Cool-down acceleration of G-M cryocoolers with thermal oscillations passively damped by helium

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Outline

- Interest in thermal stability and rapid cool-down
- SHI's helium thermal damper
- Cool-down with damper and calculations
- Modified damper gas management and results
- Additional thermal anchoring

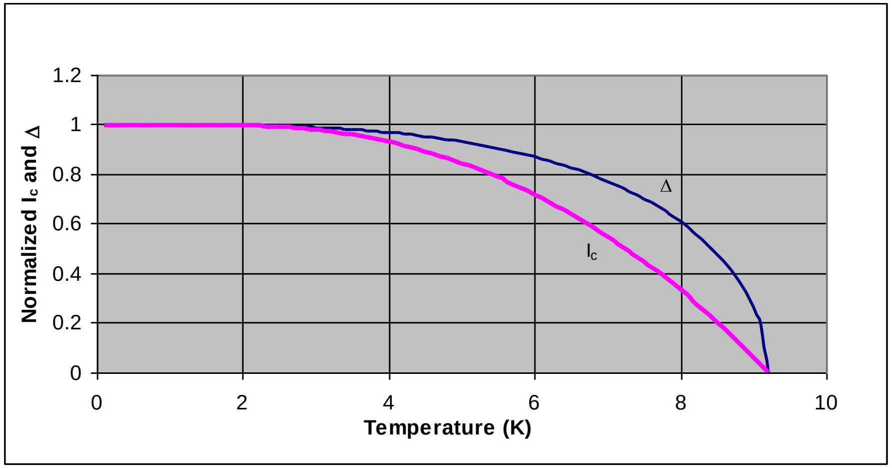
Superconducting electronic systems

- **Hypres and others have developed turn-key S.E. electronic systems:**
  - **Josephson Junction Primary Voltage Standards**
  - **Digital RF receivers**

Niobium JJ Ideal Cryo-requirements

Stable temperature

- Critical currents of Junctions and bias points are temperature sensitive



Fast cool-down

- Quick temperature excursion through superconducting / normal transition
- Extraneous magnetic flux can lower the critical current of random junctions in a circuit, affecting performance – purge by heating to T_c

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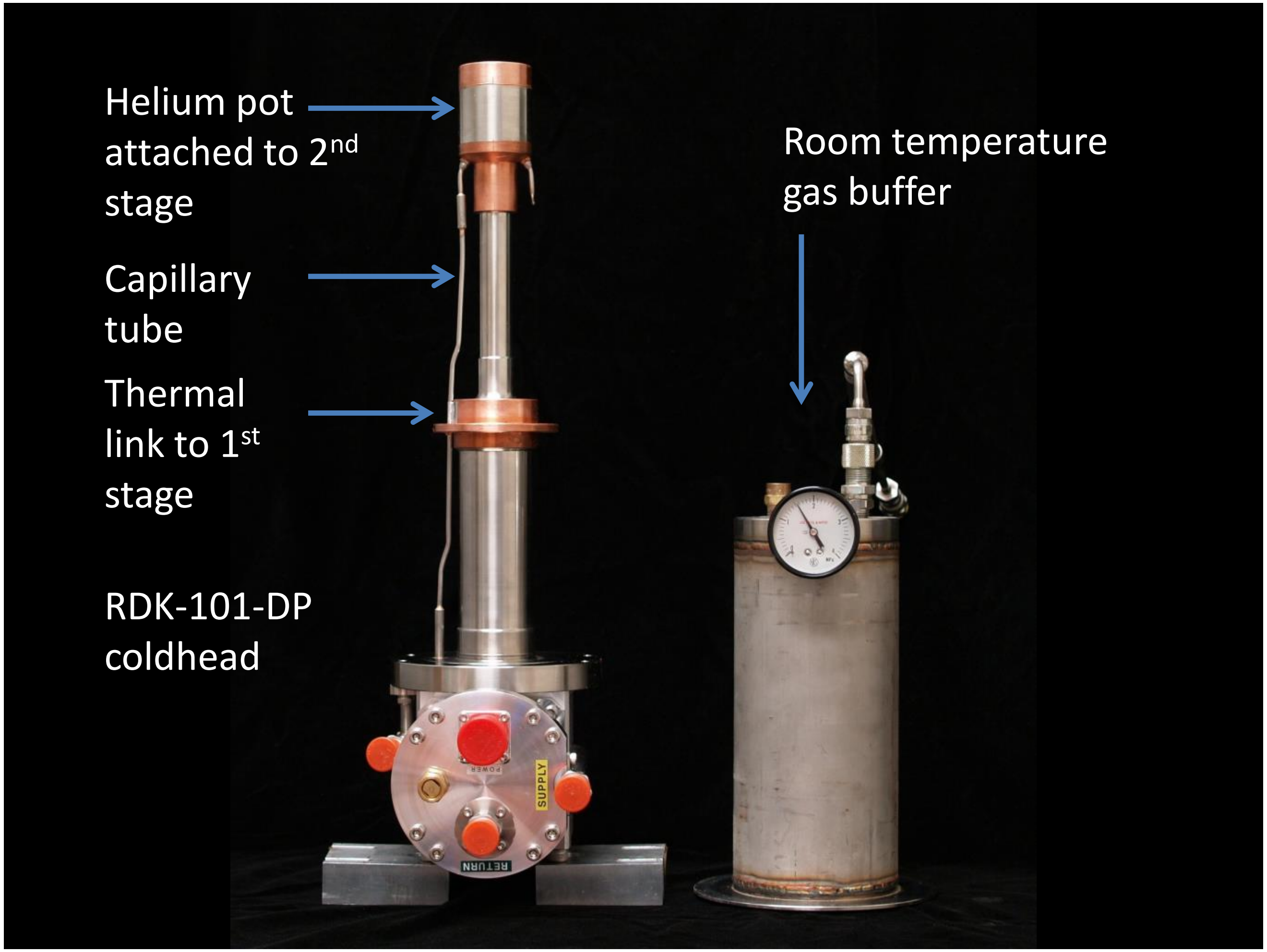
SHI RDK-101DP



