ISIS Neutron and Muon Source - Solid Methane Moderator Commissioning

Mark Telkman, Paul Morgan

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Summary

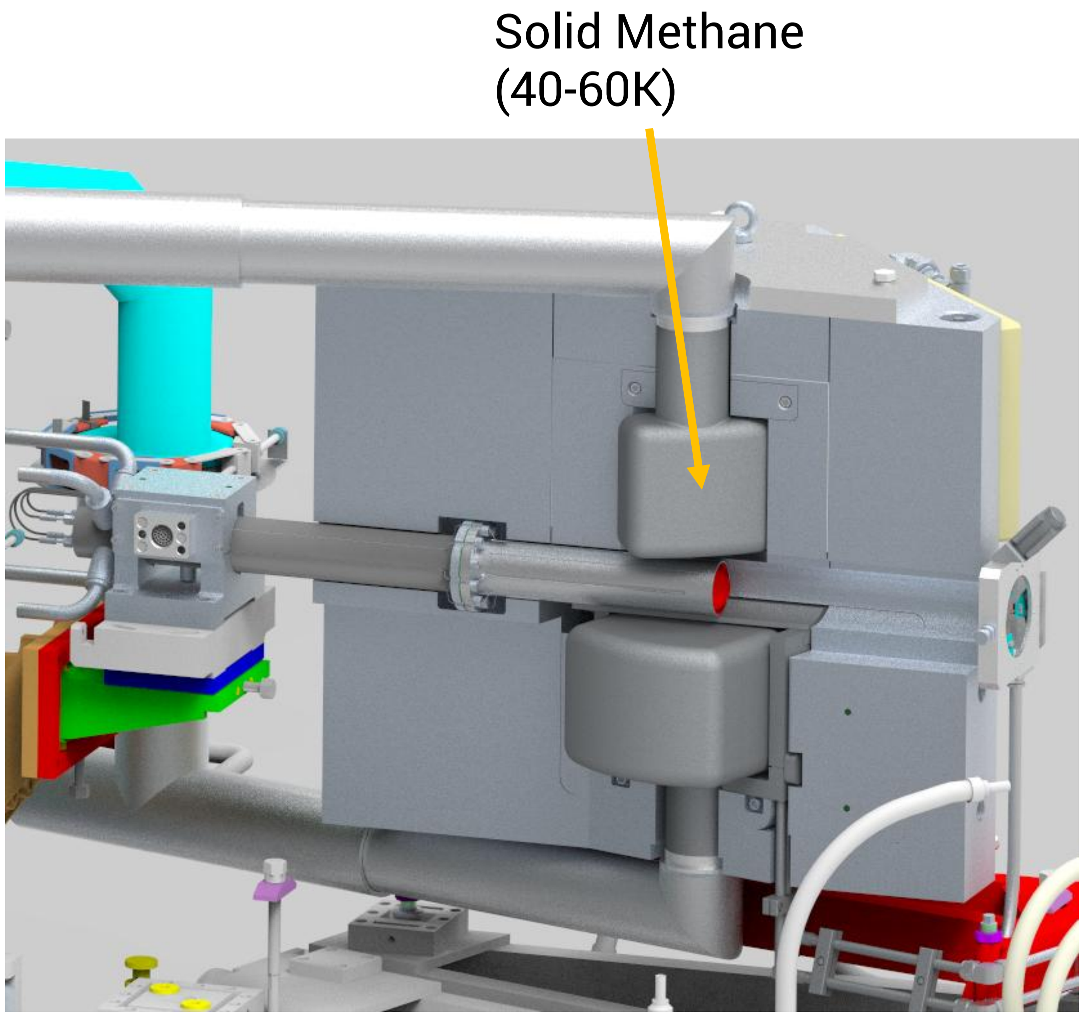
- What is the ISIS Solid Methane Moderator?
- New heat exchanger type with gadolinium poisoning foil
- New design(s) and expectations
- Commissioning tests – 2 moderators, June 2025 to now
- Results
- Conclusions(?)

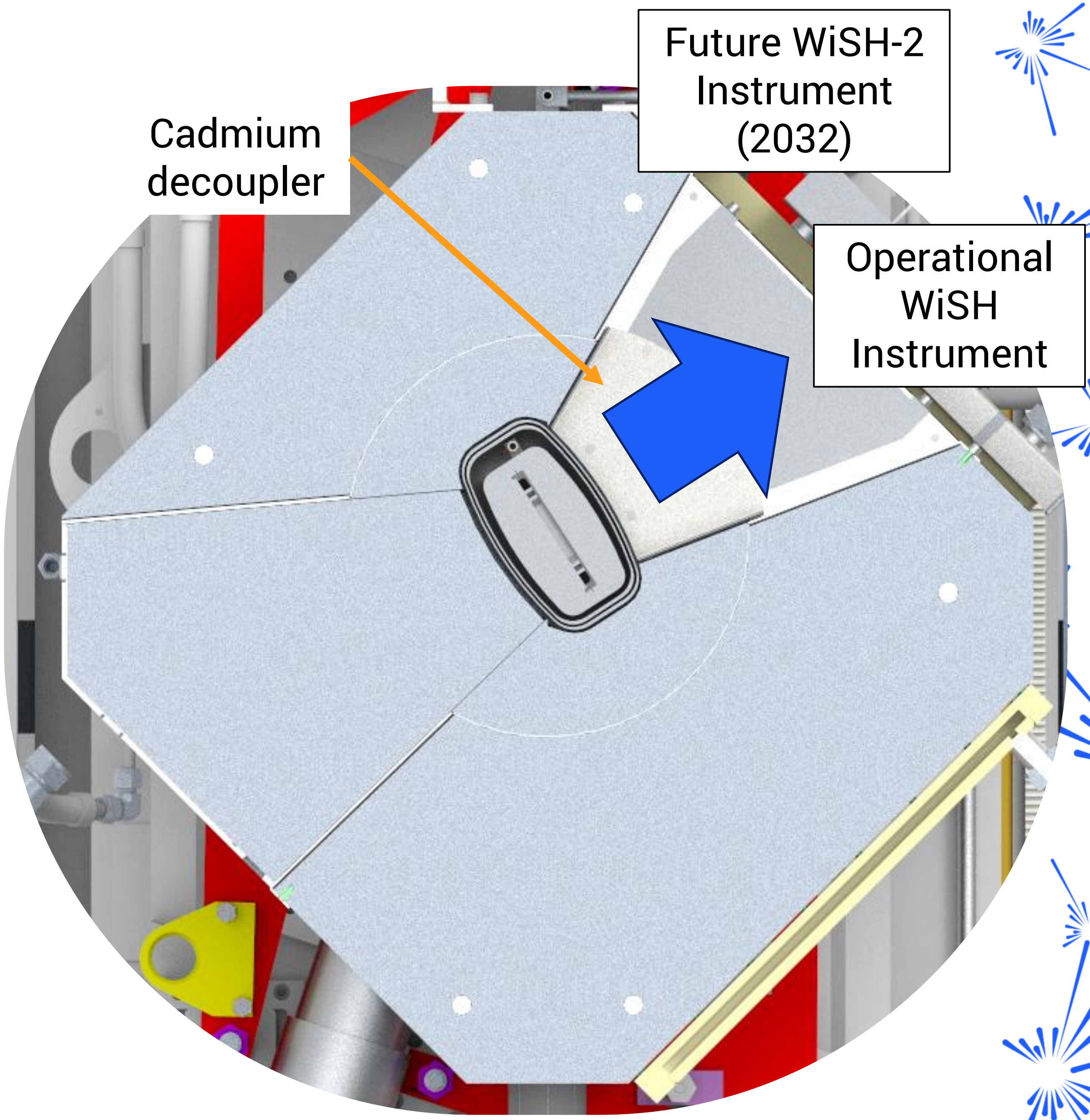
Terminology

- HEX = Heat exchanger
- DMOD = Decoupled Moderator
- Mk1 = original heat exchanger (pre DMOD 040)
- Mk2 = first new heat exchanger (used in DMOD 040)
- Mk3 = second new heat exchanger (used in DMOD 041)
- Charge = methane mass
- Charge change = process of refilling volume with new methane

Solid Methane Moderators

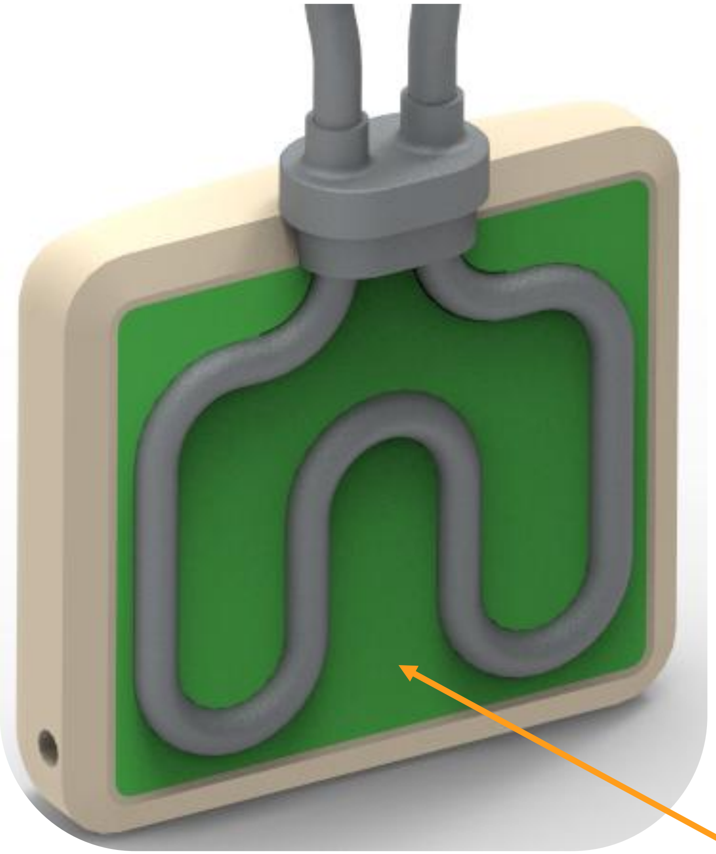
- 3.5x more efficient than hydrogen moderators, but operationally challenging due to burp pressures and deterioration
- Operating at ISIS since 2008
  - The first moderators failed
  - Recombination process of hydrogen and methane radicals in temperatures 30-90K now better understood
  - Design settled in 2011, 35 bar design limit with charge cycle lasting 17-19 hours


Solid Methane
(40-60K)


Cadmium
decoupler
Future WiSH-2
Instrument
(2032)
Operational
WiSH
Instrument

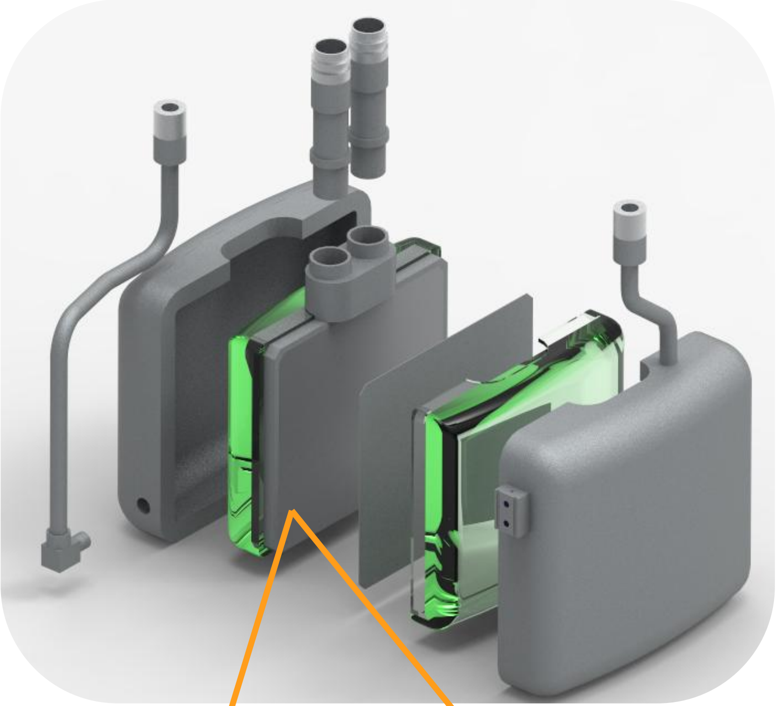
New Design

1. Tube to plate heat exchanger
2. Different flow rate (lower pressure drop)
3. Decrease in methane volume (200g to 160g)
4. Introduction of gadolinium poisoning foil
5. Aluminium foam not brazed

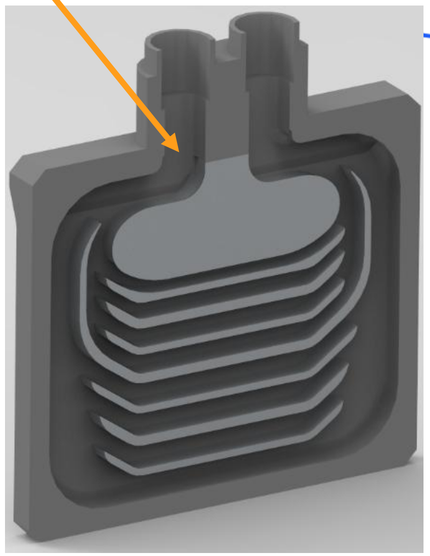


Mk1 Heat Exchanger (DMOD 001-039)

