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SPIE-DCS 2019

THEORETICAL AND EXPERIMENTAL ANALYSIS OF DEWAR THERMAL PROPERTIES

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Outline

- Background
- Methods for determining dewar properties
- Limitations and potential sources of error
- Measurements and Comparison
- Conclusion

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Background

To predict performance of an IDCA, you need to understand:

- Cooler performance
- Dewar-Detector performance

Dewar parameters:

Parameter	Unit	Description?
Heat load P_{th}	**W**	Amount of heat to be removed from the cold finger well to keep a constant detector temperature. Typically defined at 77 K
Thermal mass M_{th}	J	Amount of energy to be removed from the dewar to cool down from […] to […]. Typically defined from 296 K to 77 K
Thermal resistance R_{th}	K/W	Temperature gradient required to transport 1 W of heat from cold finger well to detector.

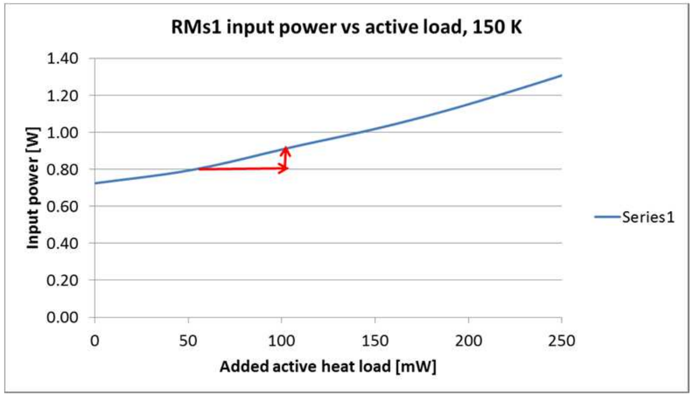
Background

The ever-present drive towards lower Size, Weight and Power

- Increase in detector temperature
- Decrease in dewar parasitics & size
- More efficient cryocoolers

SWAP requires better accuracy

- Typical input power curve:
    - Misestimation of 50 mW of dewar load
    - … results in 10% error in estimating input power



SWAP requires HOT:

- Dewar characterization at temperatures other than 150 K

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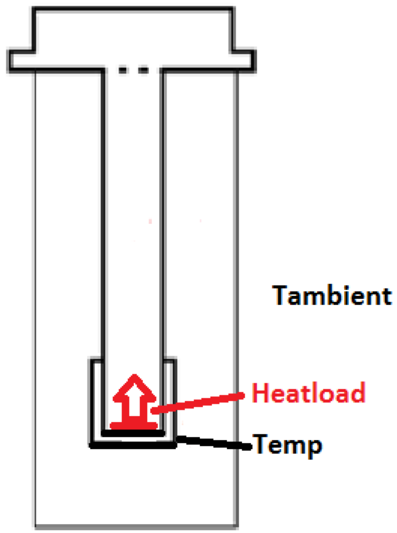
Methods for determining dewar loss

- Theoretical modelling
- Liquid boil-off (typically: N2)
- Liquid boil-off with intrinsic calibration
- Transient warm-up method (SCD / Veprik, 2015)
- Direct heat flux measurement (JPL / 1992…)

