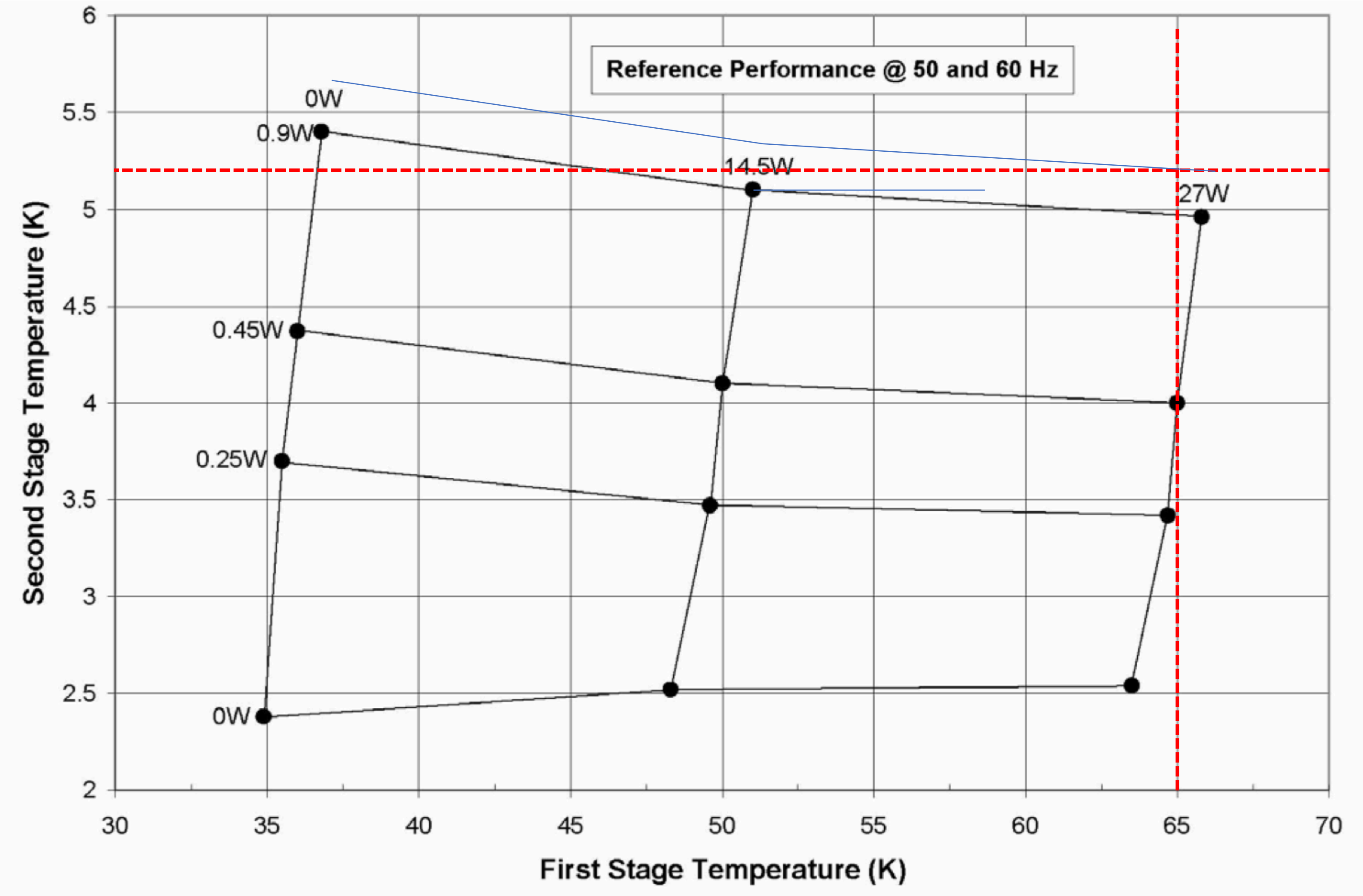
SFAB

Brief thermal analysis

SFAB PTC Load estimation



50 K PTC: 65.3 K
50 K Plate: 76.6 K
50 K Lid: 98.7 K
4 K PTC: 5.2 K
4 K Plate: 5.7 K
4 Lid: 6.8 K

1st stage Load = 26W

2nd stage load 1.05W

Estimating Radiation Loads

As discussed previously we need to account for the fact that radiation is being emitted and absorbed in a cavity. The main point here is that power incident on a surface and NOT absorbed can reflect of the emitting surface and be absorbed on a second pass. In the design of MUSCAT and previous versions of FASScam a basic method was used where an effective emissivity is chosen for either the absorbing or emitting surface and the other surface is treated as black. Typically, if two surfaces (emitting and absorbing have the same emissivity $\boldsymbol{\epsilon_e}$ then the effective emissivity (taking into account multiple reflections) is of order $\boldsymbol{\epsilon_e}/2$.