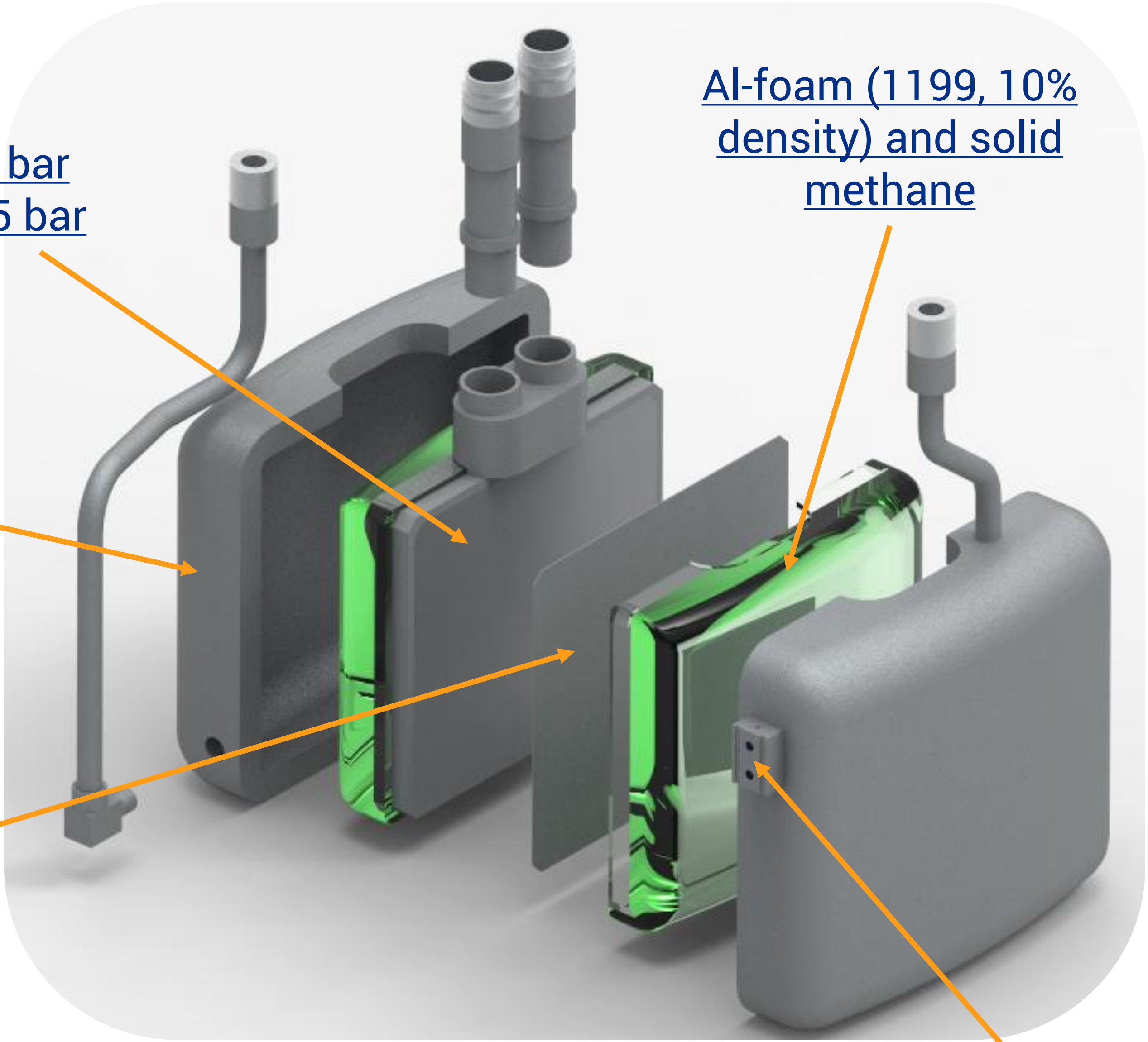
Aluminium foam (1199)-solid methane matrix



Mk2 Heat Exchanger (DMOD 040)



Mk3 Heat Exchanger (DMOD 041)


Aluminium 5083-O Heat Exchanger
Internal design pressure = 5 bar
External design pressure = 35 bar
Al-foam (1199, 10% density) and solid methane
Aluminium 5083-O shell
Design pressure = 35 bar
Gadolinium Foil (50 μm, Al-5251 sandwich)
Thermocouple location

What was Expected?

A slightly worse starting temperature but slower deterioration?

- See next slide…

Similar pressure release at charge change warm up?

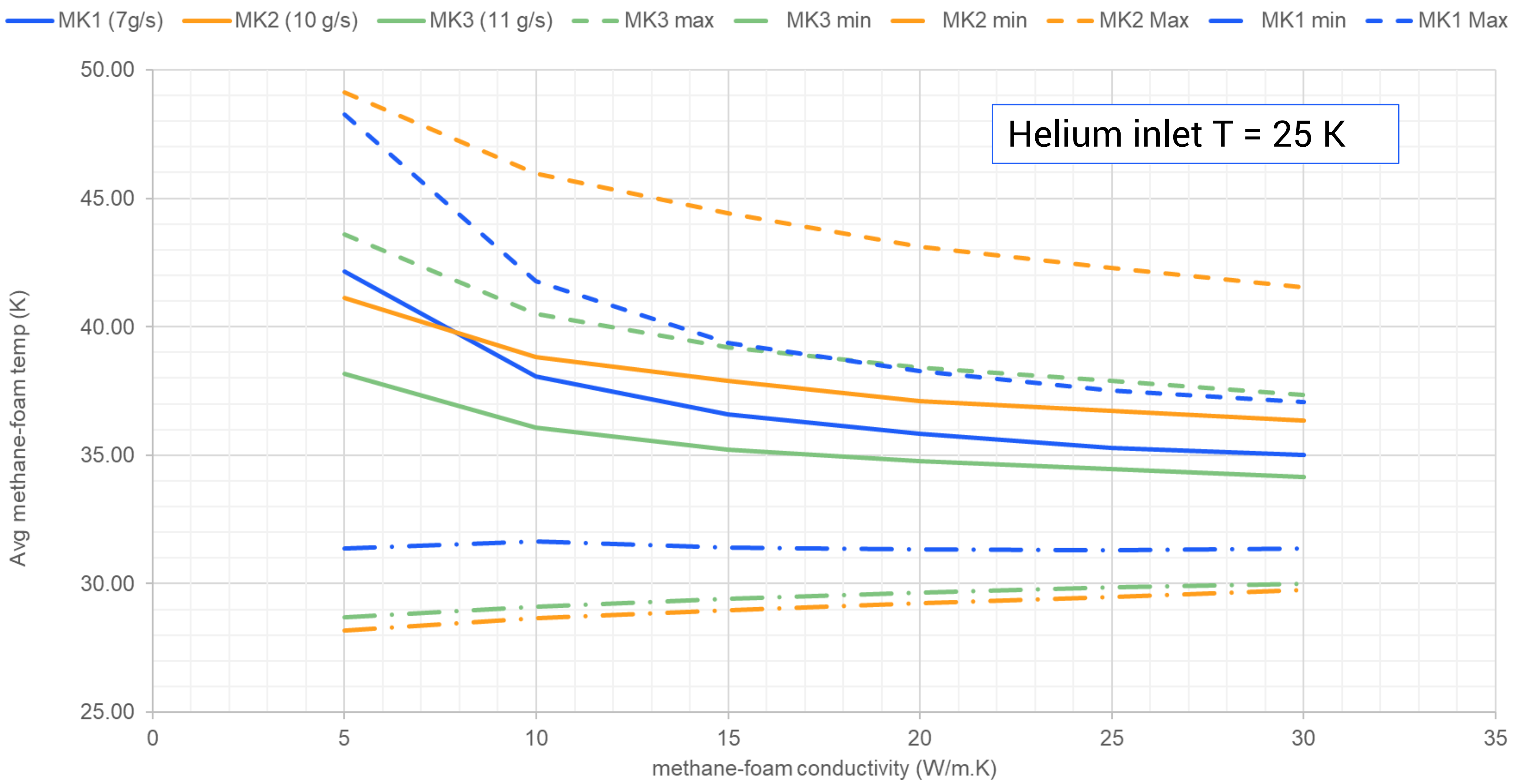
- Warming of irradiated solid methane leads to pressure release
- Less methane in new design, but unsure on its impact

Less flux, sharper resolution

- Much smaller available methane volume
- Thinner volume in viewing angle

Temperature increase predictions

- Compared Mk1, Mk2, and Mk3 at their designed flow rates
- Varying bulk thermal conductivity of methane and aluminium foam conductivity
  - "simulate" potential deterioration mechanism

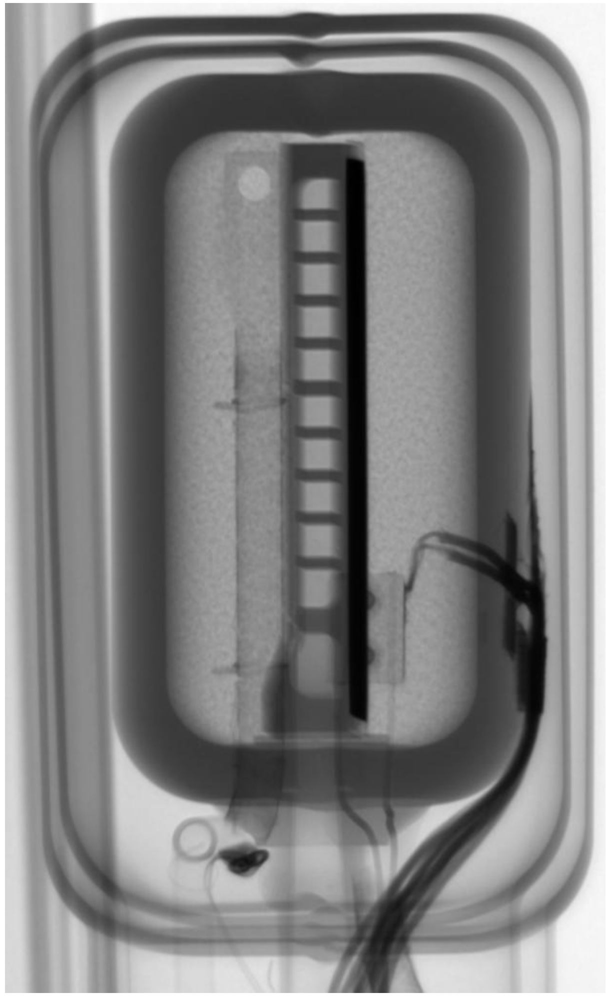


Planned tests for two new moderators

- Positioning of foil
- Pressure measurements at increasing time intervals — Ensure moderator does not fail
- Impact of poisoning foil
- Flux measurements at different helium temperatures — Deriving an “efficiency” of heat exchanger, compare to previous design
- Coldbox optimisation – increase mass flow rate to reduce temperature
- Monitor the deterioration rate

