



## Dragonfly: Investigation of Thermal Insulation via Testing and Analysis

Marisa Teti, Rolando Rodarte, Dahway Lin, Bruce Williams, Collette Gillaspie, and Kurt Gonter

Presented By  
Marisa Teti

Thermal & Fluids Analysis Workshop  
TFAWS 2024  
August 26-30, 2024  
NASA Glenn Research Center  
Cleveland, OH

- Where to?
  - Sending a rotorcraft lander to Titan
  - Titan is Saturn's largest moon
  - 7 year journey
- Titan Environment
  - 95% Nitrogen, 5% Methane
  - 92 K to 96 K (-181C to -177C)
  - 1.5 atm
  - 1/7 Earth's gravity ( $1.35 \text{ m/s}^2$ )



Photo courtesy of NASA

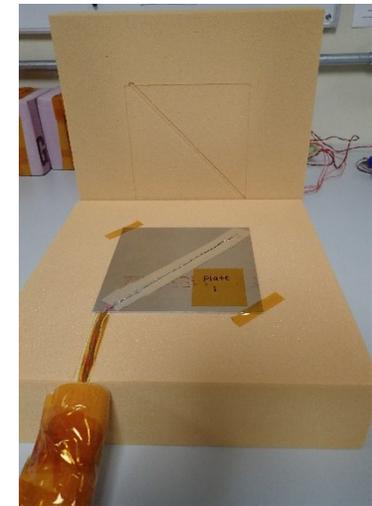
<https://science.nasa.gov/missions/dragonfly/nasas-dragonfly-rotorcraft-mission-to-saturns-moon-titan-confirmed/>

# Purpose of Foam Insulation

- Titan is extremely cold
  - Need to keep lander components near room temperature
- Why foam?
  - Thermal blankets do not work in a convective environment
  - Need a convection barrier
  - Mass efficient way of adding thermal resistance
- Other foam considerations
  - Started with 6+ foams
  - Testing helped narrow down foam insulation options
    - Solimide and Rohacell foams



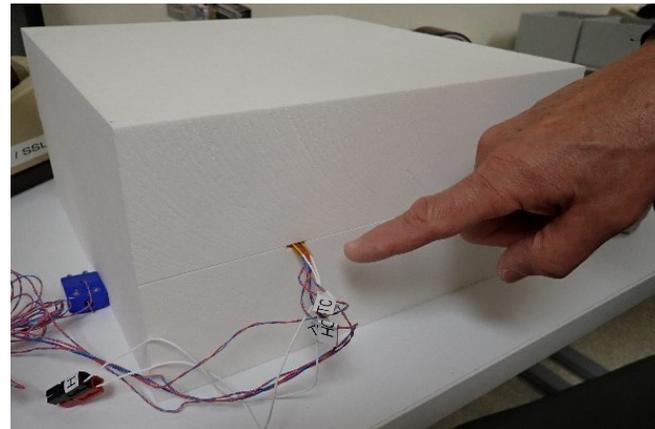
Rohacell foam

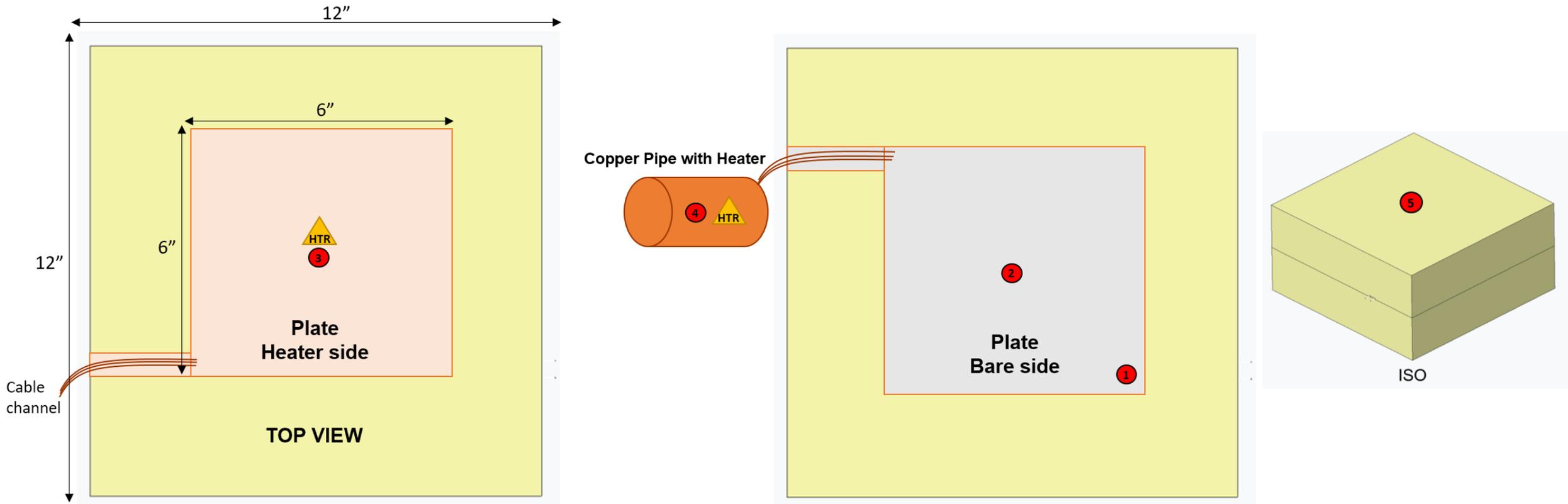


Solimide foam

# Foam Thermal Conductivity Test Configuration

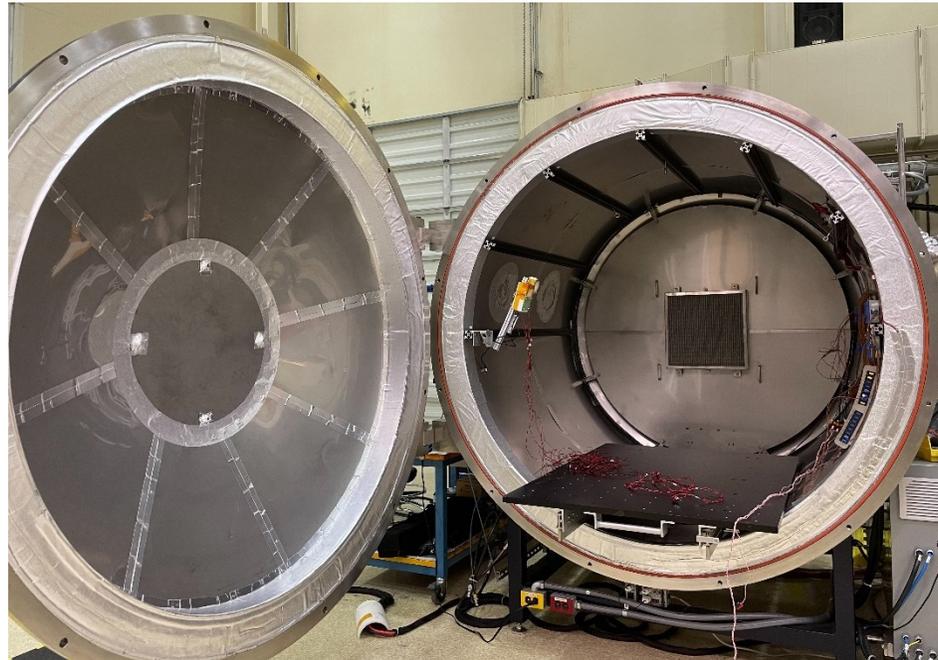
- Test Materials
  - 2 blocks of foam: 12" x 12" x 3" each
  - 1 heater plate: 6" x 6" x 1/16"
- Test Purpose
  - Evaluate the thermal conductivity of different foam options at Titan conditions since no industry data exists
  - Find a foam insulation option with low thermal conductivity and limited internal natural convection





