Comparison tests of cellular glass insulation for the development of cryogenic insulation standards

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Inter-Laboratory Study (ILS) been initiated by NASA Kennedy Space Center and LeTourneau University.

- Standard reference data is needed for cryogenic insulation material
- Objective is to explore the suitability of new methodologies for producing standard data
  - Effective thermal conductivity, $k_e(T)$ *(W/m-K)*
    - *Overall thermal conductivity across the operating temperature range*.
  - Local Thermal Conductivity, $\lambda(T)$ (W/m-K)
    - Thermal conductivity as a function of temperature.
  - Heat flux, $q(T)$ *(W/m^2)*
    - *Typical heat flux for the insulation system over the operating temperature range.*

This study resulted from many interactions and collaborations.

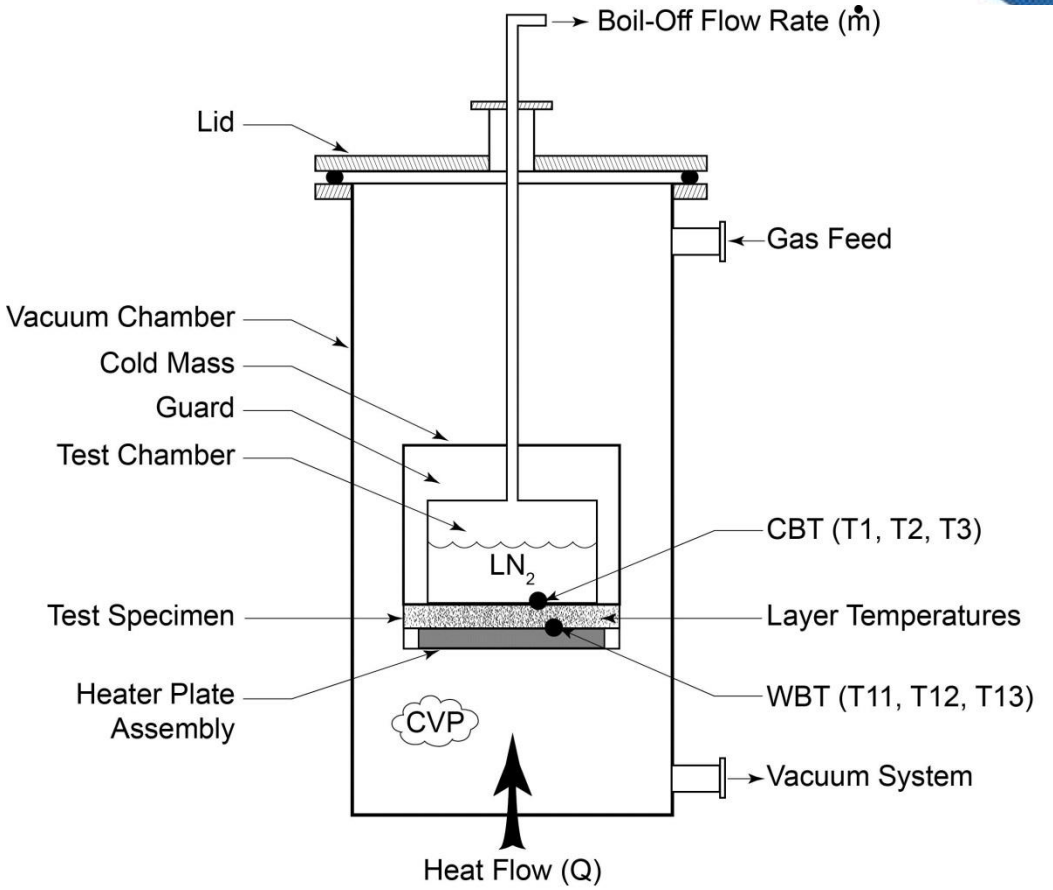
- ASTM (American Society for Testing and Materials) International Committee C16 on Thermal Insulation
  - New ASTM C1774 - Standard Guide for Thermal Performance Testing of Cryogenic Insulation Systems.
  - Revised ASTM C740 - Standard Guide for Evacuated Reflective Cryogenic Insulation.
- National Institute for Standards and Technology
- Industry Experts.

Program has practical objectives.

- Start developing standard data sets for use by engineers.
- Develop accepted baselines for the performance of novel materials and insulation systems under development.
- Provide technical insight on the heat transfer related properties through insulating materials.
  - Even homogeneous materials have temperature dependent properties
  - Insulation systems can involve complicated combinations of many materials
    - MLI alternating spacer and reflector layers
    - Many different modes of heat transfer.

ILS primary focus is on flat plate geometry using boil-off calorimetry

- Cryostat-400 apparatus was chosen:
  - Simple
  - Spare unit was available
  - Well suited for rigid, flat disk samples at ambient pressure



Principle of operation is well understood.

