



VACUUM-INDUCED CRYOCOOLING IN CRYOGEN SATURATED MATERIALS

Space Cryogenics Workshop

Monday July 17th, 2023

Adam M. Swanger

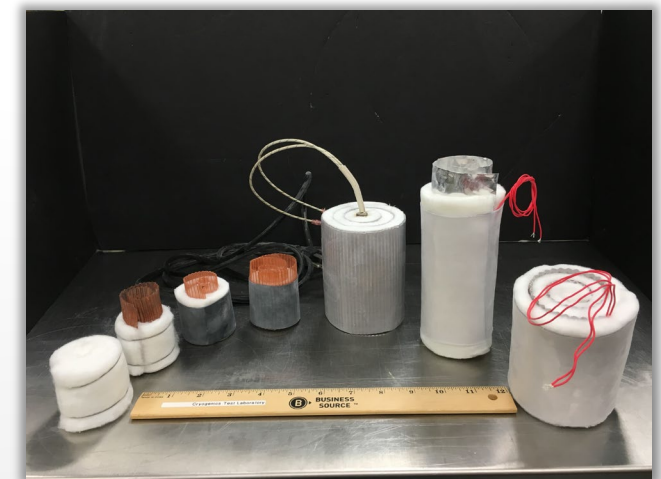
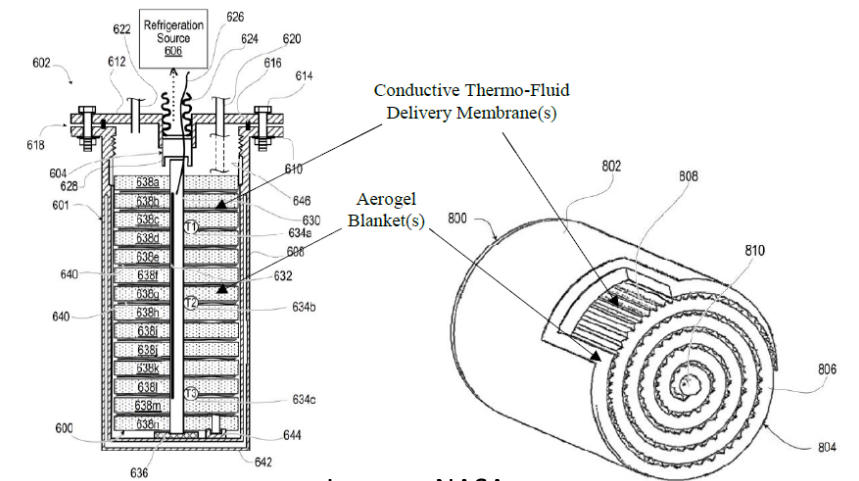
NASA Kennedy Space Center
Cryogenics Test Laboratory
KSC, FL 32899 USA
adam.m.swanger@nasa.gov

INTRODUCTION

- Cryogenics Test Laboratory at NASA Kennedy Space Center has done a lot of work with storing cryogenics in **aerogel blanket** materials

➤ Cryogenic Flux Capacitor (CFC) Technology

- It was found that **saturated aerogel blanket cools substantially** when subjected to a rapid vacuum pump-down
- This **Vacuum-Induced Cryocooling (VIC)** was shown to passively densified LN₂ during cryostat testing in 2020.....but not well characterized



INTRODUCTION

- Can VIC be exploited for in-space applications, and how?

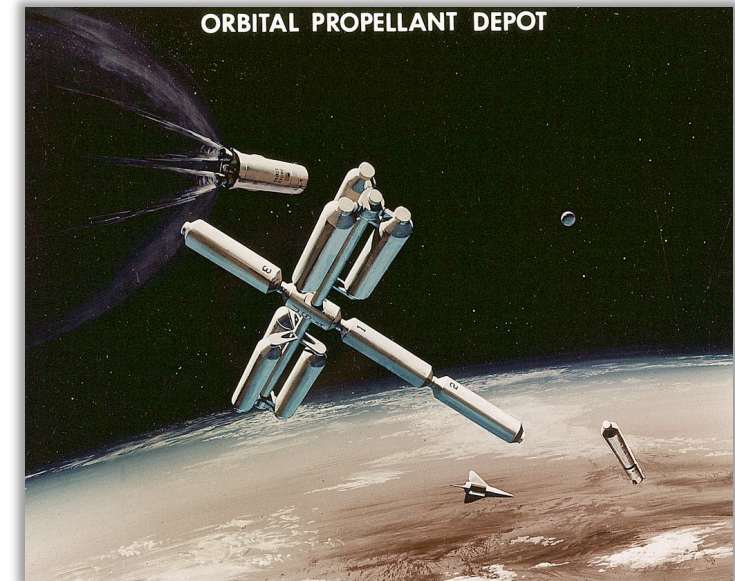
- ✓ Cryo Fluid Management (CFM)
- ✓ Space Science/Telescopes

Thermodynamic Vent System (TVS)

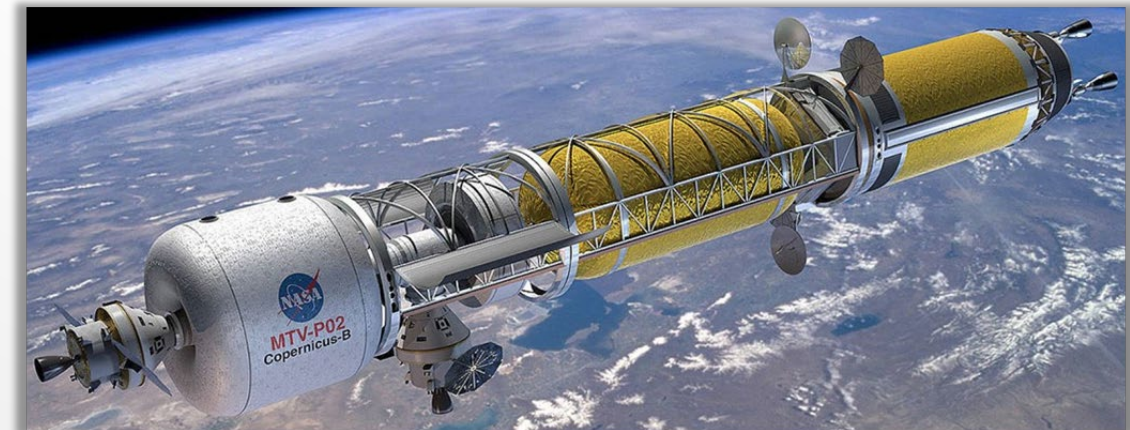
- NASA-KSC explored the used of VIC in aerogel blankets for TVS in 2022-2023



**Lab Testing to Characterize
VIC Power**



Images: NASA



TEST MATERIALS

- **Two different materials tested**

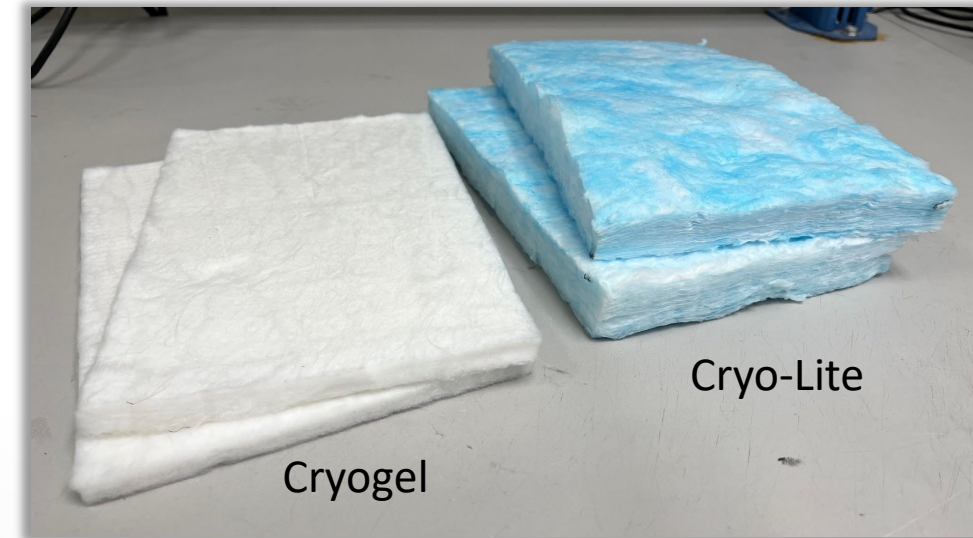
- Aerogel blanket: **Cryogel**[®] from Aspen Aerogels

- 10 mm thick
- Density = 0.16 g/cc
- Specific Surface Area ~1000 m²/g
- Adsorbent