A more rigorous approach is conducted by Mungan where the emitted and absorbed power between two cylinders is calculated:

$$P_{Mungan} = \frac{\varepsilon_S A_S \sigma}{1+\frac{\varepsilon_S A_S (1-\varepsilon_C)}{\varepsilon_C A_C}} (T_c^4 - T_s^4). \qquad P_{Basic} = \sigma T_{hot}^4 A_{absorber} \varepsilon_e$$

A_s Area of inner cylinder, A_c = area of outer cylinder $\epsilon_s = \text{permitivity of innner cylinder}$, ϵ_r=permittivity of outer cylinder, Tc is the temperature of the outer cylinder and Ts is the temperature of the outer cylinder

Estimating Radiation Loads

Whether using the Basic method or the Mungan method the big unknown is the surface emissivity. Here we will assume it is the same as we line all surfaces with low emissivity foil and do not expect a temperature dependance. We estimate the load on the PTC first stage from its temperature and the subtract the calculated mechanical load. We can then solve either P_{basic} or P_{Mungan} for emissivity. When doing this we find

ϵ_e= 3.3% for the basic method

$\epsilon_s = \epsilon_c = 5.6\%$ for the Mungan method

Note the basic method is roughly half of the emissivity predicted for the Mungan method as expected

These values (using either method) can be used to calculate the load on the 4K stage if the 1st stage temperature is known.

1^{st} stage (50K) Loads

Radiation load

1^{st} stage OD = 506mm, Height=(150+457)mm=607mm, Area=$2\times\pi(.506/2)^2 + \pi\times0.506\times0.607 = 1.36m^2$

Radiation load $P_{Rad1} = A\times\sigma\times T^4\times\varepsilon_r = 62.5W(\epsilon_r = 10\%), 31W(\epsilon_r = 5\%)$, **21W** $(\boldsymbol{\epsilon_r = 3.35}\%)$

ε_r here is the relative emissivity. This is the combination of emission and absorption efficiency between the 300K and 50K surfaces independent of environment (cavity or open). Given the 1^{st} stage temperature we see this value is of order 4%

Mechanical loading

4 x 50K legs L=180mm OD=15.88 Wall = 0.25mm Load (300K – 75K) = 0.74W

6 x Short X-links L=18mm W=2mm D=2mm Load(300-75K) = 3.6W

6 x Long X-links L=40mm W=1.5mm D=0.9mm Load(300-75K) = 0.55W

Total Mechanical Load = 4.89W

Radiation load is dominant here with the total load being of order 26W when estimated from the PTC cooler matrix for a PTC temperature of 65K

Absorbed flux=21/1.36=15.44 W/m2. $(\boldsymbol{\epsilon_r = 3.35}\%)$

2^{nd} stage 4K

Radiation load –**Assuming emissivity is the same 1^{st} stage and using upper limit of 100K measured**

2^{nd} stage OD = 454mm, Height=360mm, Area=$2\times\pi(.454/2)^2 + \pi\times0.454\times0.36 = 0.84m^2$

Using upper estimate of 1^{st} stage can temperature of 100K

Radiation load $P_{Rad1} = A\times\sigma\times T^4\times\varepsilon_r = 0.47W(\epsilon_r = 10\%), 0.236W(\epsilon_r = 5\%)$, **0.156W** $(\boldsymbol{\epsilon_r = 3.3\%})$

Using Mungan method we get 0.168W $(\boldsymbol{\epsilon_r = 5.6\%})$

Mechanical loading

4 x 4K legs L=155mm OD=15.88 Wall = 0.25mm Load (75K – 4K) = 0.085W

12 x X-links L=100mm W=4mm D=1mm Load(90-4K) = 0.2W (see FEA for choice of T_{hot})