- Temperatures measured across the sample.
  - Or through the sample for temperature variations *of* k_e
- Heat load determined from boil-off

$$Q = V_{STP}\rho_{STP}h_{fg}\left(\frac{\rho_f}{\rho_{fg}}\right).$$

- Effective thermal conductivity calculated from measurements

$$k_e = \frac{Q\Delta X_{total}}{A\left(T_{warm} - T_{cold}\right)} = \frac{4Q\Delta X_{total}}{\pi d_e^2\left(T_{warm} - T_{cold}\right)}.$$

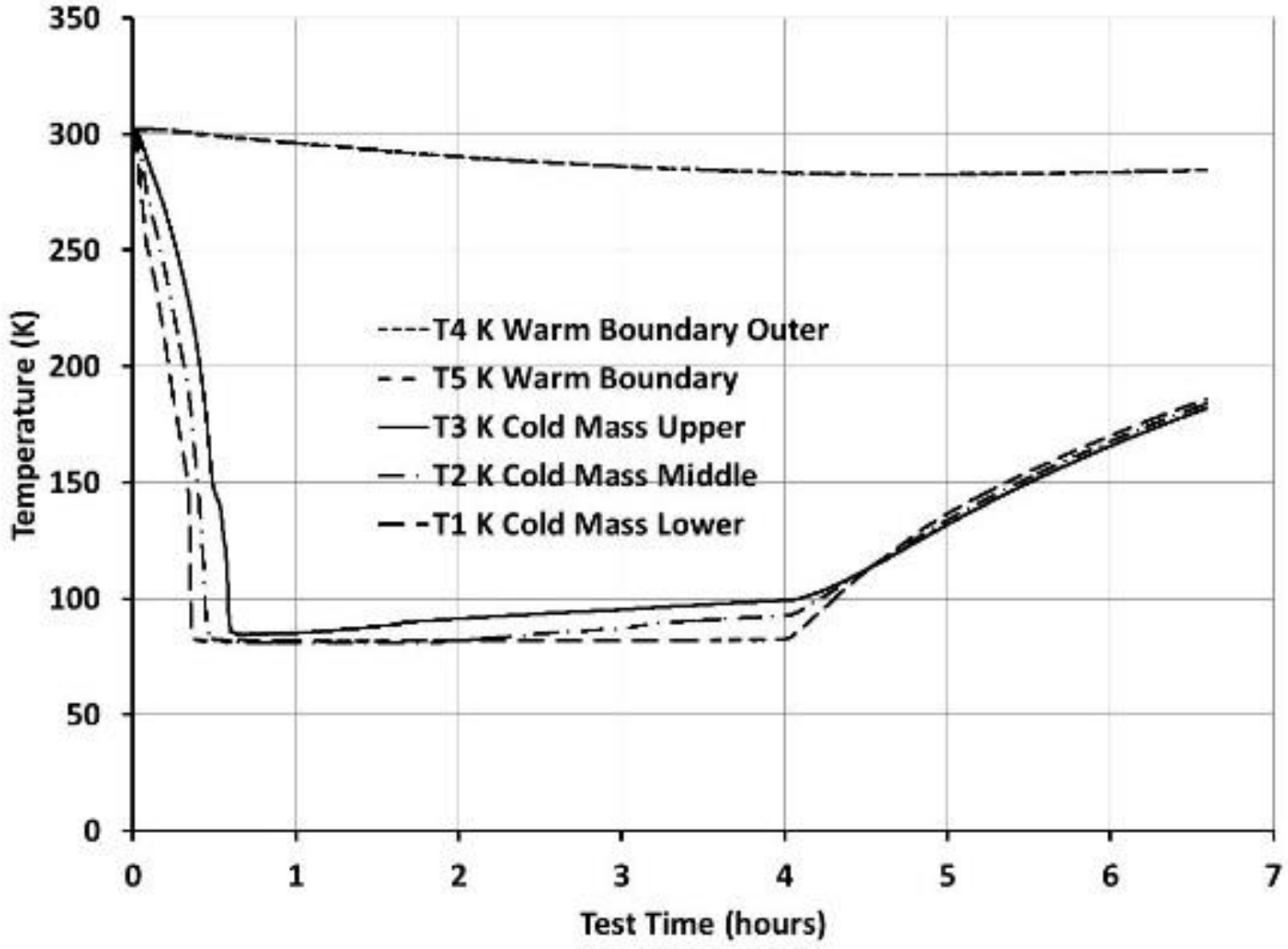
Symbol	Description	Unit
V_{STP}	Volumetric Flow Rate (at STP)	m^3/s
ρ	Density of Gaseous Nitrogen	kg/m^3
h_{fg}	Heat of Vaporization	J/g
x	Thickness of insulation system	m
d_e	Diameter, effective heat transfer (flat plate)	m
A_e	Area, effective heat transfer area	m^2
ΔT	Temperature difference	K