Gas	Boiling point @ 1 bar
N2	77.4
ARGON	87.6
XENON	165.3



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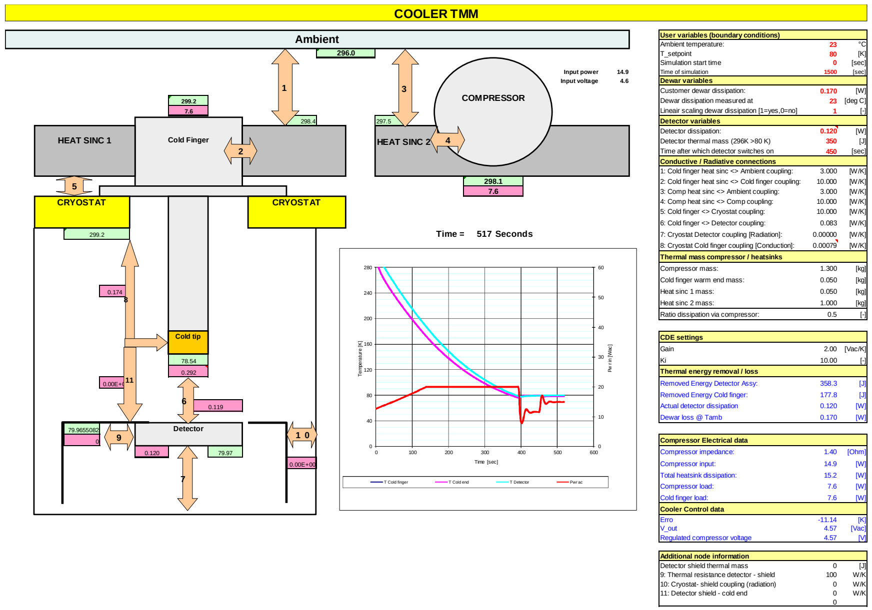
Theoretical modelling in ThermXL

Linearized model in ThermXL

- Node-based model using an Excel front-end
- Time based simulation possible

Used within Thales for cooldown time calculations

- Dewar parameters as input
- Cryocooler "fit function" as input



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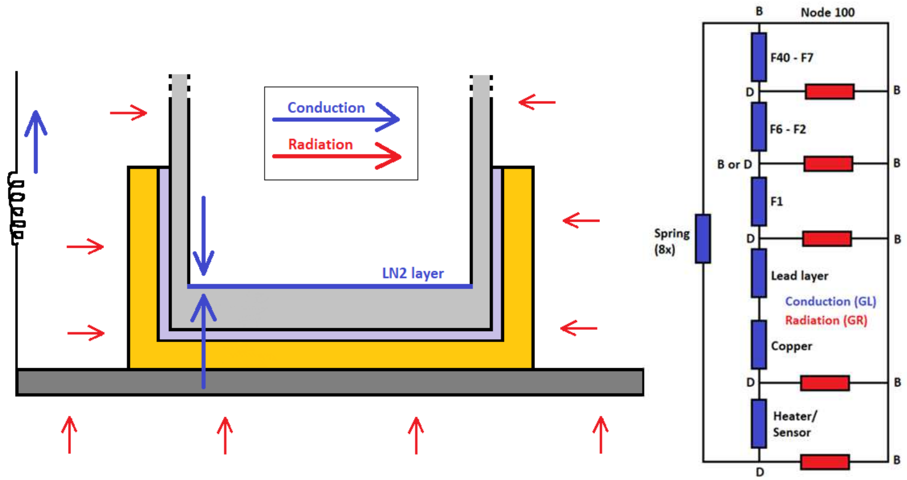
Theoretical model of dewar boil-off

Model can also be used to simulate the various dewar characterization methods

Allows both transient and steady-state simulation

- Transient for, e.g., a warm-up calorimetry measurement
- Steady-state for, e.g., a calibrated LN2 boil-off measurement



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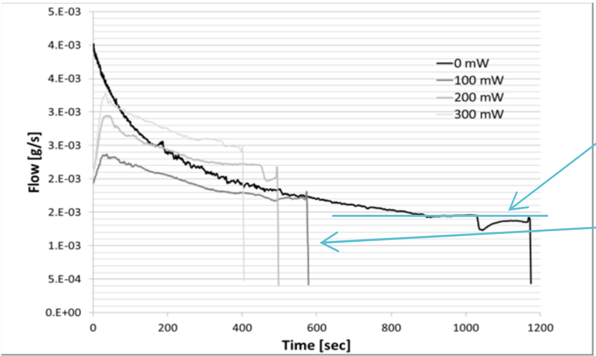
Boil-off method (with LN2)