Total Mechanical Load = 0.285W

Total Load on stage (being pessimistic) = 0.285+0.17=0.455 half of what we observe

1st Stage strap performance

PTC Head = 65.3

PTC Plate = 76.6

dT = 11.3

Data from TAI

P5 type strap

1.4W/K @ 50K, 1.16W/K @ 60K. Project 0.92 W/K @ 70K (linear extrapolation)

6 straps give 6 x 0.92 W/K = 5.52 W/K

dT to shift 25W therefore 25/5.52 = 4.5K

Straps are under performing at 60K

2nd Stage strap performance

PTC Head = 5.2

PTC Plate = 5.7

dT = 0.5

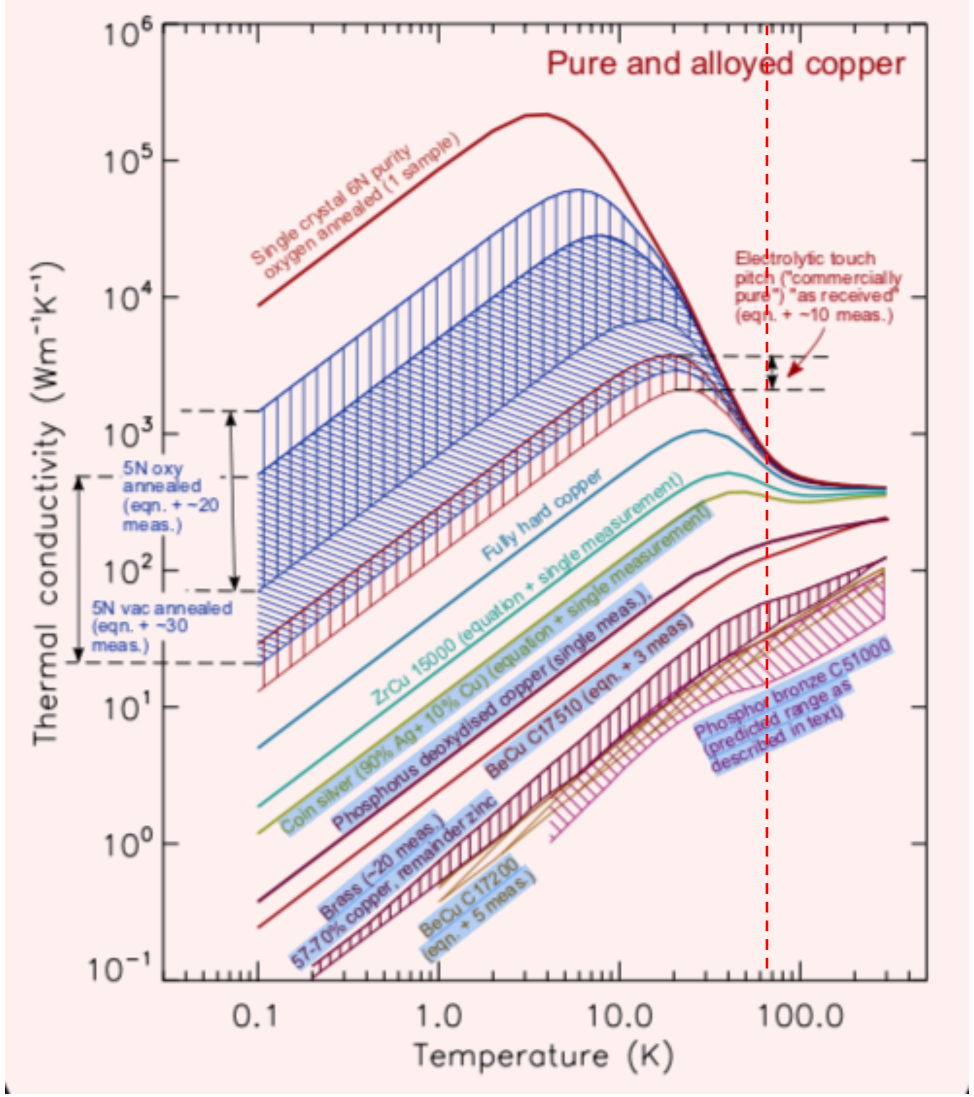
Data from Entropy

119mW/K at 3.5K
158mW/K at 4K
184mW/K at 5K

10 straps give 10 x 0.184 W/K = 1.84 W/K

dT give 1.84*0.5 = 0.92W load (consistent with estimated power)