- Fiberglass-Melamine: **Cryo-Lite**[®] from Lydall

- 25 mm thick
- Density = 0.016 g/cc
- Specific Surface Area ~1 m²/g
- Absorbent

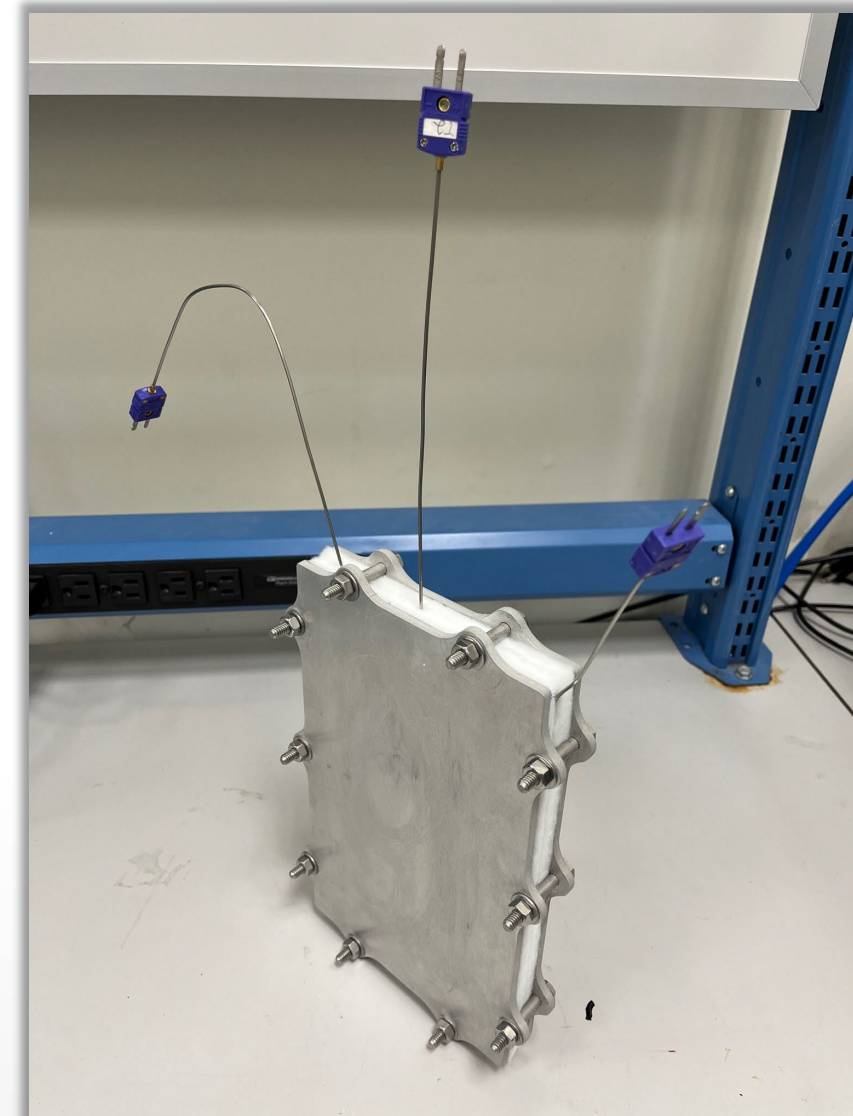
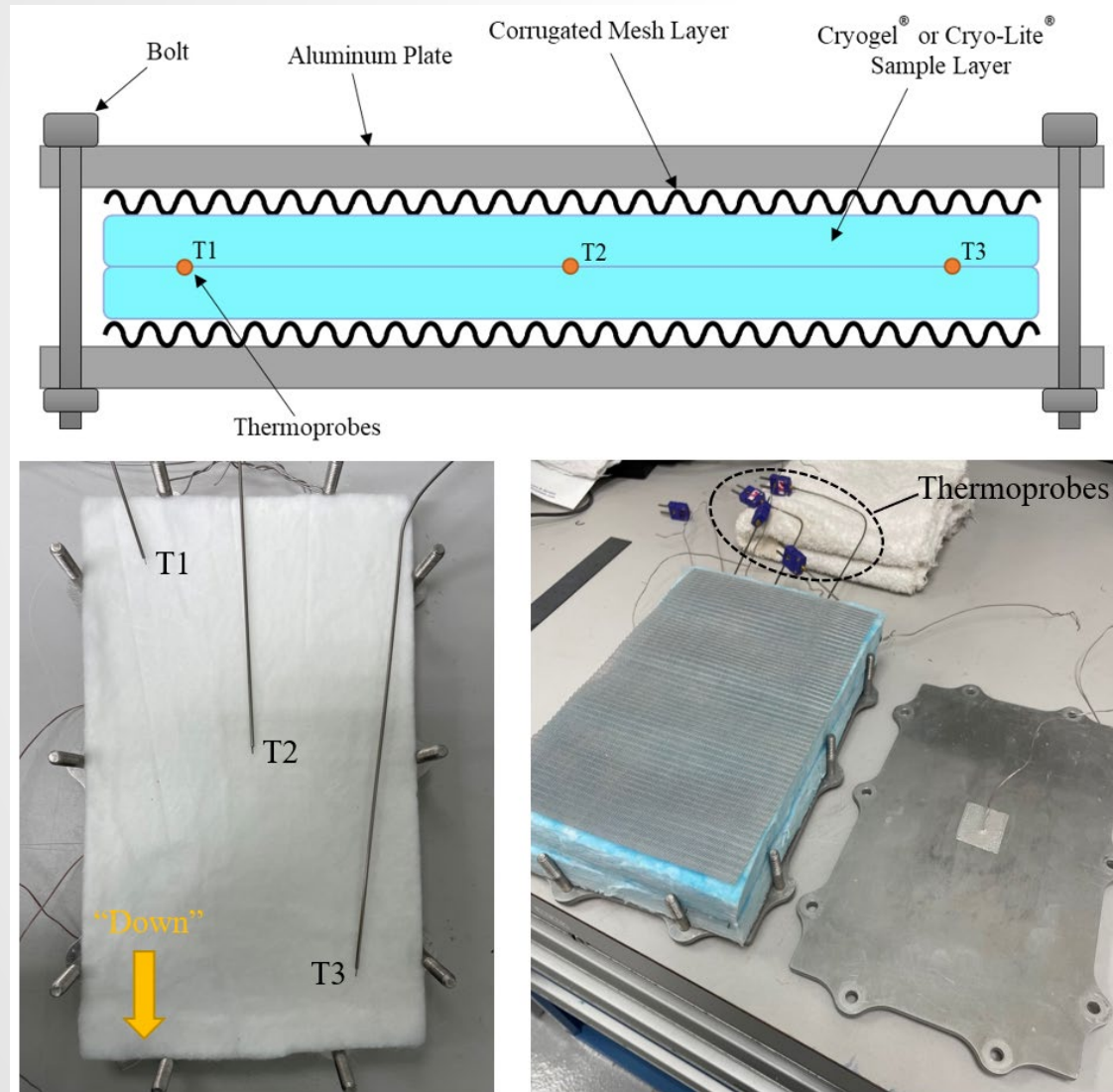
Image: Author



6" x 10" (152 mm x 254 mm)

TEST ARTICLE

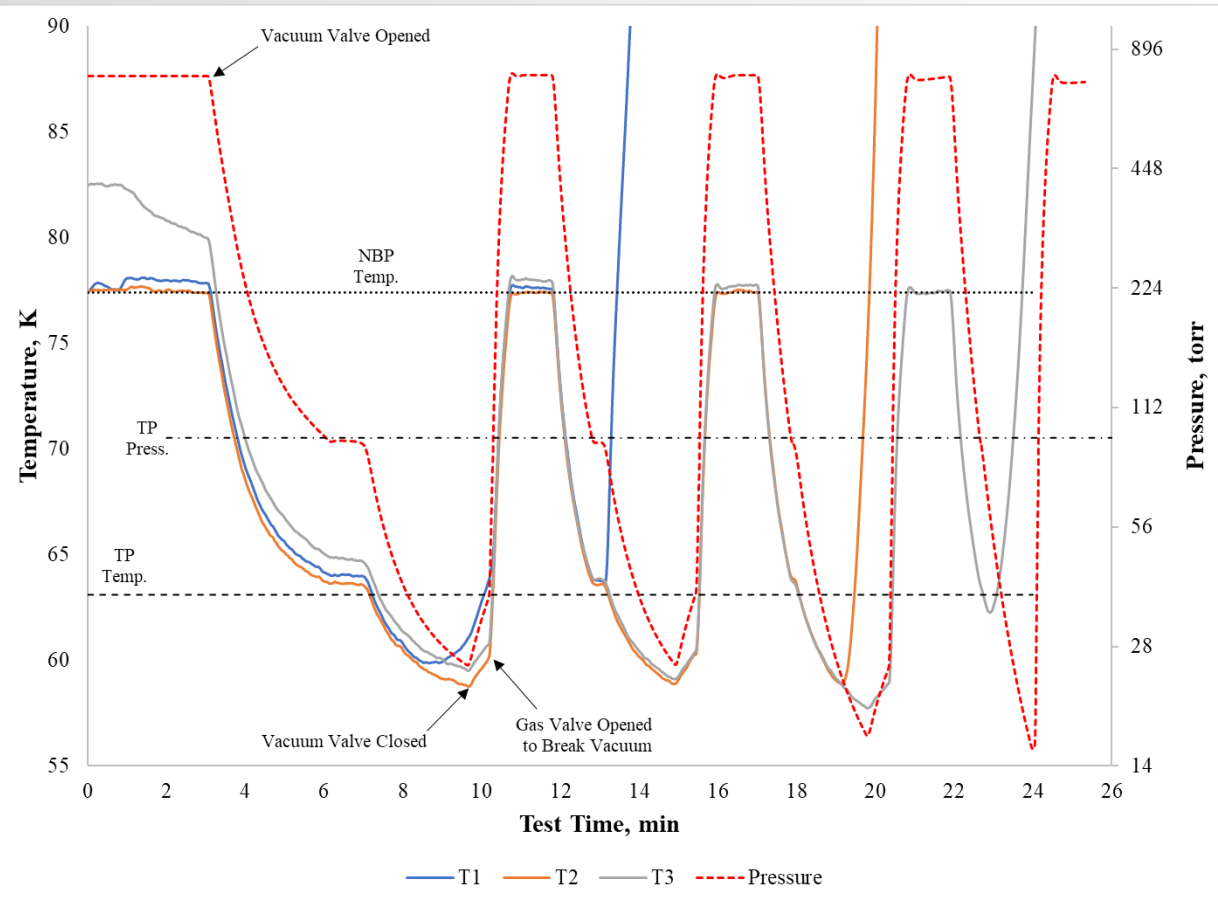
- **Cryogel**
compressed 21%
- **Cryo-Lite**
compressed 78%
- 3x type-E thermoprobes w/in-house, 3-point calibration
- Three TC locations to determine if VIC is localized
- T2 used for post analysis