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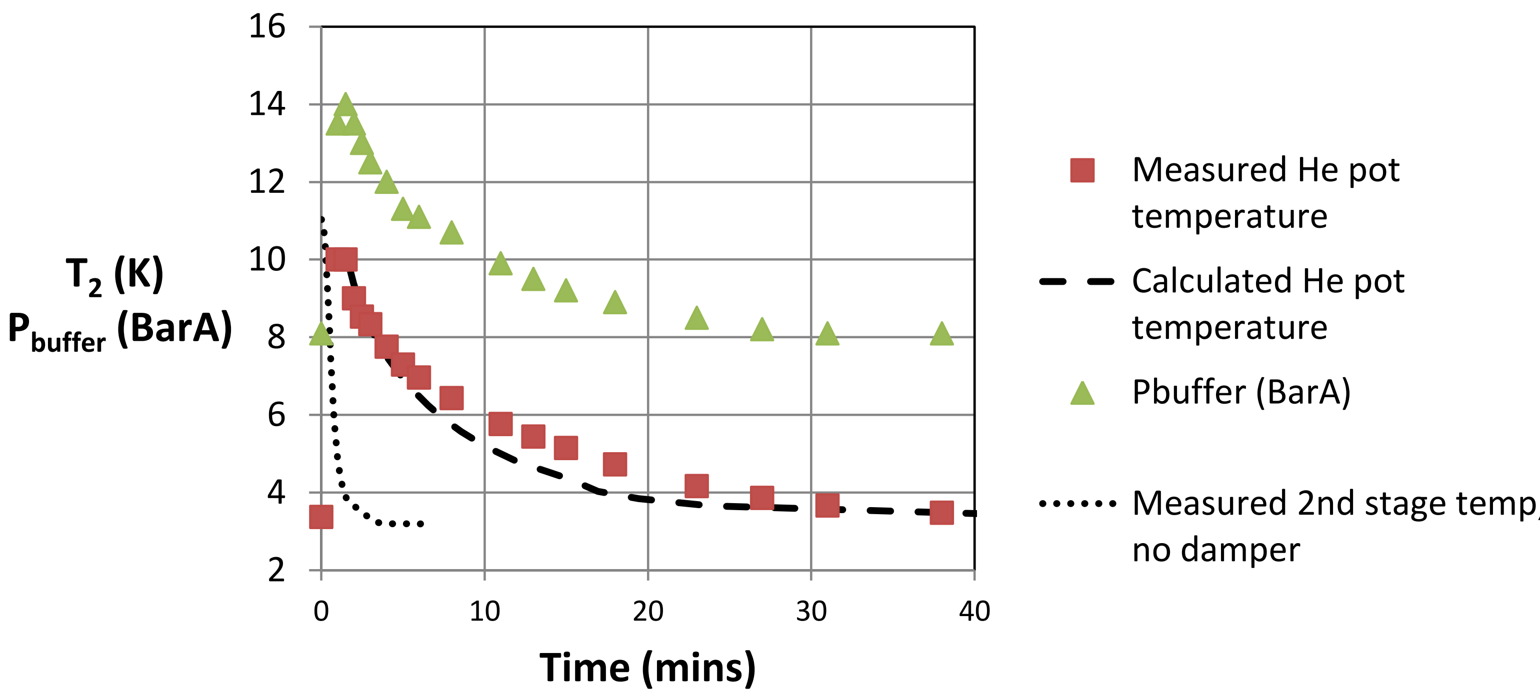
Damper/No damper Cool-downs