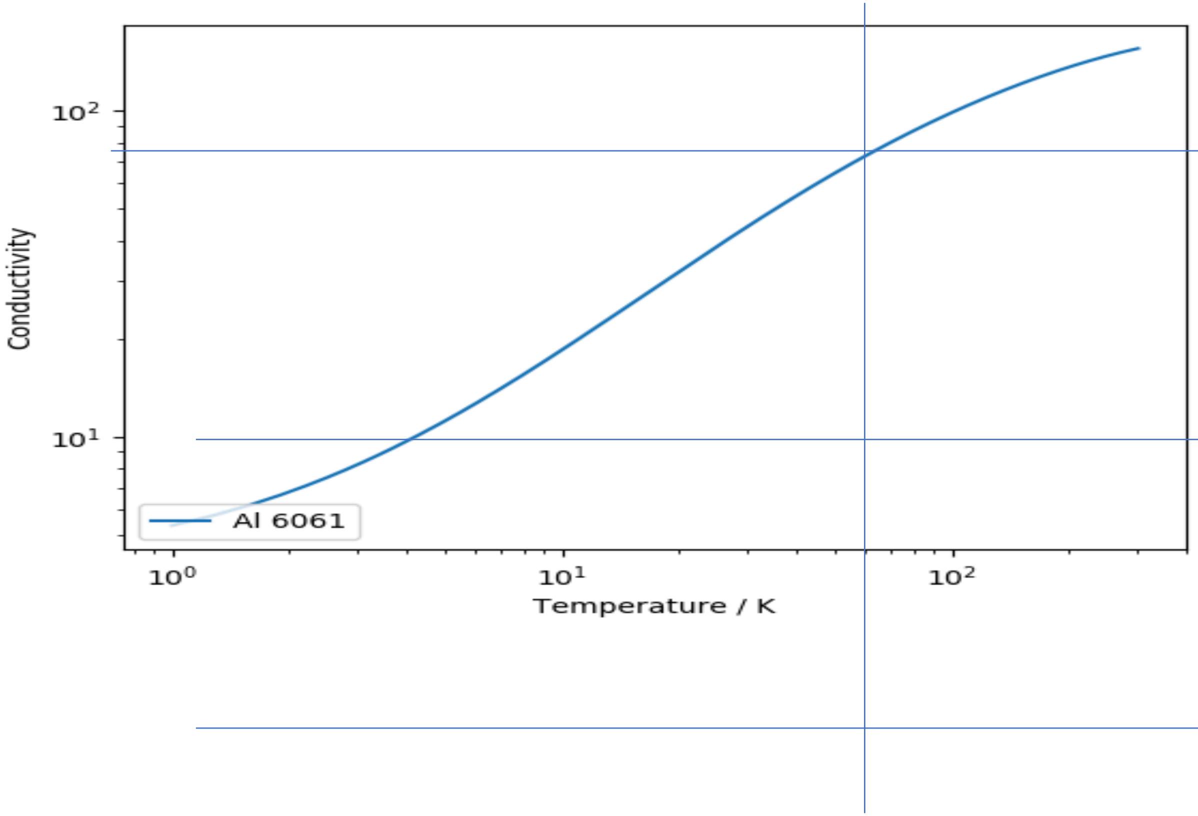
Copper Grades

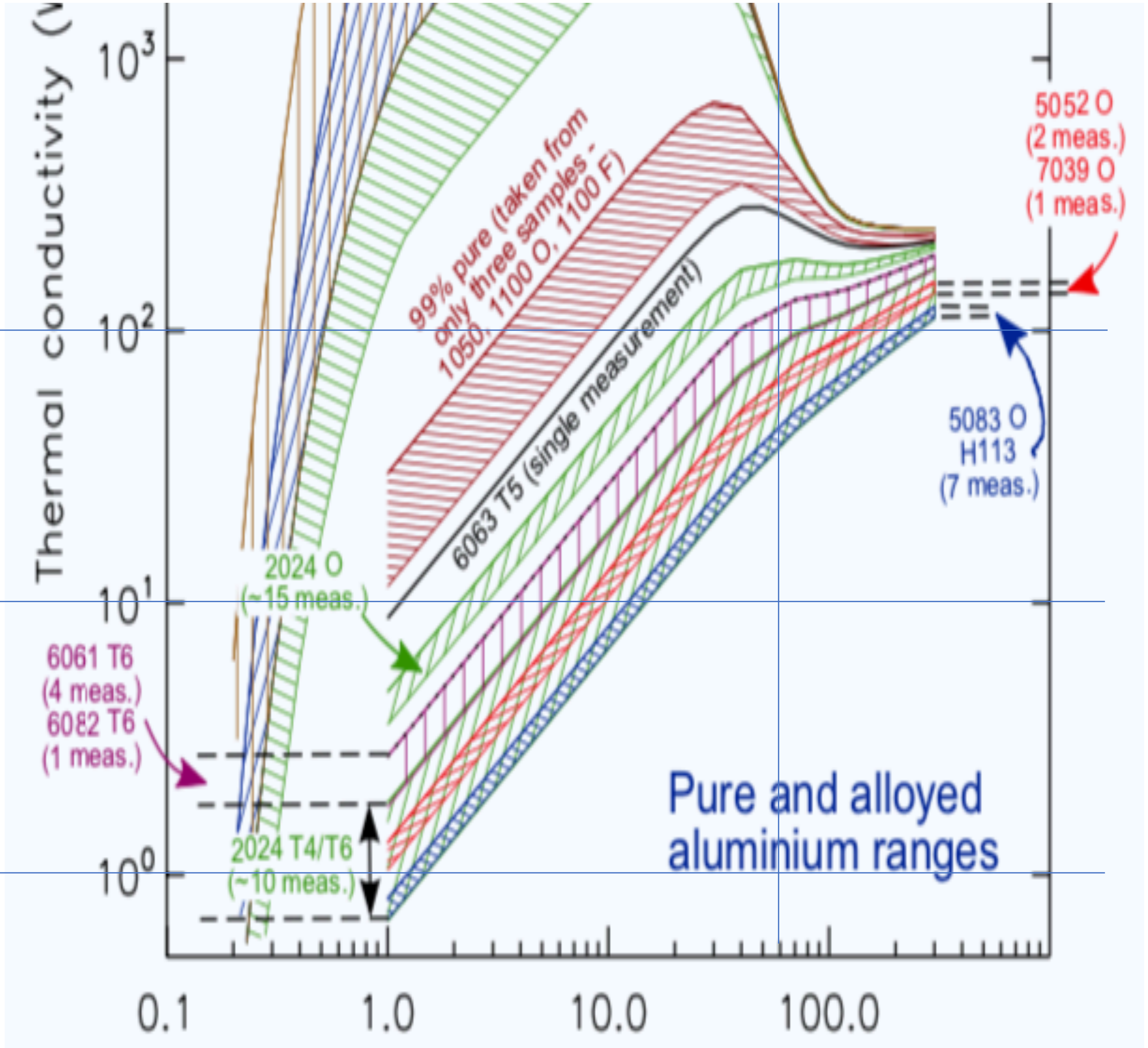


Note all very similar properties above 60K