Images: Author

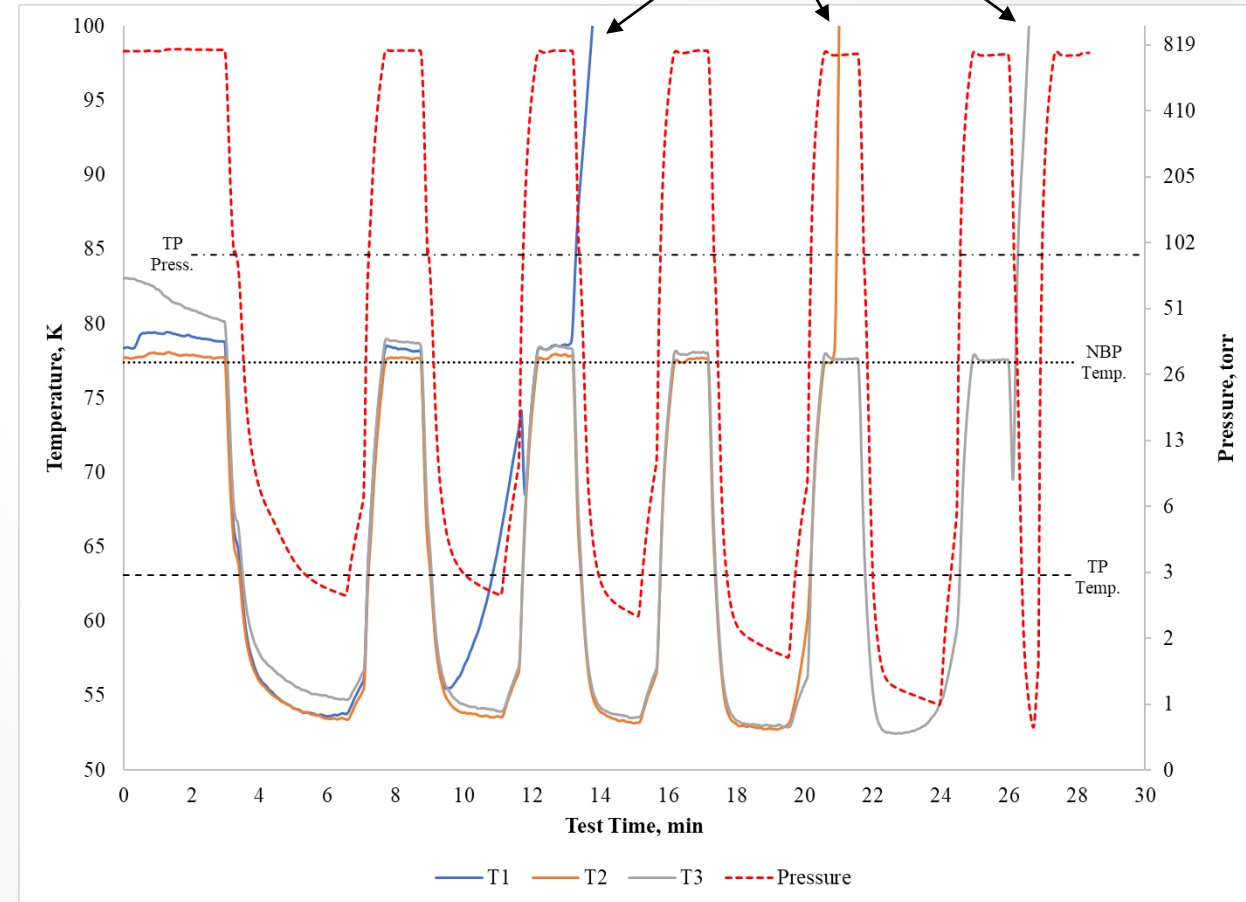
TEST RESULTS

7



Cryo-Lite – Liquid Nitrogen – Small Pump

- Min temp. = 57.3 K
- 4 total pump-down cycles until “dry”

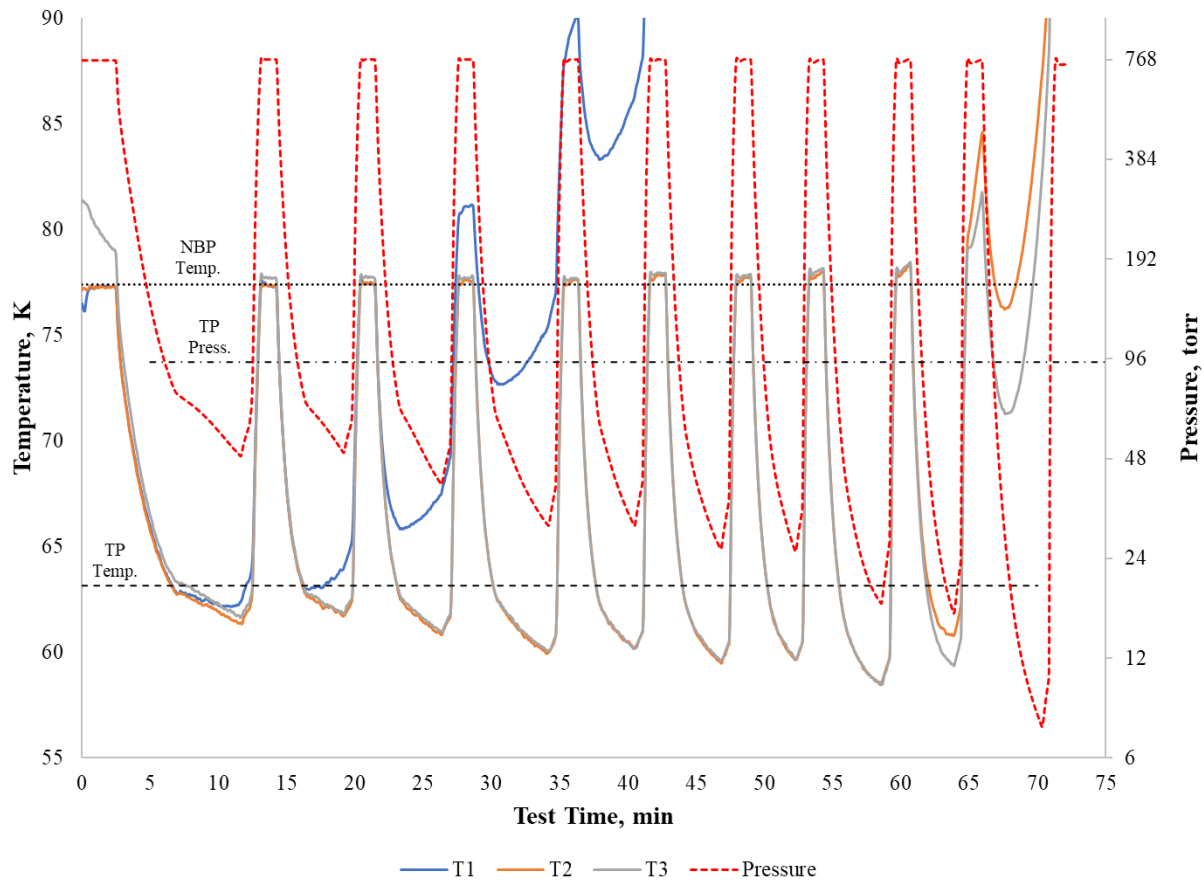


Cryo-Lite – Liquid Nitrogen – Big Pump

- Min temp. = 52.5 K
- 6 total pump-down cycles until “dry”

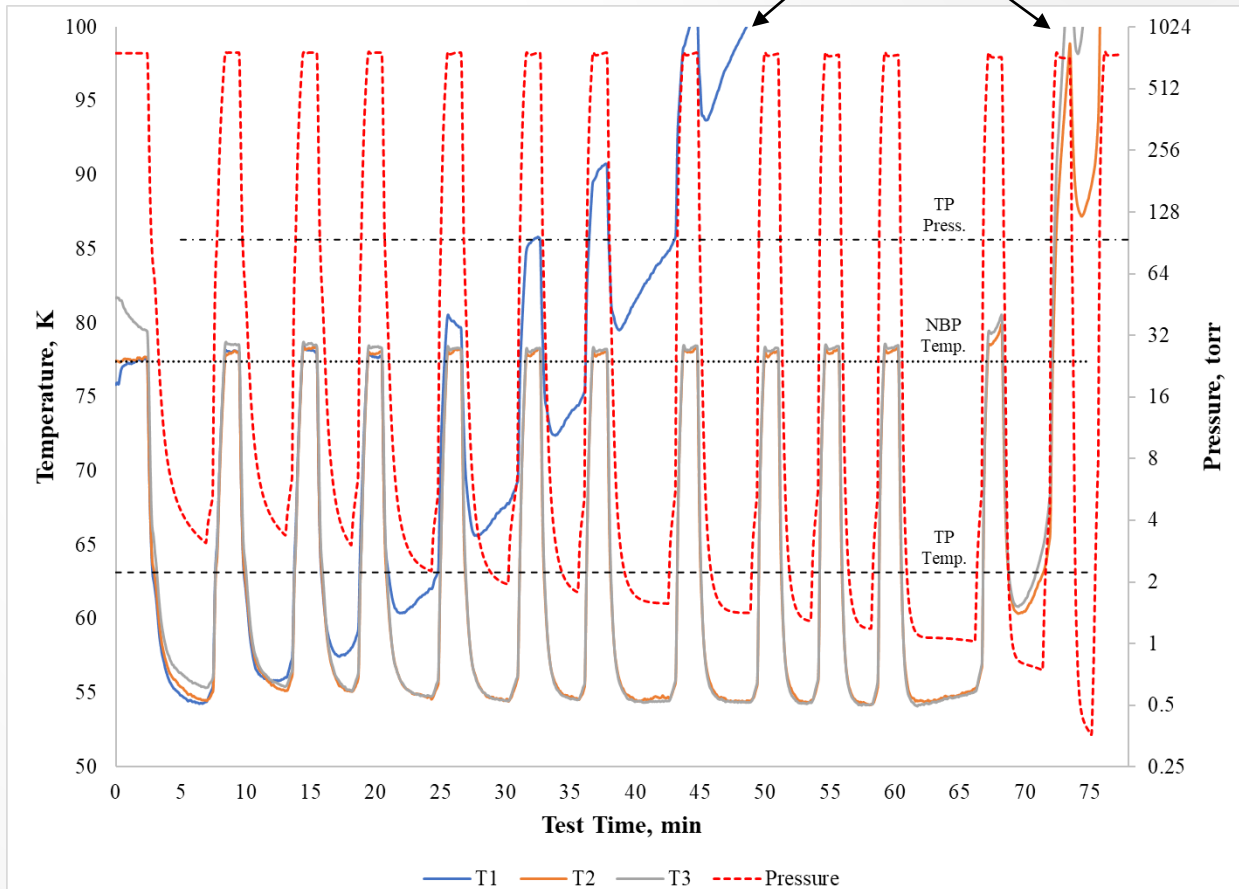
TEST RESULTS

8



Cryogel – Liquid Nitrogen – Small Pump

- Min temp. = 58.5 K
- 10 total pump-down cycles until “dry”



Cryogel – Liquid Nitrogen – Big Pump

- Min temp. = 54.1 K
- 13 total pump-down cycles until “dry”

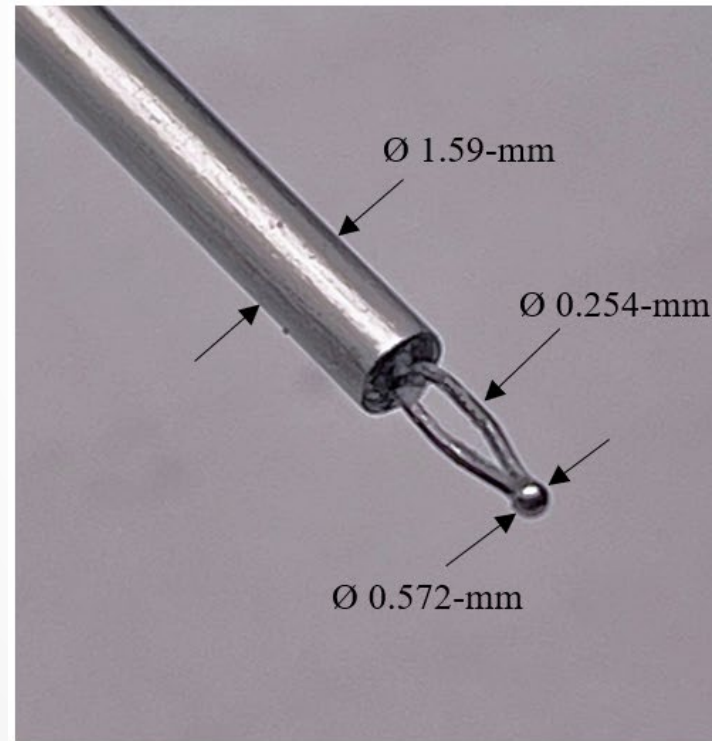
ESTIMATION OF VIC POWER

- Use T2 thermocouple weld bead as the heat power meter
- Type-E: Chromel & Constantan
 - $C_p(T)$ published by Sundqvist

