Appendix H

The challenges of modelling helium gas conduction and helium seal interfaces in ESATAN-TMS r7

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Abstract

The Meteosat series of spacecraft are meteorological satellites, providing a range of data that inform weather forecasts across Europe. Two instruments going on the MTG (Meteosat Third Generation) satellites will be calibrated using the blackbody targets that are being designed at RAL Space.

Modelling of the ground based blackbody calibration targets was done in ESATAN-TMS r7. The targets use a helium gas gap heat switch as the main aspect of the thermal control system. This talk will cover the challenges involved in modelling the gas conduction, and will present the current implementation.

Other aspects of the design, such as determining the conductance across a complex interface involving a helium seal will also be discussed. This presentation will also touch on the correlation of the thermal model post prototype testing.

The challenges of modelling helium gas conduction and helium seal interfaces in ESATAN-TMS r7

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RAL Space

European Space Thermal Analysis Workshop
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Science & Technology Facilities Council

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Outline

- Meteosat
- Blackbodies
- Design overview
- Thermal challenges
  - Helium Conduction
  - Helium seal interface
- Next steps

Meteosat

MFG 1979—2011

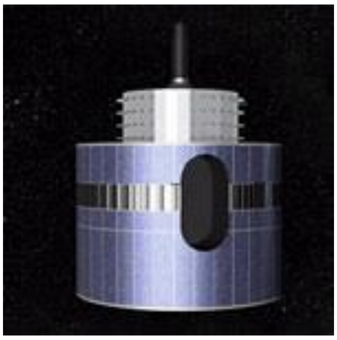

Image credit: ESA

MSG 2002—2019

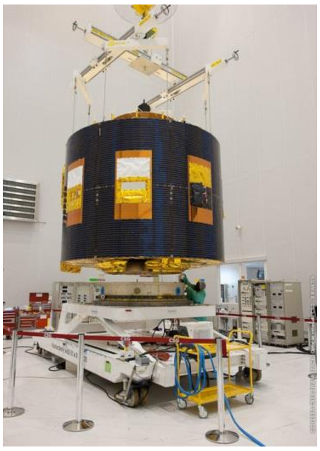

Image credit: ESA

MTG 2018—2038

Image credit: Eumetsat

MTG

- MTG-S
  - IRS (Infra-red Sounder) by OHB
- MTG-I
  - FCI (Flexible Combined Imager) by TAS-F

- Two sets of customer requirements
  - One calibration blackbody design

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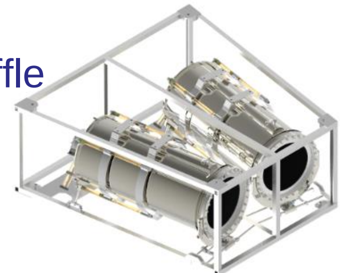
Blackbody calibration target

- Target of accurately known temperature and high (~1) emissivity
- Precisely controlled
  – Better than instrument can measure
- Used to calibrate instrument
- Often a baseplate surrounded by a baffle



Calibration blackbody

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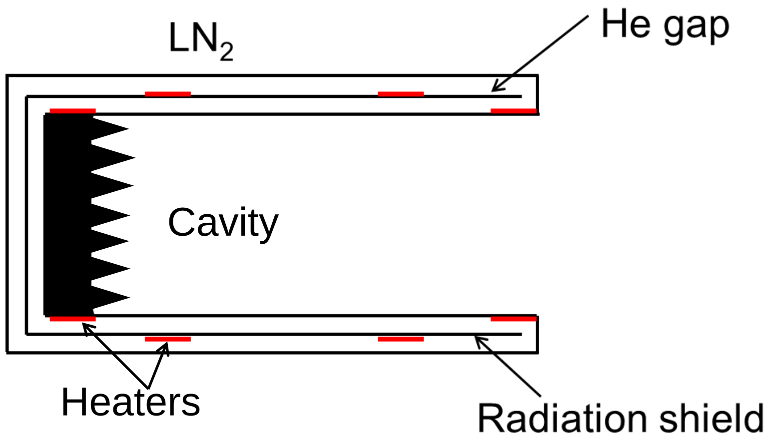
MTG blackbodies thermal challenges