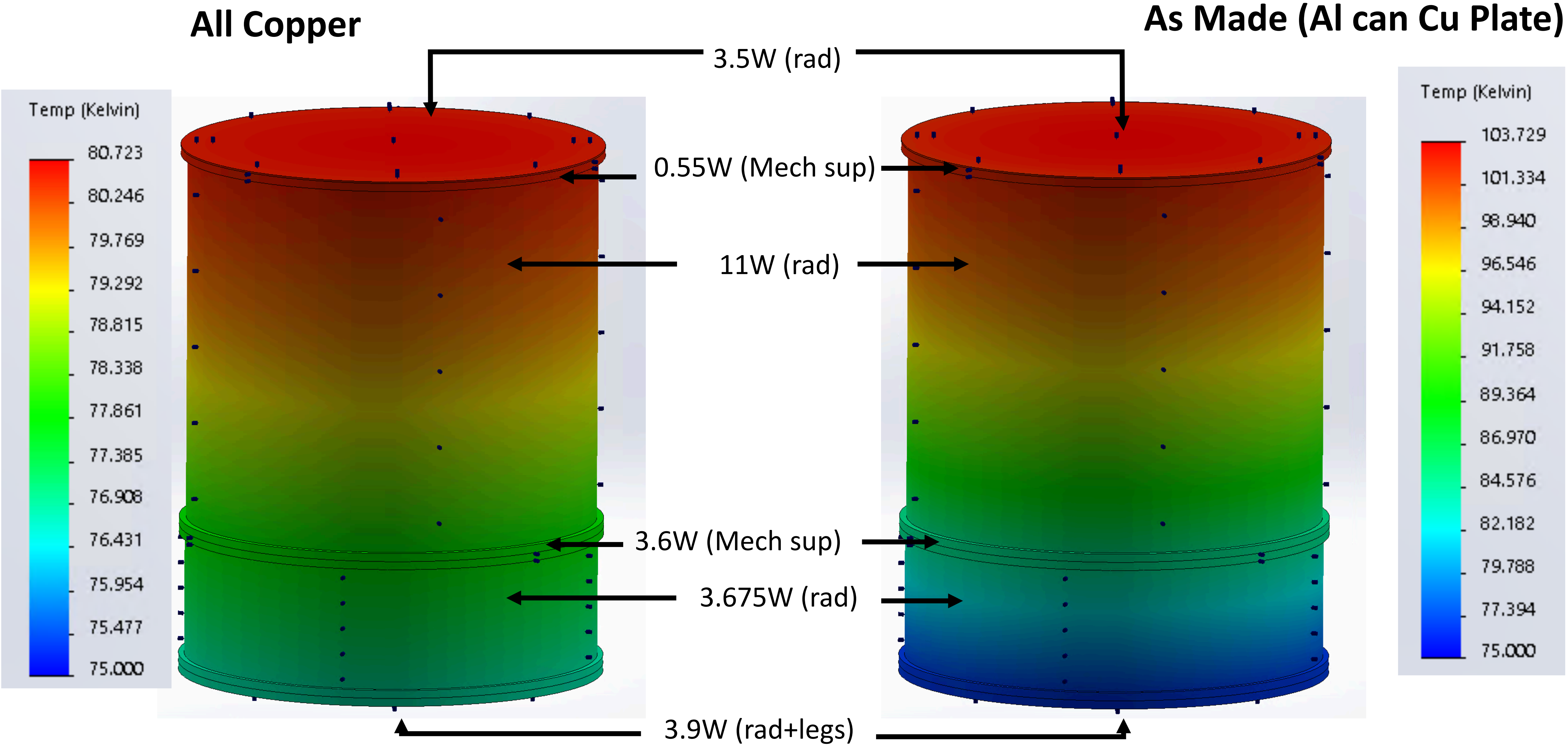
Aluminium thermal data

6061 Modelled 6082 USED

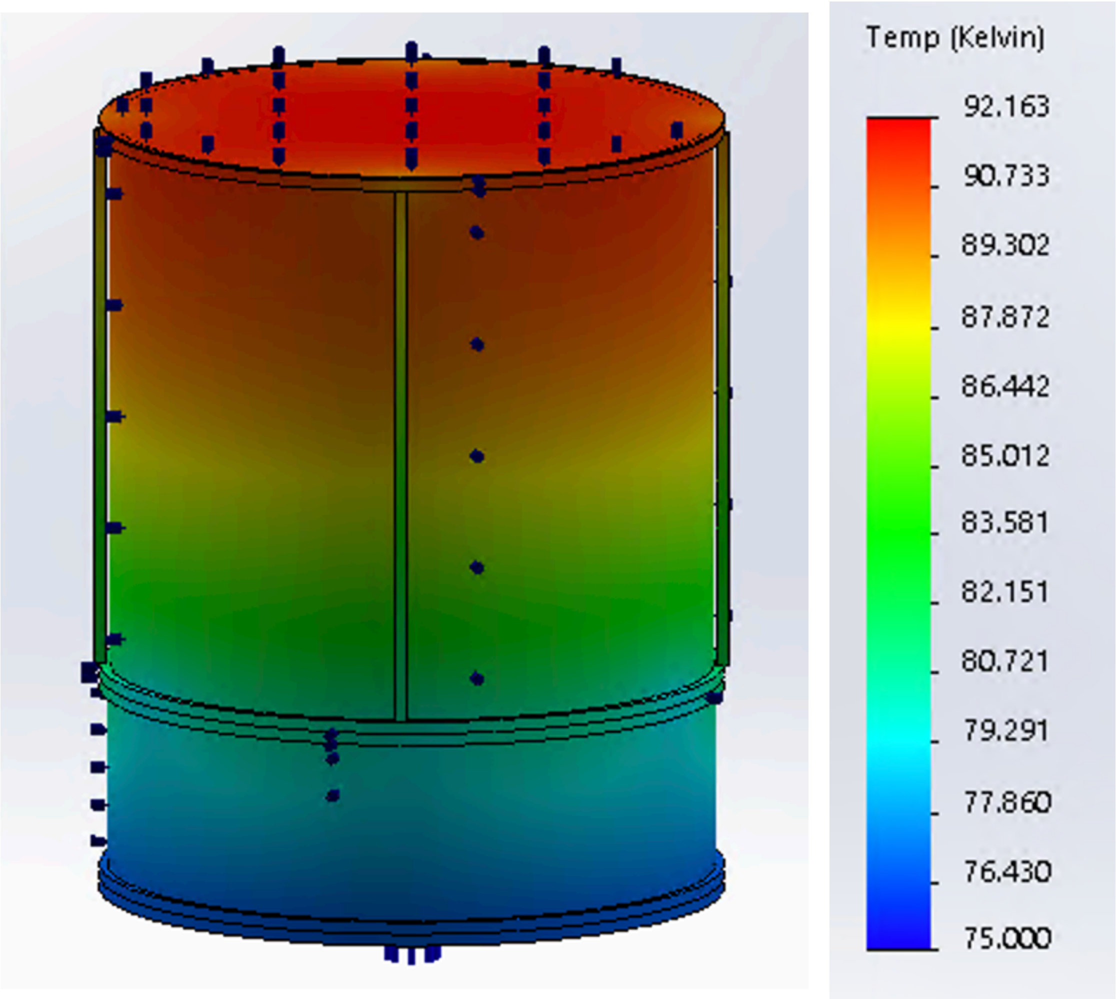