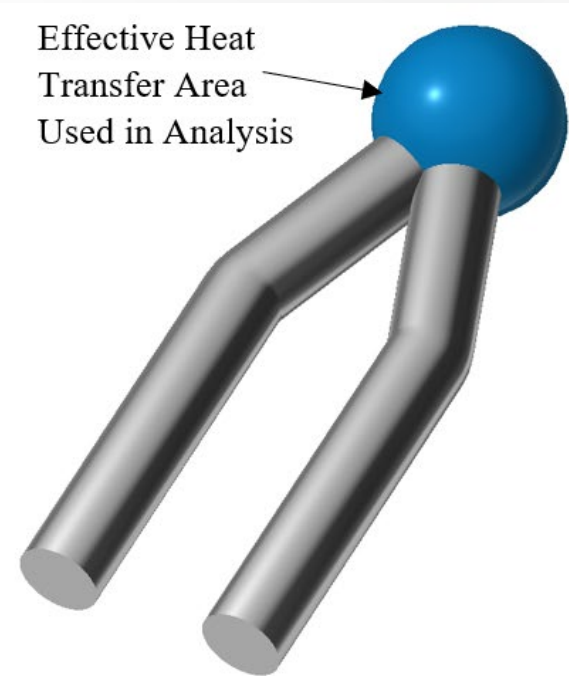
From Pump-Down Data

$$E_{\text{bead}} = \frac{V_{\text{bead}} T_{\text{bead}}}{2} (\rho_{\text{ch}} C_{P,\text{ch}} + \rho_{\text{co}} C_{P,\text{co}}) \text{ [joules]}$$

From Sundqvist



Images: Author

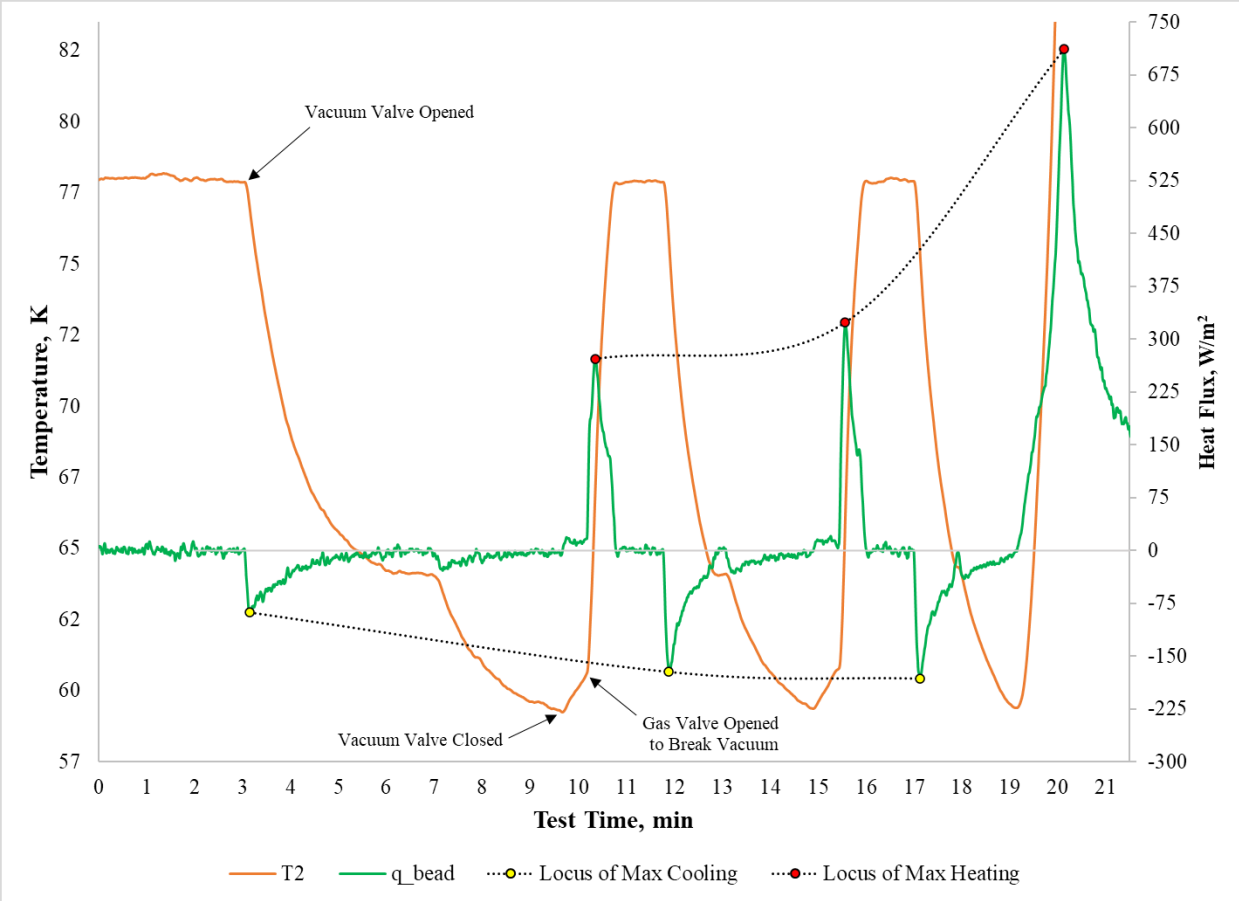


Effective Heat Transfer Area Used in Analysis

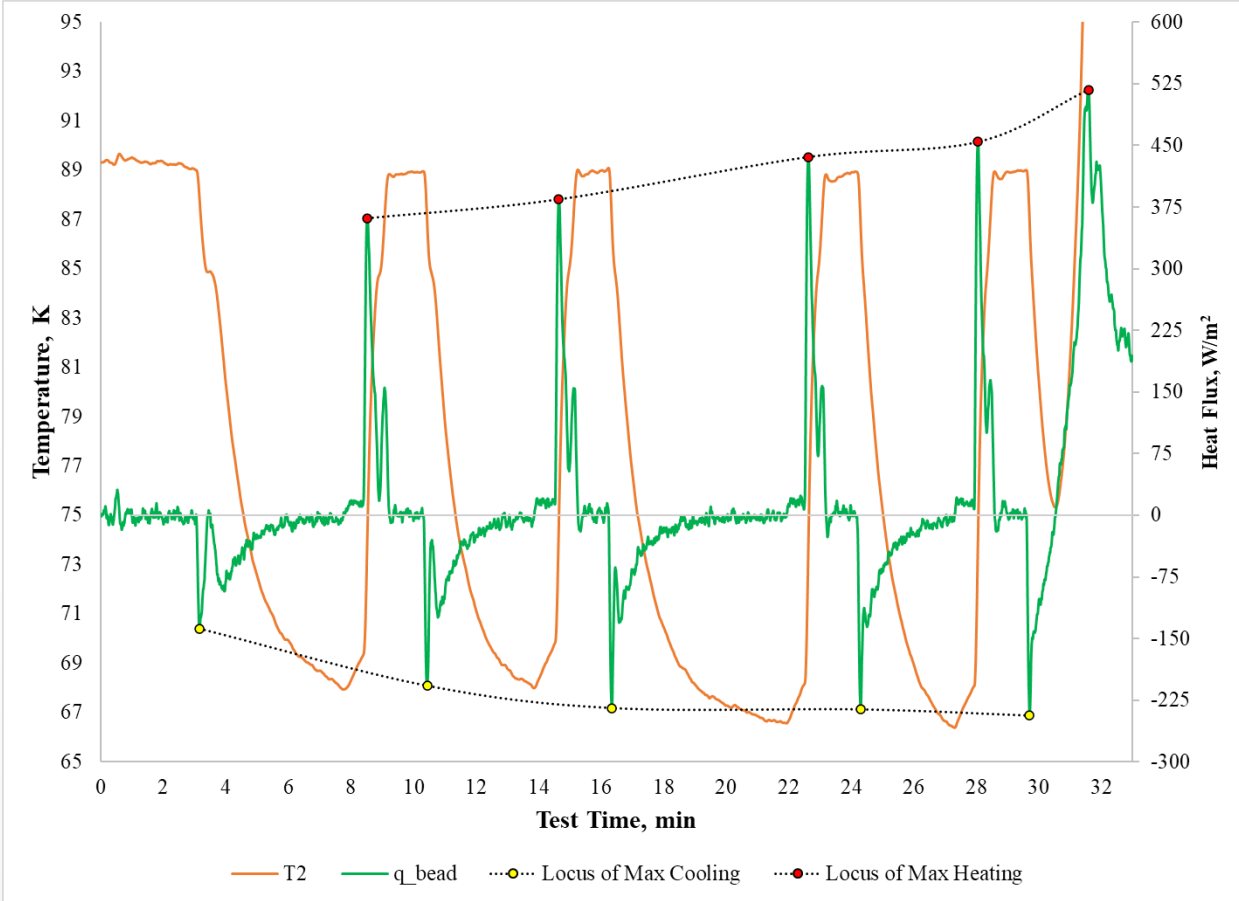
$$q_{\text{bead}} = \frac{\Delta E_{\text{bead}}}{A_{\text{eff}} \Delta t} \left[\frac{\text{W}}{\text{m}^2} \right]$$