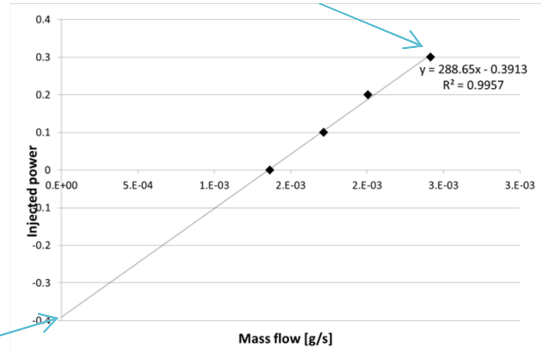
Insert LN2 in dewar cold finger

Wait for "last drop boil"

Measure multiple slopes with added load

Flow rate "last drop" used to determine dewar heat load

Slope much higher than 200 J/g



Added load to calibrate measurement

- Actual heat absorbed by N2 flowing out is higher than only evaporation – potential large difference. Dependent on dewar geometry.

Requires consistent interpretation – what is the "last drop boil" point?

Only usable at boiling temperature of liquid (very few practical options – LN2)

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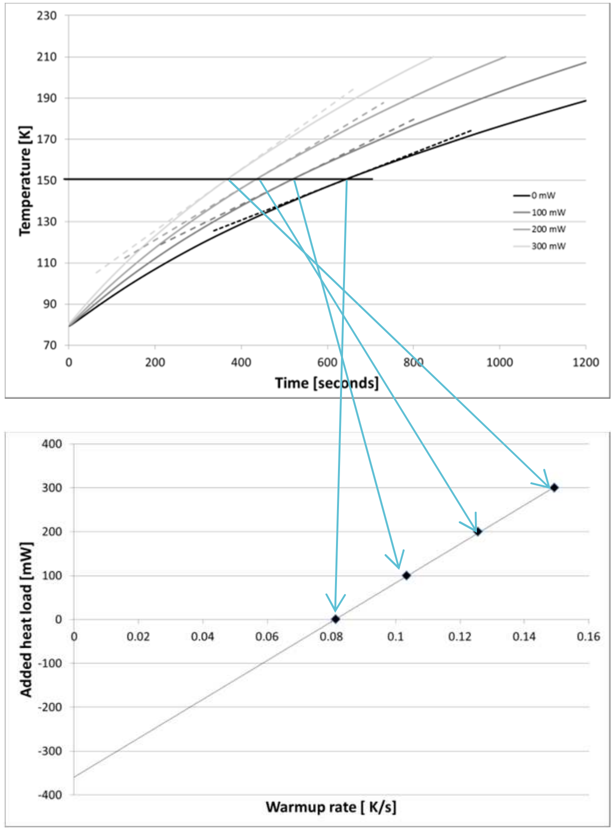
Multi-slope warm-up

Derive the dewar losses from warmup rate

- Cool down the dewar first (LN2 boil-off)
- Start measurement immediately after boil-off
- Warmup rates as a function of temperature
- Calibrate by performing multiple curves with added heat load

Several advantages

- No operator interpretation required
- Gives thermal mass as well as dewar heat load
- Gives dewar load at all intermediate temperatures



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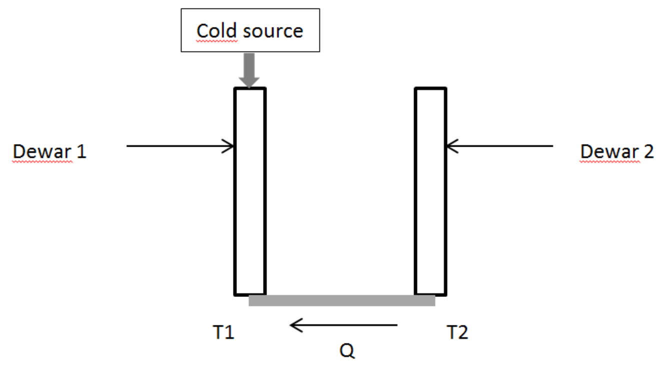
Heat flux measurement