- **Large operating temperature range**
  – **100–370 K**
- Small temperature gradient requirements
- Transition between temperatures in 0.1 K steps
- Transition 16 K in 30 minutes
- 3 kW power limit

Helium gas gap



Helium conductivity in a gas gap

Helium thermal conductivity in a helium gas gap

$$k(T) = k_{bulk}(T) \cdot \left(1 + \frac{8}{3} \cdot \frac{k_{bulk}(T) \cdot T}{e \cdot p \cdot \sqrt{3 \cdot R \cdot T}} \cdot \left(\frac{1}{\alpha_1} + \frac{1}{\alpha_2} - 1\right)\right)^{-1}$$

k_{bulk} is the bulk conductivity of He
T is temperature
e is the gap thickness
p is the pressure of the gas
R is the specific gas constant
α is the thermal accommodation factor

Equation from:
'Active-mirror-laser-amplifier thermal management with tuneable helium pressure at cryogenic temperatures', A. Lucianetti et al., Optics Express, Vol 19, Issue 13, pp. 12766 – 12780, 2011.

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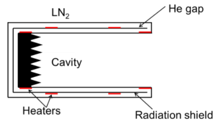
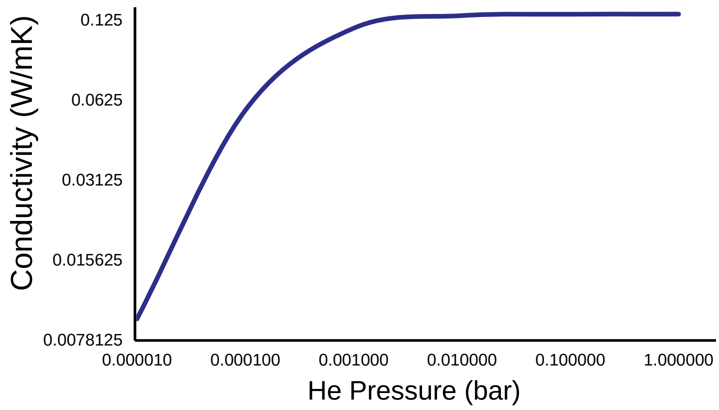
Helium pressure and thermal conductivity





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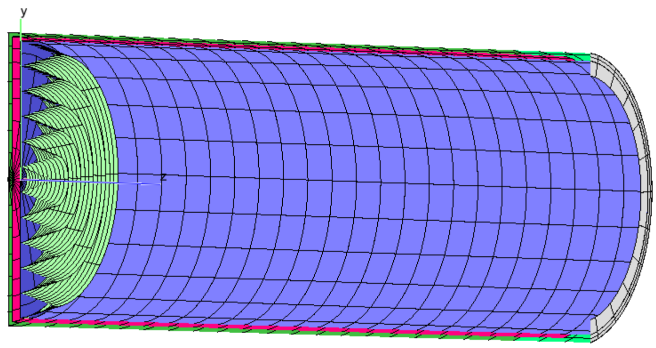
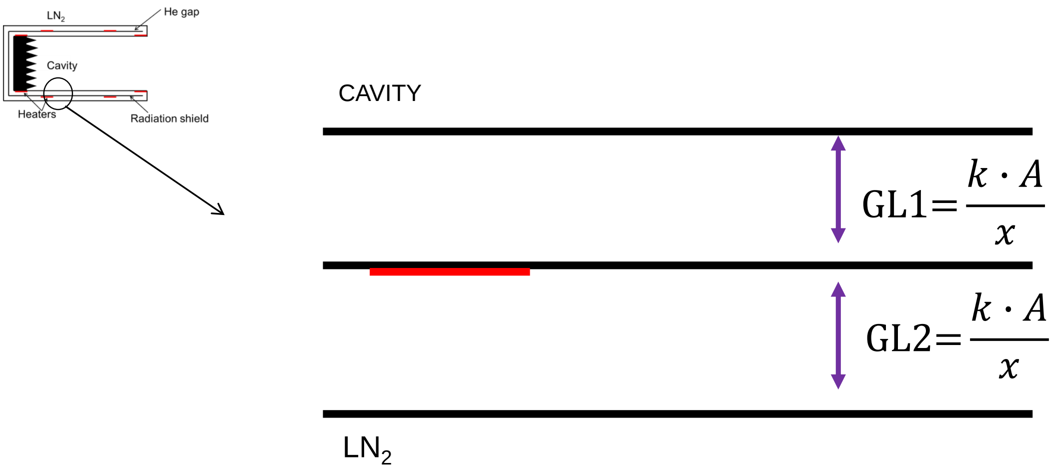
Main thermal modelling challenges