- 5 thermocouples, Kapton heater on plate
- ZeroQ heater: thermocouple wires wrapped around copper tube, Kapton heater, and aluminum tape with goal of no heat leak through cable channel

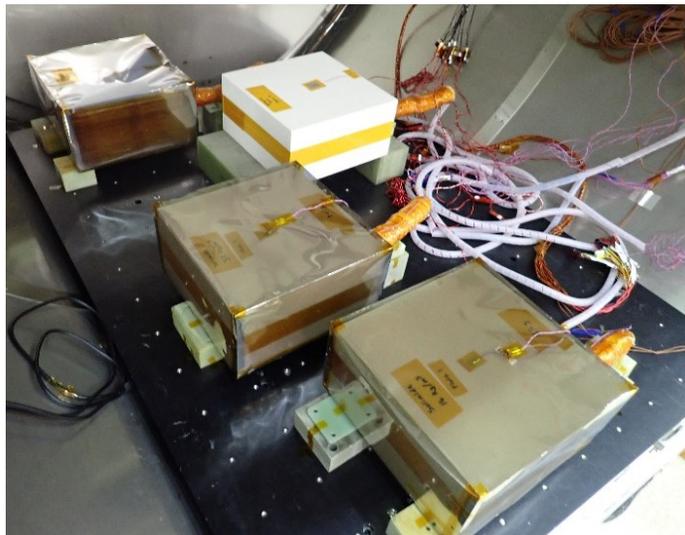
- Titan Pressure Environmental Chamber (TPEC)
  - 5' diameter and 5' extendable platen
  - Ability to reach Titan environmental conditions
    - Temperature range (-180C to +150C)
    - Adjustable pressure from 1.0 atm to 1.6 atm
    - Convection coefficient due to wind speed from blower



- Configuration
  - Horizontal and vertical orientation to check for internal convection
  - Encapsulation and no encapsulation for contamination concerns
  - Sitting on G10 blocks to allow air flow underneath