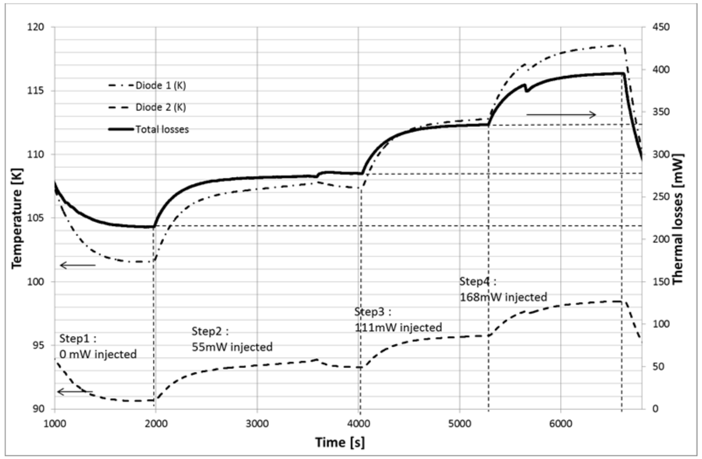
Measured via ΔT

- Uses cold source other than cryoliquid
- Heat bridge with known Rth



Advantages

- Can be used for any cold temperature
- Very direct measurement of heat flux
- Useful for off-state parasitics as well (eg space cooler)



Disadvantages

- Requires calibration of self heat load
- Can not be used with real-world IR dewar
- Bulky

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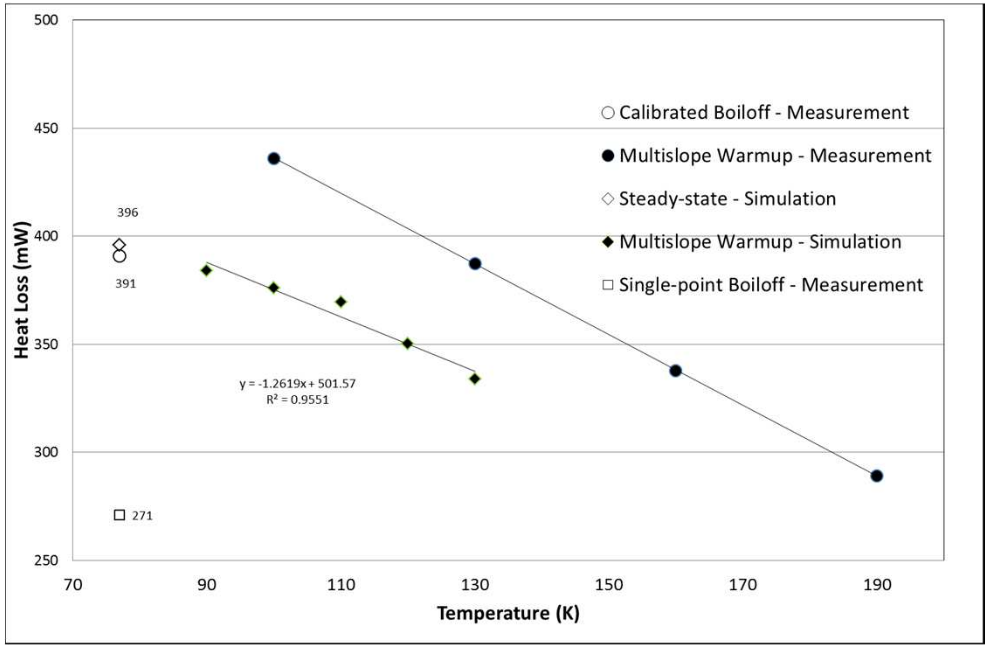
Comparison: Warmup vs Theoretical Model vs Calibrated Boil-Off