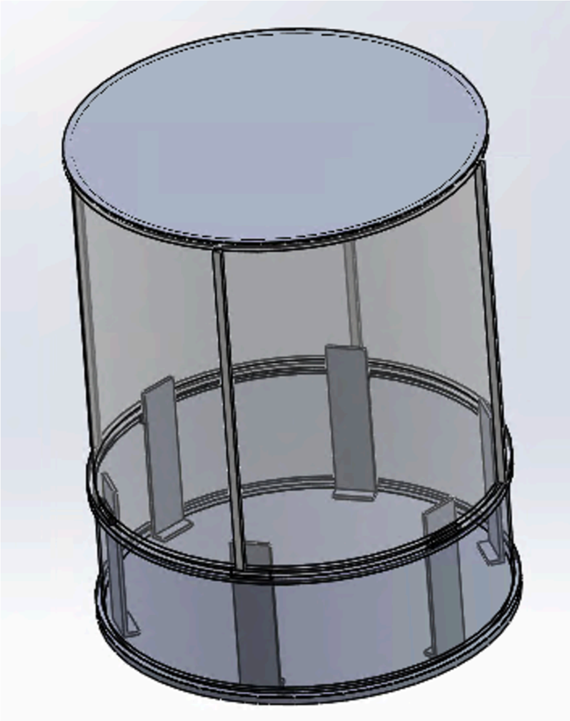


Thermal FEA 50K can



Adding Copper Straps to 1st stage shield





Copper straps and bars added inside and outside of 2nd stage shield

Emissivity check against MUSCAT

MUSCAT 1st stage load from PTC load curve is of order 48W (T=42K)