- **Helium conductivity**
- Helium seal interface



Helium gas conduction modelling



$$GL1 = \frac{k \cdot A}{x}$$

$$GL2 = \frac{k \cdot A}{x}$$

$$k(T) = k_{bulk}(T) \cdot \left(1 + \frac{8}{3} \cdot \frac{k_{bulk}(T) \cdot T}{e \cdot p \cdot \sqrt{3 \cdot R \cdot T}} \cdot \left(\frac{1}{\alpha_1} + \frac{1}{\alpha_2} - 1\right)\right)^{-1}$$

Helium gas conduction in ESATAN

```
 $LOCALS
 # GENCODE LOCALS - DO NOT REMOVE
#


     $REAL

####  FOR 0.025 mbar intermediate He pressure unhash below

                 #Modelling of Helium Gas Conductance - conductivity value
      GL1=5.0;        # k = 0.021563  at 0.025 mbar
      GL2=5.206052;
      GL3=0.514395;
      GL4=0.2214;
####  FOR 1 bar He pressure unhash below


   #   GL1 = 16.60581;      # based on k =0.071 at 1 bar
   #   GL2 = 17.29014;
   #   GL3 = 1.708;
   #   GL4 = 0.735;

     $CHARACTER
```

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Helium gas conduction in ESATAN

```
# applying gas conduction values between radiation shield and cavity
 FOR KL1 = 11000 TO 11527 DO
     KL2 = KL1 + 11000;
     GL(KL2,KL1)= GL1/528;
 END DO

# applying gas conduction values between radiation shield and LN2 jacket
 FOR KL1 = 21000 TO 21479 DO
     KL2 = KL1 + 7000;
     GL(KL1,KL2) = GL2/480;
 END DO
```

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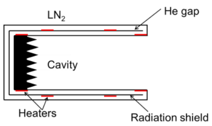
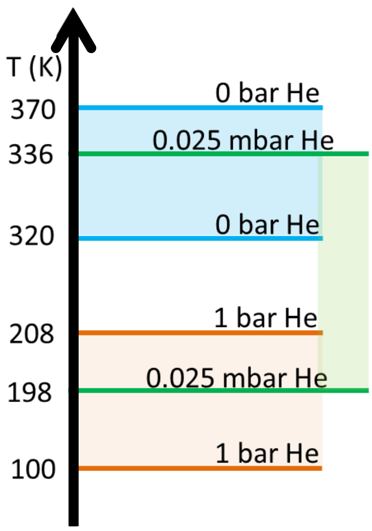
Three He pressure set points needed





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Helium conduction – limitations of equation

- Temperature of helium
- Perpendicular conduction modelled only
- Gas gap modelled O(1mm) much larger than conventional gas gaps
- Larger surface area than a conventional gas gap heat switch
- Curved surface