Vertical configuration



Horizontal configuration



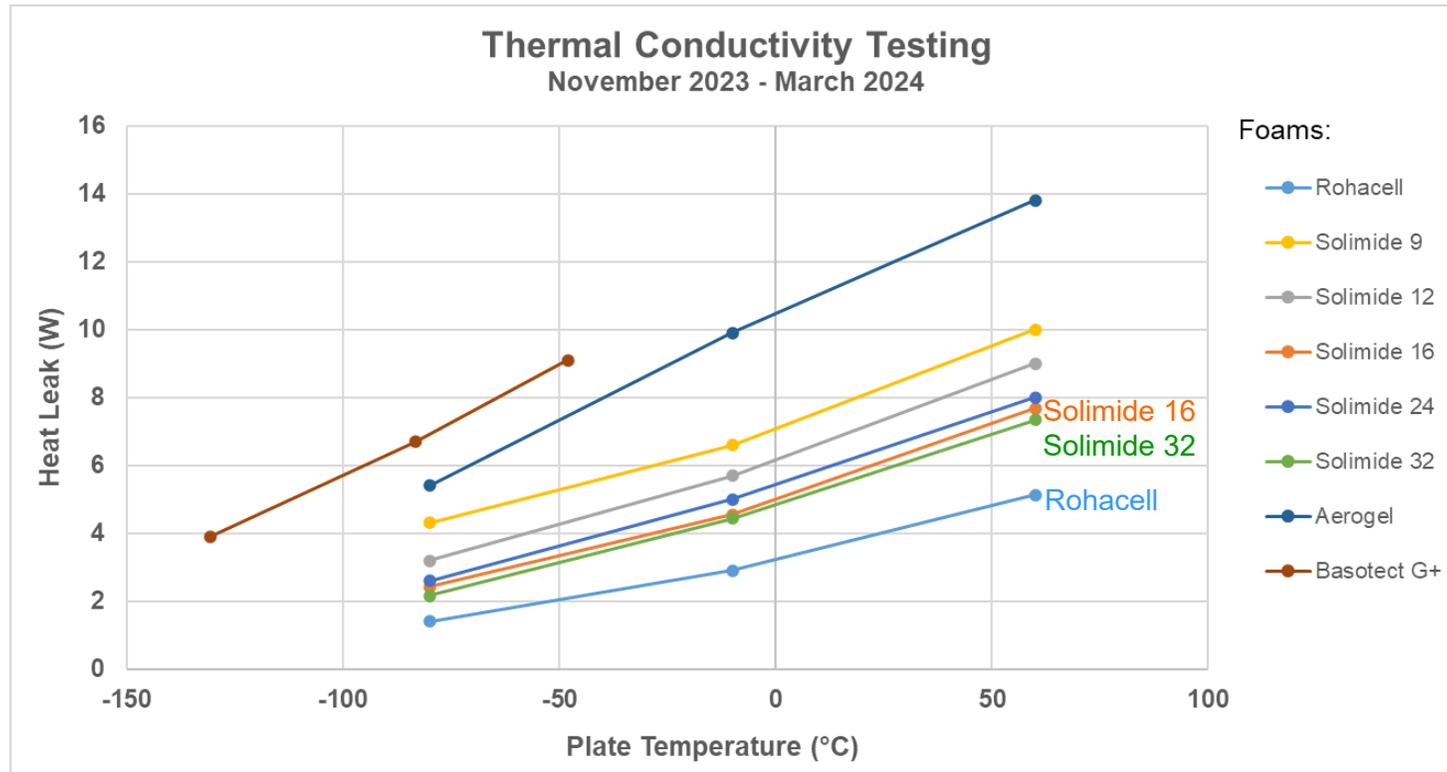
Solimide foam fully taped with Kapton



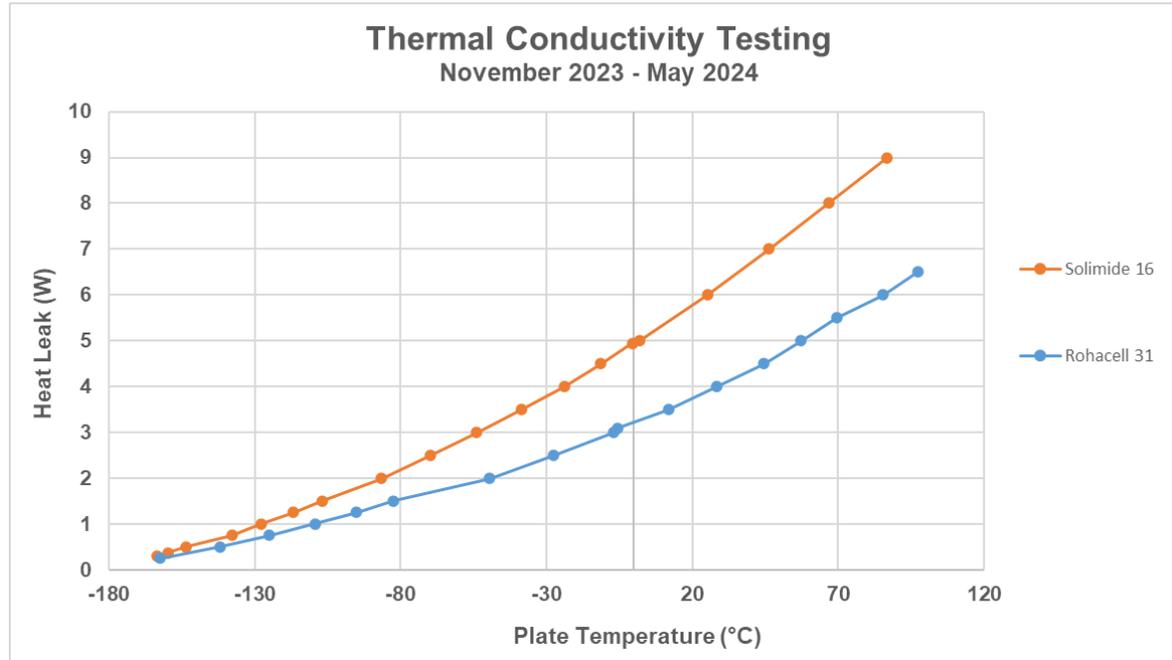
Bare Rohacell foam

- Test Procedure

- Temperature control heater plates to -80C, -10C, and +60C
- Let stabilize for approx. 2 hours until meets criteria: <0.5 W/hr
- Record power



- Test Data
  - Solimide and Rohacell have lowest heat leak = lowest thermal conductivity
- Test Procedure
  - Manually control heater plates to powers between 0.3 and 9.0 Watts
  - Let stabilize for approx. 2 hours and record temperature
  - Collected 10+ data points





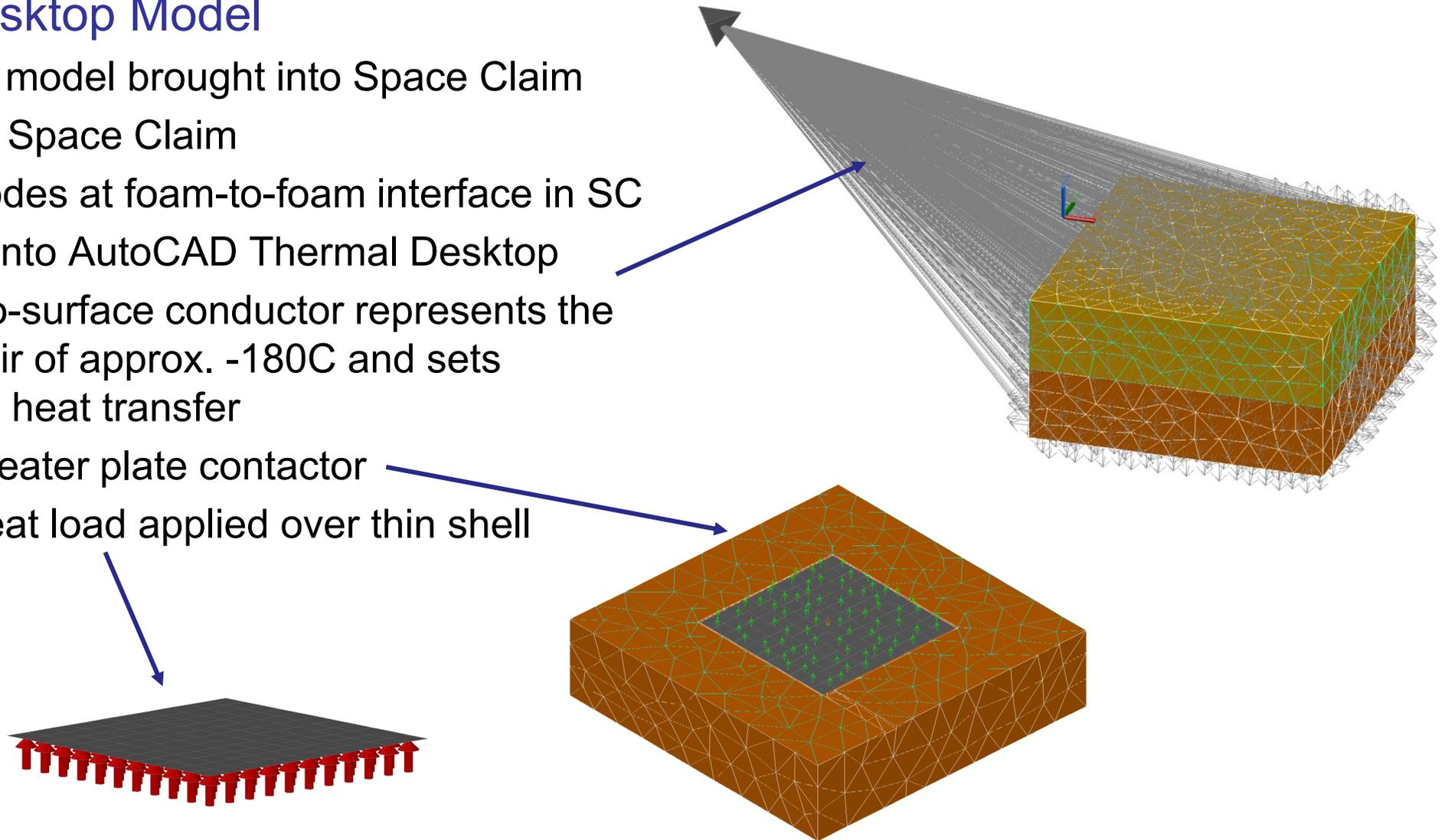
# Foam Thermal Conductivity Foam Characteristics



- Foam Considerations
  - Solimide density =  $16 \text{ kg/m}^3$ 
    - Open cell foam
      - Responds quickly to changes in pressure i.e. vacuum
    - Flexible and lower density
  - Rohacell density =  $31 \text{ kg/m}^3$ 
    - Closed cell foam
      - Does not respond quickly to changes in pressure
    - Brittle and higher density
- Recent testing focus on Solimide

