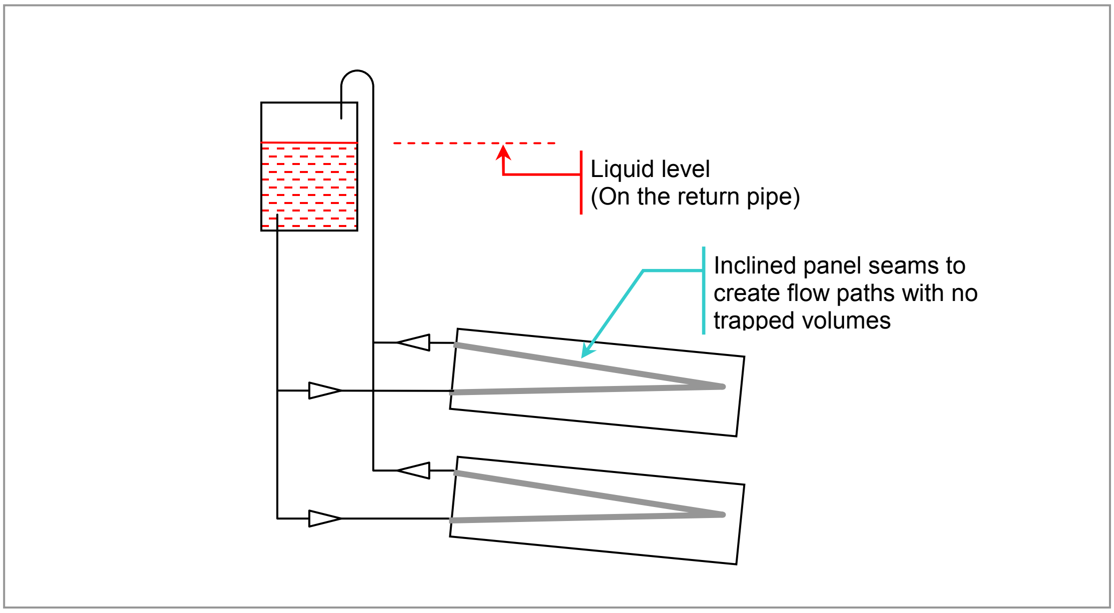
It should be noted that the cooling power is the difference of two calculated numbers and is therefore subject to errors.

However the cooling could be assisted by a small flow rate of liquid nitrogen. In the extreme this might all flash to vapour at one end of the screen and the heat conduction along the stainless steel from one end of the screen to the other is very poor.

Outer perimeter	1.450	m
Inner perimeter	0.655	m
Length	3.84	m
Stainless steel thickness	3.2	mm
Temperature	200	K
Thermal conductivity	13.0	W / m.K
Heat flux area	0.0212	m²
Maximum permissible temperature	50	K
Heat conduction	3.6	W

The heat conduction 3.6 W with a temperature gradient of 50 K is not significant given the cooling power required to cool the screen.

Therefore, in order to cool the screen it will be necessary to use a liquid nitrogen flow rate and to include a seam in the panels which will divert the nitrogen flow to the far end. The seam must be inclined at a gradient so that the nitrogen vapour is always rising as shown in the attached diagram and here are no trapped volumes.



It is still be advisable to use radiation cooling from magnet assembly for the initial part of the cooldown and introduce the nitrogen cooling gradually as the temperature of the radiation screen is increased. A cooldown profile is attached.

Temperature sensors should be included on every panel to monitor against channelling.

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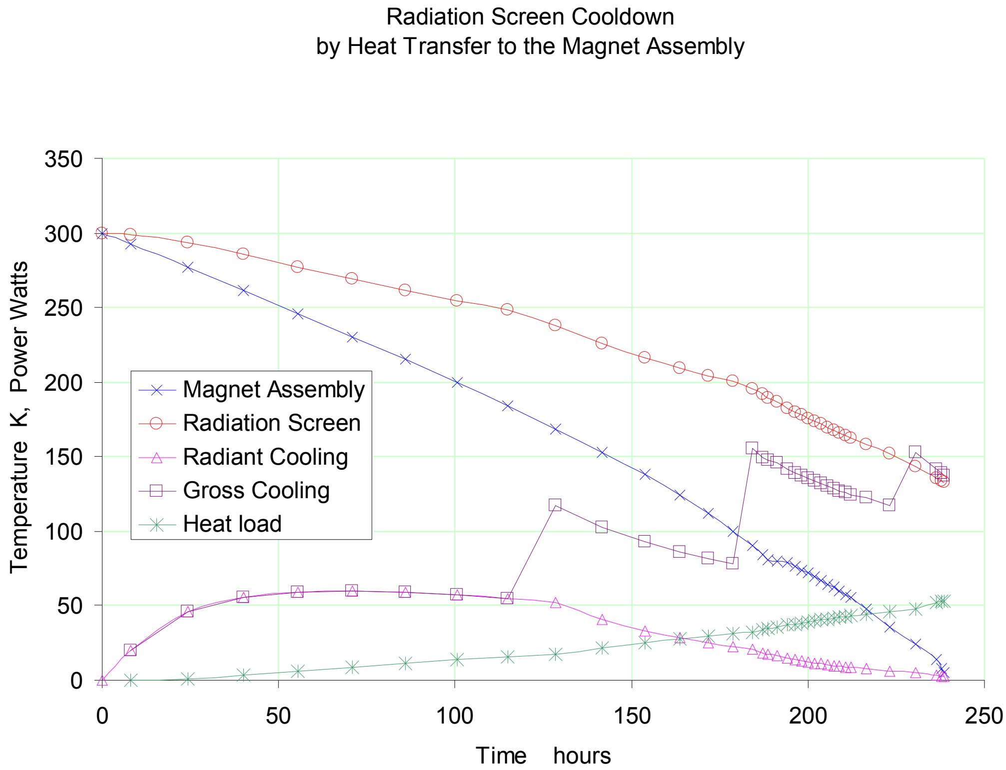

The purple line (squares) show the nitrogen cooling power increasing (in discrete increments) and cooling the screen to below 130 K at which point the danger of thermal shocks is minimised.

CONCLUSION

The recommendations are as follows:

- ~ Rotate the outer screen panels so that the supply is always at the low point and the return at the high point.
- ~ Modify the panel seams so that the flow paths do not present any trapped volumes.
- ~ Provide thermal isolation between the flow path and the chimney. The chimney is cooled by the return path.
- ~ The cooldown should be done slowly and use radiant cooling from the magnet assembly.
- ~ Include temperature sensors on every panel to check that channelling is not occurring.
- ~ Accept that the system is less a thermosyphon circulation and more a liquid level equilibration.

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