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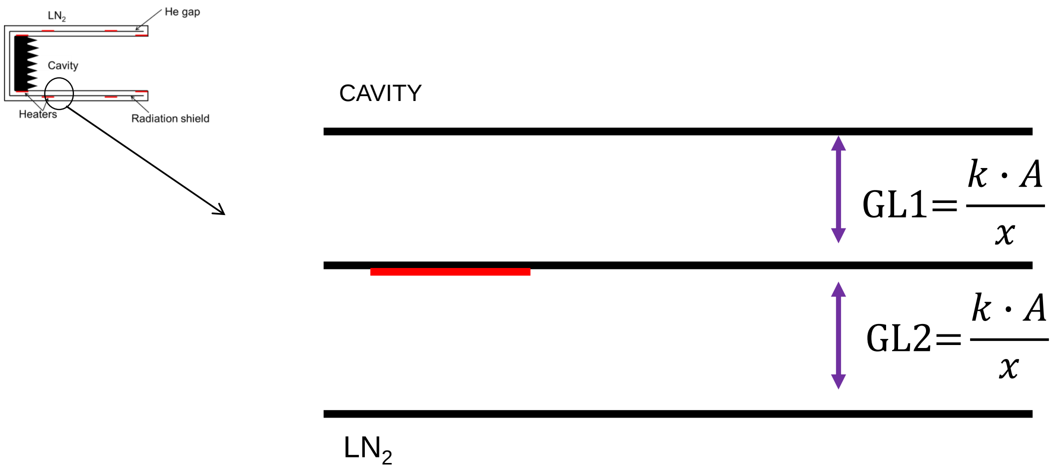
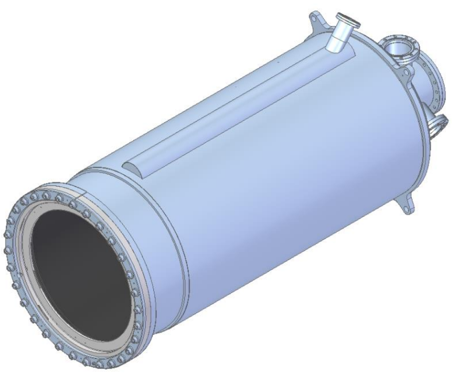
Dynamic helium gas conduction

```
# applying gas conduction values between radiation shield and cavity
  DO I = 11000,11527,1
     J = I + 11000
     KL1 = INTNOD(CURRENT,I)
     KL2 = INTNOD (CURRENT,J)
     XKL3 = (GETT(KL1) + GETT(KL2))/2  # average temperature (T of He)
     XKL4 = INTRP1 (XKL3,He_T_v_k,1)  # bulk conductivity from array
     XKL5 = XKL4*((1+(8/3*XKL4*XKL3/e1/press/(3*8314/4.0026*XKL3)**0.5*(1/alf +1/alf-1)))**(-1)) # k value in gas gap
     XKL6 = XKL5*0.00245662 / e1 *XKL7
     CALL SETGL(CURRENT,KL2,KL1,XKL6 )   # GL value based on average area of node
 END DO
```

Helium gas conduction modelling



Breadboard Model Testing



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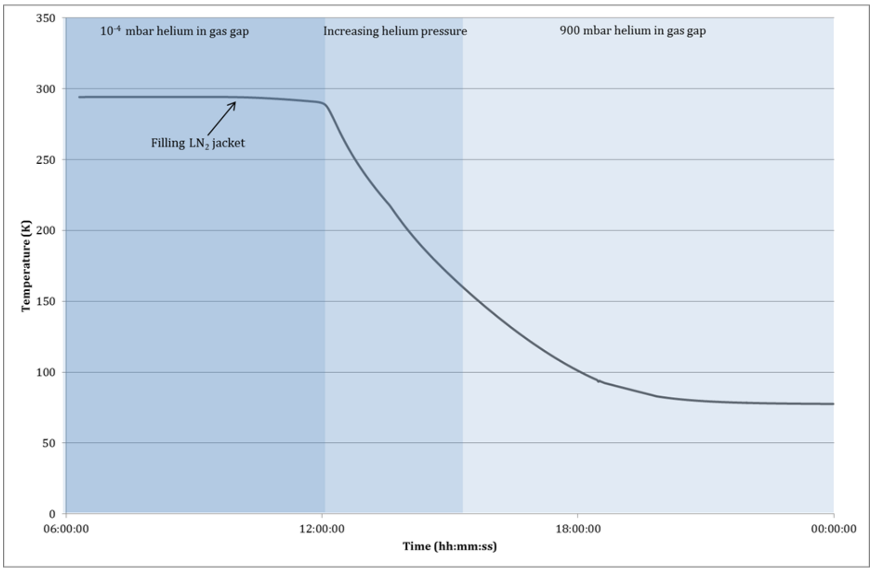
Helium conduction from testing