- Thermal Desktop Model

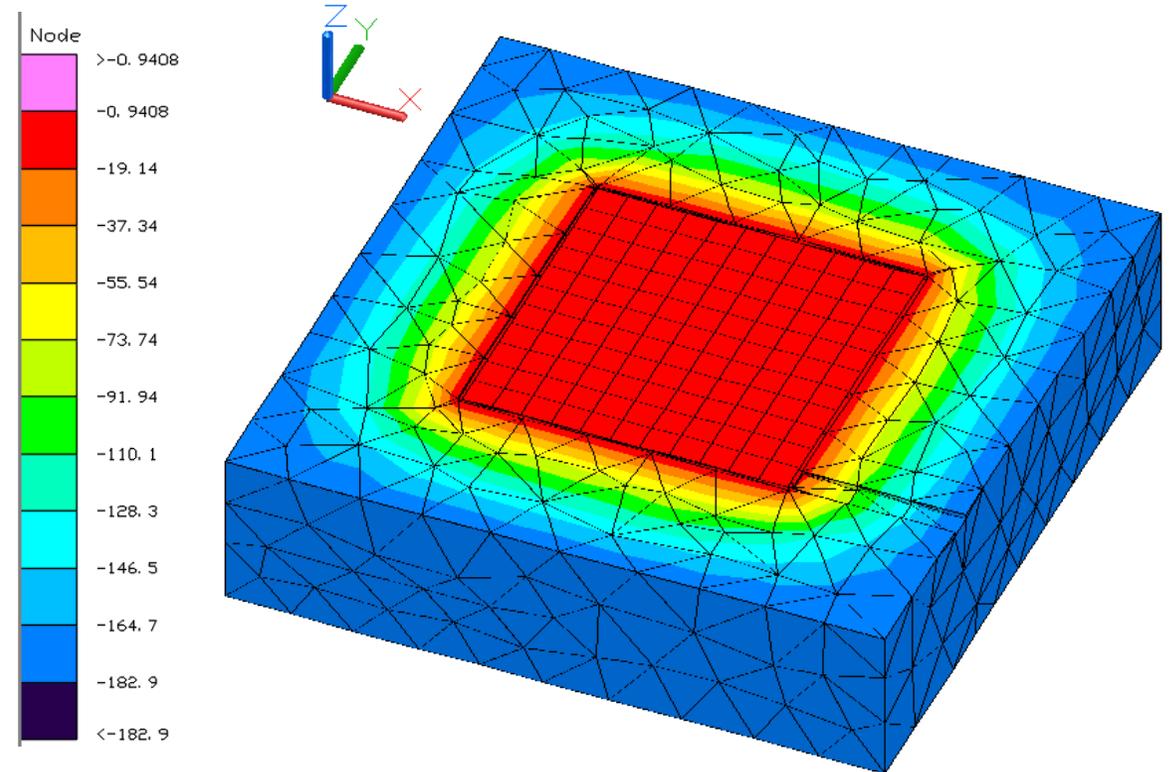
- Creo CAD model brought into Space Claim
- Meshed in Space Claim
- Merged nodes at foam-to-foam interface in SC
- TD Direct into AutoCAD Thermal Desktop
- Air node-to-surface conductor represents the chamber air of approx. -180C and sets convective heat transfer
- Foam-to-heater plate contactor
- Surface heat load applied over thin shell



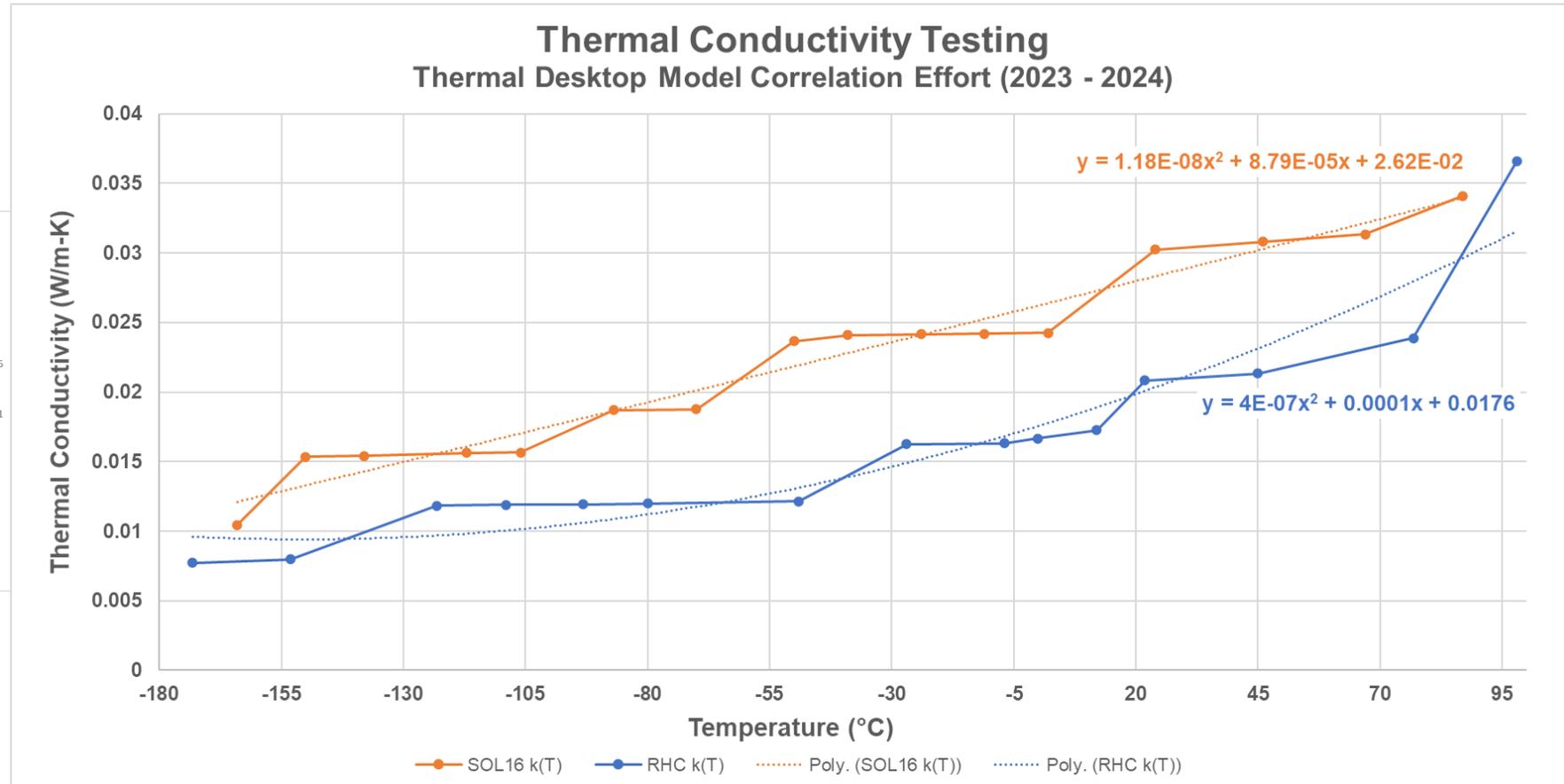
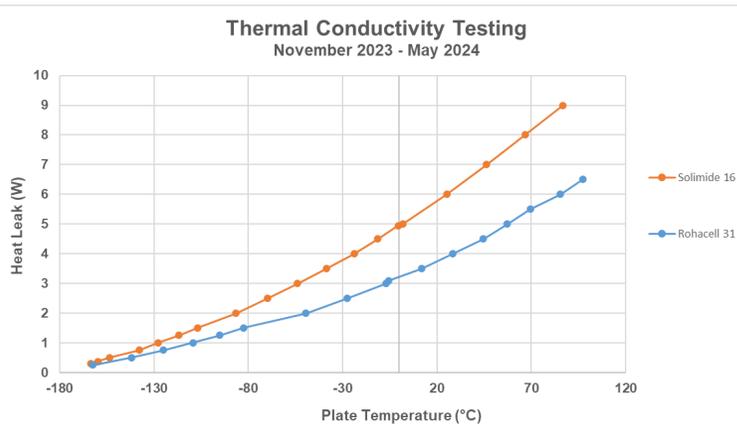
- Thermal Desktop Model
  - Adjusted  $k(T)$  curve in Thermal Desktop thermophysical properties until node data matched TC data within  $\pm 3C$