Time Step

ANALYTICAL RESULTS

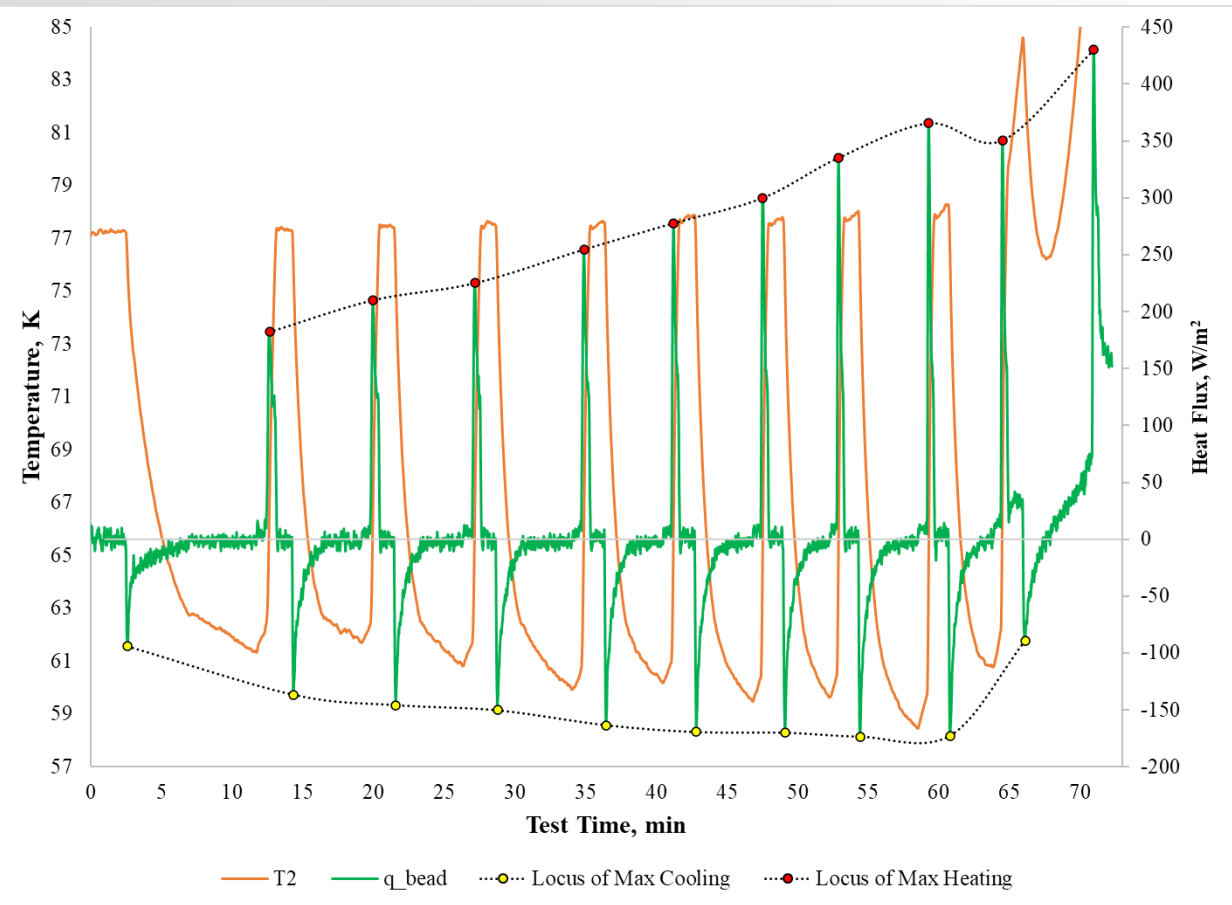


Cryo-Lite – Liquid Nitrogen – Small Pump

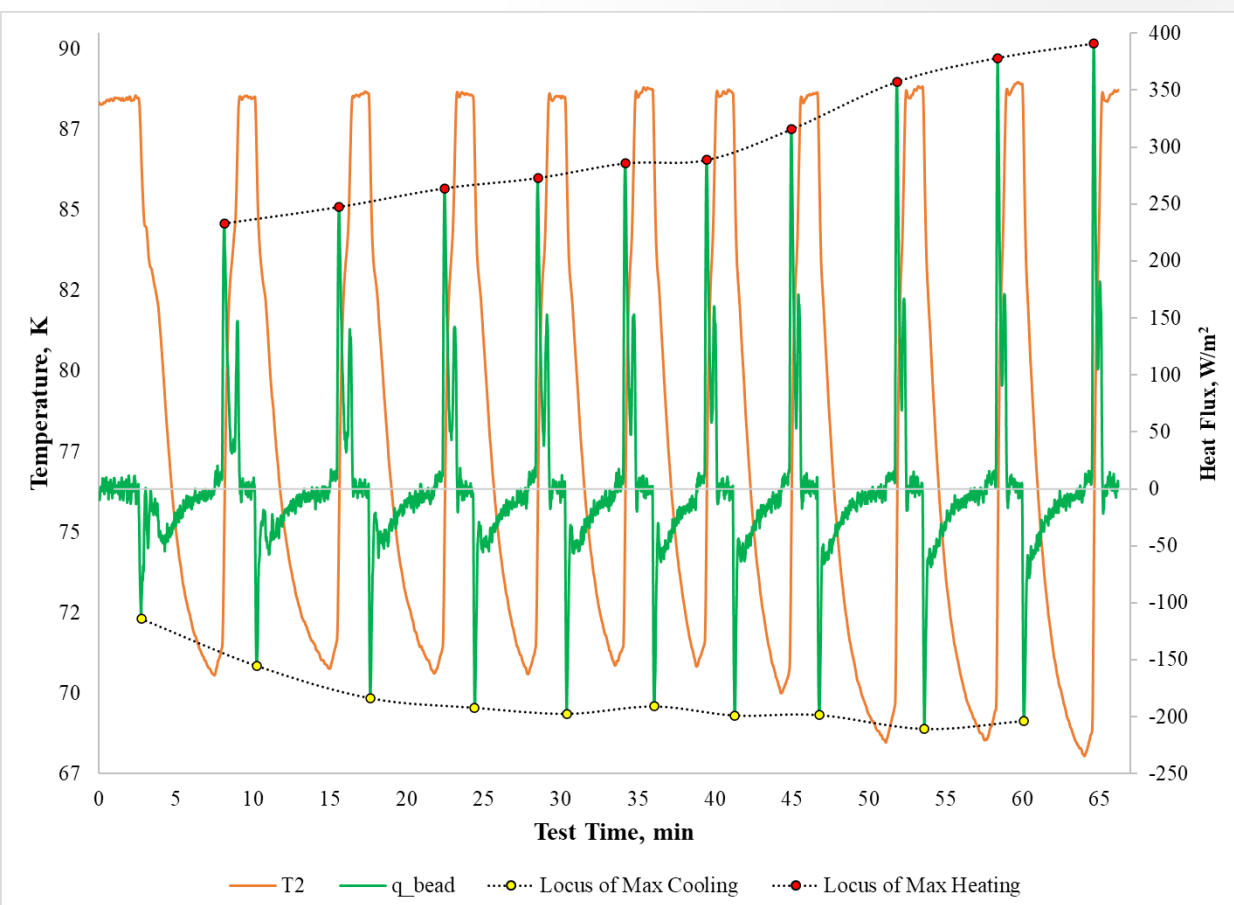


Cryo-Lite – Liquid Argon – Small Pump

ANALYTICAL RESULTS

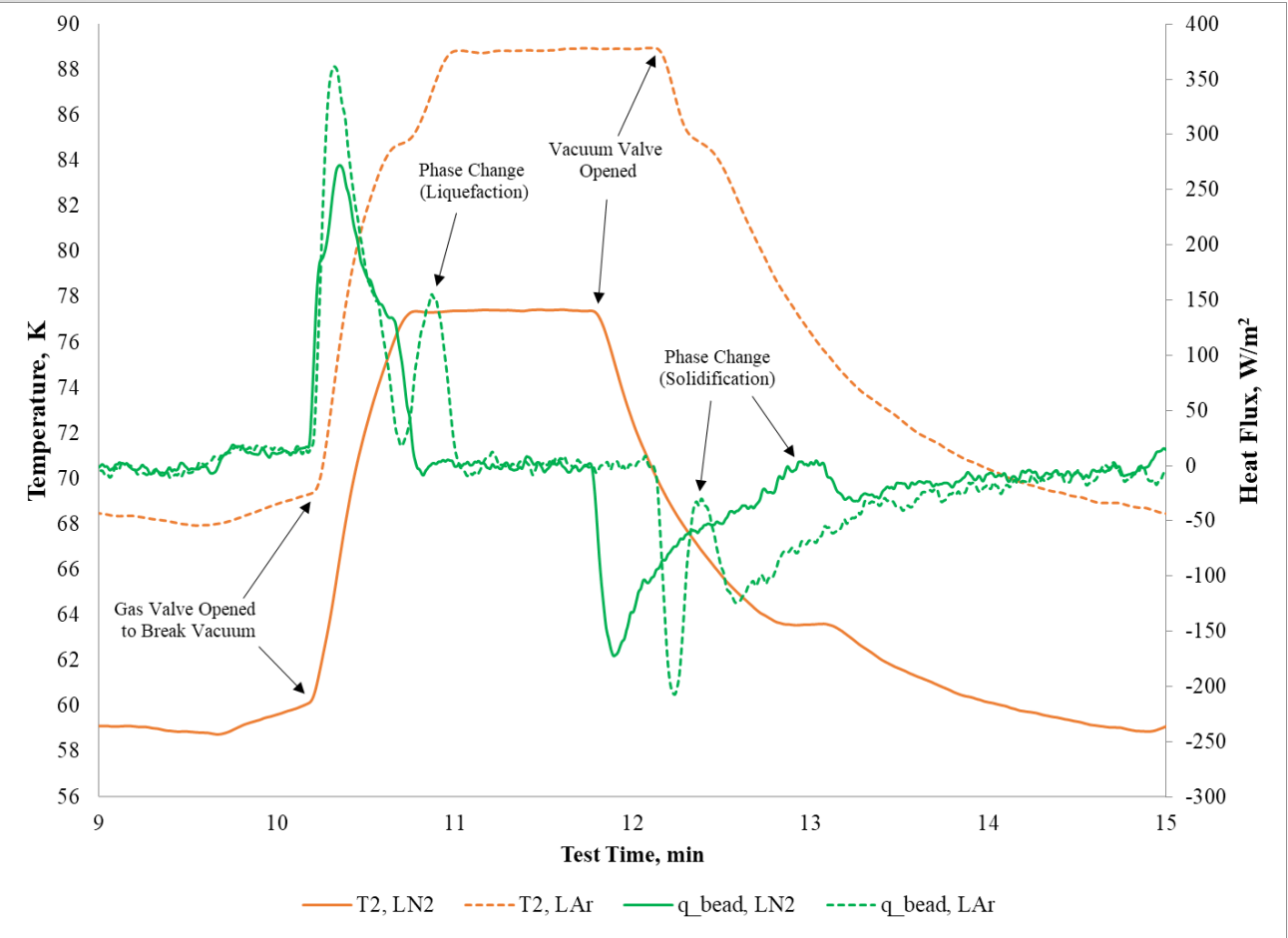


Cryogel – Liquid Nitrogen – Small Pump



Cryogel – Liquid Argon – Small Pump

ANALYTICAL RESULTS



	Liquid Argon		Liquid Nitrogen	
	Cryo-Lite®	Cryogel®	Cryo-Lite®	Cryogel®
Peak Cooling Heat Flux, W/m ²				
Small Vacuum Pump	-243.6	-210.7	-181.8	-173.4
Large Vacuum Pump	-642.2	-528.7	-552.1	-529.0
Minimum Measured Temperature, K				
Small Vacuum Pump	66.3	67.5	57.7	58.5
Large Vacuum Pump	57.9	60.0	52.5	54.1