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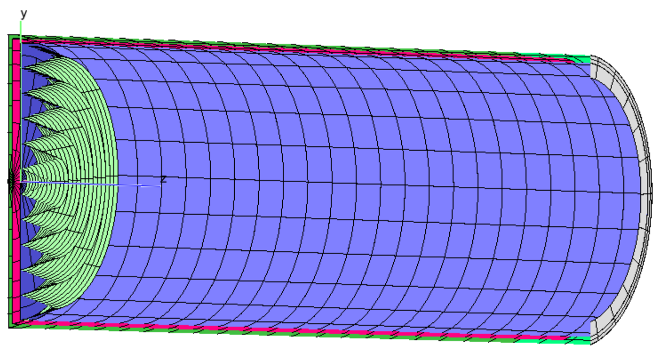
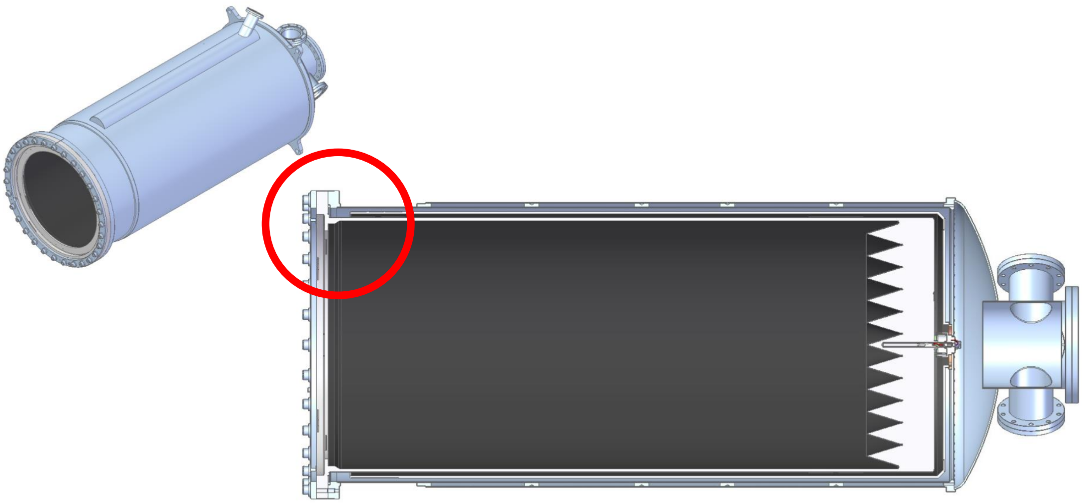
Main thermal modelling challenges

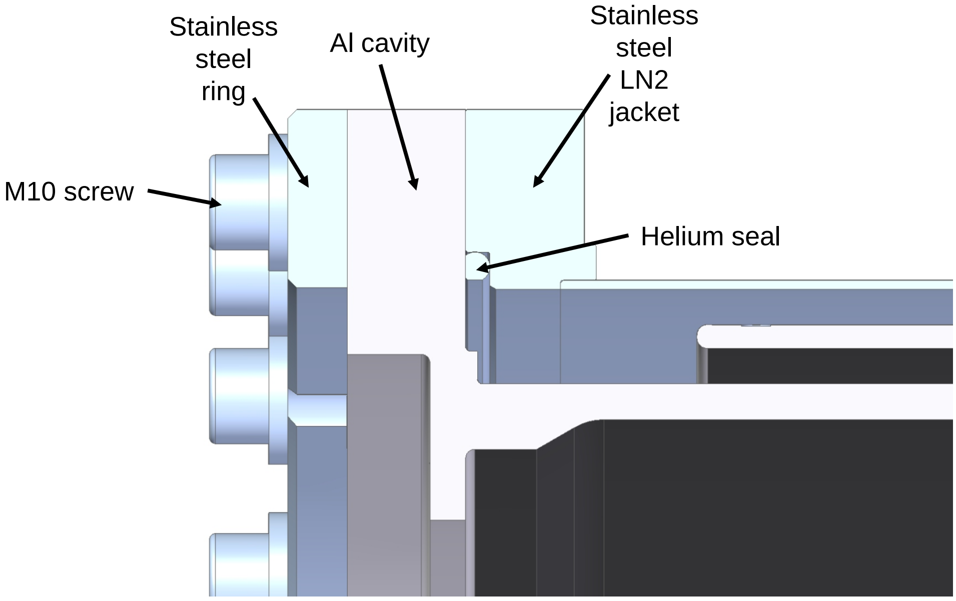
- Helium conductivity
- **Helium seal interface**