- "Deflux" excursion cool-down much longer with damper
- Buffer pressure follows dropping He pot temperature
- Calculated cool-down agrees reasonably well with measurement

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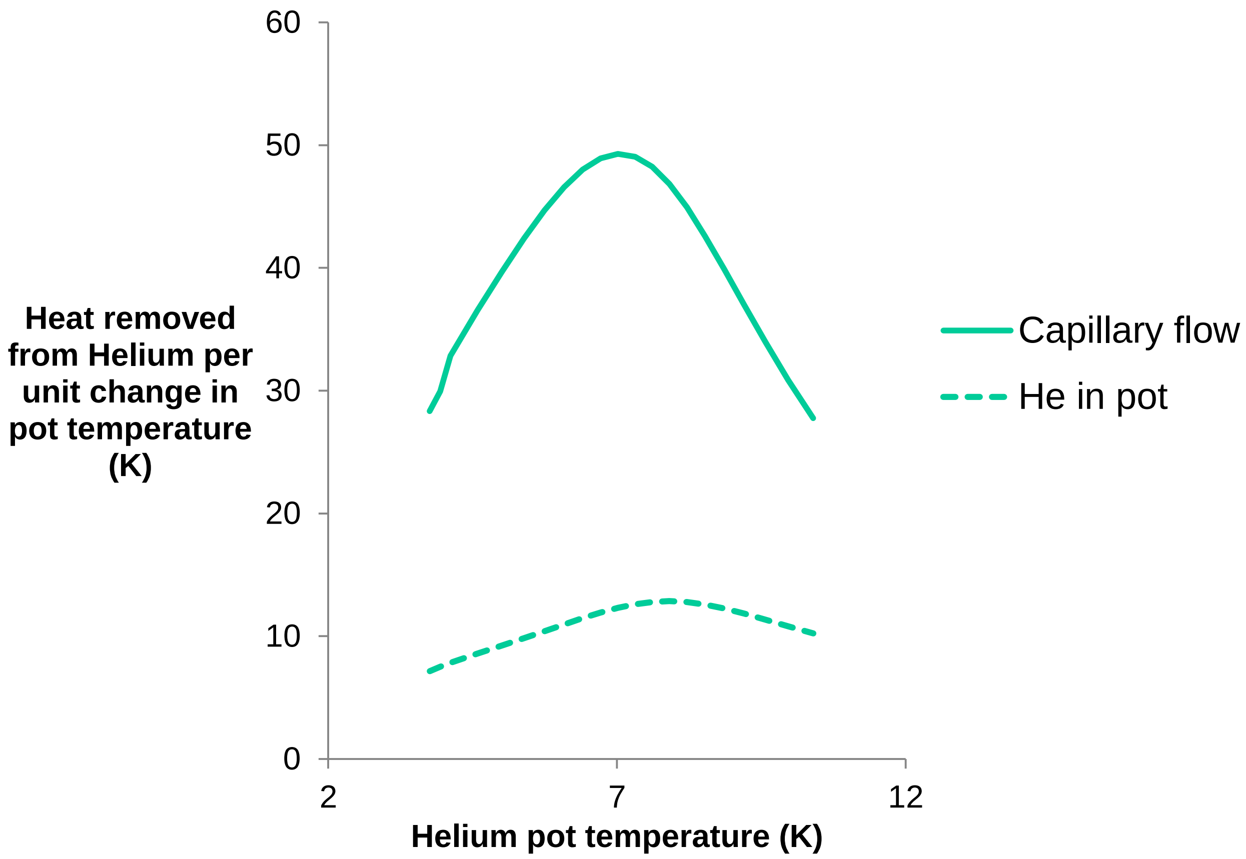
Dominance of heat from capillary flow