Zoom-In: Cryo-Lite – Liquid Nitrogen & Argon – Big Pump

ANALYTICAL RESULTS

- Taking the **second-to-last pump-down cycle from each test** as a reference, using the small vacuum pump.....
 - 12.5% of the total ΔT achieved happened from the time that pump-down was initiated to the peak
 - Effective Pumping Time (t_{eff}): Time from when pump-down was initiated to when the heat flux dropped to 95% of its peak value
 - Average t_{eff} and q_{bead}
 - ✓ **Small Pump**: $t_{\text{eff}} = 117 \text{ sec}$, $q_{\text{bead}} = -58 \text{ W/m}^2$
 - ✓ **Big Pump**: $t_{\text{eff}} = 45 \text{ sec}$, $q_{\text{bead}} = -199 \text{ W/m}^2$
 - t_{eff} accounted for 44% of total pump time for the reference cycle across all tests, and 90% of the total heat removal

OPEN QUESTIONS/POINTS OF INTEREST

- **Understanding the physical cooling mechanism involved**
 - Cryo-Lite should only be vaporization & sublimation, but desorption should also be in play for Cryogel
 - Data clearly shows phase-change behavior in Cryogel → Capillary condensation/freezing?
- **Regardless of test configuration, pressure always bottomed-out around 1 torr**
 - Originally thought to be mechanical limitations of the pumps, but pump curves say otherwise.....
 - For Cryo-Lite, the gas release rate is primarily governed by heat of fusion
 - Are the heats of fusion below the freezing point known?

CONCLUSION

- Vacuum-Induced Cryocooling (VIC) in the materials/cryogens tested showed meaningful performance, and could be promising for future space missions
- At comparable sample volumes, Cryogel provided 2.5 times more vacuum pump-down cycles than Cryo-Lite, and the VIC was more non-localized in Cryogel than Cryo-Lite
- Greater pumping power afforded greater cooling, as well as a more efficient use of the stored cryogen mass
 - **What would happen in the infinite vacuum pump of space!**
- Need further testing with different cryogens → LH_2 would be interesting!

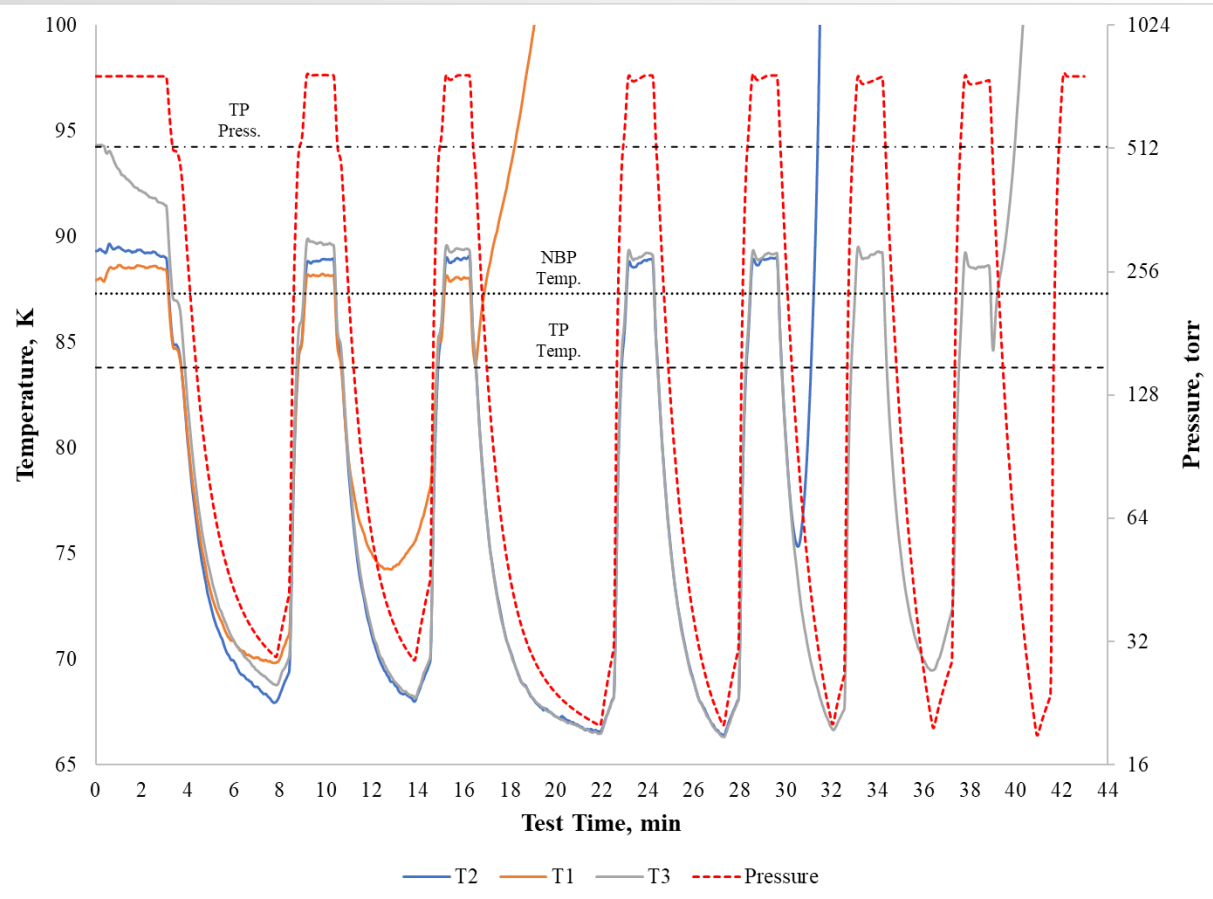


THANK YOU FOR
YOUR ATTENTION!

QUESTIONS?