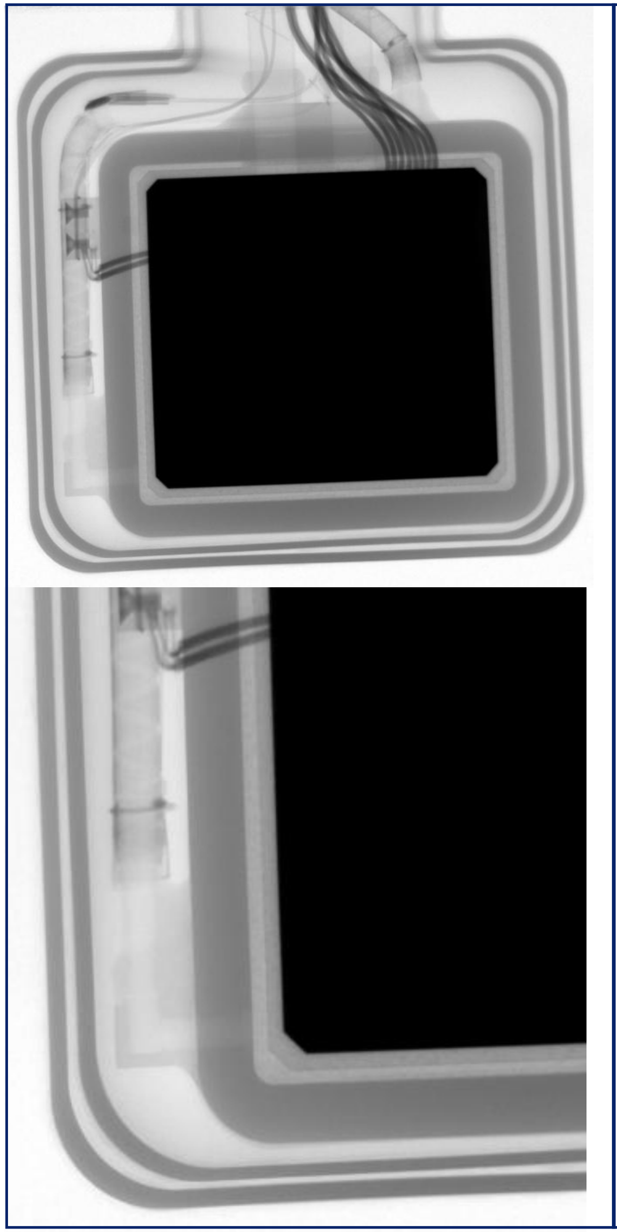
Neutron Imaging

DMOD 040

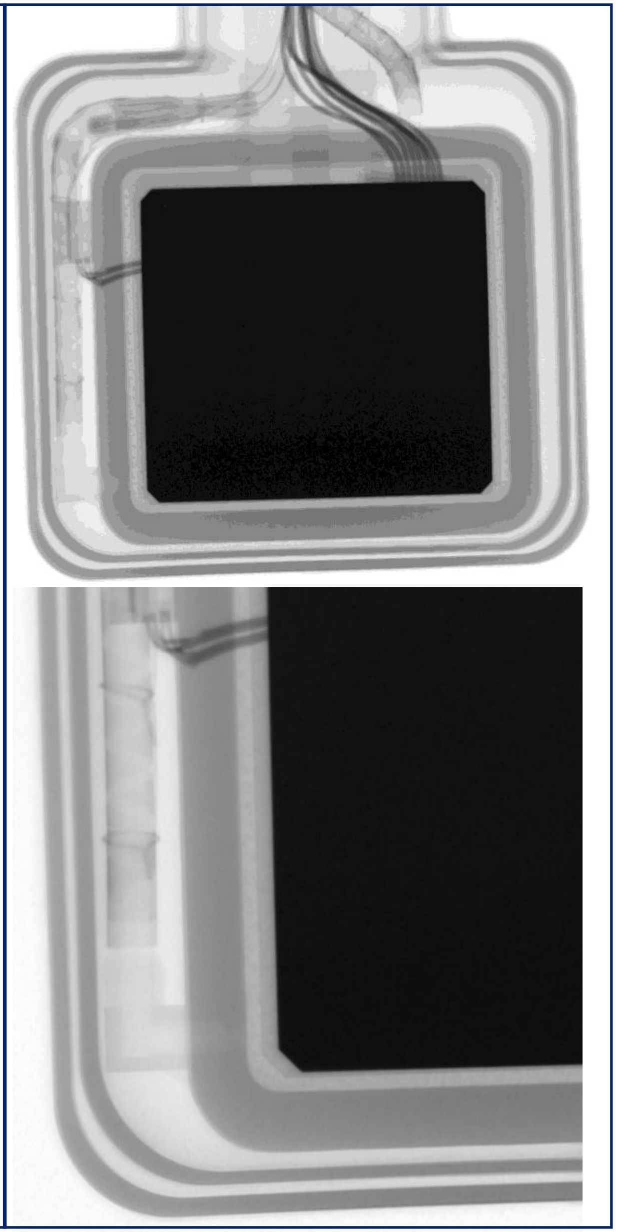


DMOD 041

DMOD 040

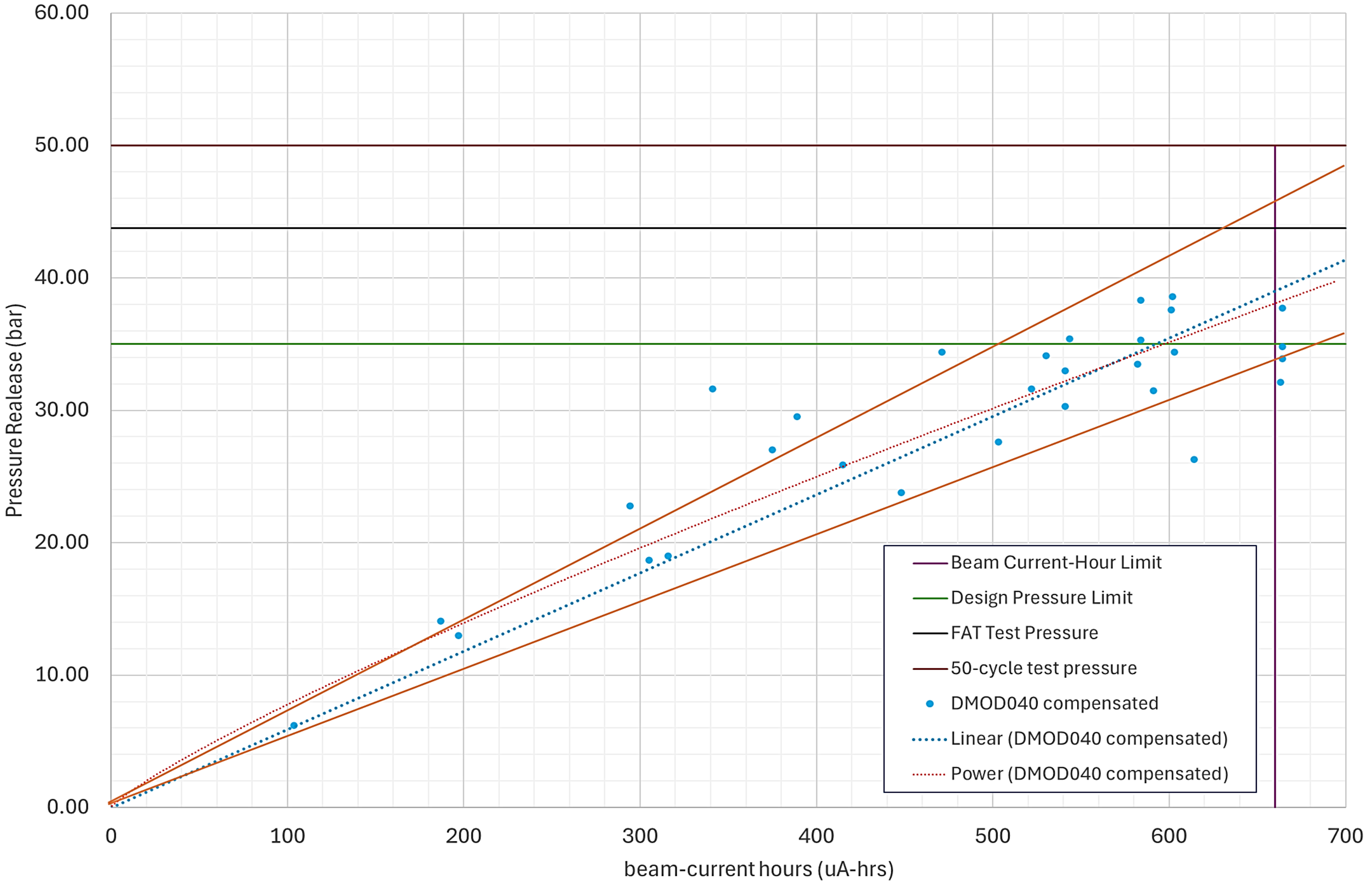


DMOD 041



Charge Change Pressure Releases – DMOD 040

- Incrementally increased charge run time
- Scattered results
- Hard to plot line of best fit
- Upper and lower-bound limits
- Can we trust the data?



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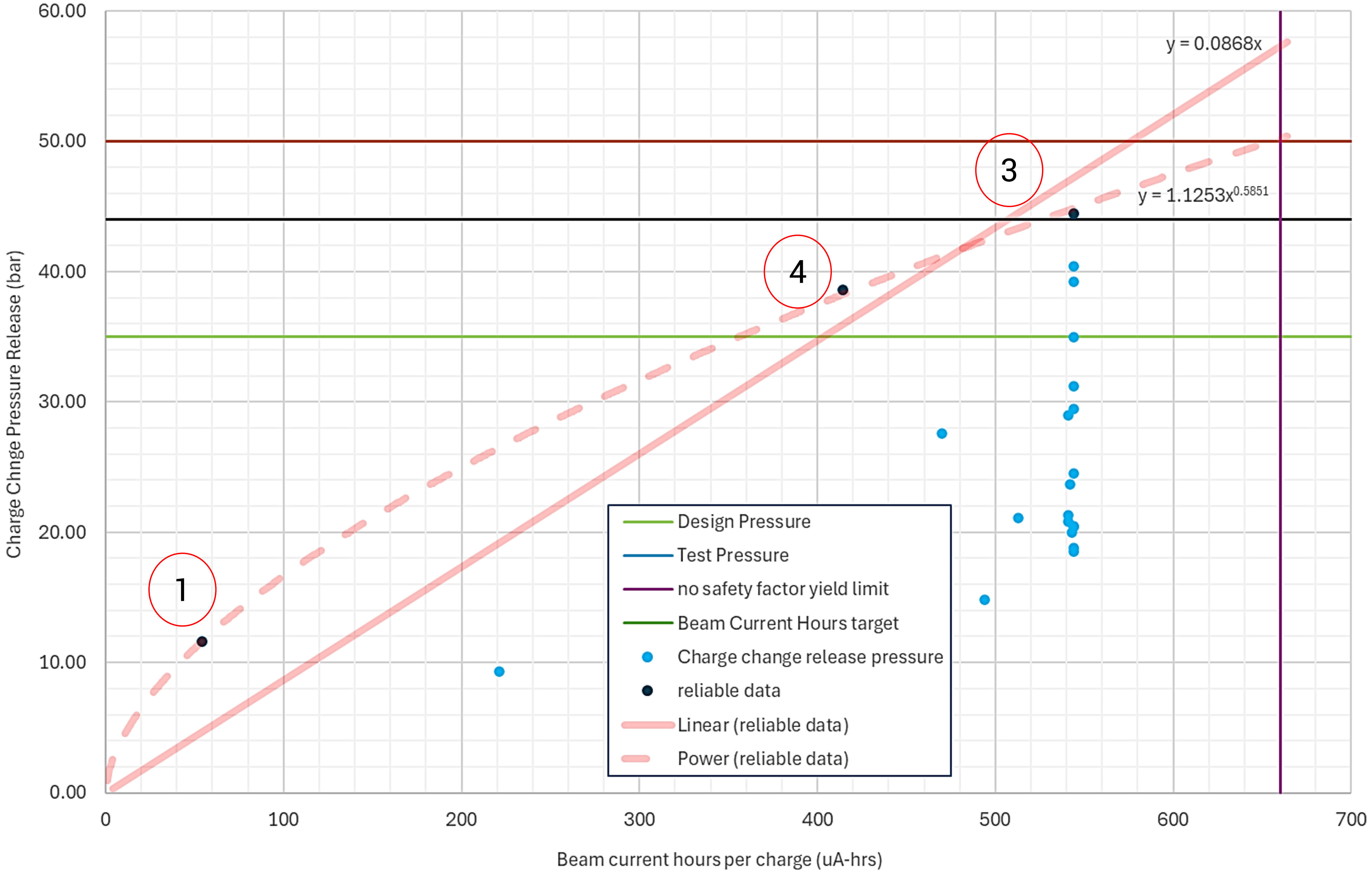
Charge Change Pressure Releases – DMOD 041

- Strain gauges started to fail early – glue?
- Use reliable readings to plot best fit
- Which line to use?
- Time limit stuck at 540uAh
- Assessment on increasing run time to original limit



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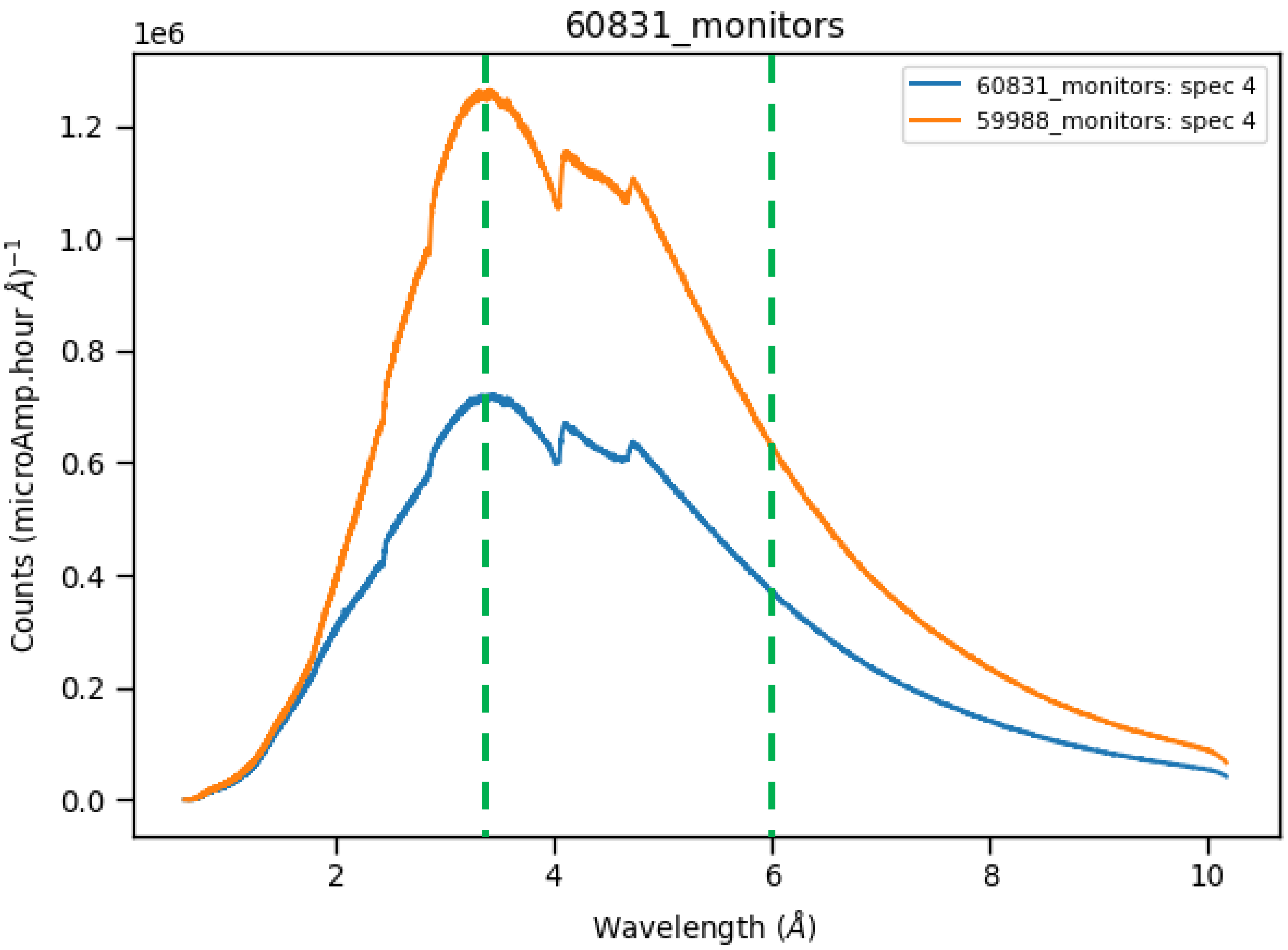
Poisoning Foil Impact

DMOD 039 - T_{He}=27 K; T_{mod} = 52.5 K
DMOD 040 - T_{He}=19 K; T_{mod} = 53.0 K

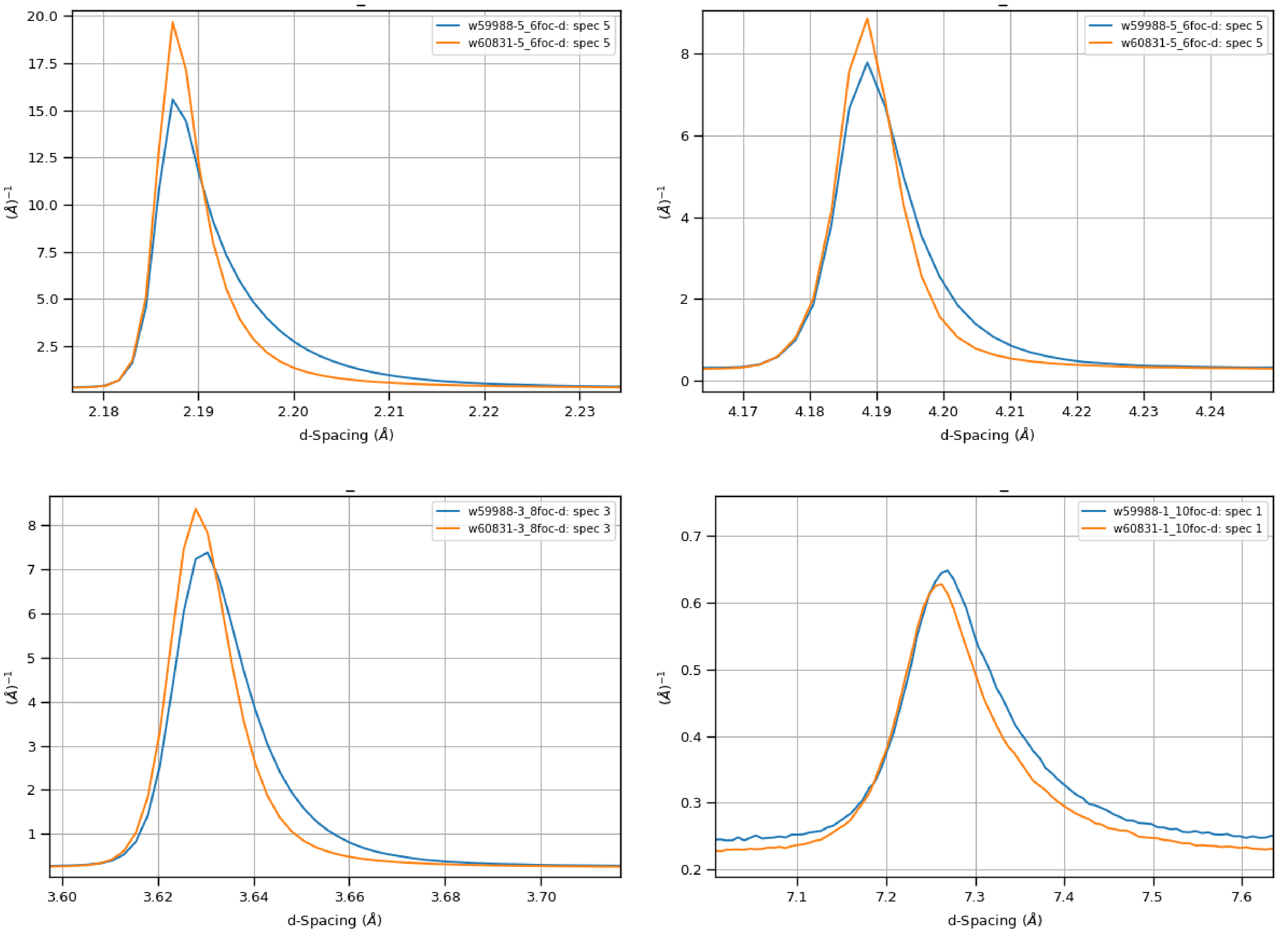
- Initial findings
- Peak in same position = same methane temperature
  - But poisoned design required 8K colder helium!
- Ratio between moderators 10% lower than Monte Carlo Simulation