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Calculated cool-down

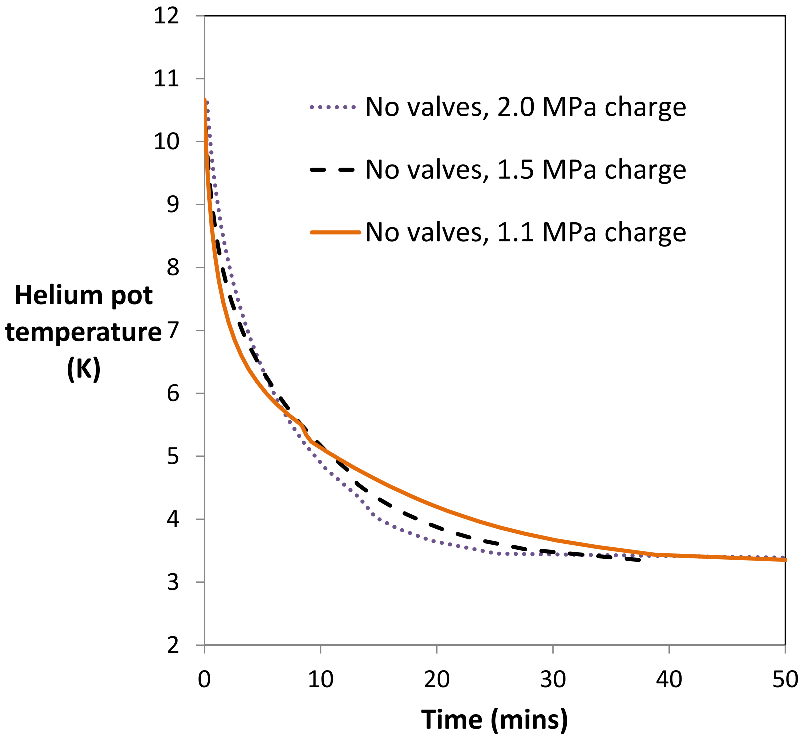
- **Energy balance**

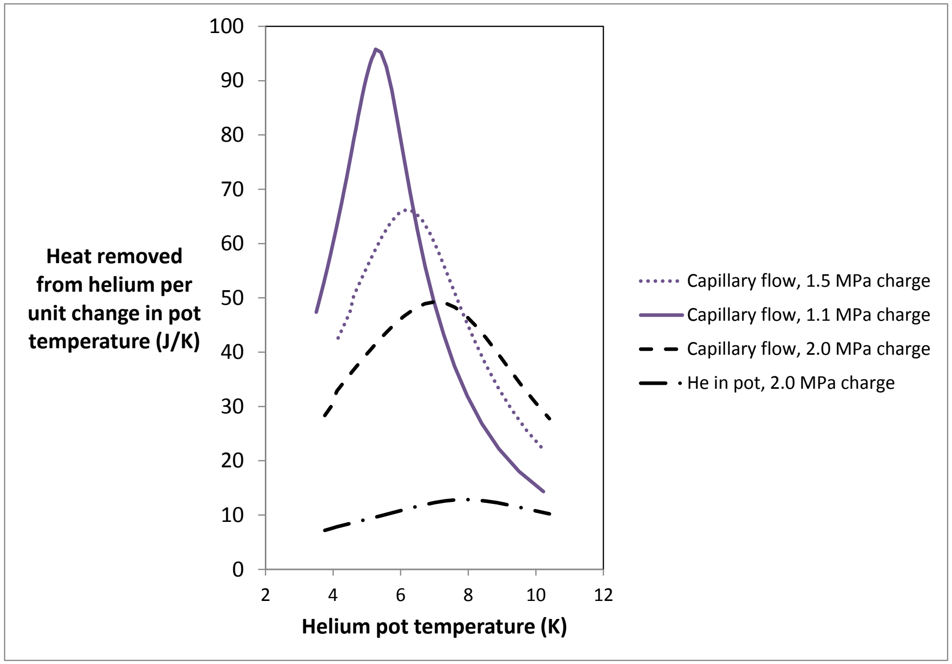
$$\dot{Q}_{ref} = m_p C \dot{T}_p + \Delta h \dot{m}$$