The mechanical load is of order 8W

So the radiation load is of order 40W

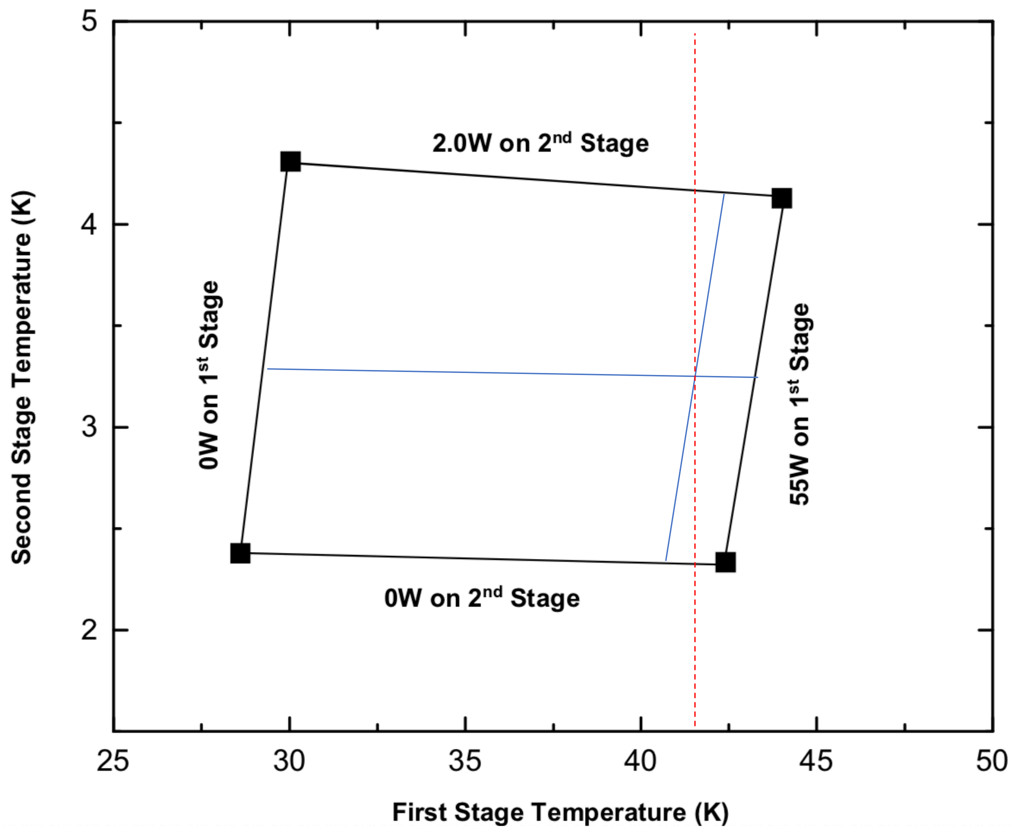
The 1stage shield surface area is roughly 2.8m2

So the flux absorbed is roughly 40/2.8 = 14.2 W/m2

The gives a resulting emissivity of order 3.1%

NOTE FOR MUSCAT – The radiating and absorbing surfaces are lined with low er foil. For the first SFAB run only the inside of the vacuum can and the outside of the 4K can were lined.

Emissivity seems similar between systems



Potential sources of power on 2nd stage not accounted for.

<u>50K Filter stack</u> – The filter stack on the 50K plate has an aperture area of 230mm x 180mm. Assuming the final thermal leaves the filter stack with an emissivity of 10%, if the filters are at 150K and all power is absorbed on the 2nd stage an additional **<u>0.12W</u>** will be seen.

<u>Lining of emissive surfaces</u>. The SFAB build did not line radiating and absorbing surfaces with low emissivity foil in the same way as MUSCAT did. The inside of the vacuum can is lined and the outside of the sides of the 4K can are lined. It could be possible that not lining the emitting inside surface of the 1st stage can could lead to additional load not accounted for using the models stated here. An increase in by a factor of 2 in emissivity could produce an addition **<u>0.17W</u>** load on the second stage

The underside of the 4K plate does have area not accounted for in the model so far. There is an additional Aluminium fridge shield

<u>Wrong estimation of emissivity</u>. Using a 1st stage shield temperature of 100K (measured), the Mungan method for calculating radiative load requires each surface to have an emissivity of 22% to provide a radiation load of the **<u>0.7W</u>** (0.3 mechanical) required to put of order **<u>1W</u>** on the second stage. If these values are applied to the 1st stage load the first stage would have of order 80W radiation load. This seems unfeasible

<u>A light leak or cable loads unaccounted for</u>

Generally hard to find of order 0.5W additional load

Options going forward

- Line inside and outside of 1st stage shield and remaining area of 4K shield.
- Reduce cross-sectional area of the 12 50-4K cross links. Can save 0.1W load here.
- Reducing temperature of 2nd stage shield by adding Copper strapping from 100-90K saves $90^4/100^4$ =0.65 (0.17 to 0.11W) of radiation load.
- Note the 80K load from an all-Copper can would give $80^4/100^4$ =0.4 (0.17 to 0.068W) of radiation load but would be over 3 times heavier.