Poisoning Foil Impact

Blue: no-poisoning
Orange: Gd-poisoning

- Reduction in long asymmetric tails
- Good agreement with Monte Carlo simulations regarding peak shapes



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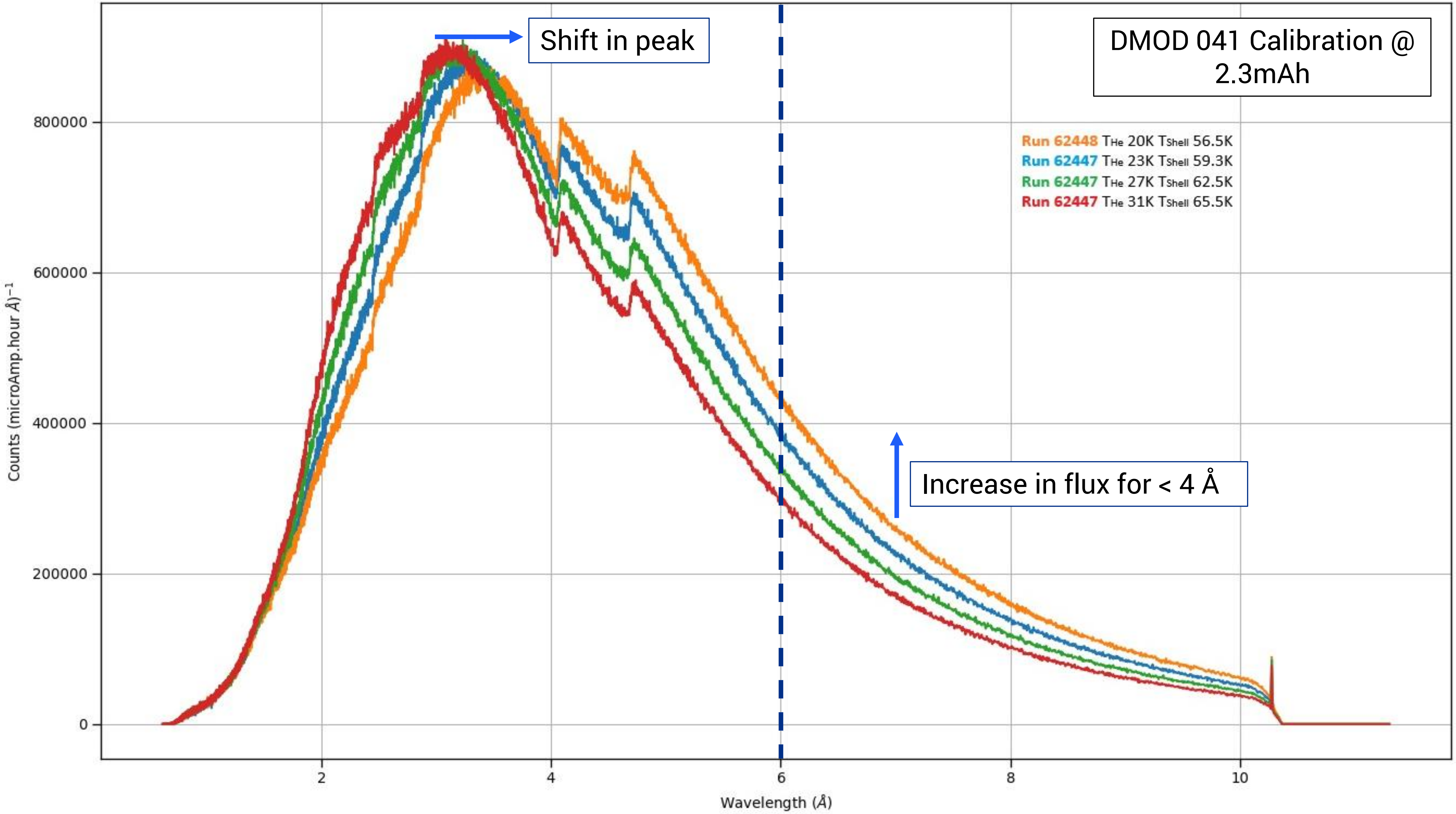
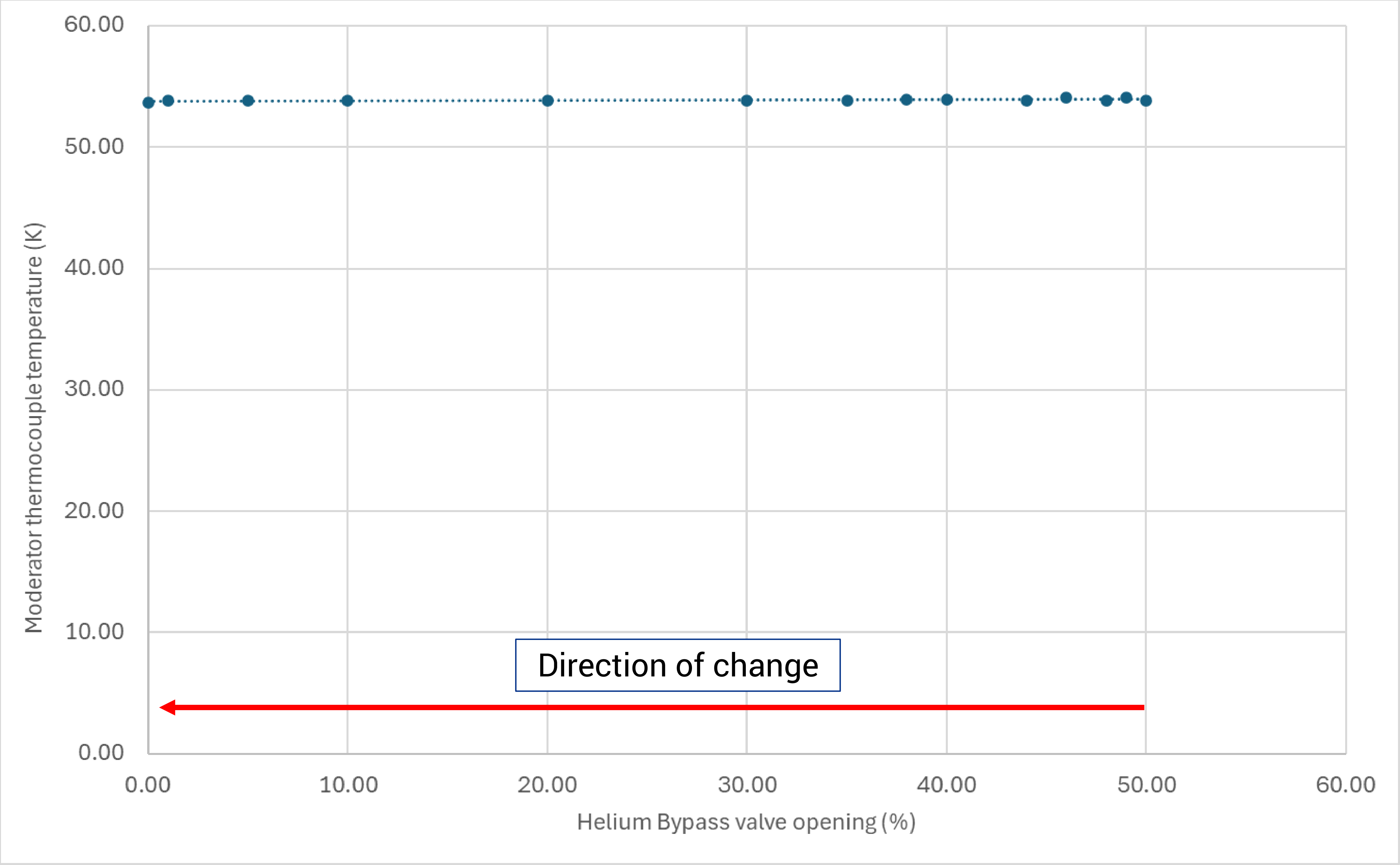


Shift in peak
DMOD 041 Calibration @ 2.3mAh
Run 62448 THe 20K TShell 56.5K
Run 62447 THe 23K TShell 59.3K
Run 62447 THe 27K TShell 62.5K
Run 62447 THe 31K TShell 65.5K
Increase in flux for < 4 Å
Counts (microAmp.hour Å)⁻¹
Wavelength (Å)
0
200000
400000
600000
800000
2
4
6
8
10

Coldbox optimisation

- increased mass flow rate through heat exchanger
- No impact on thermocouple temperature
- No impact seen on WISH detectors



Why?

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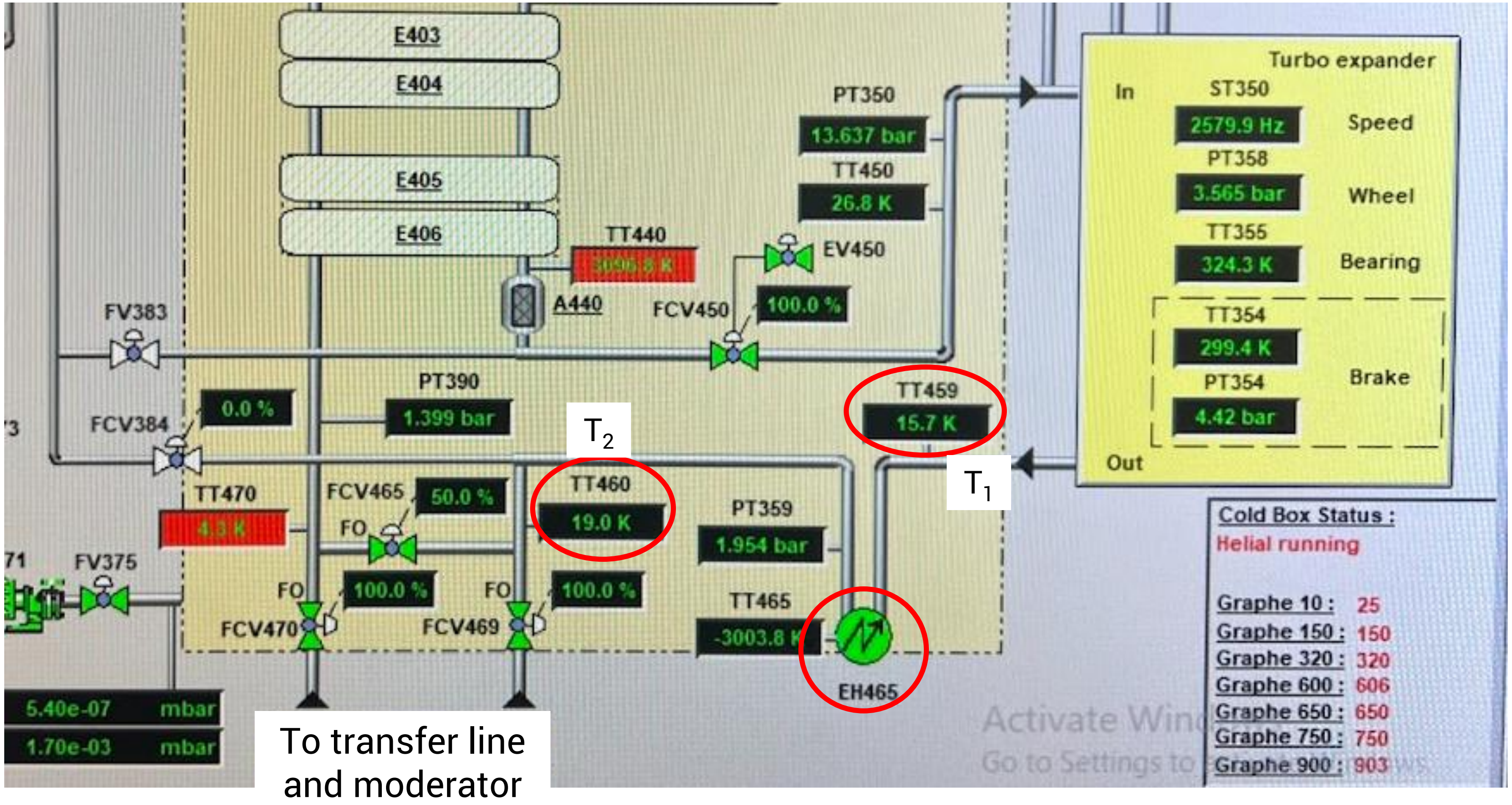
Real Mass flow rate?