- **Mass in He pot known function of pressure, so defining temperature**

$$m_p = M - \frac{M_{He} V_b}{R T_{amb}} \left\{ P_p + \Delta P_i \right\}$$

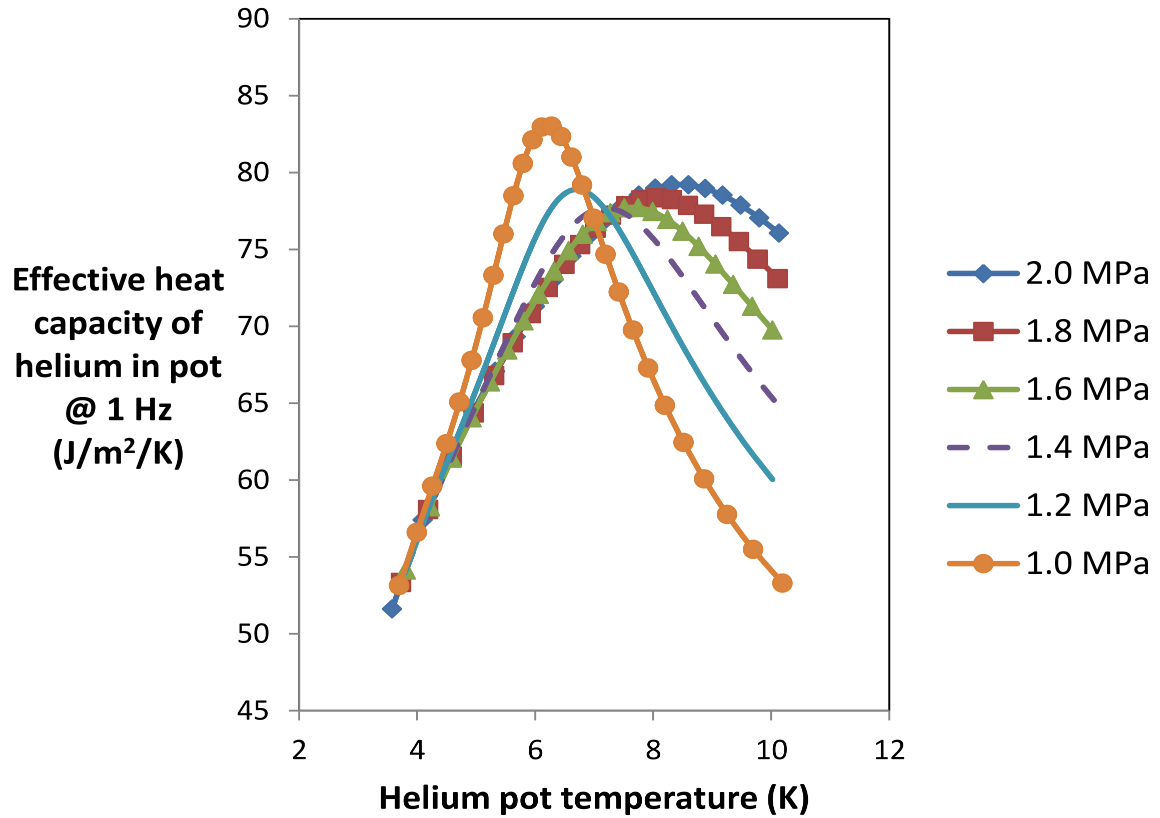
Low charge pressure cool-downs





- Lower charge pressure results in *longer* cool-down time
- Total mass flow through capillary is *increased* and peaks at lower temperature
- Rapidly changing density near critical point

Damping effectiveness vs charge pressure



- **Thermal skin depth** $\boldsymbol{\delta = \sqrt{\frac{\alpha}{\pi f}}}$ **~ 0.1mm**
- **Damping effectiveness/unit area** $\sigma = \delta c_p \rho$