Ex. Solimide 16 Model

Heat Leak (W)	TC Temp (C)	Node Temp. (C)	$\Delta T$ (C)
0.5	-153.6	-154.3	0.7
2.5	-69.9	-71.9	2.0
5.0	1.60	-0.9	2.5
9.0	86.8	87.1	-0.3



- Thermal Desktop Model
  - Applied “line of best fit” polynomial to achieve  $k(T)$  curve for Solimide at Titan conditions





# Foam Thermal Conductivity Takeaway

- Material properties found at Titan conditions
  - $k(T)$  curve has been used for larger scale test model correlations
    - Including the current full scale lander thermal model
- Dragonfly is unique
  - No industry data available
  - Needed to conduct testing to collect thermal conductivity values

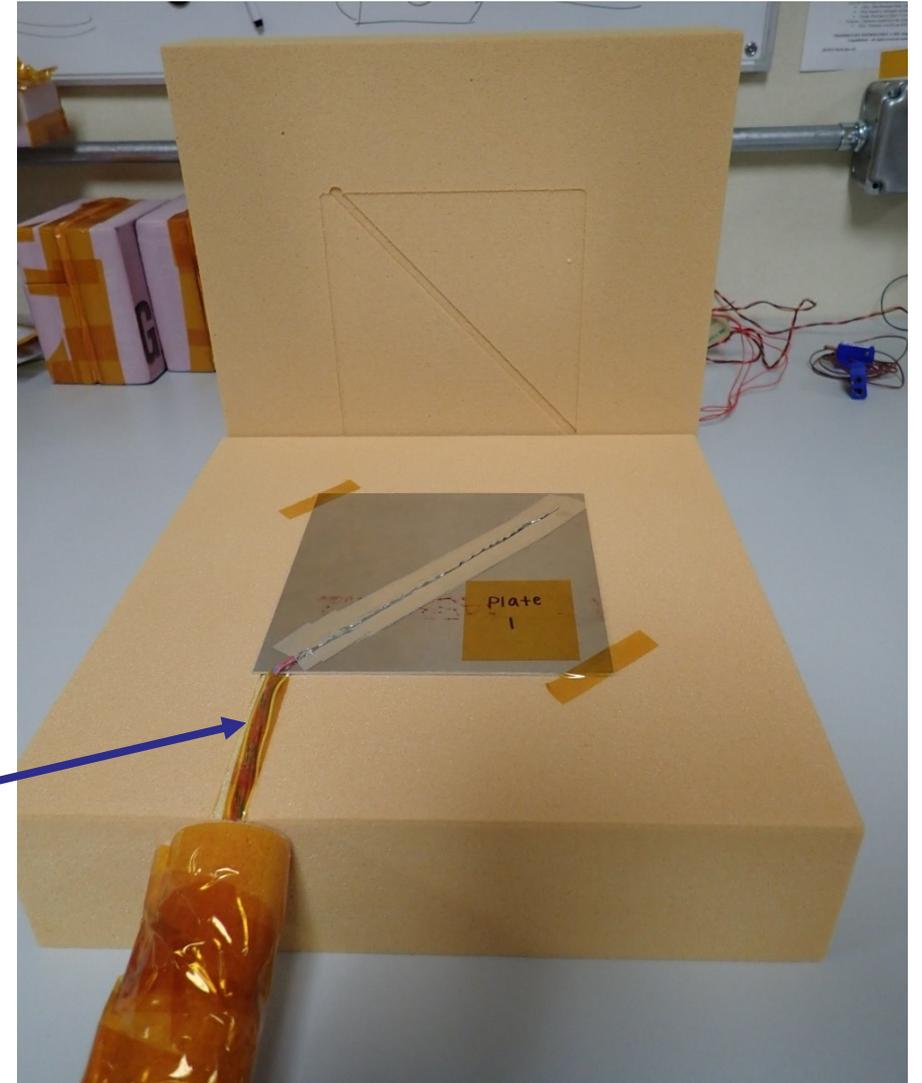
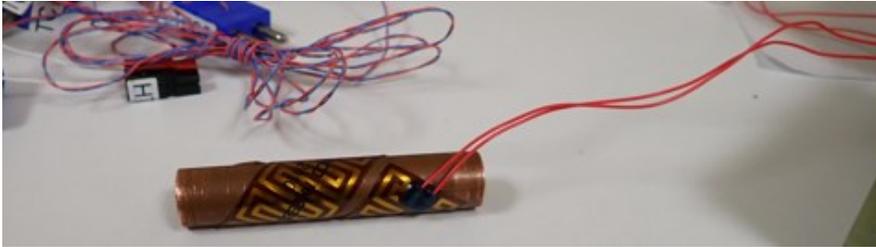


Marisa Teti, [marisa.teti@jhuapl.edu](mailto:marisa.teti@jhuapl.edu)