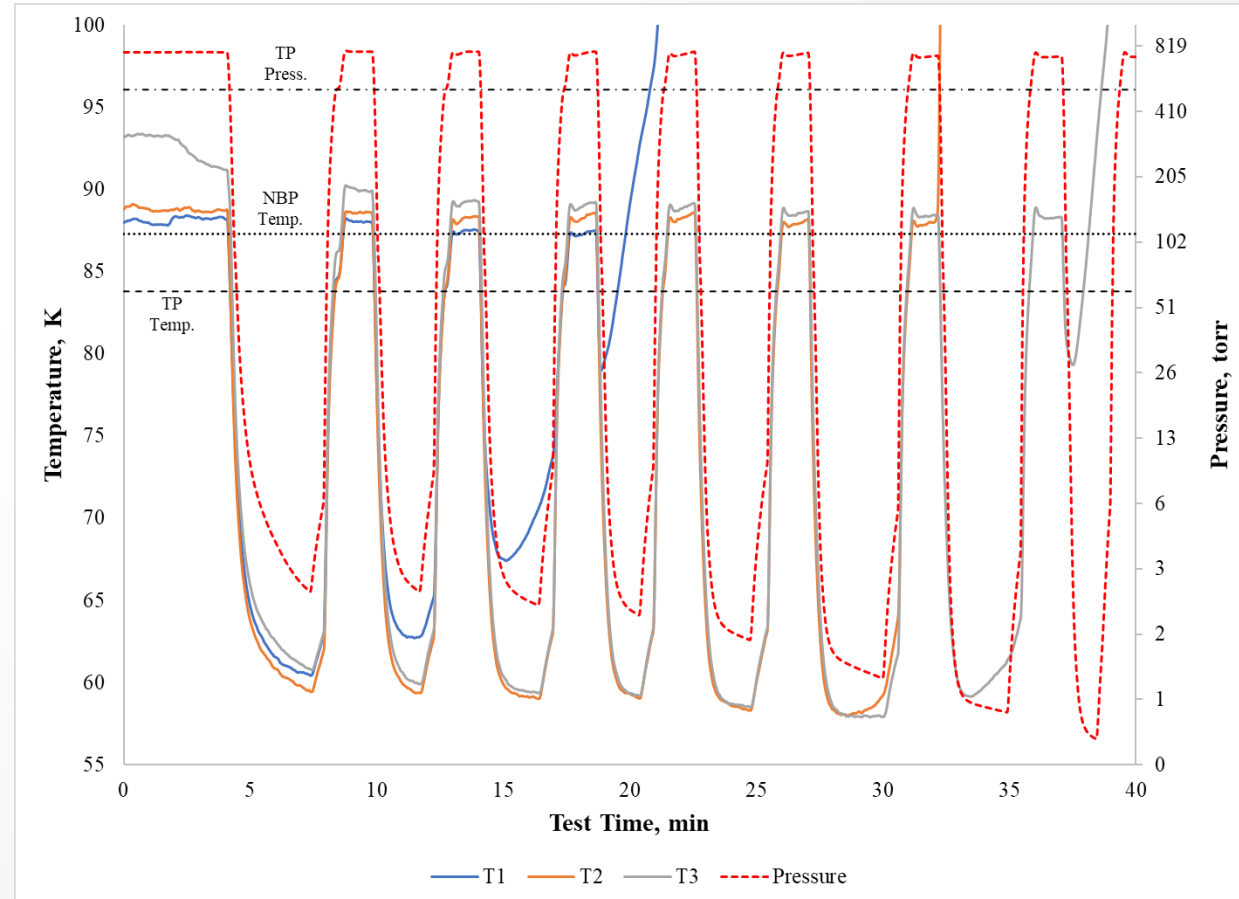
BACK-UP—TEST RESULTS

17



Cryo-Lite – Liquid Argon– Small Pump

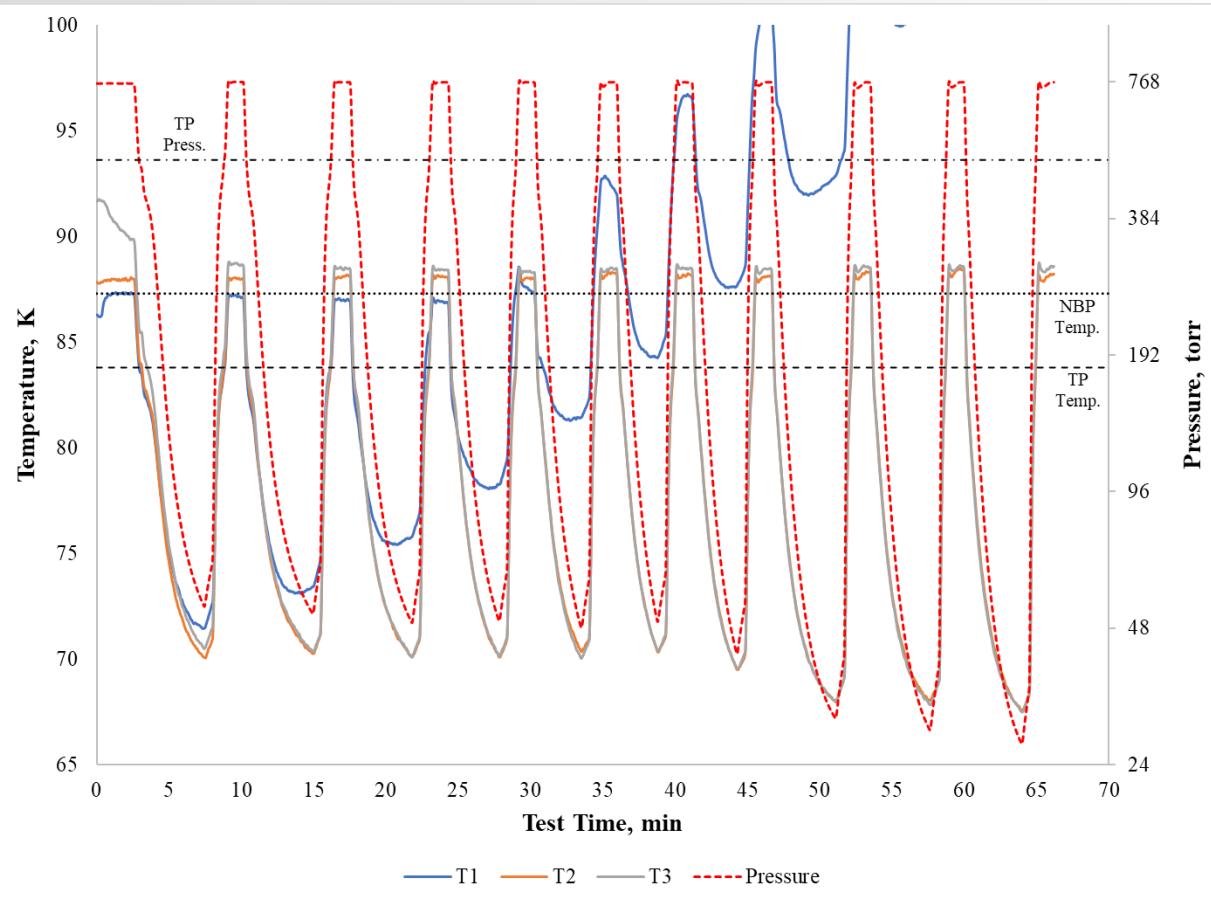
- Min temp. = 66.3 K
- 7 total pump-down cycles



Cryo-Lite – Liquid Argon – Big Pump

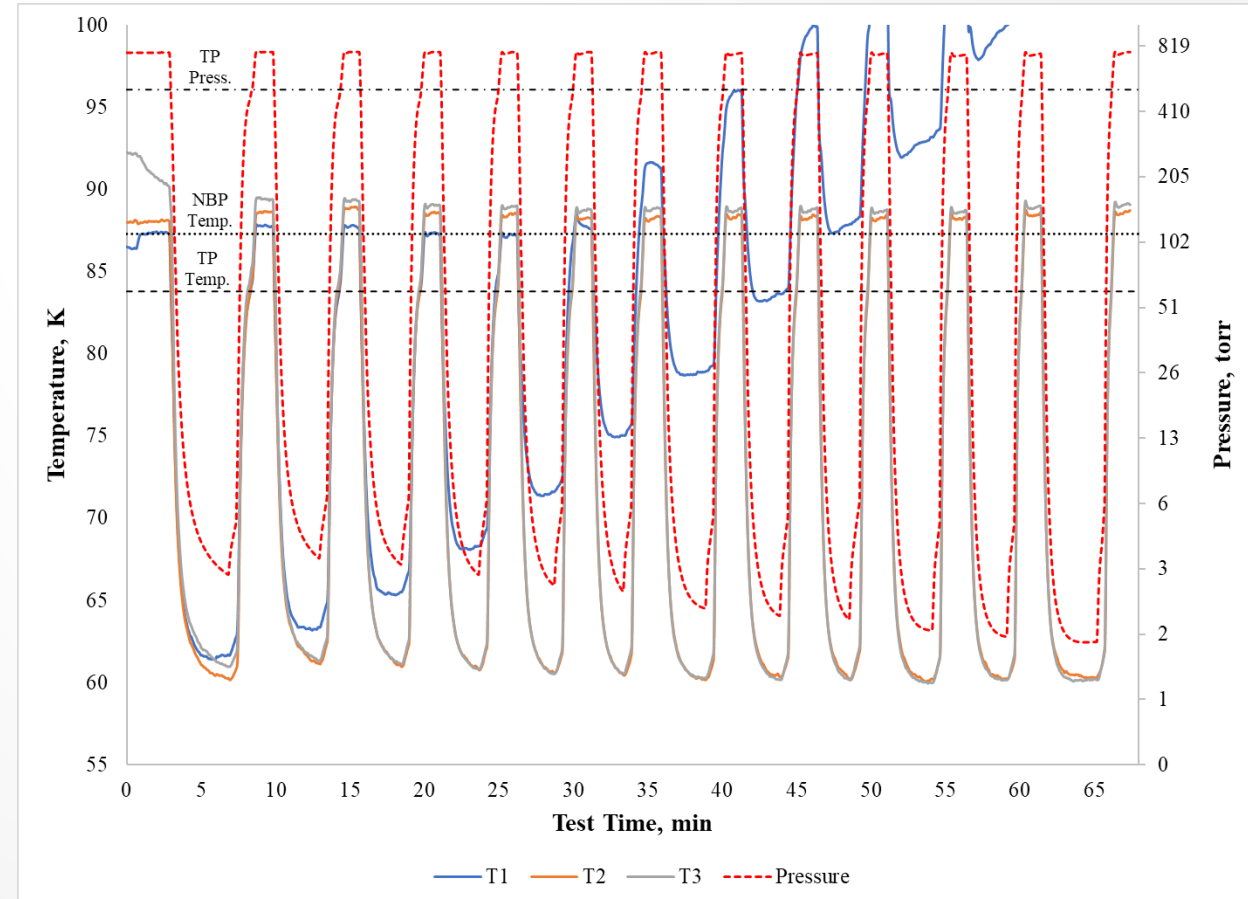
- Min temp. = 57.9 K
- 8 total pump-down cycles