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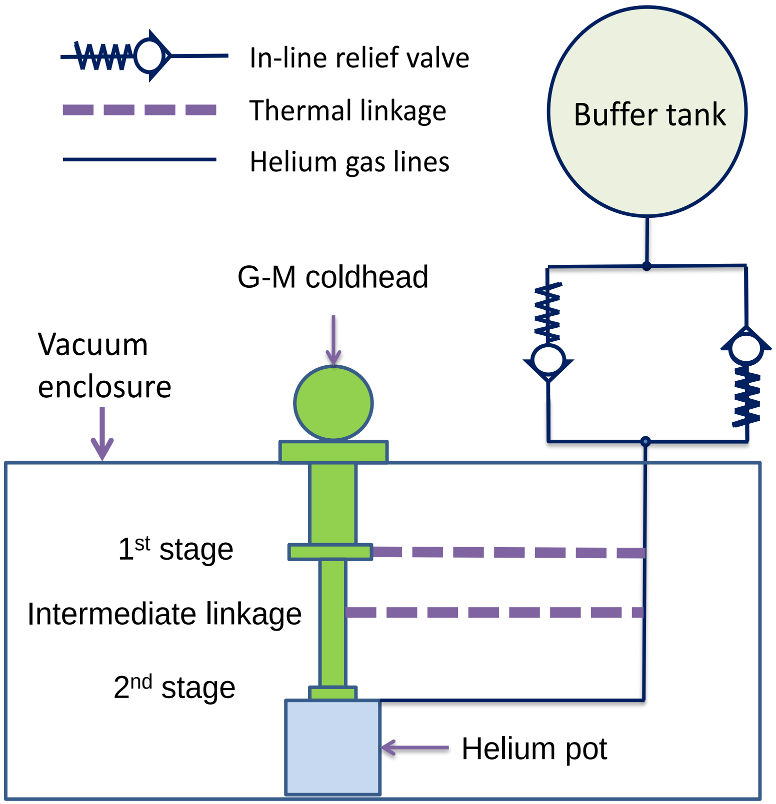
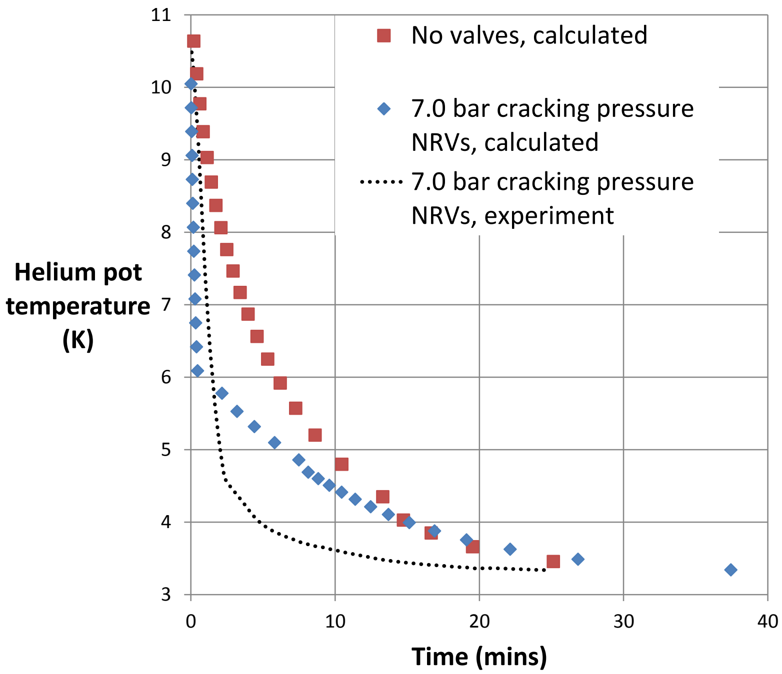
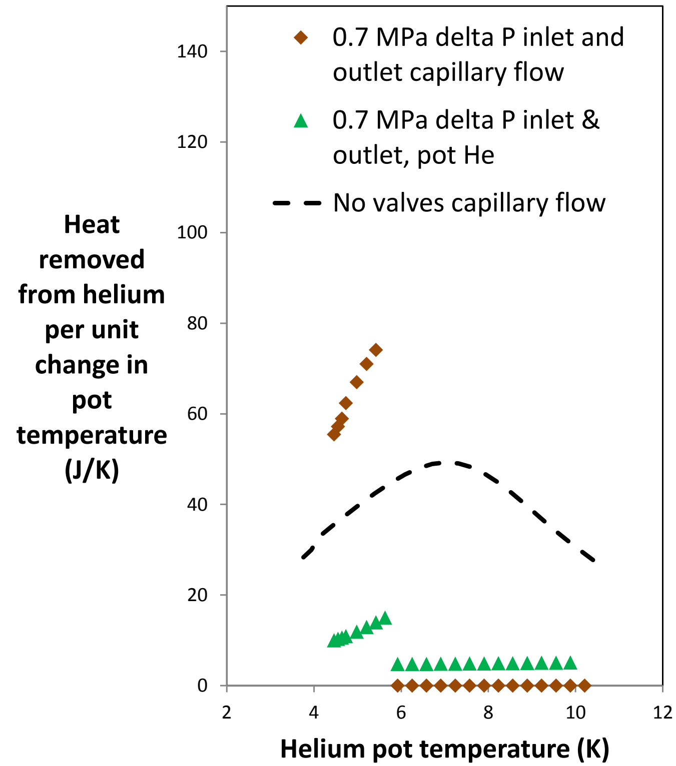
Modifications to He damper



- **Modifications work passively**
  - **Spring-loaded non-return valves set to ~1/3 charge pressure (0.7 bar)**
  - **Additional thermal linkage at lower temperature**

Cool-down with 0.7 MPa c.p. NRVs





- **Measured cool-down is dramatically faster than without valves…. WHY??… ..Vapor-lock?……Thin film of liquid?**
- ***Calculated* time to 4 K is no different, in spite of 55% reduction in total capillary flow ---- heat load shifted to lower temperatures**