Cryostat-400 in the lab at LeTourneau

Typical cellular glass foam disk test specimen

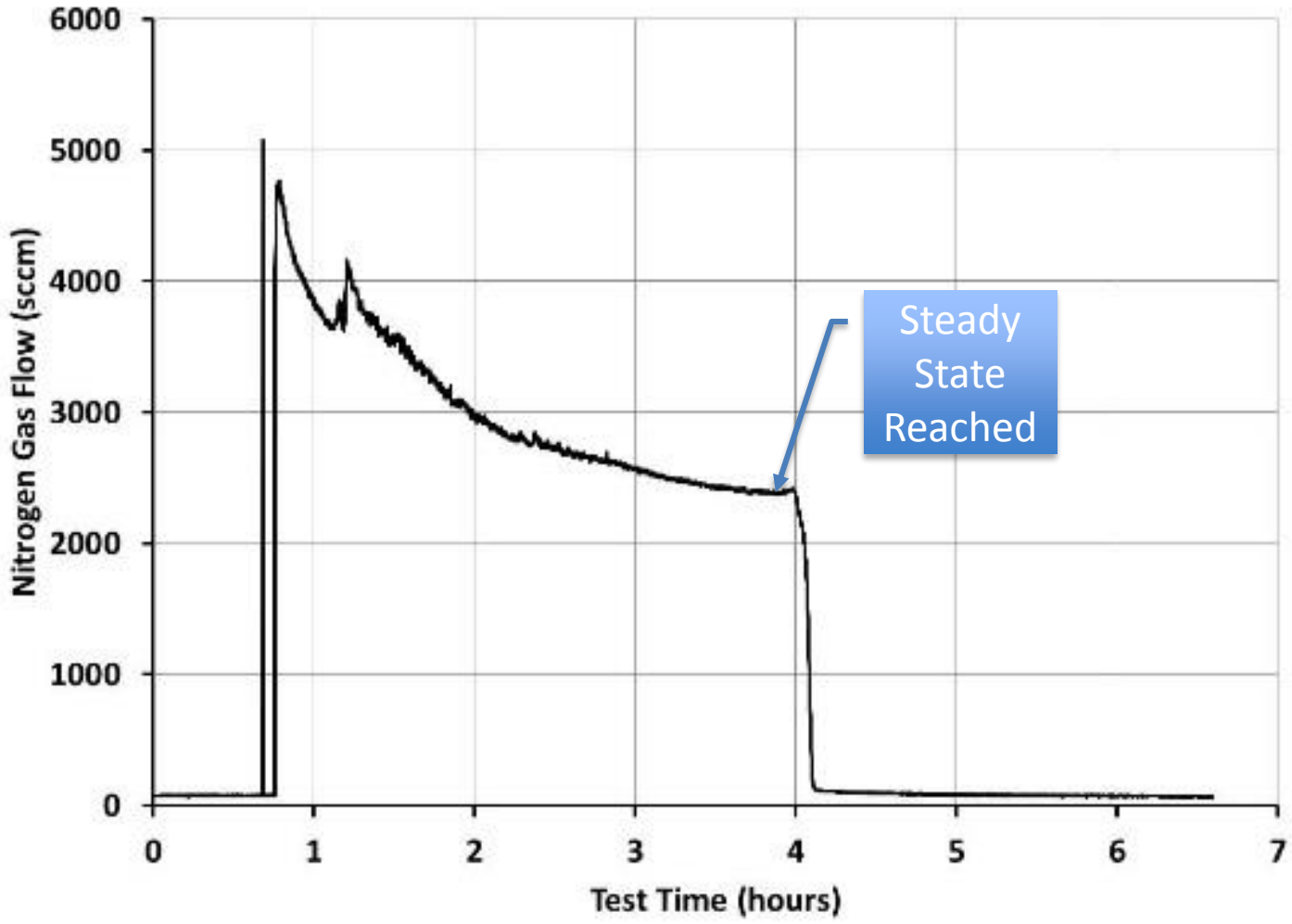
Typical temperature measurements from Cryostat-400

- Sample L101 cellular glass foam disk 8 Specimen #2 Test 2.