Helium seal interface



Helium seal interface



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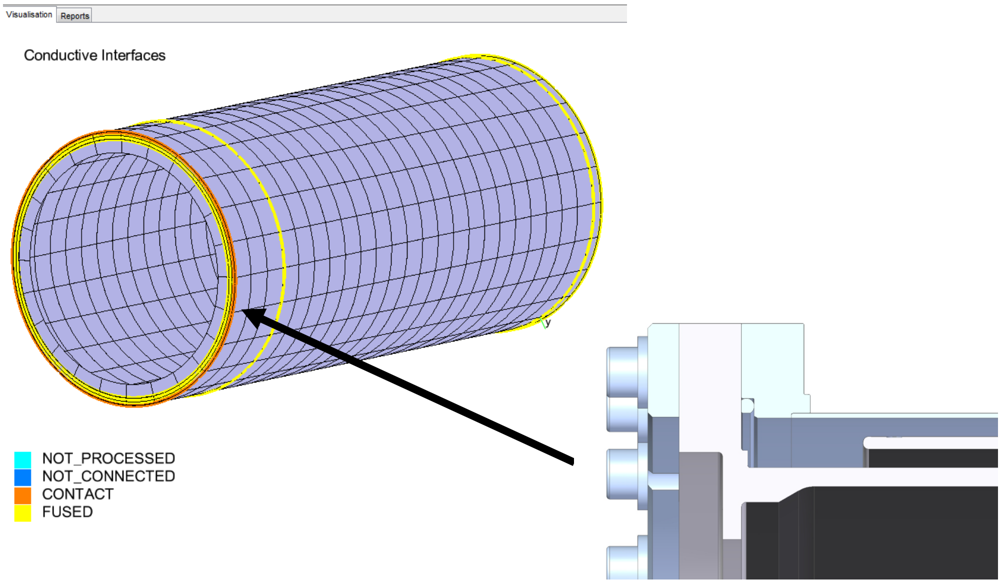
Helium seal interface