Measurements performed on test dewar with 10mm cold finger bore



Conclusion:

- Calibrated Boil-off, static model, and transient model are in good agreement
- Warmup gives a much higher value for dewar heat load
- Single-point boil-off gives a much lower value for dewar heat load -> difference depends on CF geometry

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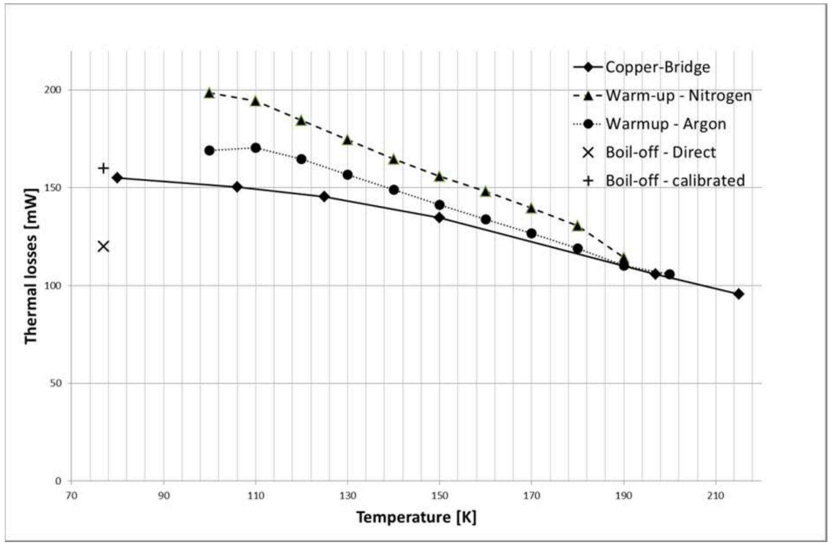
Comparison: Direct Heat Flux vs Warm-Up vs Boil-Off

Measurements performed on test dewar with ¼” cold finger bore

Conclusion:

- Heat flux measurement and calibrated boil-off are in good agreement
- Boil-off without direct calibration gives a lower heat load
- Warmup gives a higher heat load
- Warmup result dependent on starting temperature



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So the methods are not in perfect agreement…

… but which one is right?

Experiments performed to test influence of:

- Presence of vapor column during warm-up method
- Influence of boiling LN2 on temperature gradient in cold finger
- Influence of thermal mass on warm-up method

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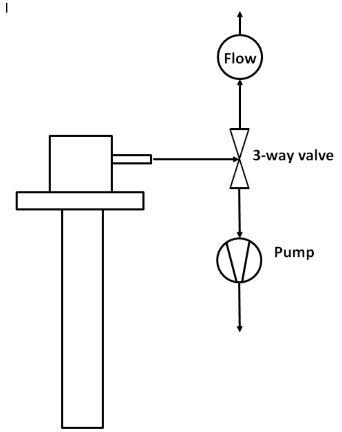
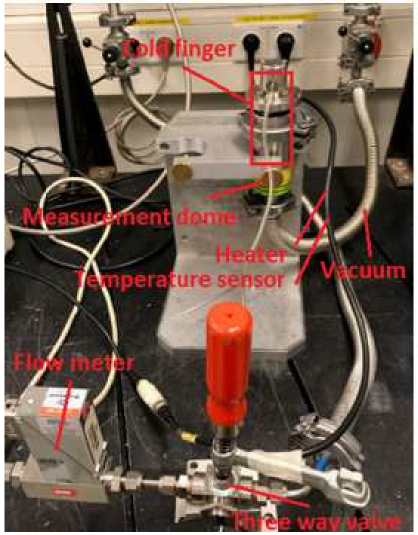
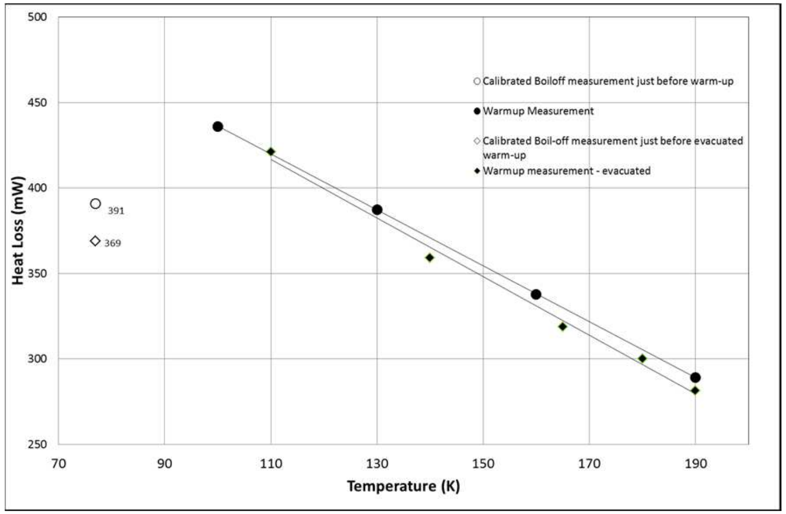
Experiment: Warm-up with and without pumped cold finger bore