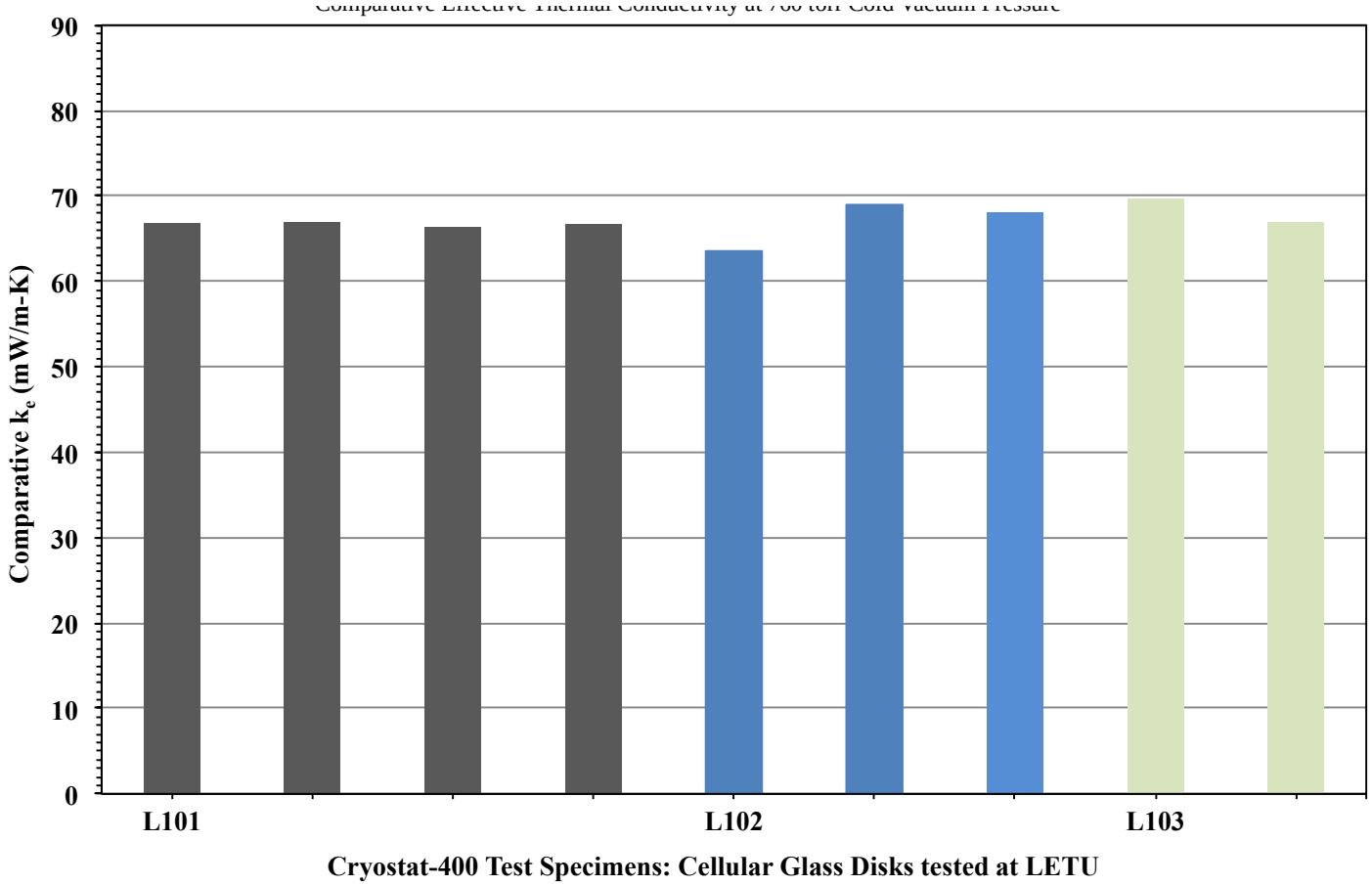
Boil-off flow measurements

- Sample L101 cellular glass foam disk 8 Specimen #2 Test 2 .