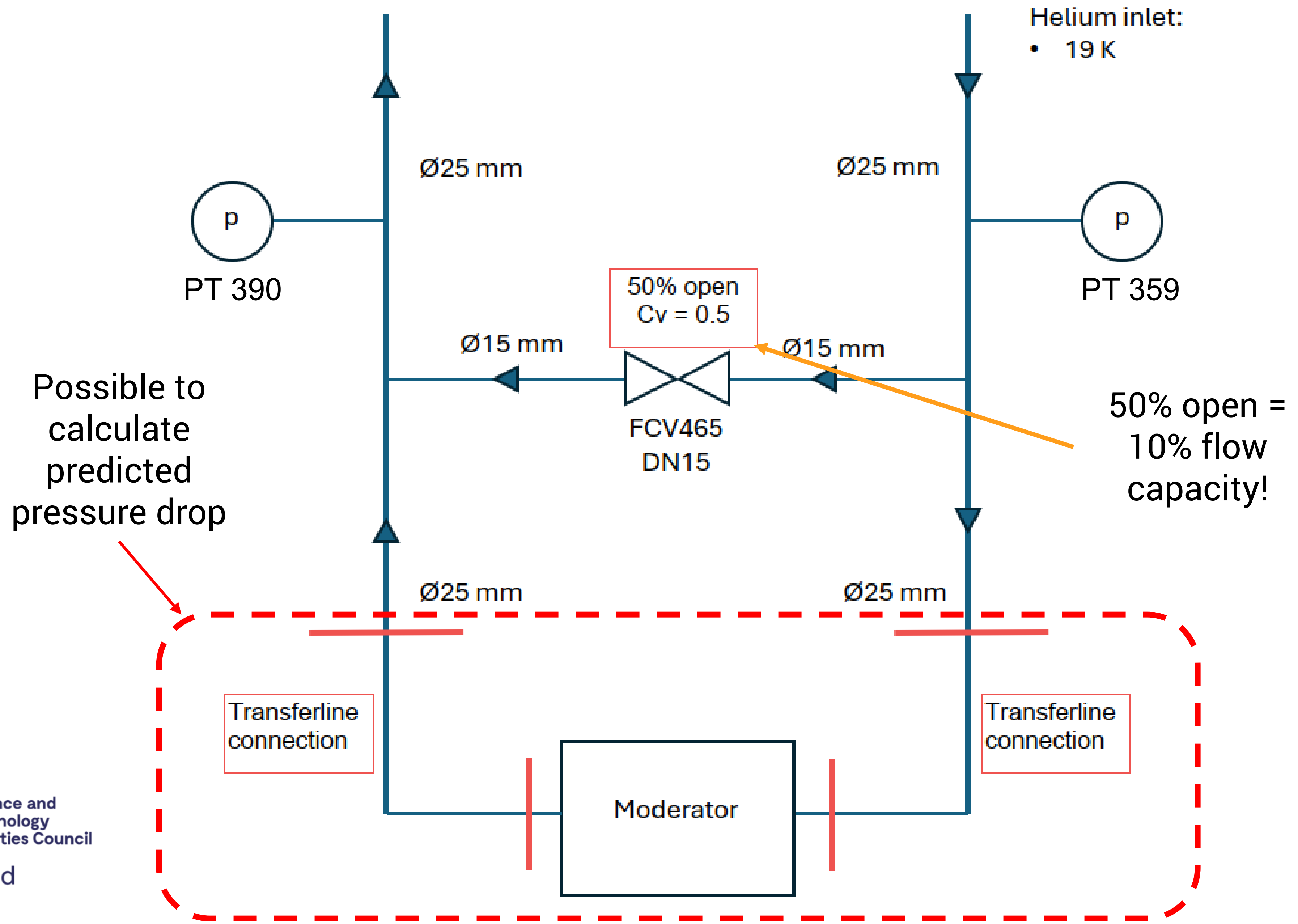
$$\dot{Q} = \dot{m} C_p \Delta T$$

- Full flow through turboexpander
- ΔT = 3.3 K
- Cp ~ 5280 J/kg.K
- Q = 450 W
- $\dot{m}$ = 25.8 g/s

- What happens with bypass open?

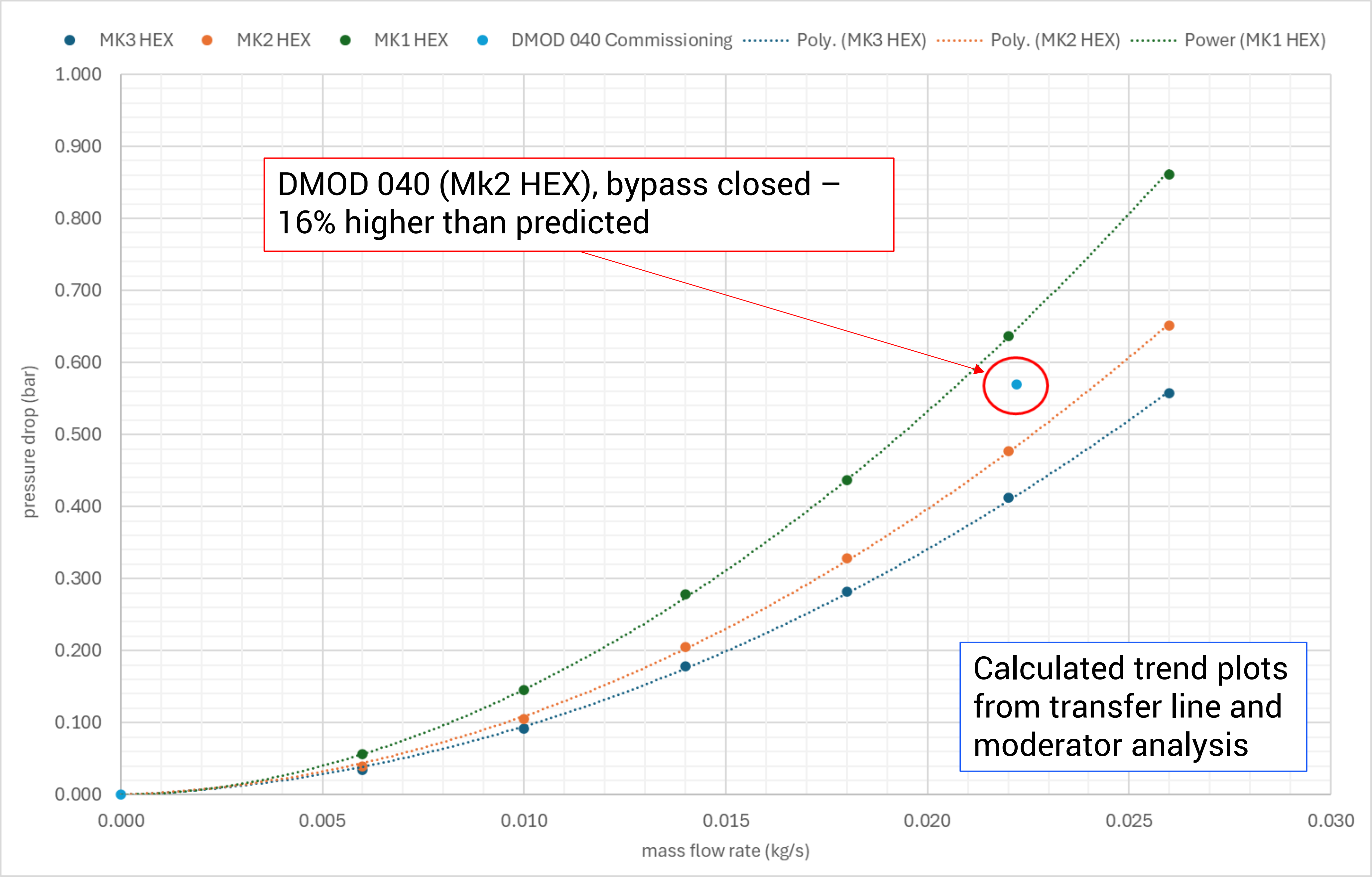


Deriving pressure drop and mass flow rates



Pressure drop vs mass flow rate

- Closing bypass on DMOD 040 gave a data point
- Flow rate derived from heater output
- Apply 16% error for future prediction
- We are operating at higher flow rates than expected!



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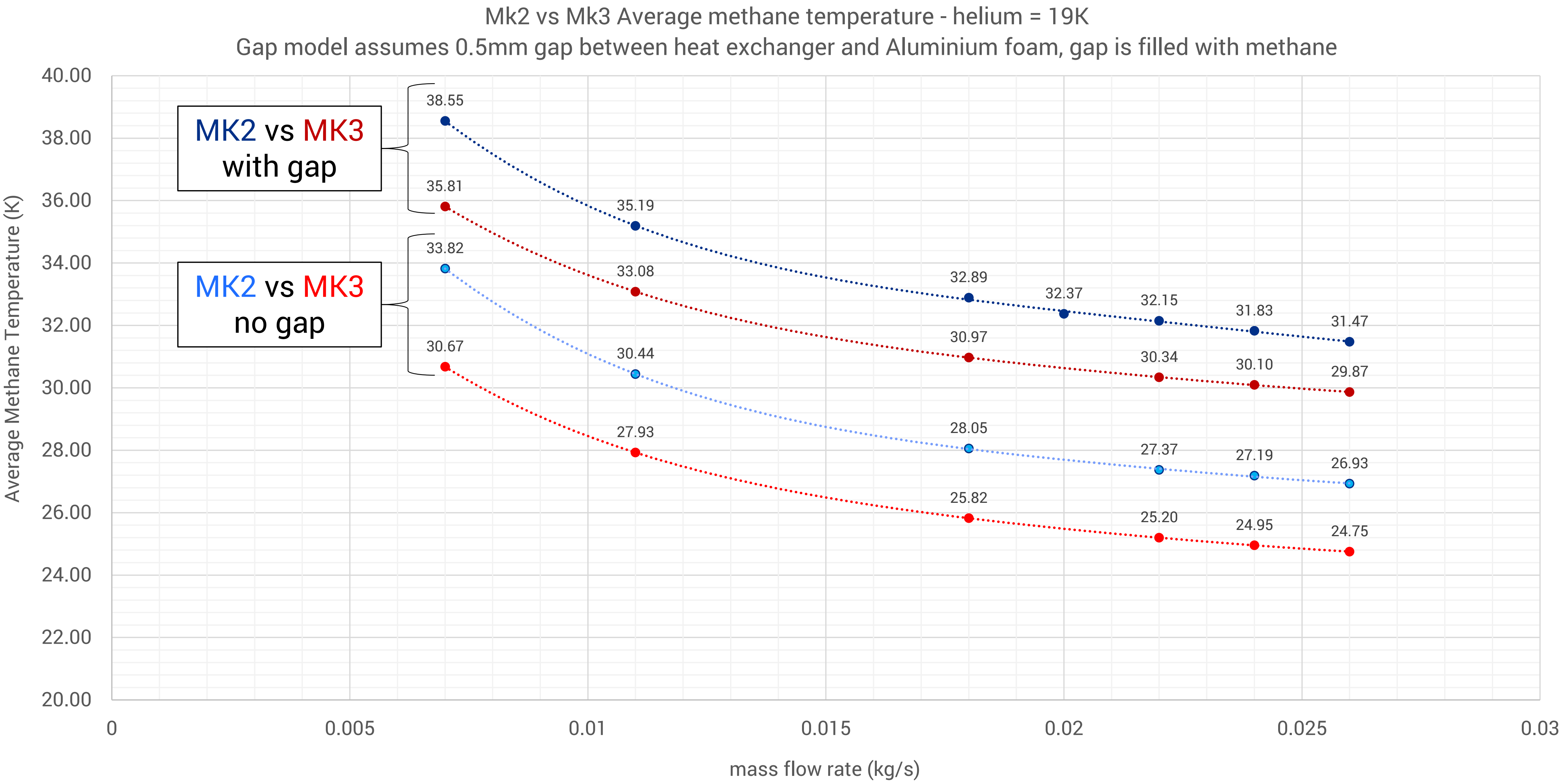
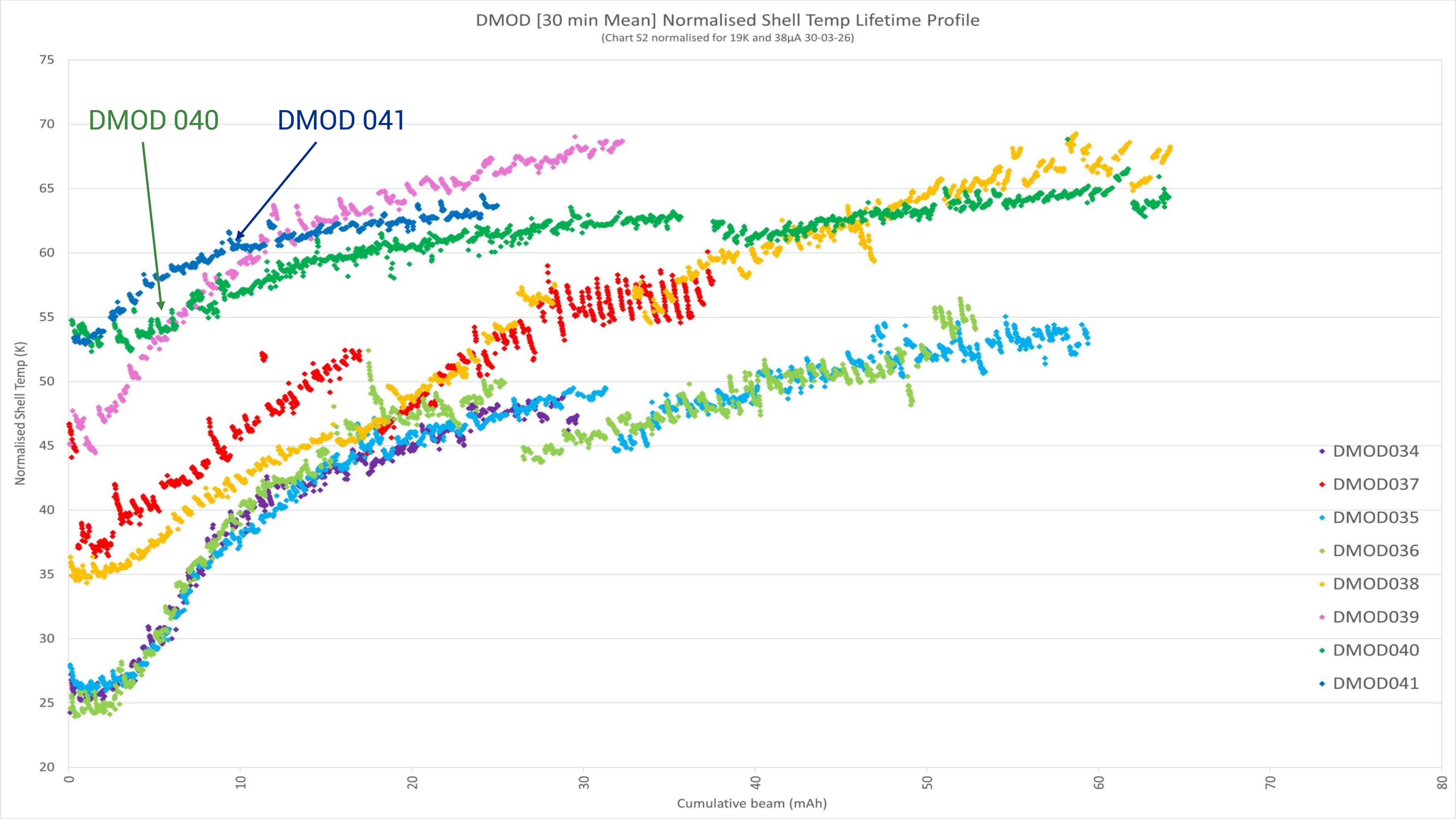
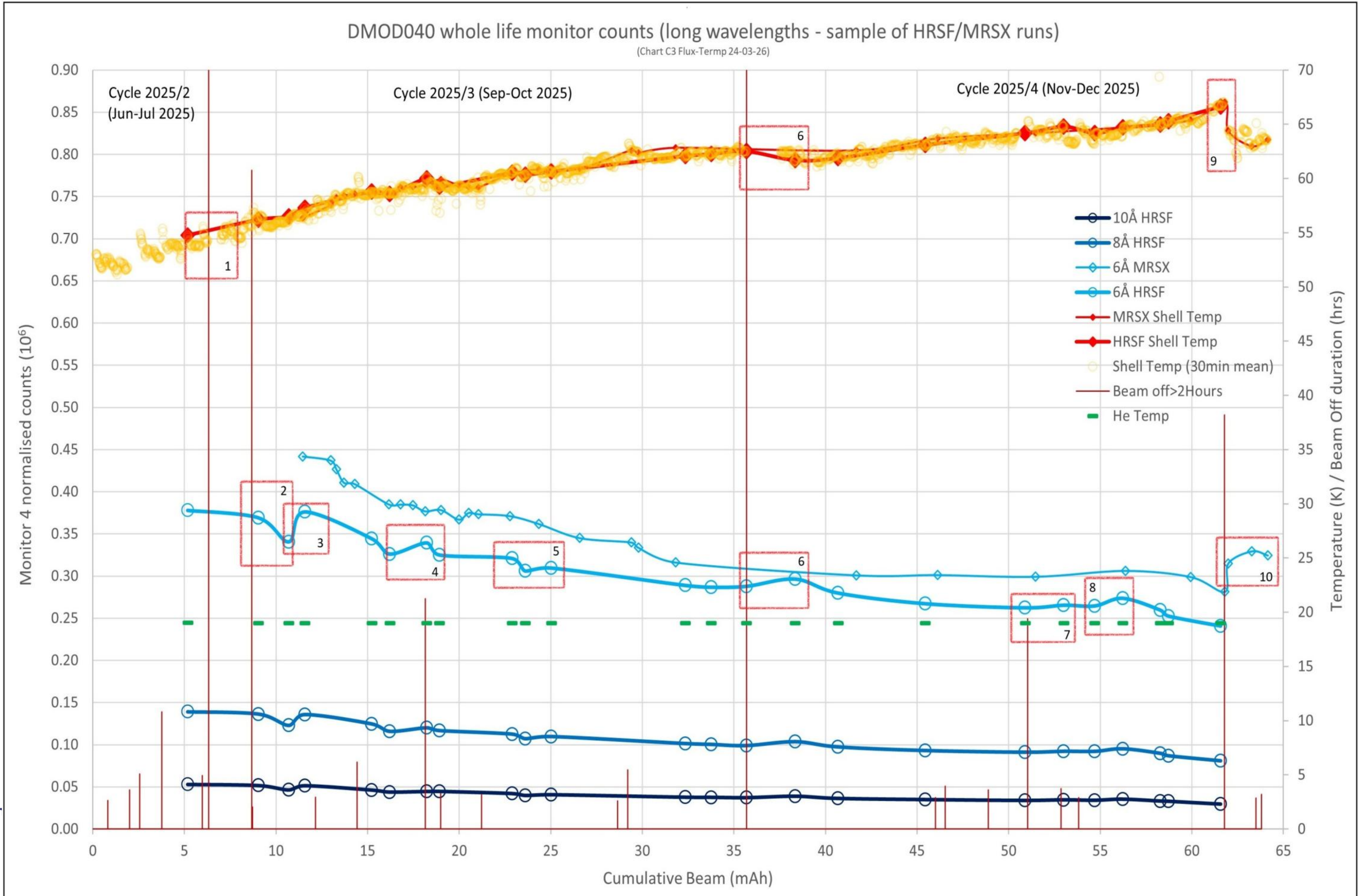
More CFD – temperature vs flow rate