**THANK YOU**

**Supplemental**

- ZeroQ heater

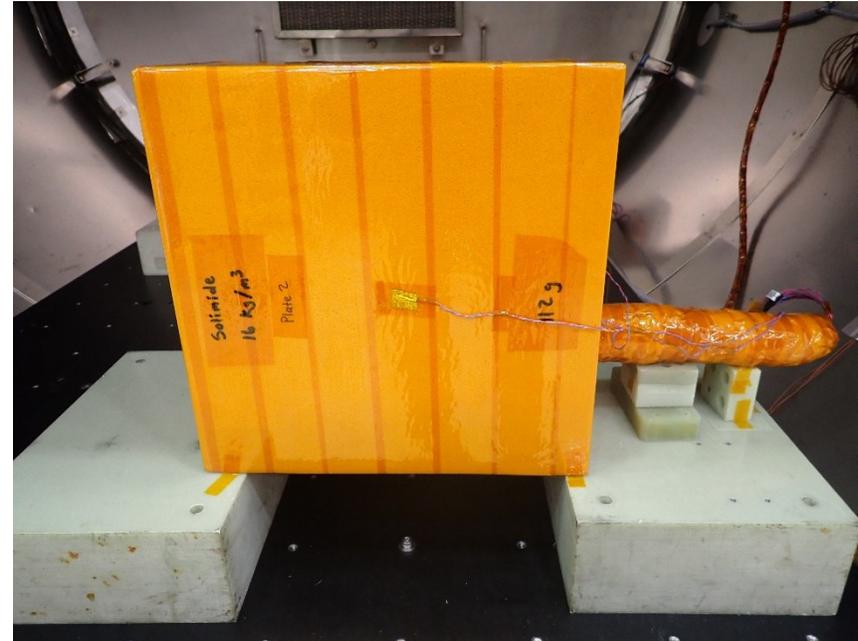


Airflow is blocked with un-densified Solimide foam in cable channel

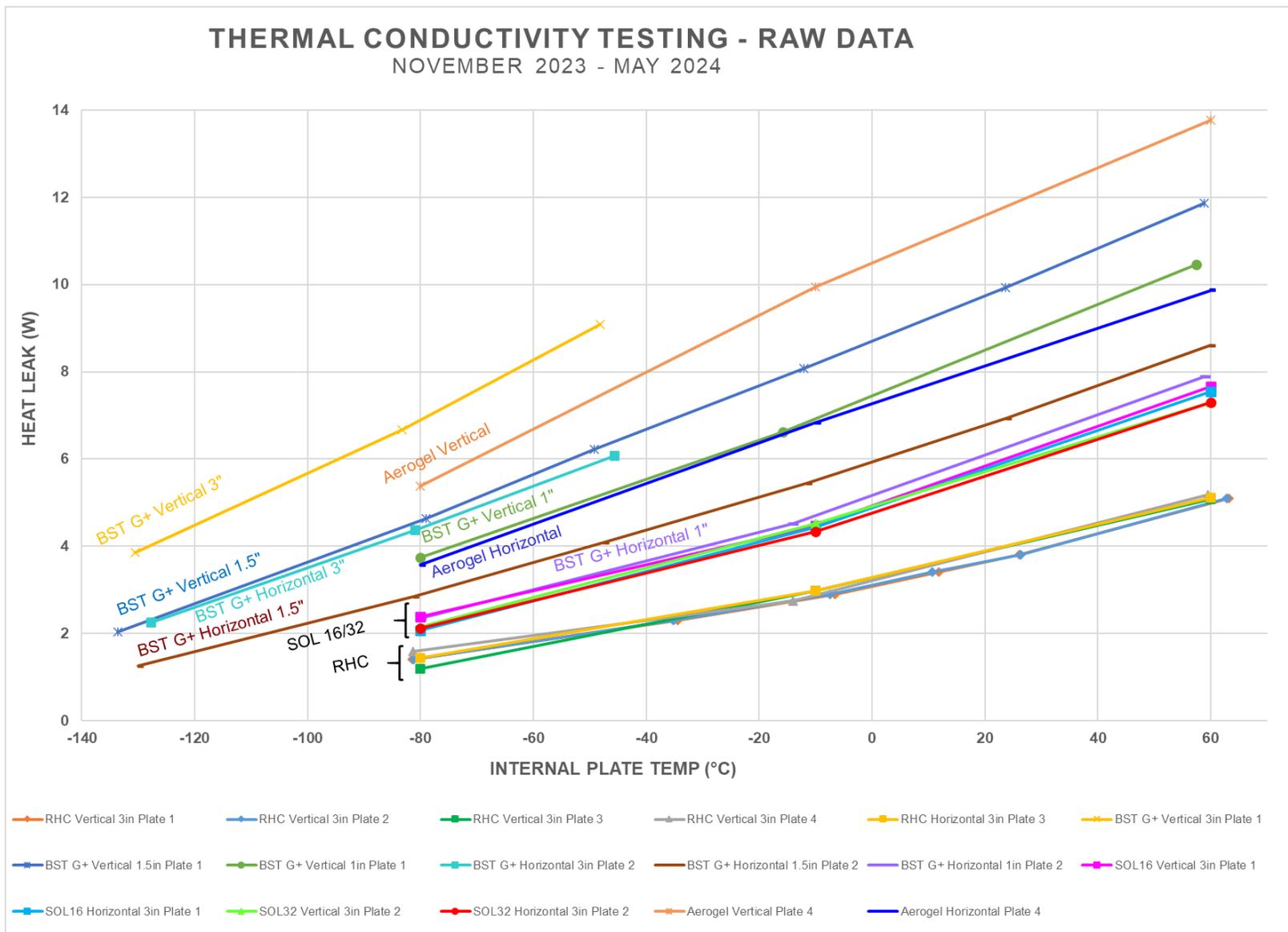
- Encapsulation
  - Vented with X-acto knife pokes