Conclusion:

- No significant effect of vapor column conduction
- Measurement reproducibility of calibrated boil-off within 25 mW

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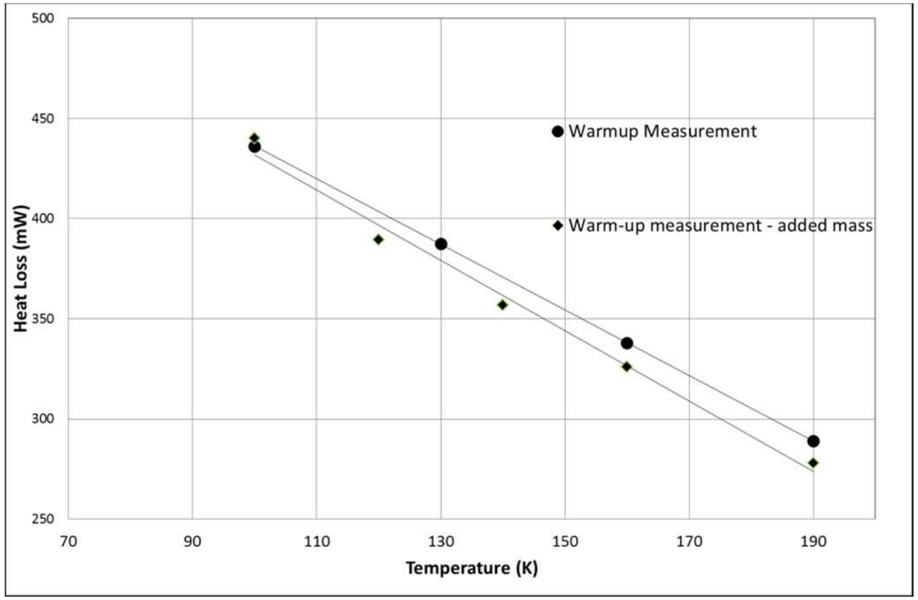
Experiment: Warm-up with and without added mass



Conclusion:

- No significant effect of added mass of 3.5 grams of copper
- Quasi-static assumption for warmup method remains valid