DMOD [30 min Mean] Normalised Shell Temp Lifetime Profile
(Chart S2 normalised for 19K and 38µA 30-03-26)
DMOD 040
DMOD 041
Normalised Shell Temp (K)
Cumulative beam (mAh)
75
70
65
60
55
50
45
40
35
30
25
20
0
10
20
30
40
50
60
70
80
DMOD034
DMOD037
DMOD035
DMOD036
DMOD038
DMOD039
DMOD040
DMOD041

- Plot flux count at different wavelengths over time
- Compare with shell temperature tracking
- Assess this against previous moderator design…



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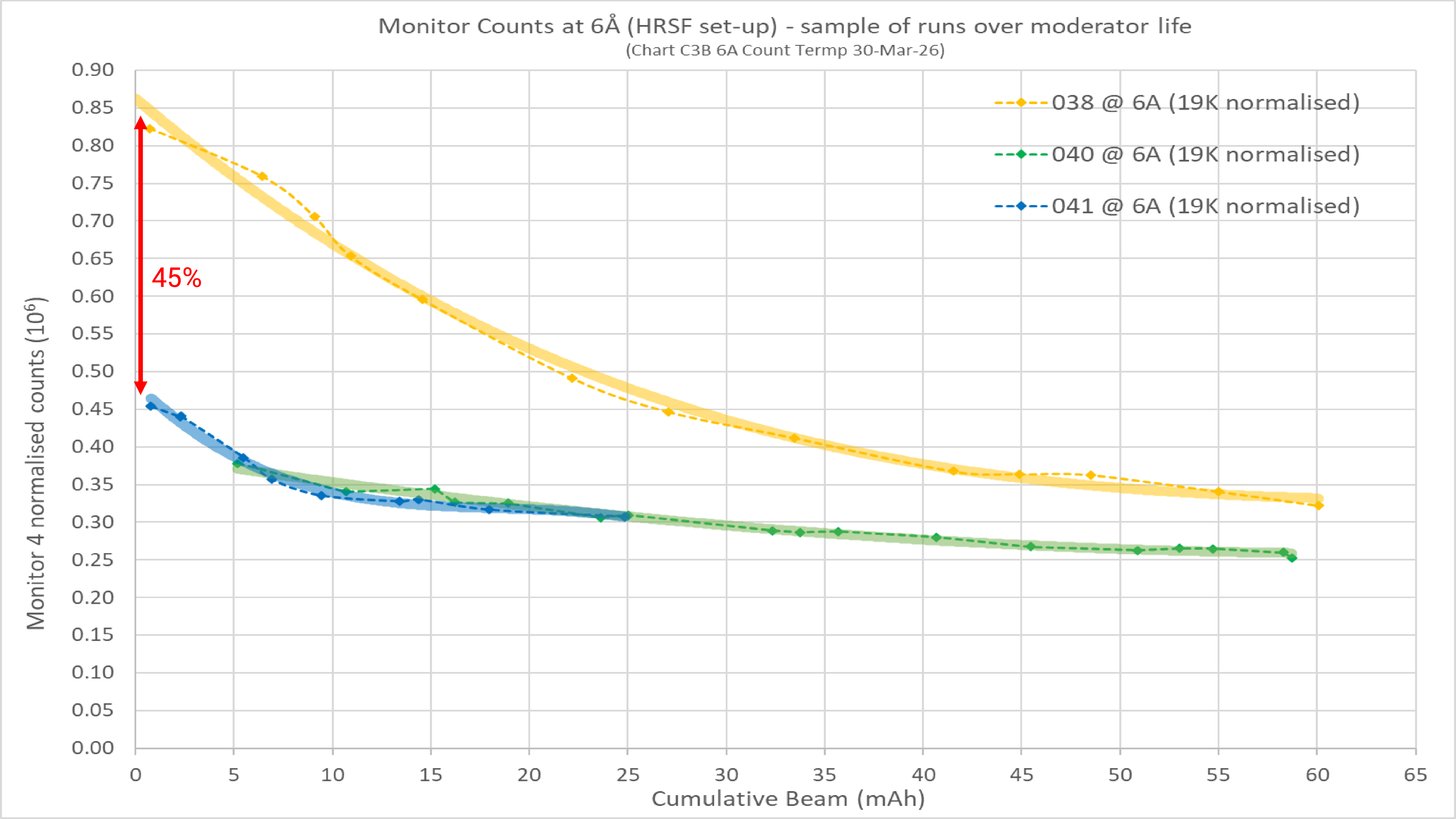

Monitor Counts at 6Å (HRSF set-up) - sample of runs over moderator life
(Chart C3B 6A Count Termp 30-Mar-26)
Monitor 4 normalised counts (10^6)
Cumulative Beam (mAh)
45%
038 @ 6A (19K normalised)
040 @ 6A (19K normalised)
041 @ 6A (19K normalised)
0.90
0.85
0.80
0.75
0.70
0.65
0.60
0.55
0.50
0.45
0.40
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.00
0
5
10
15
20
25
30
35
40
45
50
55
60
65

DMOD 041 commissioning problems

- User-cycle was delayed – lost commissioning time and staffing issues!
  - Coldbox settings not same as DMOD 040 – lower mass flow rate
- Helium inlet temperature sensor failed at the start of the run – good fix put in place
- Issues with charge changes
- Thermocouple temperature high – very sure this is false
- Accelerator issue halfway through cycle – another week off!
- Performance similar to DMOD 040:
  - Lower mass flow rate, does it make a significant difference?
  - Why? Modelling errors?
  - Helium temperature higher than sensor says?

Conclusions

Positives:

- The poisoning foil was a success
- Moderator ran for two user cycles
- Deteriorated at a slower rate than the original brazed design
- Provided insight into degradation mechanisms
- More experience in operating cryogenic system
- Results shows where to focus on for design development

Negatives:

- The moderator is warmer than desired
- Charge change pressure release higher anticipated
- DMOD 041 coldbox settings not same as DMOD 040
- Heat exchanger needs redesigning for higher flow rates
- Helium cernox temperature sensor failed and now has a small error after fix

A big thank you

Target Design Group:
- Paul Morgan
- David Jenkins
- Dan Coates
- Ste Gallimore

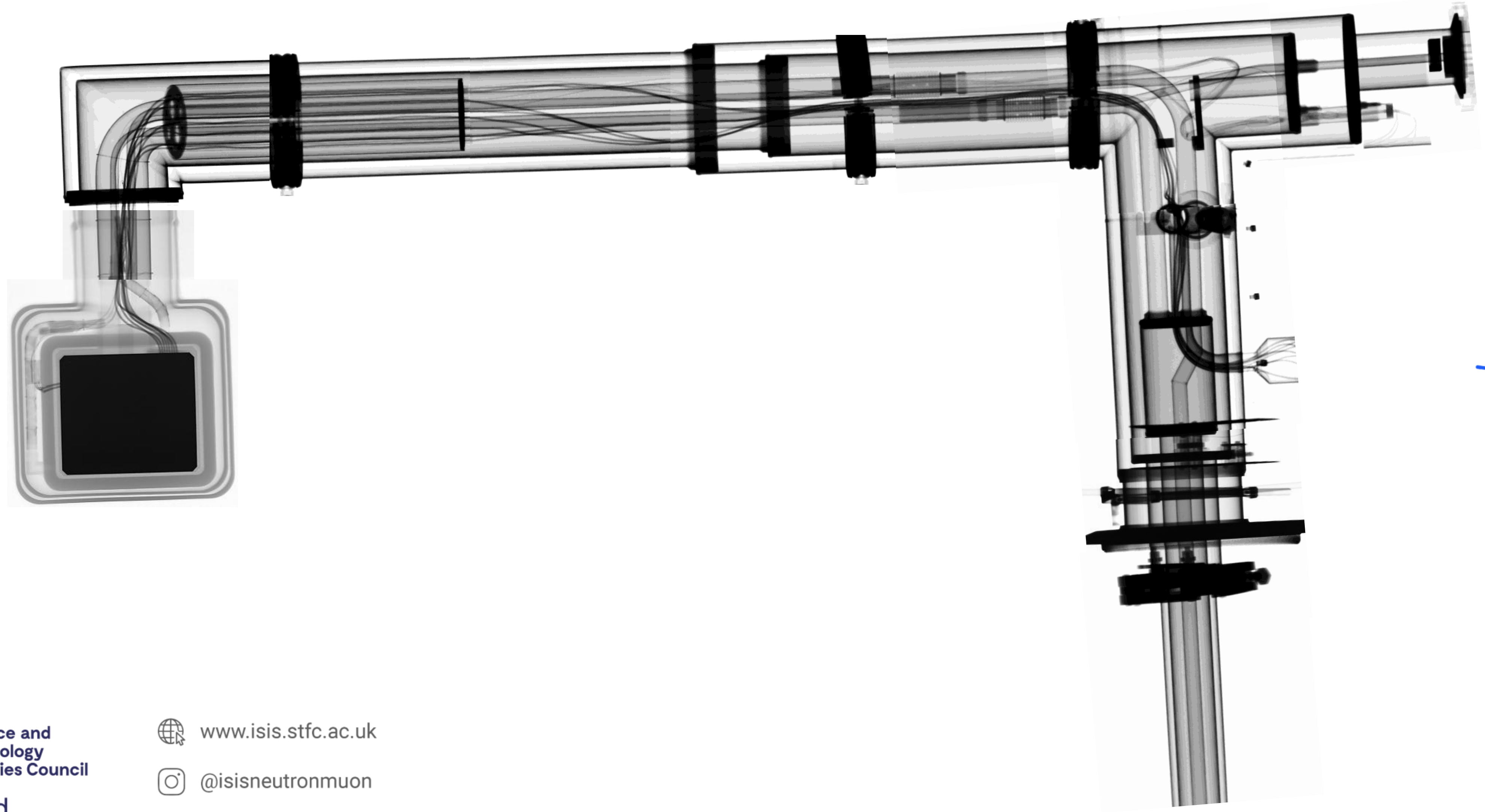
ISIS Neutronics:
- Goran Skoro
- Rob Bewley
- Steven Lilley

Target Operations:
- Julius Bullock
- Henry Russell
- Graham Wallace
- George Torrington
- Jon Chapman
- Jeremy Moor