**Kenlam bag tight fit**



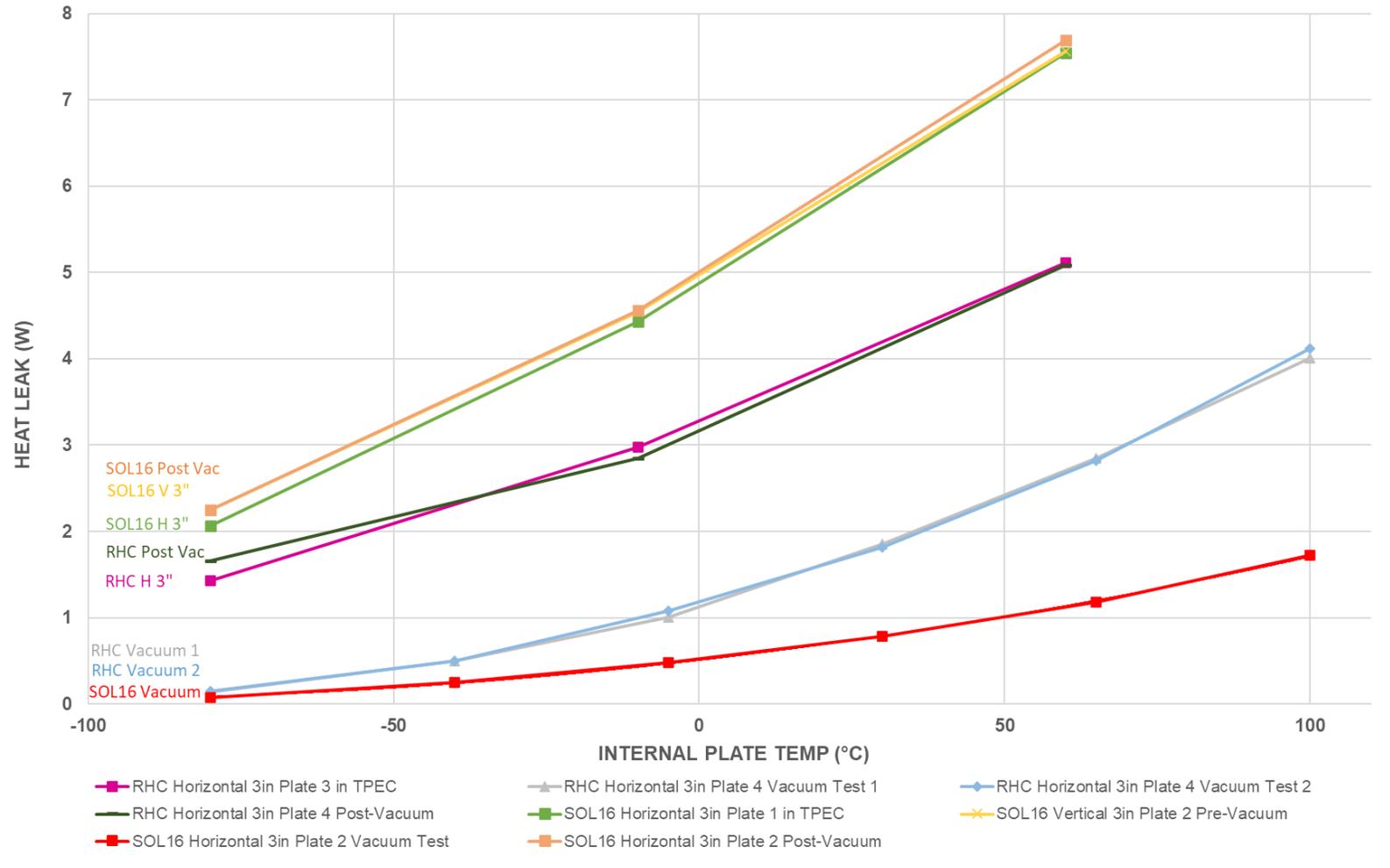
**Kapton tape strips**

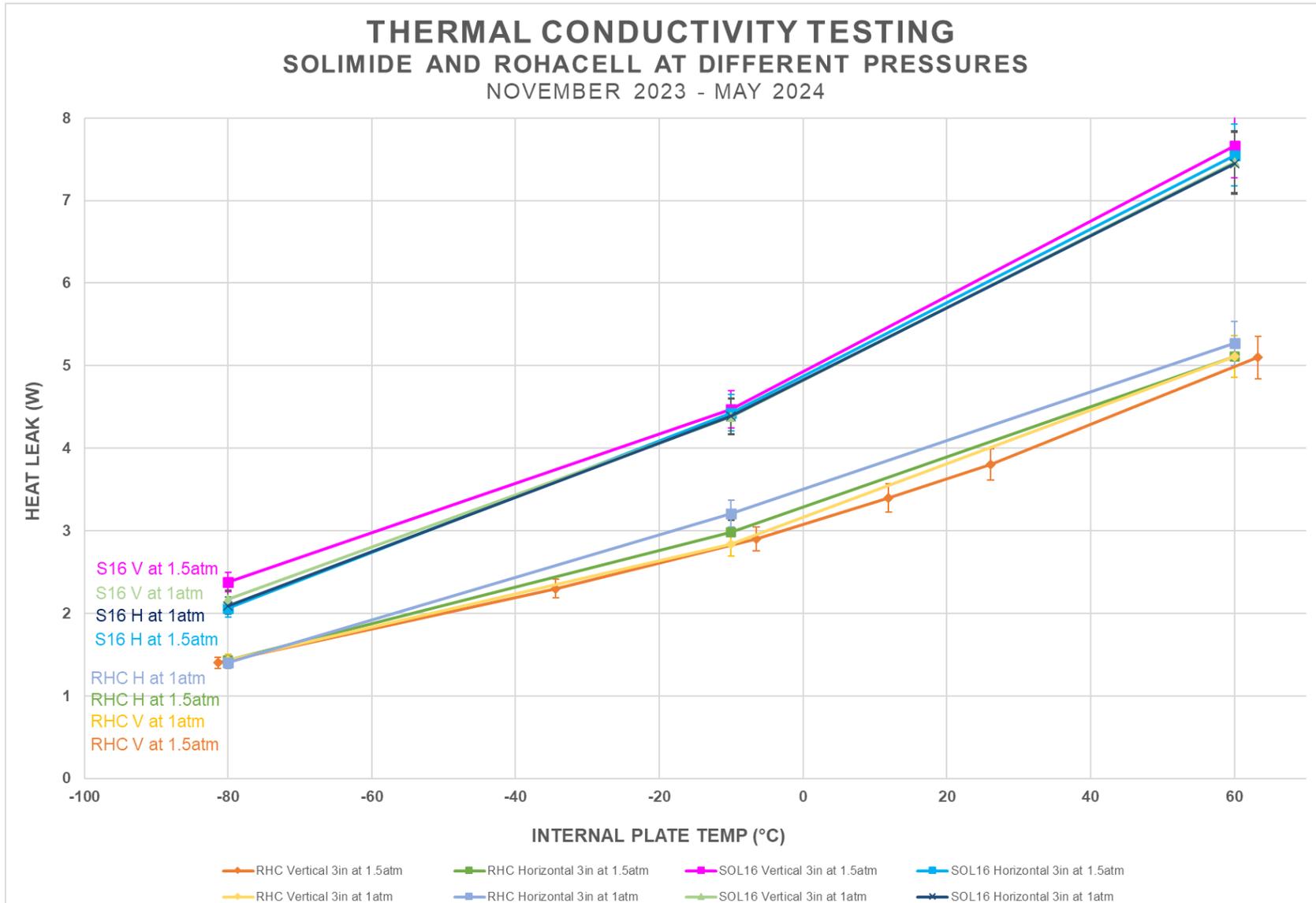


## THERMAL CONDUCTIVITY TESTING VACUUM TESTING COMPARISON NOVEMBER 2023 - MARCH 2024

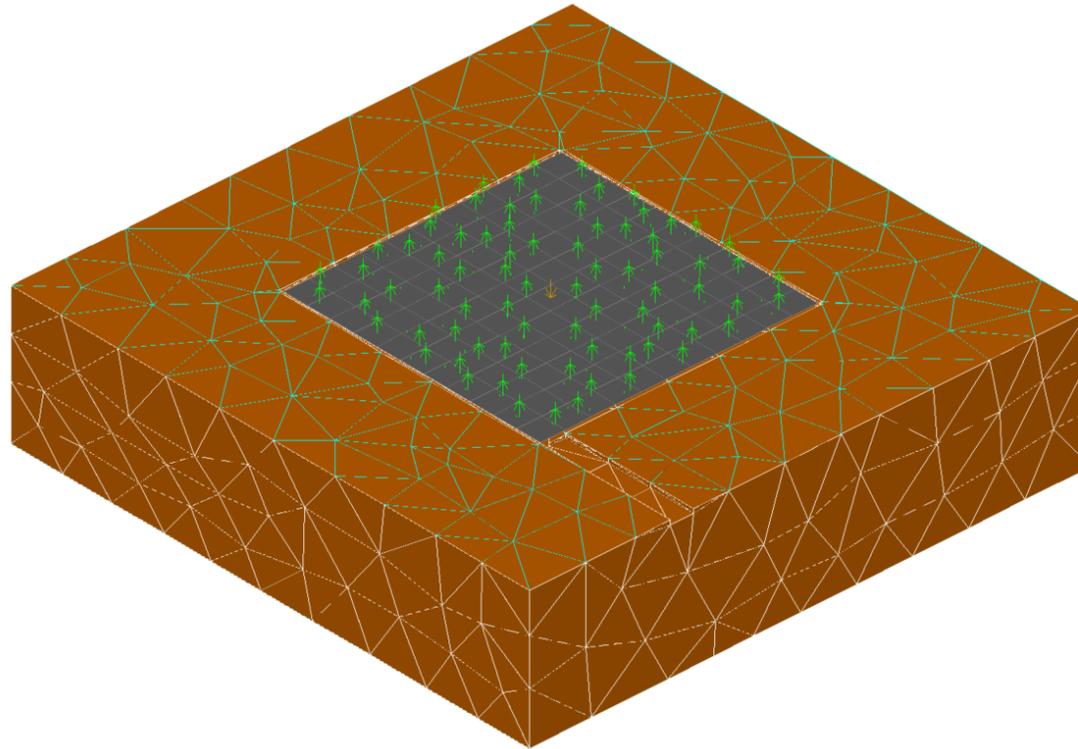
TPEC Chamber: 1.5 atm, -180°C  
& OCF Vacuum Chamber

Bare Rohacell &  
Solimide covered with Kapton Tape

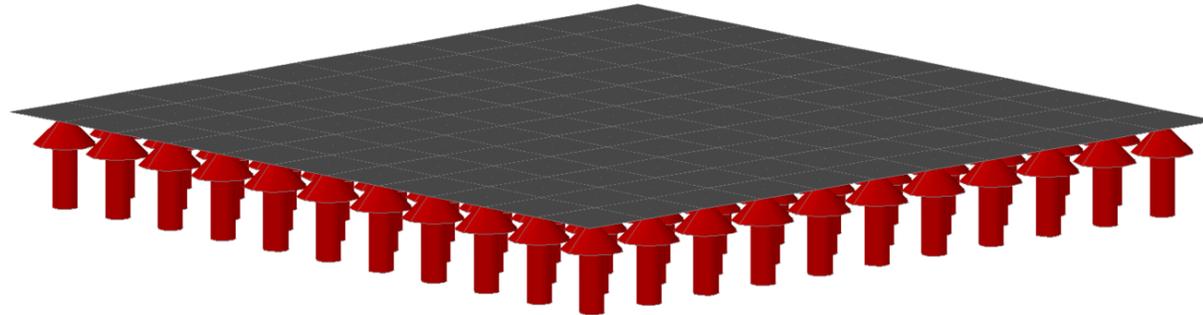




- Contactors
  - Foam to Heater Plate contactors
  - Titan N<sub>2</sub> air gap = 0.001 inches



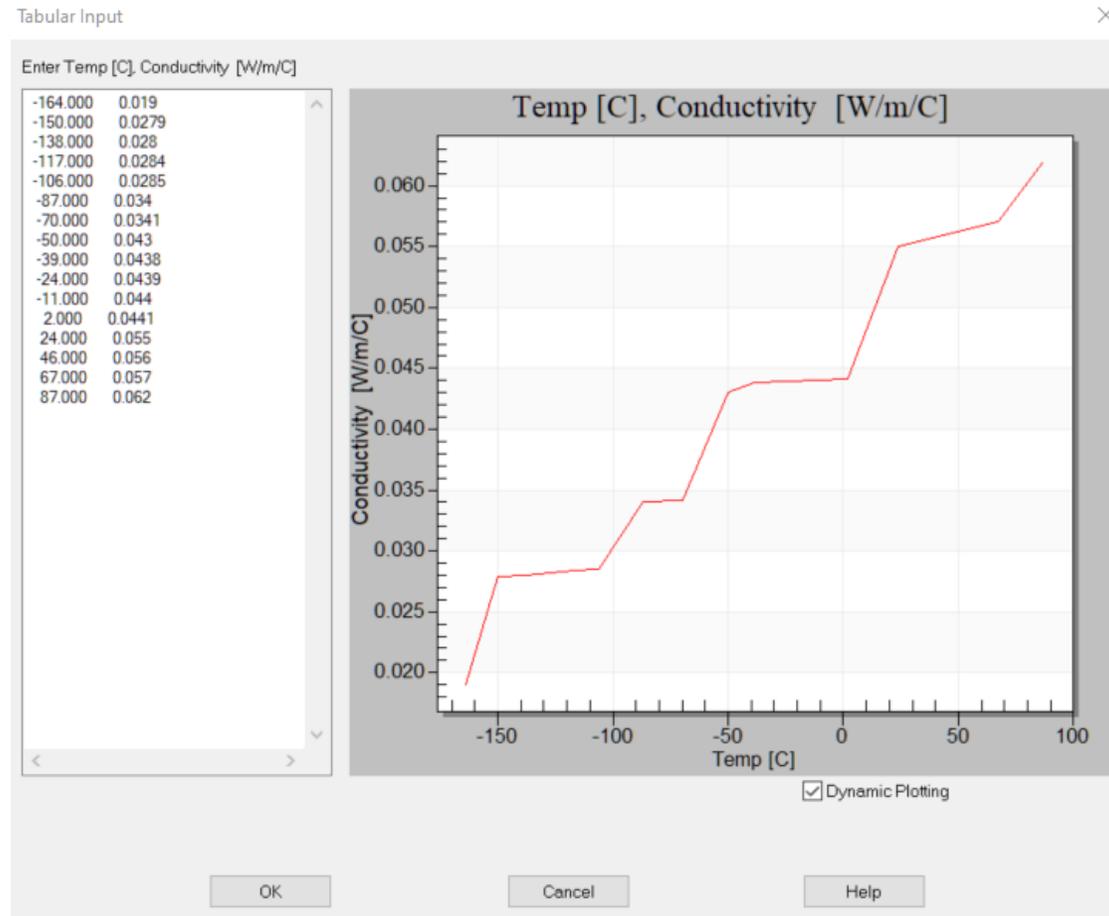
- Surface heat load over thin shell
  - Represents 6" x 6" heater plate
- Heater Plate
  - Set to Aluminum 6061 thermophysical properties
  - Set thickness 1/16"





# Model Assumptions

- Conductor
  - Air to external foam surfaces conductor assumes  $h = 35 \text{ W/m}^2\text{K}$
- Contactor
  - Foam to Plate contactor assumes an air gap of Titan  $\text{N}_2 = 0.001$  inches
- Chamber air temperature
  - Average of chamber air TC over 30 minutes before end of case, approx.  $-180\text{C}$
- Model inputs
  - Heat load = power recorded from test
  - Convection coefficient
  - Chamber air



- Solimide 16 at 5 Watts