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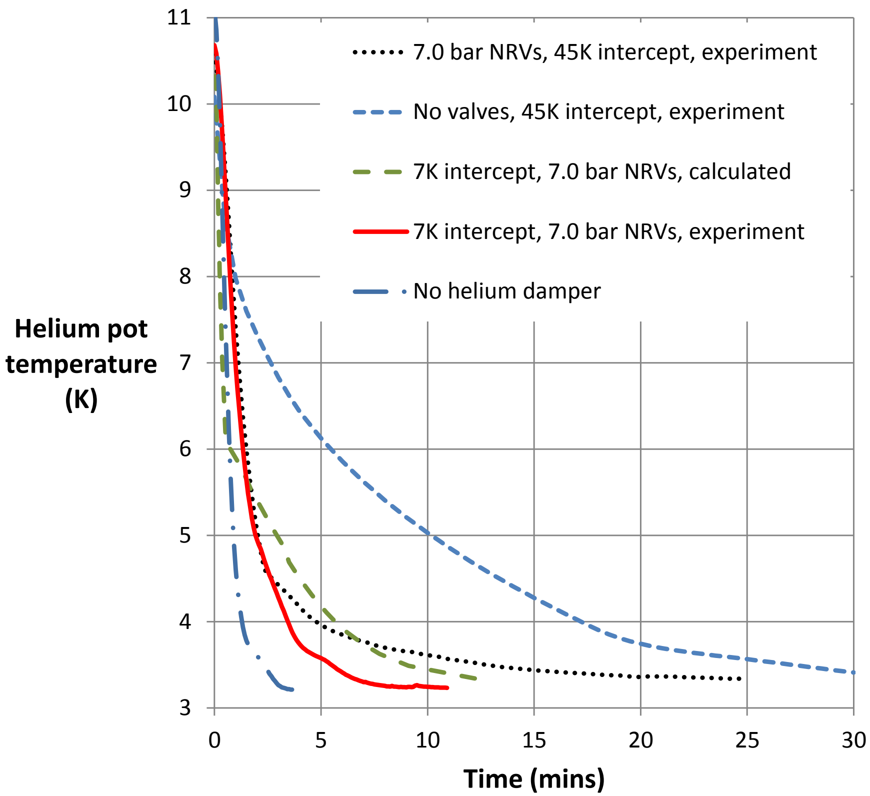
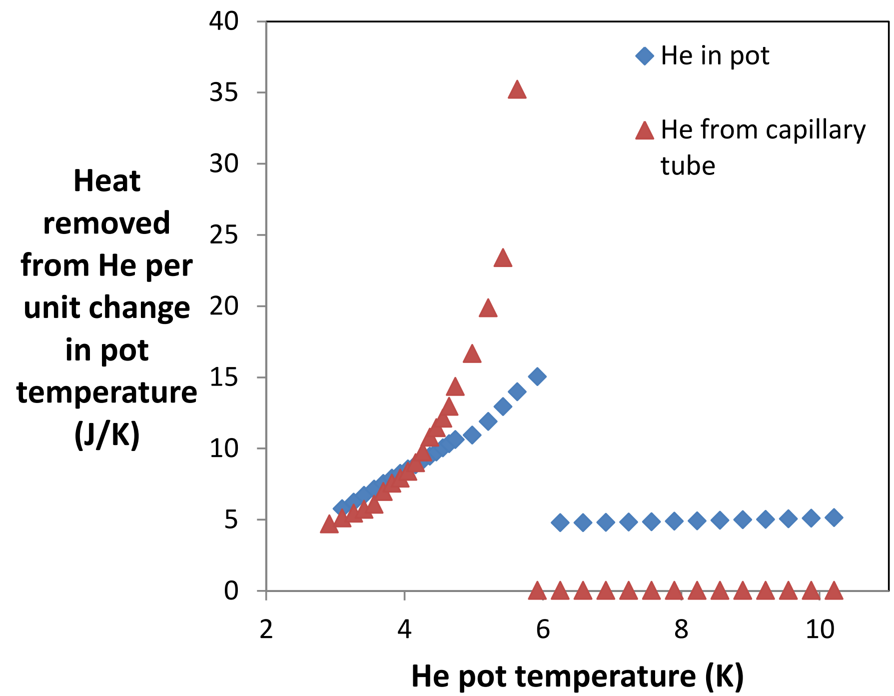
Addition of 7K thermal intercept to capillary





- Even faster, approaching no-damper time
- Still faster than calculated

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Conclusion

- **Cool-down from 10K is retarded by warm He injected into He pot**
- **Reduction of charge pressure *increases* cool-down time**
- **In-line relief valves passively restrict buffer-pot mass flow, with dramatic reduction in cool-down time**
- **No reduction in damping**
- **Additional inter-stage thermal intercept reduces time to nearly twice un-damped system**