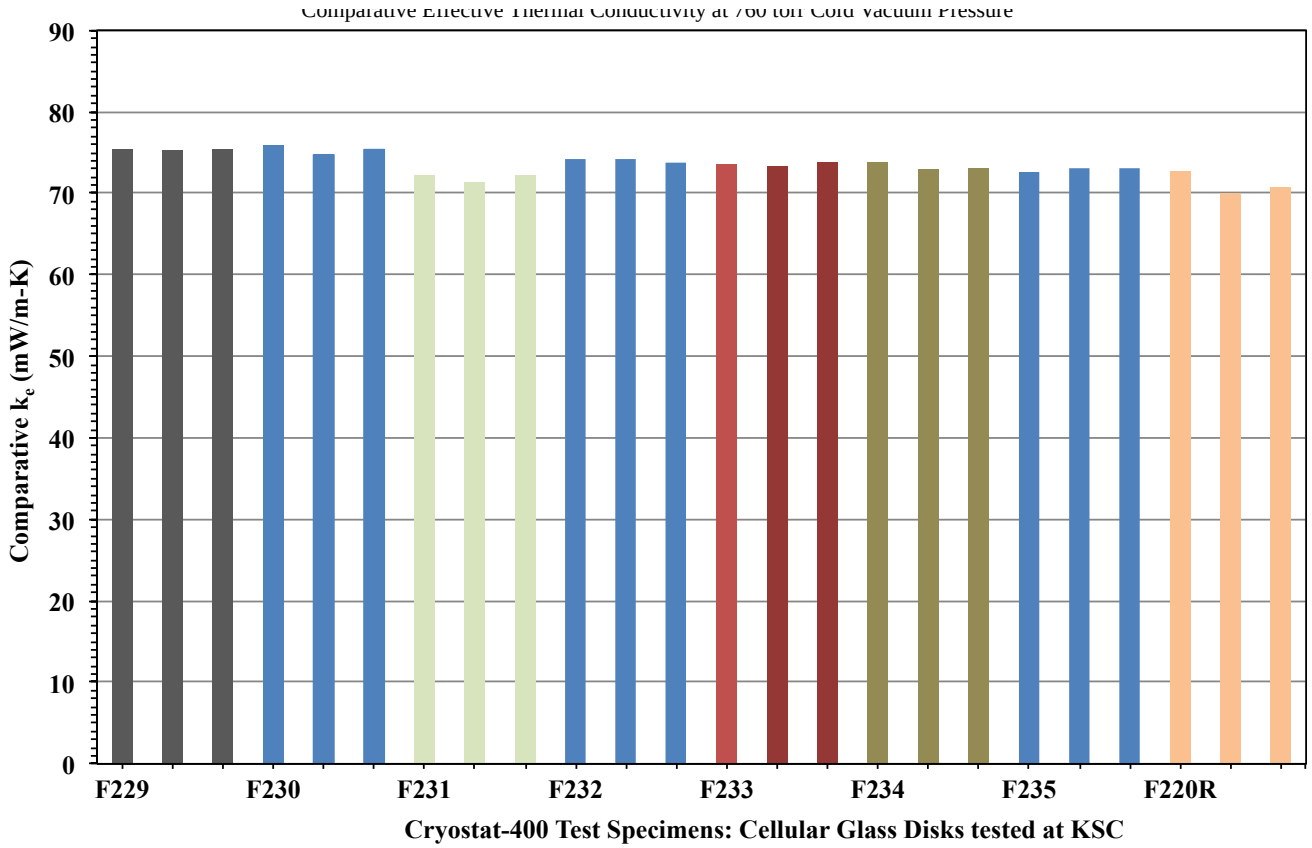
Cryostat-400 results for comparative k_e of cellular glass foam disks tested at LETU:

- Cold Boundary temperature 78 K
- Warm boundary temperature varied between 276 K and 290 K



Cryostat-400 results for comparative k_e of cellular glass foam disks tested at KSC:

- residual gas nitrogen
- boundary temperatures approximately 78 K and 293 K



Summary of results from the two laboratories

LETU Summary

- Total of 9 runs
- Avg. k_e = 67.1 $mWm^{-1}K^{-1}$
- Variation ~2.6 %
- Offset 6.3 $mWm^{-1}K^{-1}$
- Most likely due to different WBT