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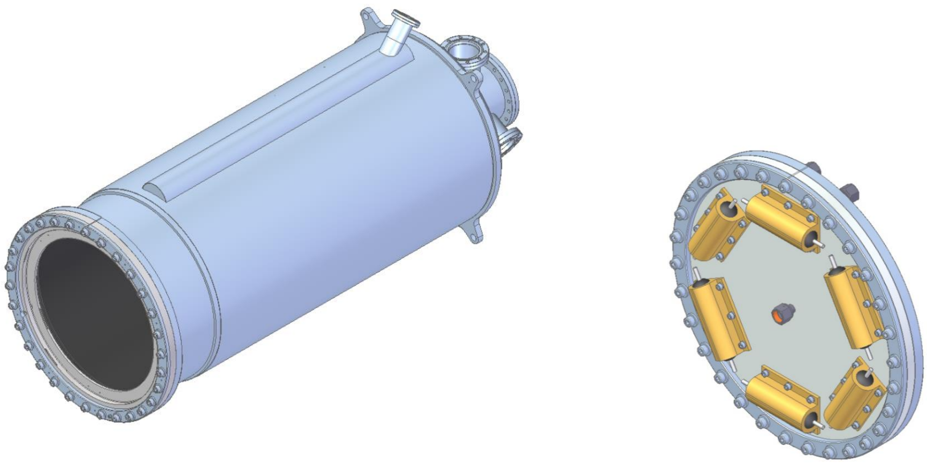
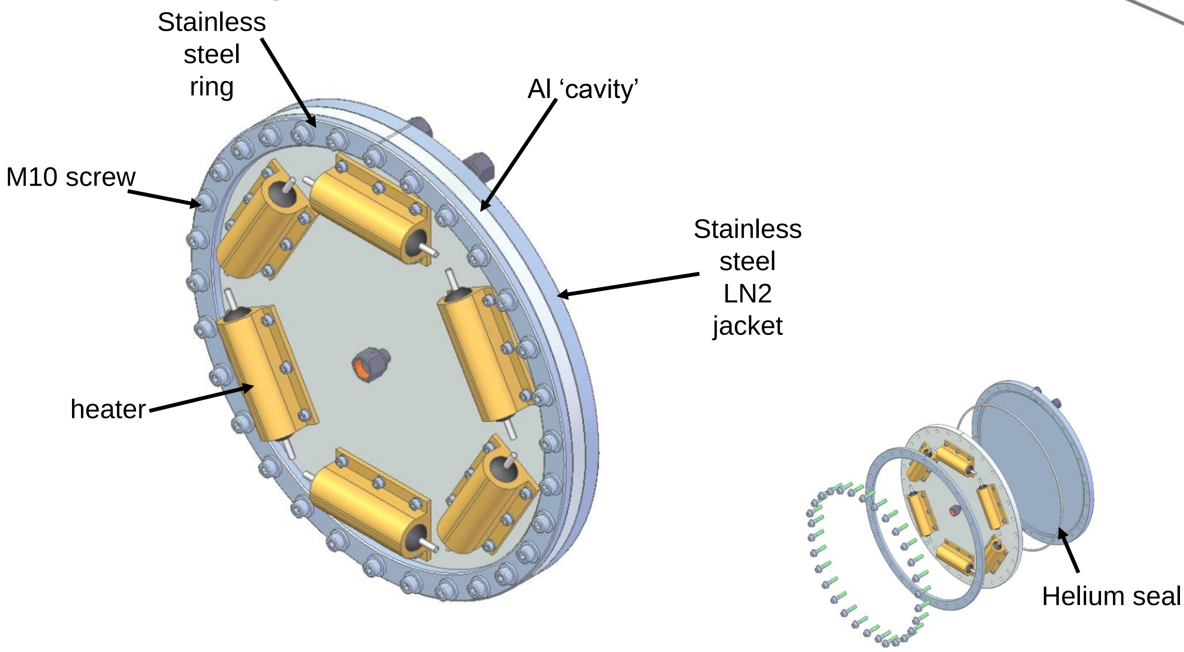
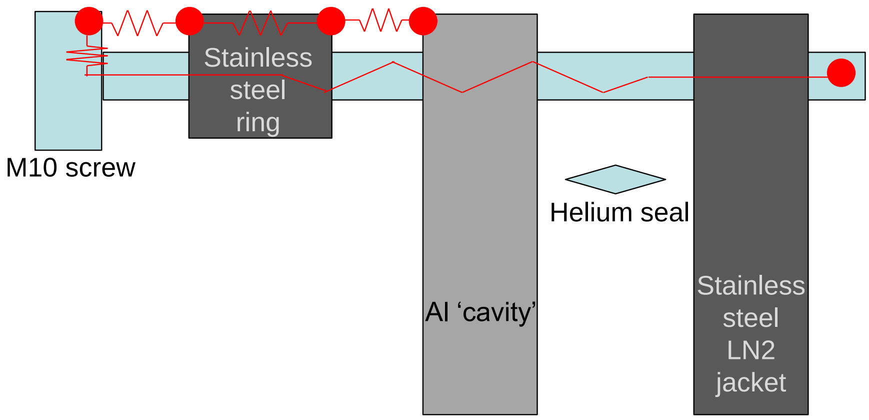
Dummy seal interface



Dummy seal interface



Dummy seal interface



Next steps

- Using model to improve bulk temperature changes
  - Modelling transient ‘helium assisted’ cooldowns
- Performing helium seal test
  - Verifying the conductive path through the interface, and correlating model further with findings

Thank you

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