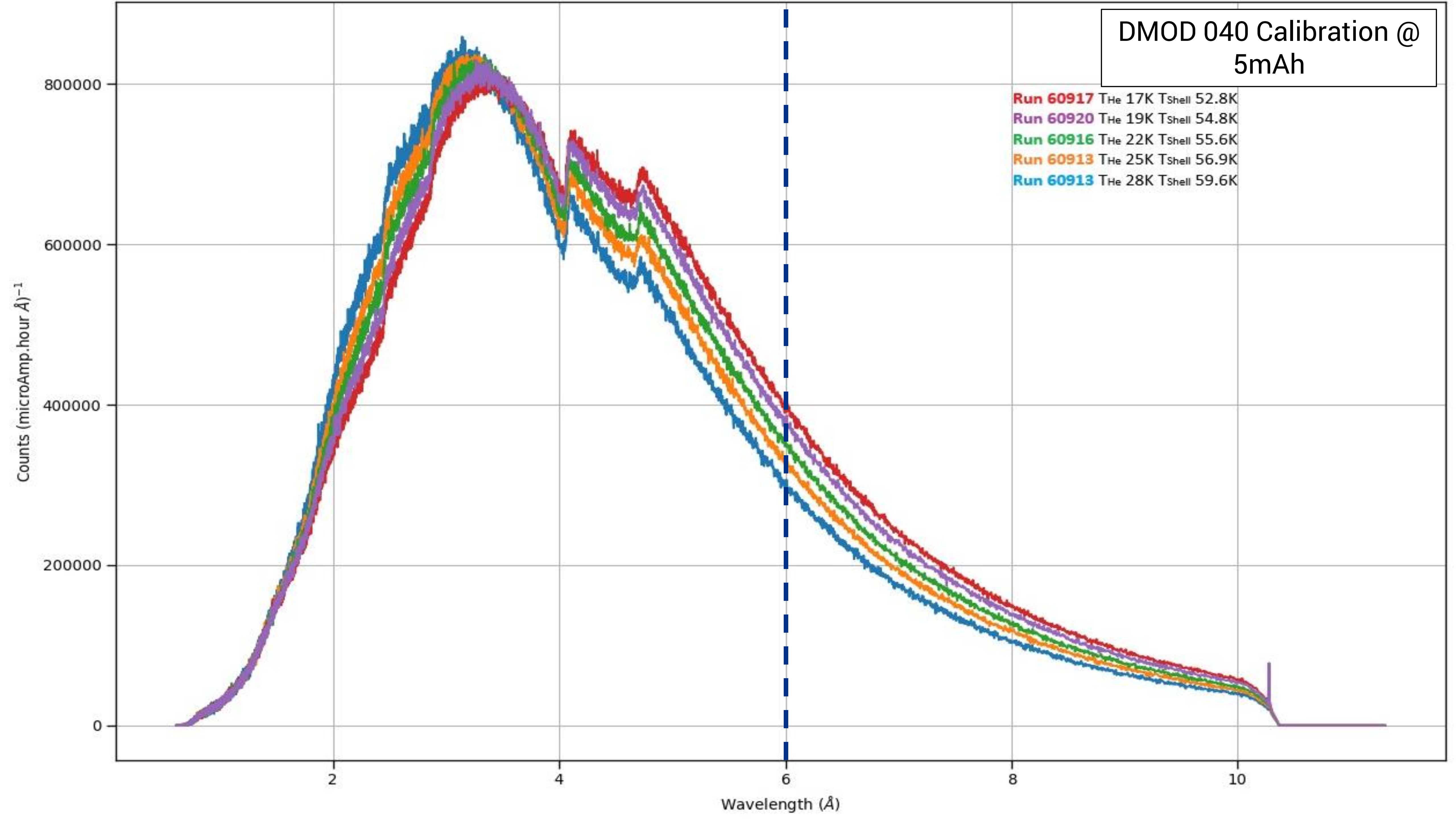
Target Control Operations:
- Rajesh Gupta
- Alex Baker

WISH Instrument team – Pascal Manuel, Dmitry Khalyavin, Fabio Orlandi

Questions?



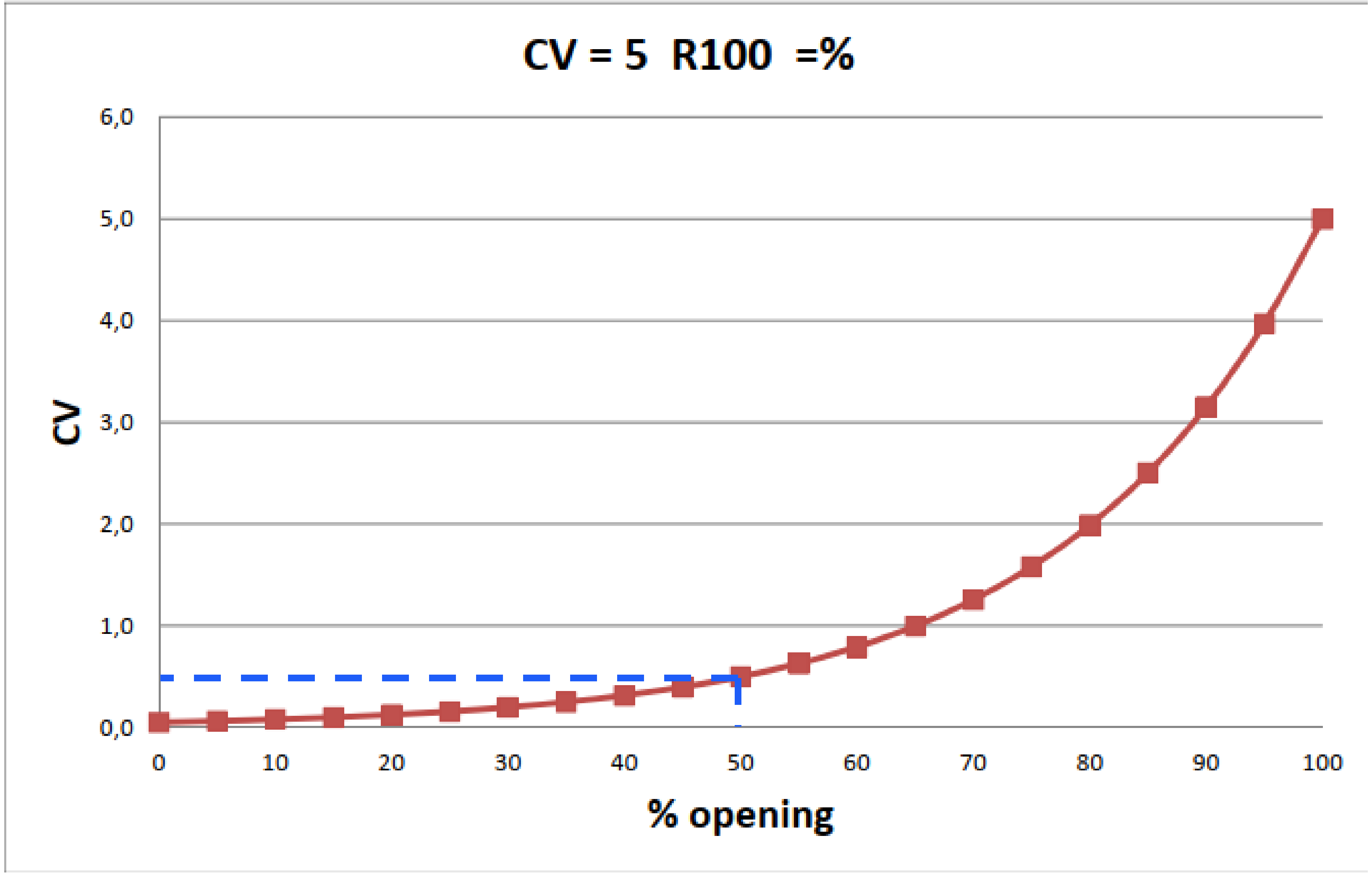
Appendices



DMOD 040 Calibration @ 5mAh
Run 60917 THe 17K TShell 52.8K
Run 60920 THe 19K TShell 54.8K
Run 60916 THe 22K TShell 55.6K
Run 60913 THe 25K TShell 56.9K
Run 60913 THe 28K TShell 59.6K
Counts (microAmp.hour Å)⁻¹
800000
600000
400000
200000
0
2
4
6
8
10
Wavelength (Å)

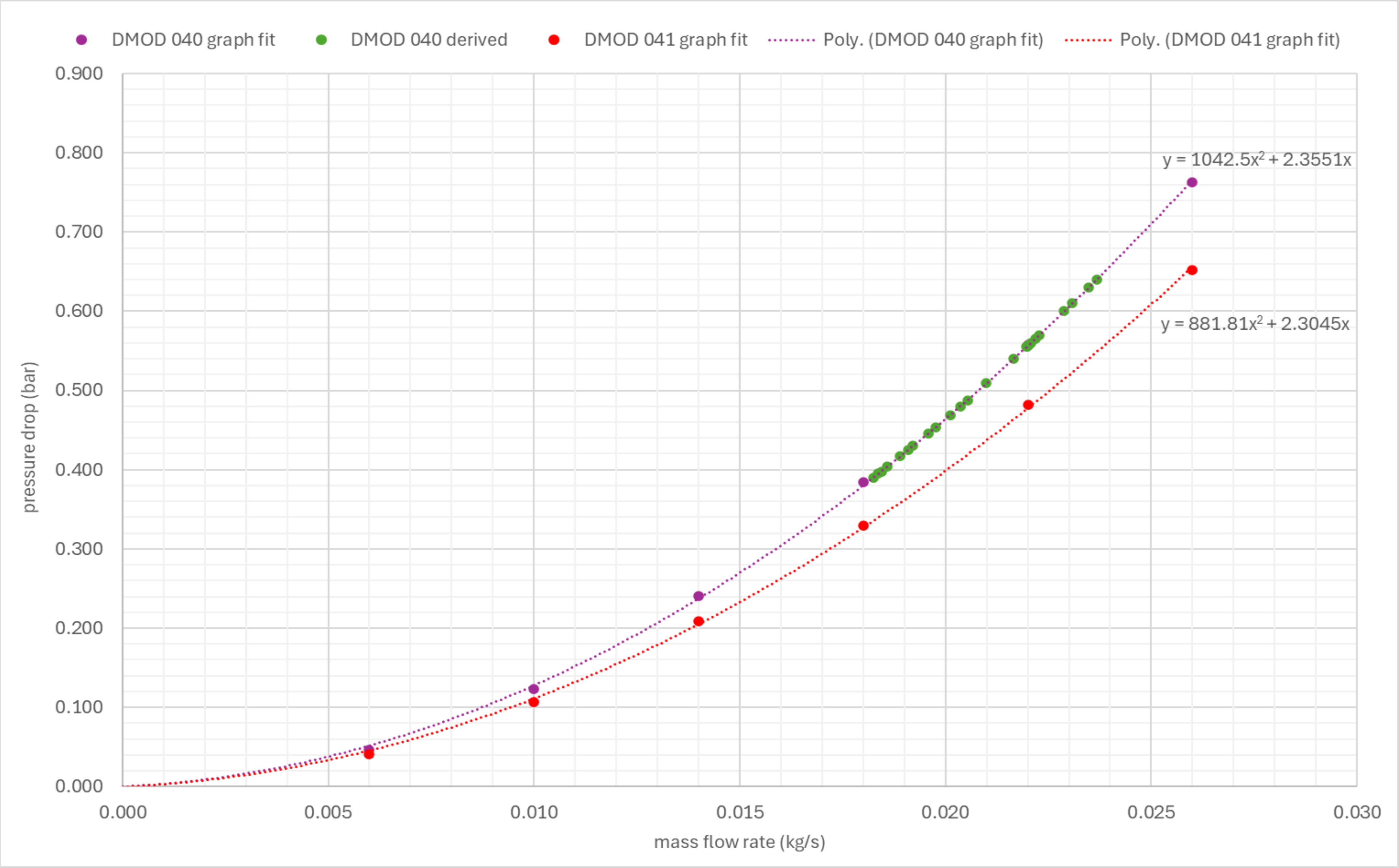
Bypass valve

- 50% open = 0.5 Cv
- 100% open = 5 Cv
- So, 50% open means 10% flow capacity!



Pressure drop vs mass flow rate

- Using new relationship, can estimate mass flow rate based on pressure drop in system