BACK-UP—TEST RESULTS



Cryogel – Liquid Argon – Small Pump

- Min temp. = 67.5 K
- Did not reach max number of pump-down cycles

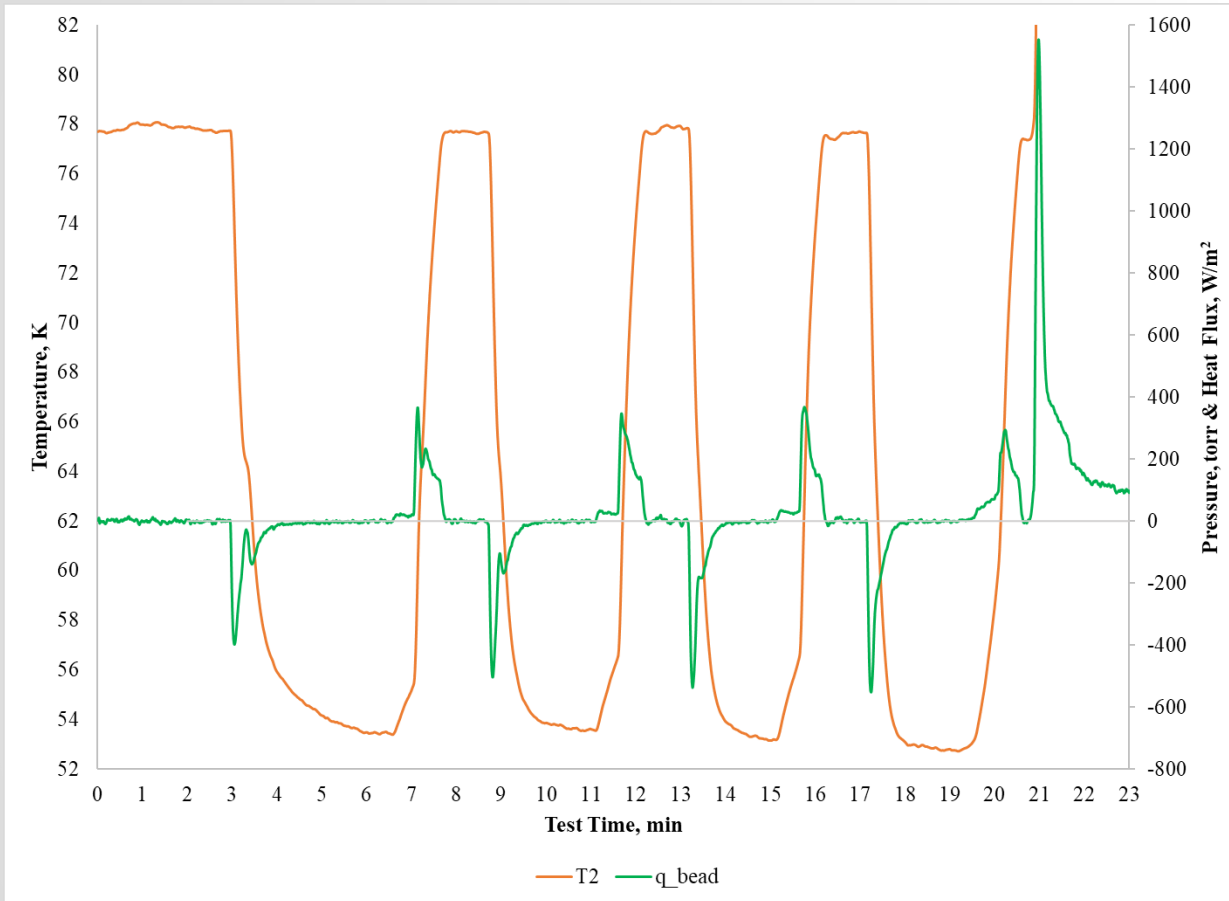


Cryogel – Liquid Argon – Big Pump

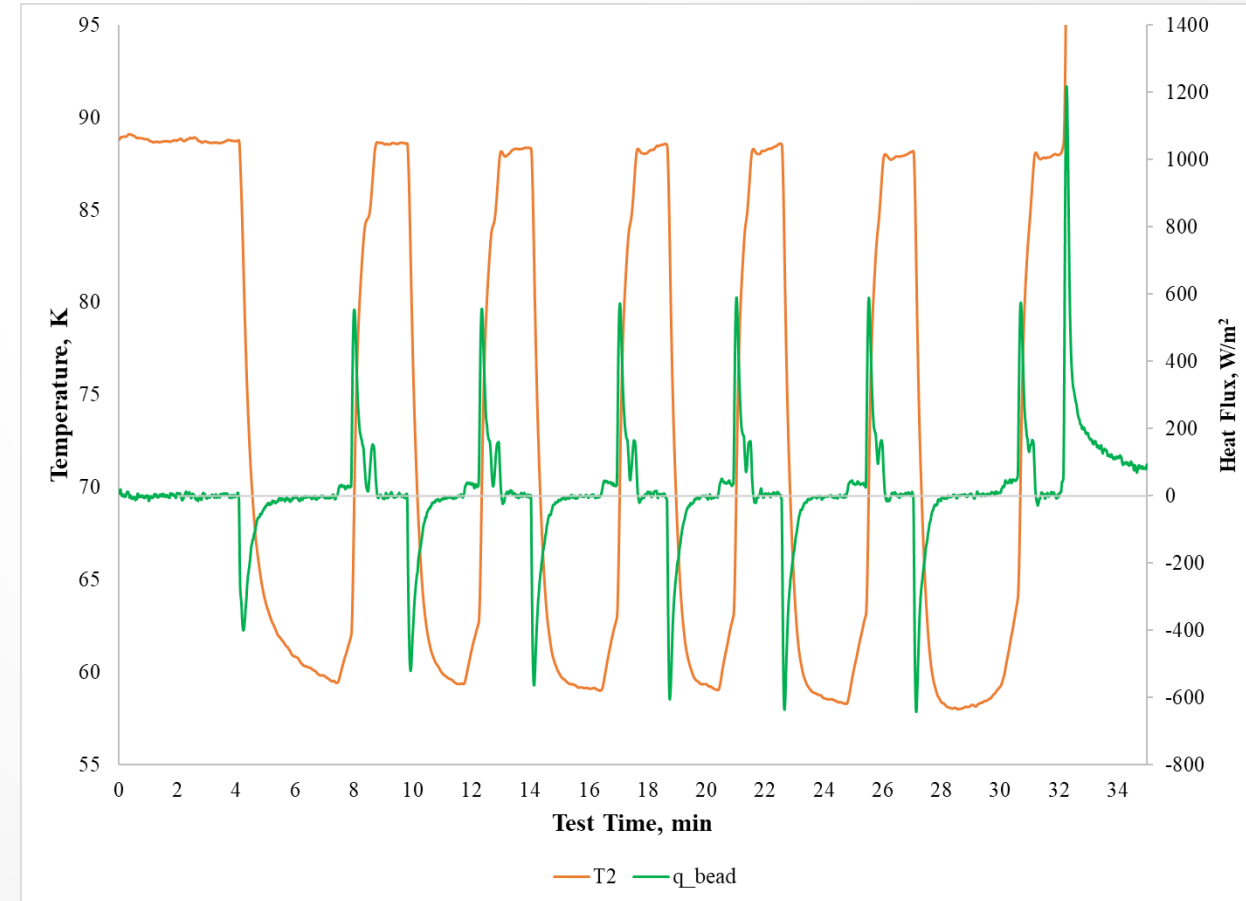
- Min temp. = 60 K
- Did not reach max number of pump-down cycles

BACK-UP— ANALYTICAL RESULTS

19

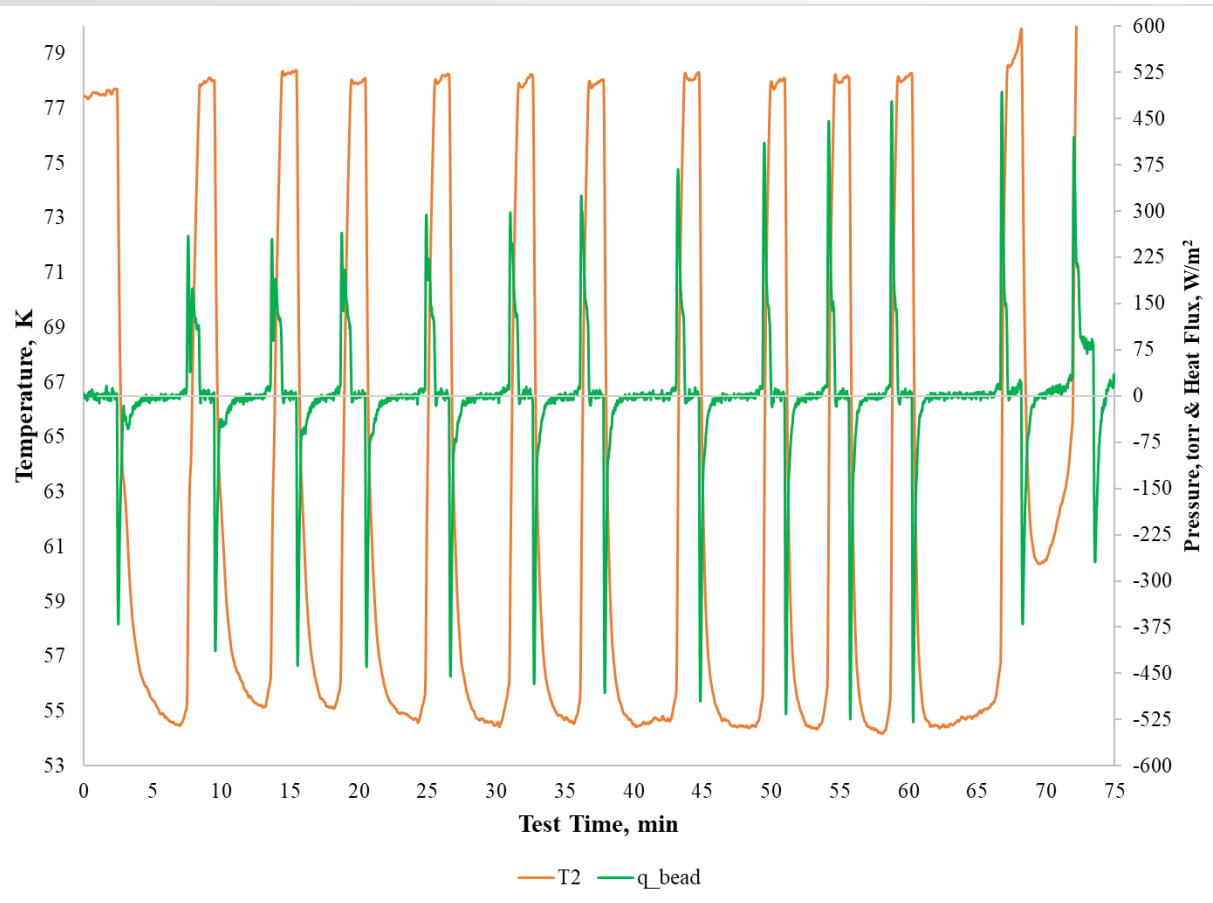


Cryo-Lite – Liquid Nitrogen – Big Pump

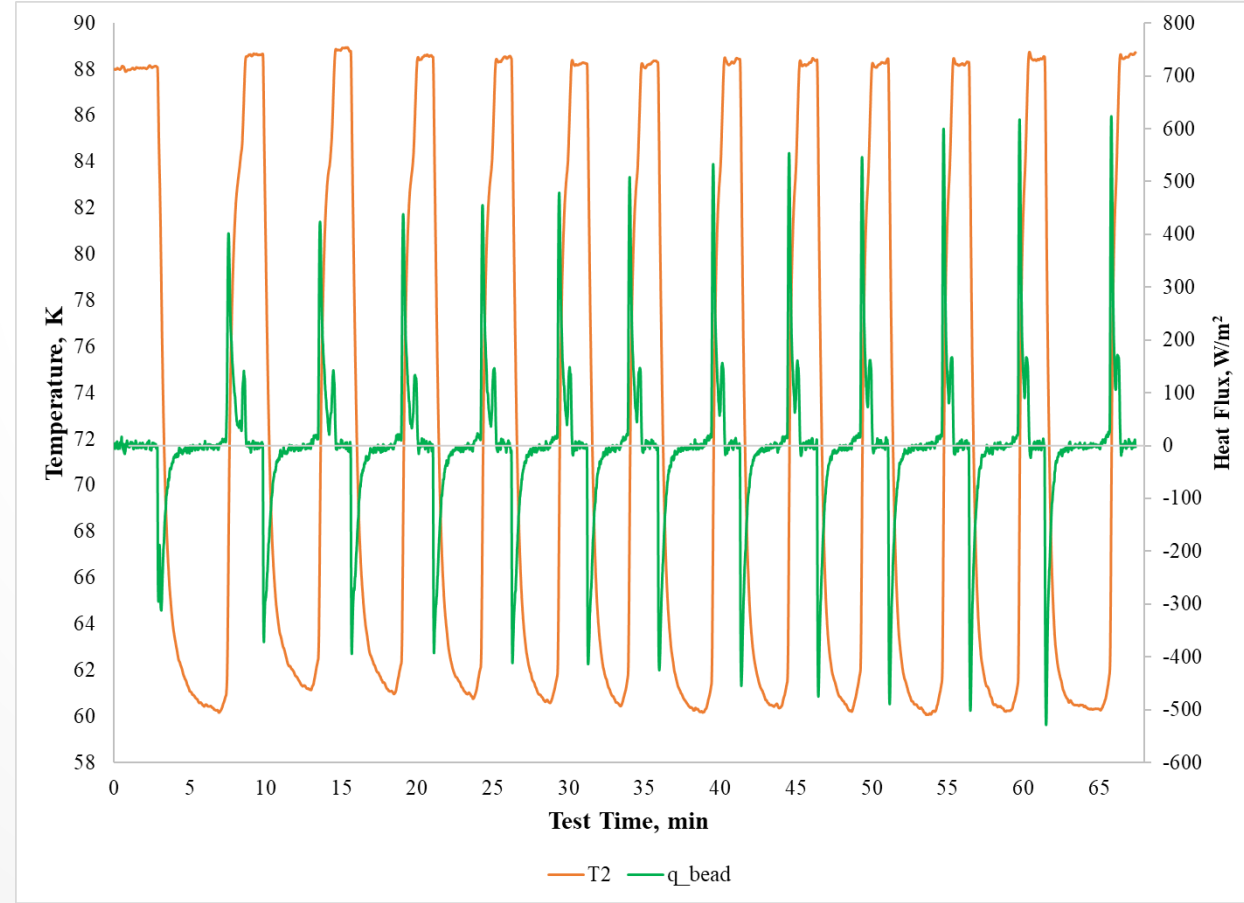


Cryo-Lite – Liquid Argon – Big Pump

BACK-UP— ANALYTICAL RESULTS



Cryogel – Liquid Nitrogen – Big Pump



Cryogel – Liquid Argon – Big Pump