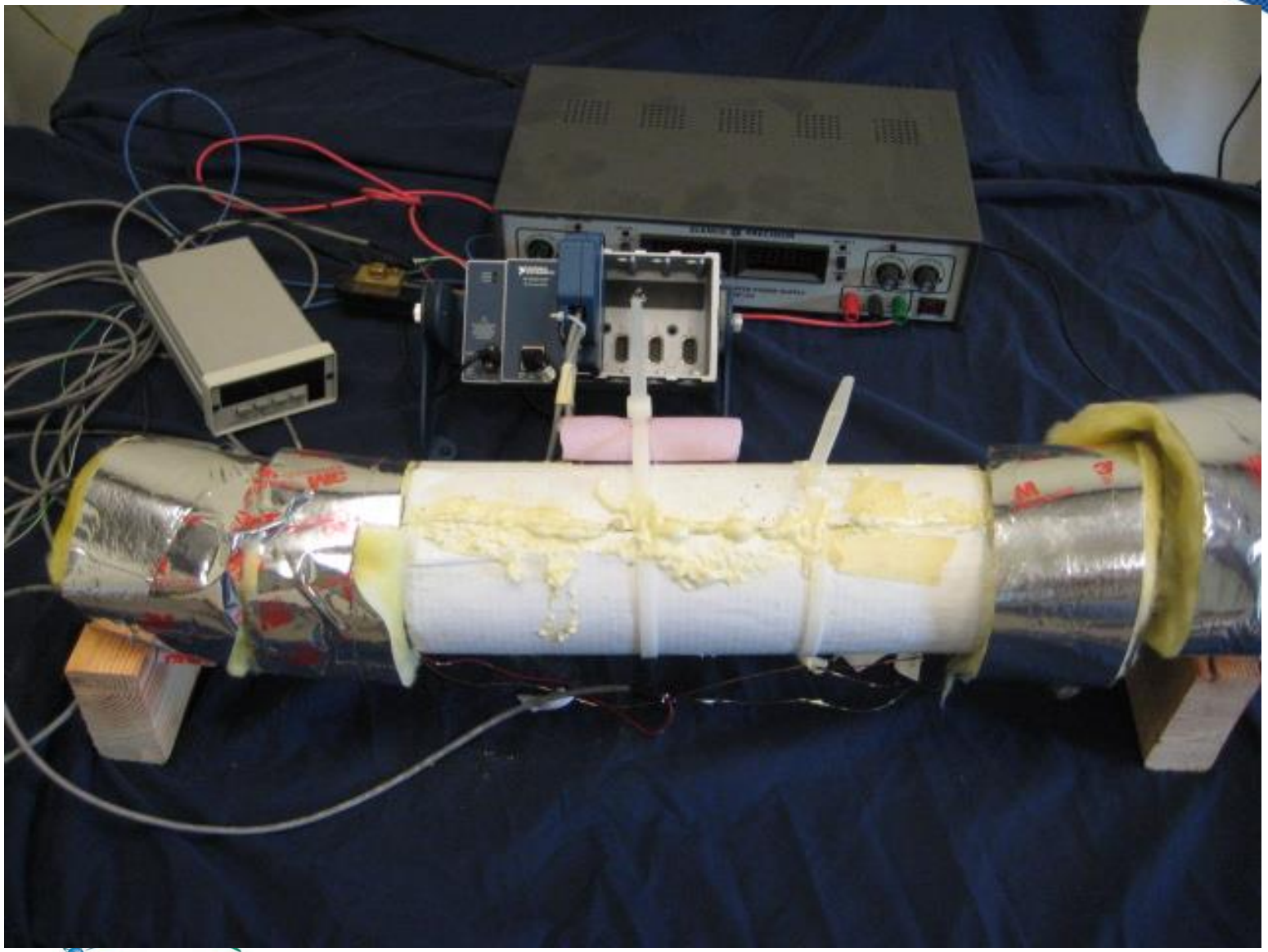
NASA CTL Summary

- Total of 24 runs
- Avg. k_e = 73.4 $mWm^{-1}K^{-1}$
- Variation ~2%

Alternate test method development: Cylindrical (Pipe) Insulation tester

- *Alternate geometry provides flexibility*
  - *Not all materials available flat.*
  - *Can wrap blankets, tapes, and other types of insulation*
- *Cylindrical geometry is non-linear temperature variation in radial direction (i.e. $ln(R_o/R_i)$)*
- *Concept suitable for immersion of the tester in an isothermal bath*
  - *Room temperature (present results ~300 K)*
  - *Ice bath (273 K)*
  - *Liquid Nitrogen (80 K)*
  - *Measure variation with temperature.*
- *Concept was based on previous initial work*

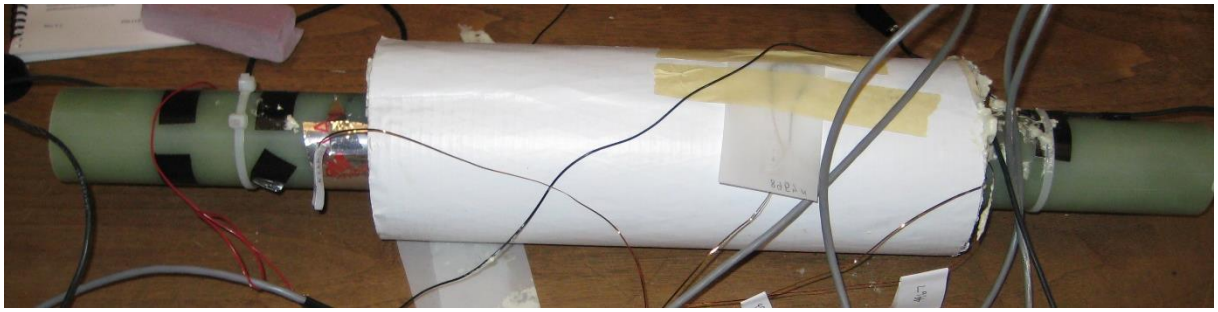
Pipe tester system components



CryogenicsTestLab
KENNEDY SPACE CENTER

Construction and operation of pipe tester

- G-10 rod core
- Nichrome heater wire
- Thermal conducting layer over the heater (Al foil)
- Insulation to be tested



$$k_{measured} = \frac{Q \ln(D_{outer}/D_{inner})}{2\pi L(T_{outer} - T_{inner})}$$

- Known geometry (Length, ID, OD)
- Measure heater power (DC current and voltage)
- Measure temperatures (outer and inner at 3 locations on heated surface)

Commercial pipe insulation (Foamglas) chosen for initial measurements

6/7/2015 FOAMGLAS Pipe Insulation,2 In. ID,2 ft. L,Black - Pipe Insulation - 19NG30|557523 - Grainger Industrial Supply

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Pipe Insulation, 2 In. ID, 2 ft. L, Black

FOAMGLAS

Price $17.37 / each

Deliver one time only

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1 Add to Cart

+ Add to List

Availability for Qty 1 Go

Shipping Pickup

Ships from supplier. Expected to arrive on or before **Fri. Jun 19.**

Ship to: 75601 (Change)