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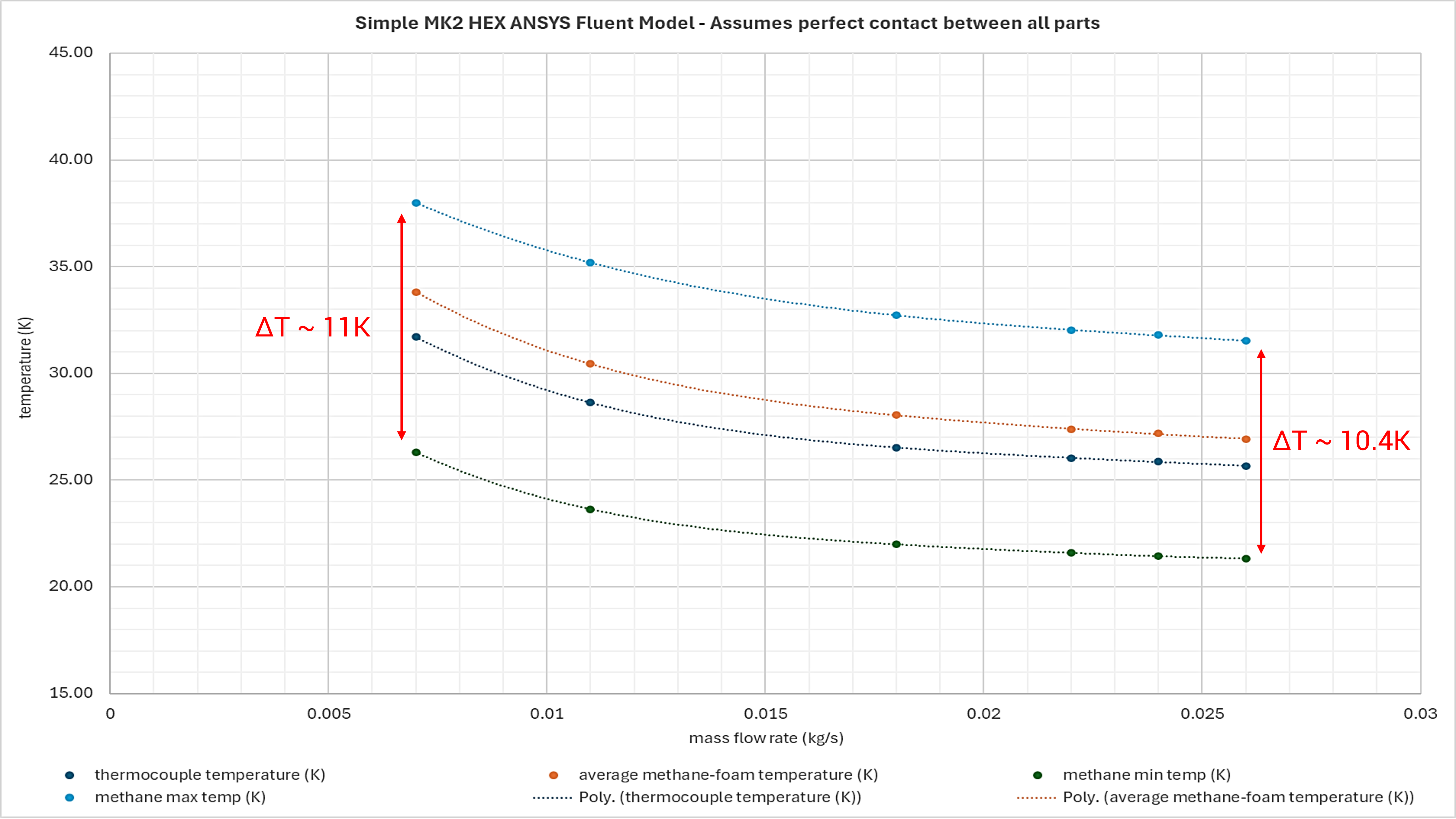
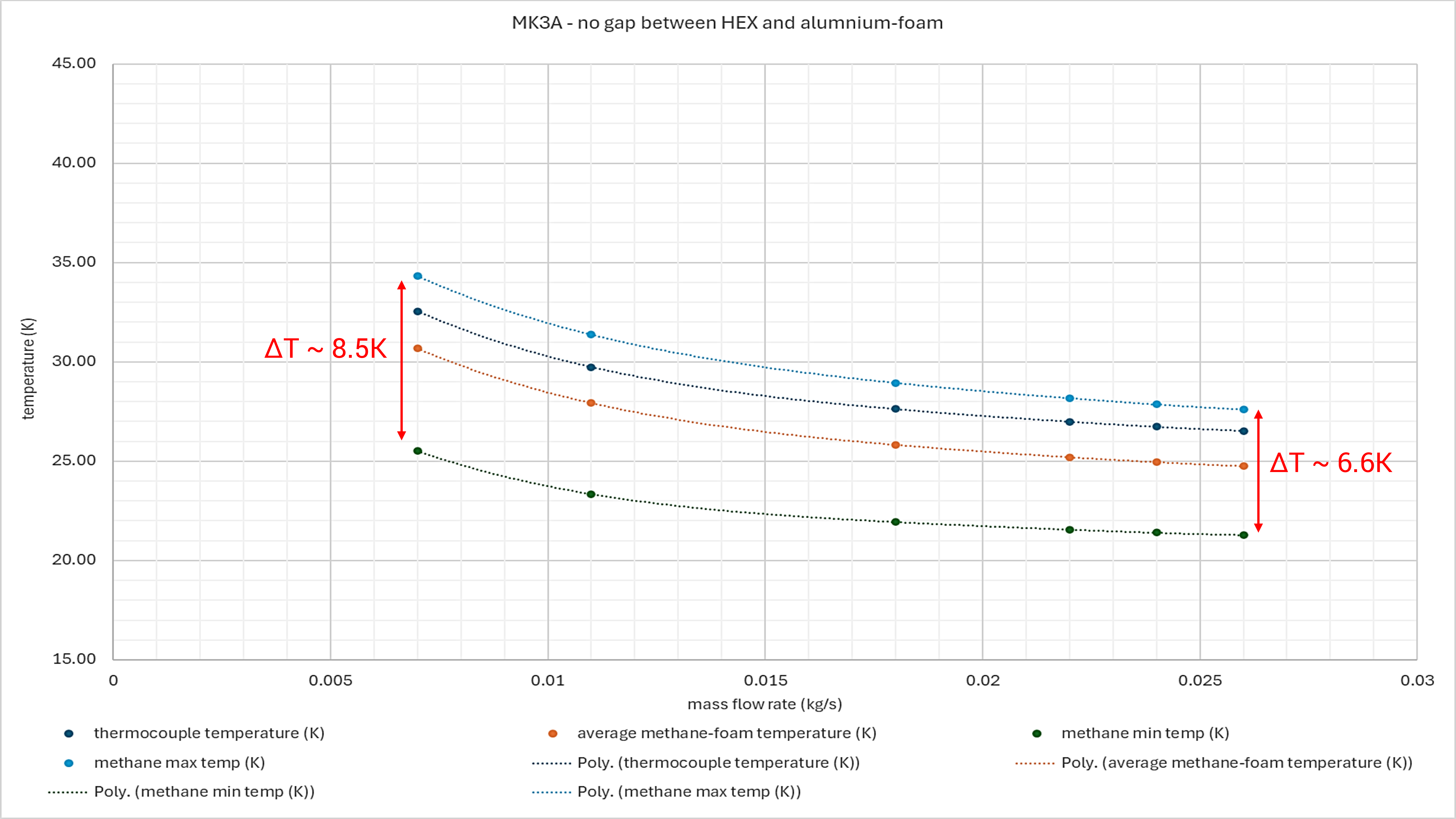
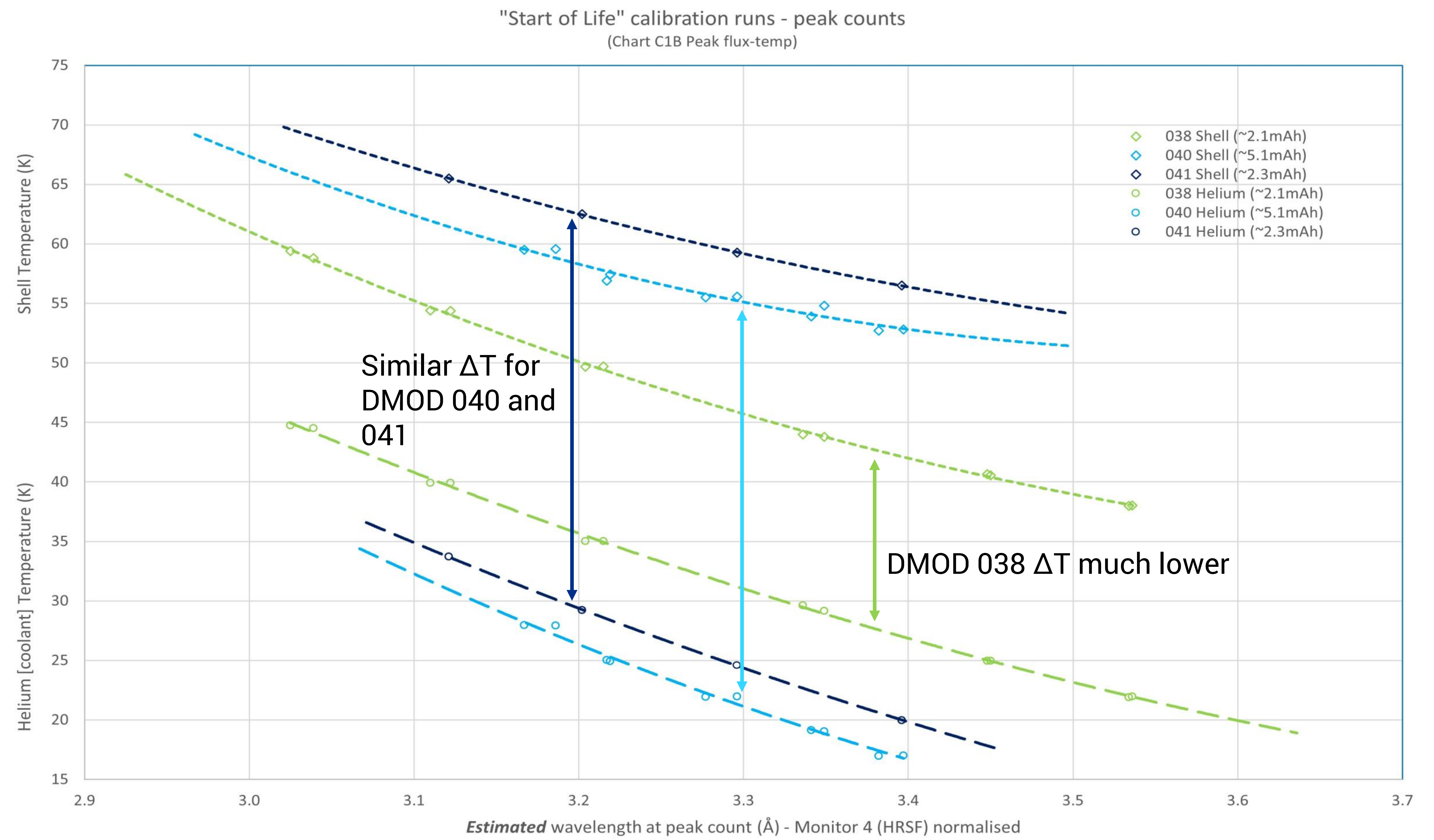

Simple MK2 HEX ANSYS Fluent Model - Assumes perfect contact between all parts
45.00
40.00
35.00
30.00
25.00
20.00
15.00
temperature (K)
ΔT ~ 11K
ΔT ~ 10.4K
0
0.005
0.01
0.015
0.02
0.025
0.03
mass flow rate (kg/s)
thermocouple temperature (K)
average methane-foam temperature (K)
methane min temp (K)
methane max temp (K)
Poly. (thermocouple temperature (K))
Poly. (average methane-foam temperature (K))



MK3A - no gap between HEX and alumnium-foam
45.00
40.00
35.00
30.00
25.00
20.00
15.00
temperature (K)
0
0.005
0.01
0.015
0.02
0.025
0.03
mass flow rate (kg/s)
ΔT ~ 8.5K
ΔT ~ 6.6K
thermocouple temperature (K)
average methane-foam temperature (K)
methane min temp (K)
methane max temp (K)
Poly. (thermocouple temperature (K))
Poly. (average methane-foam temperature (K))
Poly. (methane min temp (K))
Poly. (methane max temp (K))


"Start of Life" calibration runs - peak counts
(Chart C1B Peak flux-temp)
Shell Temperature (K)
Helium [coolant] Temperature (K)
Estimated wavelength at peak count (Å) - Monitor 4 (HRSF) normalised
038 Shell (~2.1mAh)
040 Shell (~5.1mAh)
041 Shell (~2.3mAh)
038 Helium (~2.1mAh)
040 Helium (~5.1mAh)
041 Helium (~2.3mAh)
Similar ΔT for DMOD 040 and 041
DMOD 038 ΔT much lower

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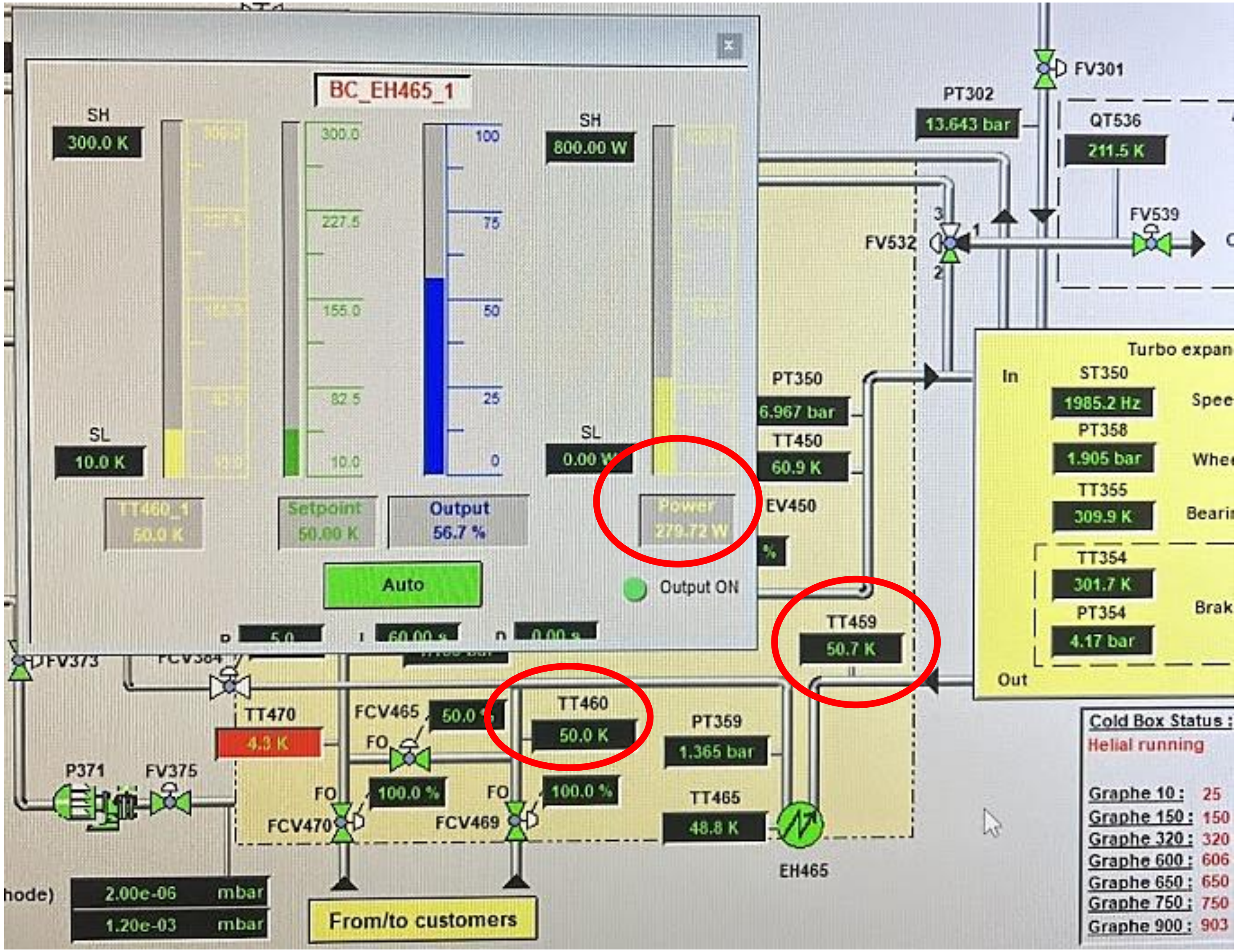
Temperature sensor issue…

- Beam off setting
- 50.7 K, plus 280W heat, gives… 50K!!!
- Use pressure drop and predicted flow rate vs pressure drop plot
- Assume TT459 works!



Temperature sensor issue…

Predicted error in TT460_1 reading (using TT459_1 reading when heater power =0)