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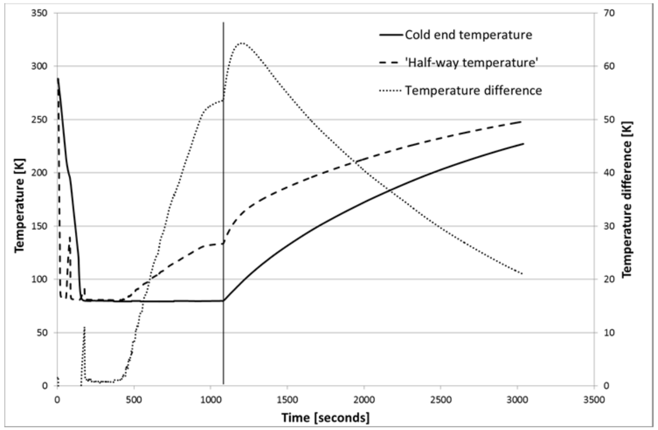
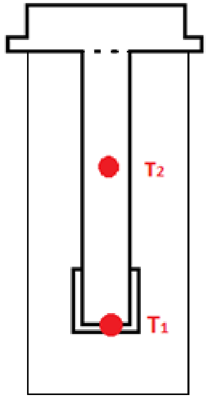
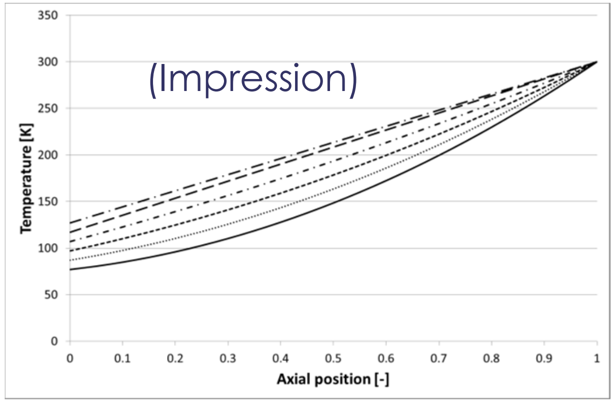
Experiment: Thermal gradient during last-drop boiling







T2 jumps up right after last-drop:

- Clear influence on thermal gradient

Conclusion:

- Significant (cooling) effect of gas flow on gradient along cold finger
- Gas absorbs more heat than simply the evaporative heat
- Gas also influences cold finger conduction

Conclusion

Good agreement between some methods

- Calibrated boil-off, thermal modelling, and direct heat flux measurement are in good agreement
- Clear influence of the gas flow inside the cold finger
- However, this is for the most part compensated in the calibrated method

Differences between multislope warm-up and other methods not yet understood

- Higher heat load reported by warm-up
- Apparent dependency on starting temperature (different slopes with different starting temperatures)
- At this stage, the warm-up method is not understood well enough to be a reliable benchmark

So what should a dewar manufacturer do?

Direct flux measurement as performed not possible

- Dewar already closed off

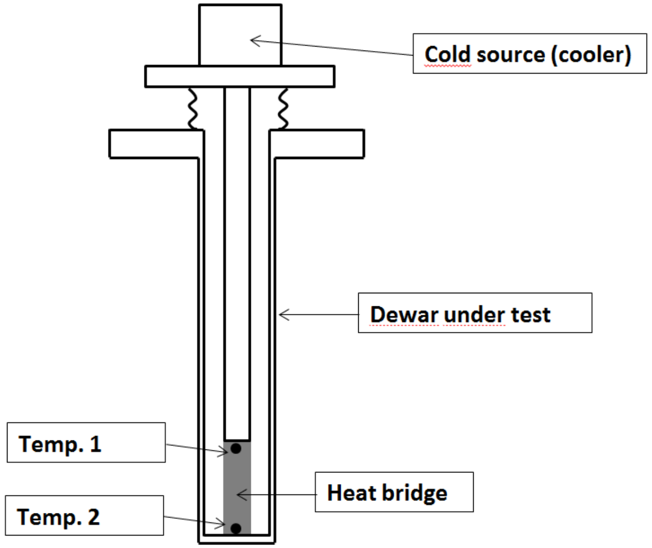
Multi-slope or calibrated boil-off only possible with mock-up dewar

- Heater is needed for these measurements

More work is needed to understand warm-up method

- Differences not fully understood

Adaptation of direct flux measurement can be proposed



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Thank you for listening

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