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For Iron Pipe Size	1-1/2"
Temp. Range	-450 Degrees to 900 Degrees F
Approx. "R" Value	3.45
Color	Black
Standards	ASTM E84, E96,E136 Non Combustible,C692,C240, Corrosion Resistant

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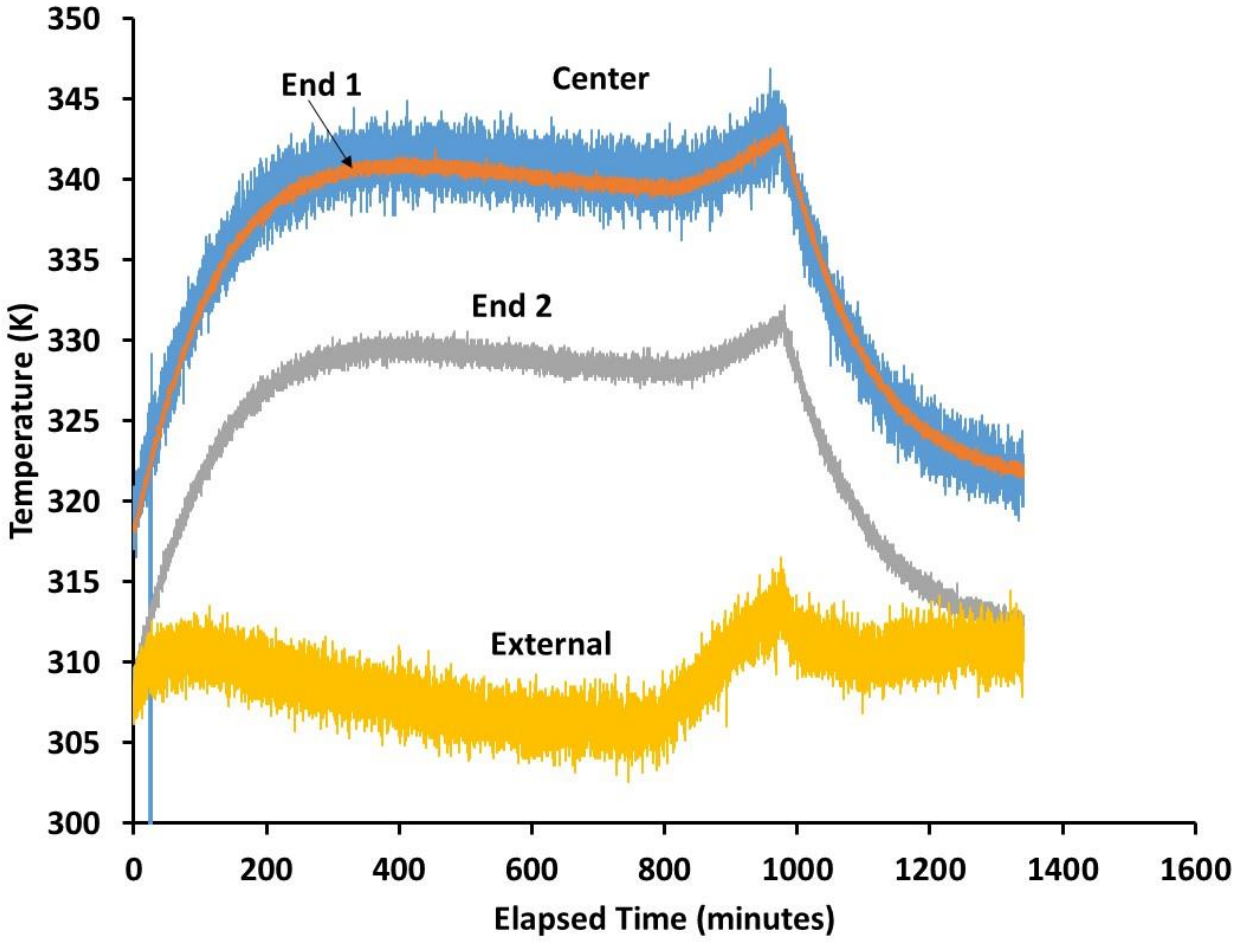
Pittsburgh Corning

Protecting Companies and Their People Worldwide

Thermal Conductivity	W/mK 0.040 @ 10°C 0.042 @ 24°C	Btu-in/hr.ft^2.°F 0.28 @ 50°F 0.29 @ 75°F
Specific Heat	0.84 kJ/kg.K	0.18 Btu/lb.°F
Thermal Diffusivity	4.2 x 10^{-7} m^2/sec	0.016 ft^2/hr