Sumitomo SRDK-101D-A11

Parameters	Value
Heat Load (Manufacturer Spec)	0.1 W at 4.2 K and 5 W at 60K
Heat Load (Measured)	0.2 W at 4.2 K and 6 W at 53K
Input Power	1.3 kW, 100±10 V (60 Hz)
Compressor Size	0.45 × 0.385 × 0.40 m^3
Cold Head Dimension	0.13 × 0.226 × 0.442 m^3
Compressor Weight	42 kg
Cold Head Weight	7.2 kg

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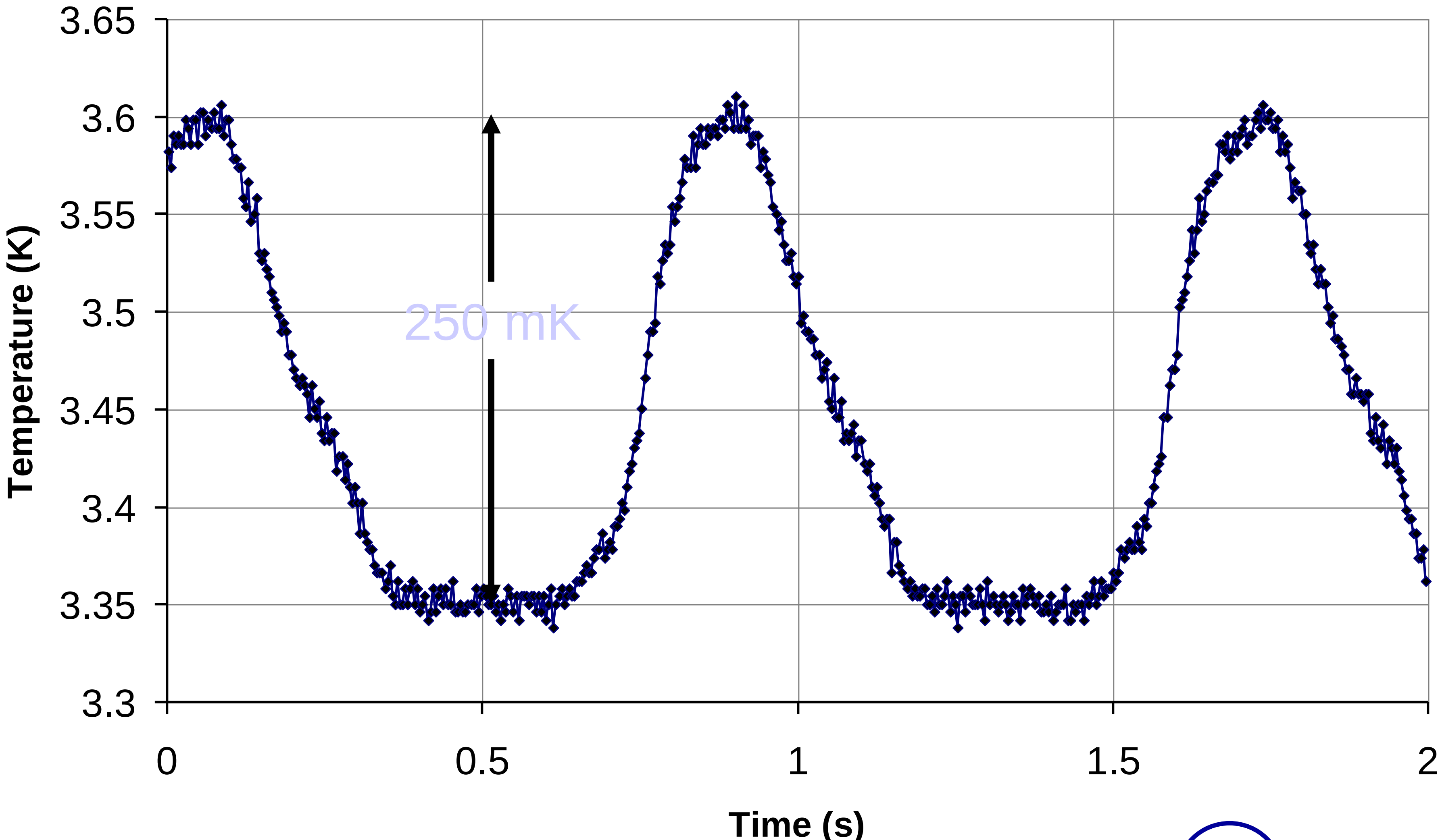
Temperature Oscillations of Sumitomo Cooler



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