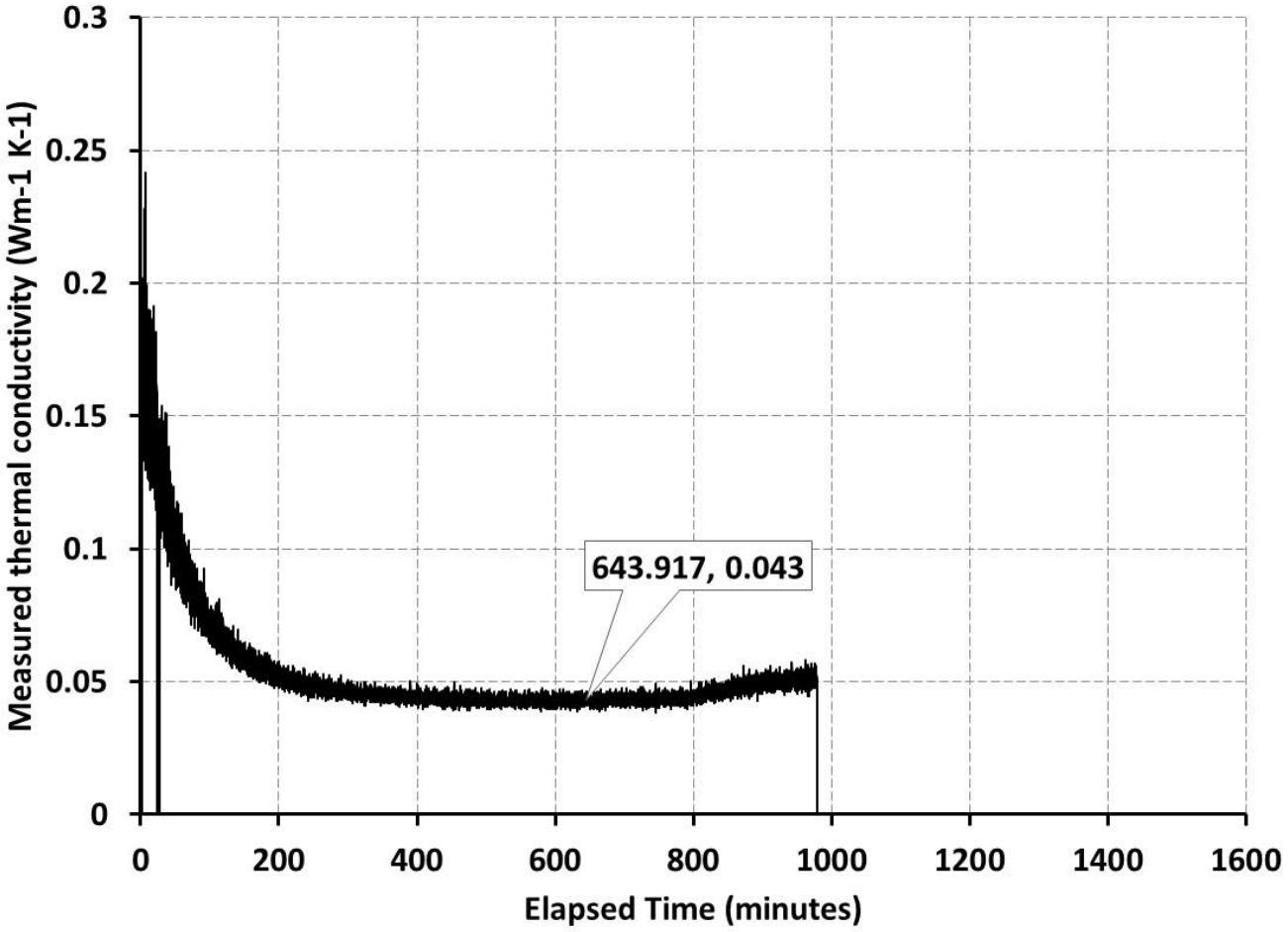
Temperature measurement for pipe geometry test.

- One end temperature not consistent.



Instantaneous thermal conductivity during a measurement.

- Commercial Foamglas sample result



Conclusions and Future Plans

- A preliminary Inter-Laboratory Study of foam insulation materials has initiated by NASA Kennedy Space Center and LeTourneau University.
- The initial focus is ambient pressure cryogenic Boil-off testing using the Cryostat-400 flat-plate instrument.
- Comparison of LETU and KSC/CTL data on cellular glass disk samples have been conducted.
  - Generally in agreement
  - LETU is slightly lower than KSC

- Other materials can be tested.

Conclusions and Future Plans

- Pipe test apparatus designed at LETU for cylindrical samples
- Initial testing on a similar material to ILS Foamglas
  - Measured k agrees with vendor data
  - Large uncertainty due to thermometer issue

- Future will investigate thermometer options

- Plan to develop thermal model
  - Help to assess accuracy and sensitivity to measurements
  - Provide understanding of temperature distribution.

- Need to encase the system so that the apparatus can be immersed as originally conceived.
  - So far only room temperature measurements conducted
  - Will enable other temperatures (Ice Bath 273 K, Liquid Nitrogen 80 K)

Acknowledgements

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