Repeatability of Cryogenic Multilayer Insulation

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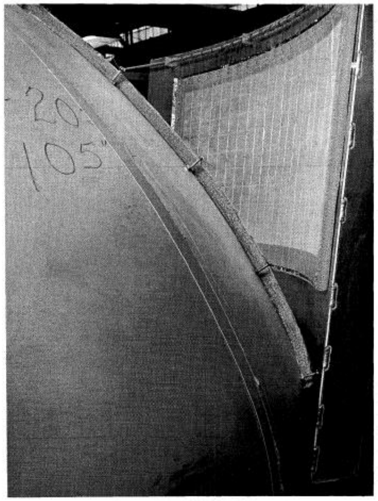
July 12, 2017

Cryogenic Engineering Conference

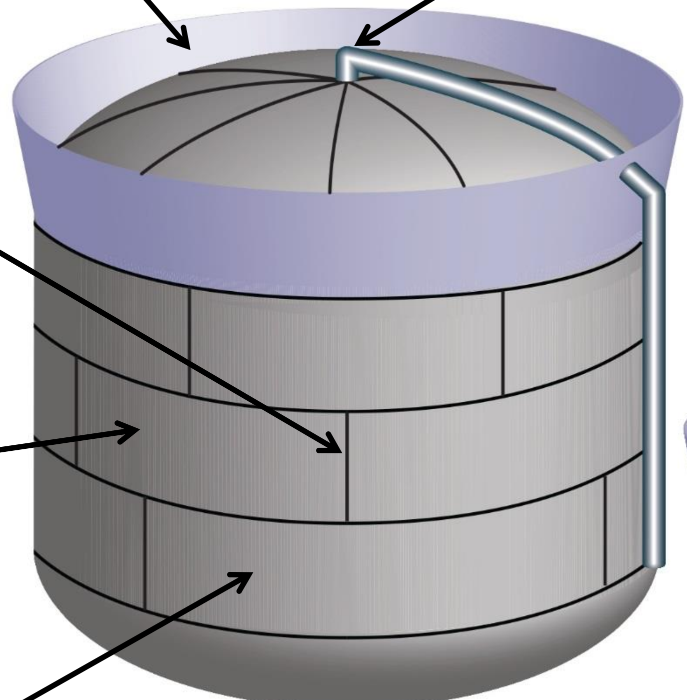
Improved Fundamental Understanding of Super Insulation (IFUSI)



Skirt Integration

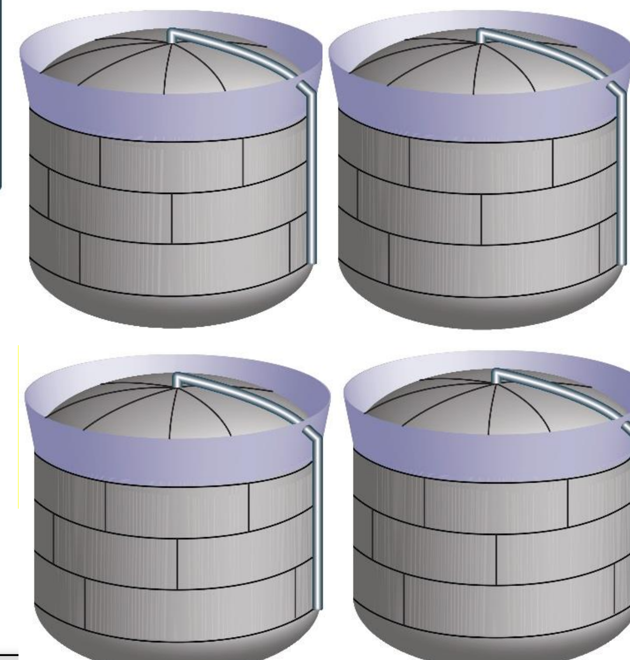
Penetration Integration:
- NASA-TP-2012-216315

Seams



MLI Blankets
- Traditional
- SS-MLI
- Hybrid

Repeatability



Tape, Pins & Attachments

Multilayer Insulation Repeatability Experiment

The objective is to quantify variation in thermal performance due to the blanket fabrication process and due to standard blanket installation processes on a well-controlled system and to determine if there is a difference in this repeatability due to the value of the warm boundary temperature. For implementation this is broken out into two objectives

- **Measure the thermal performance repeatability of multiple identical MLI blankets on the same calorimeter under the same conditions with a cold boundary temperature of 20 K or 77 K and a "high" warm boundary conditions (~300 K).**
- **Measure the thermal performance repeatability of the same MLI system installed and reinstalled on a calorimeter multiple times.**

Phases of MIRE

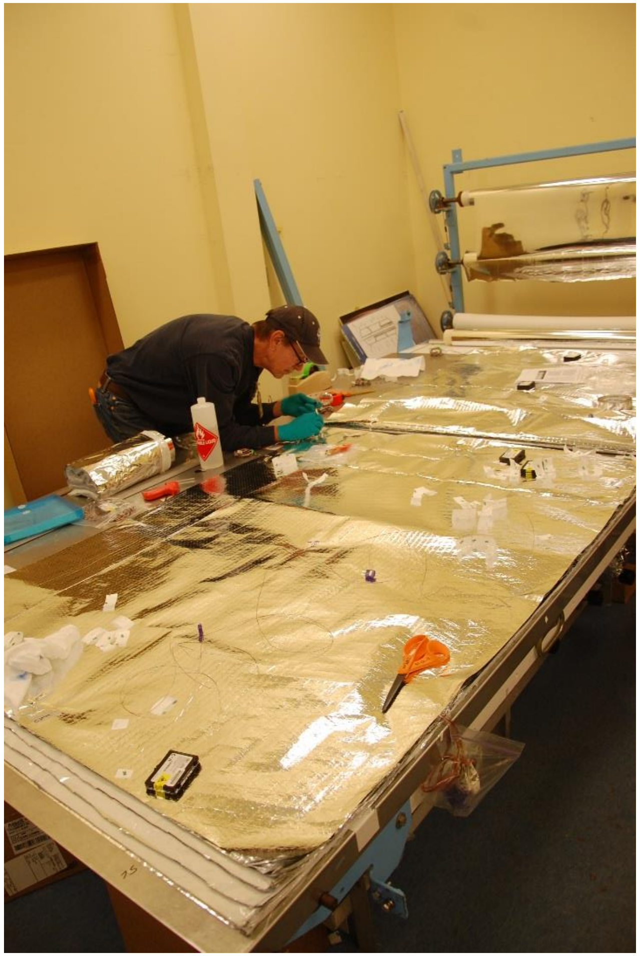
Two phases of MIRE:

- Phase 1: Directed work via Grant to Florida State University (FSU)
  - GRC provided test coupons (5)
    - 25 reflective layers
  - Two Temperature Ranges:
    - 20 K and 300 K (first series - completed)
    - 20 K and 100 K (second series – not completed)
  - Two types of repeatability
    - Between coupons
    - With same coupon
- Phase 2: Competed testing (awarded to Yetispace, completed)
  - Fabrication of 10 coupons
    - 10 reflective layers
    - 2 Thermocouples within each blanket
  - Temperature boundaries: 77 K to 300 K
  - Calorimeter selected by proposer (Yetispace working with FSU)
  - Testing each blanket once

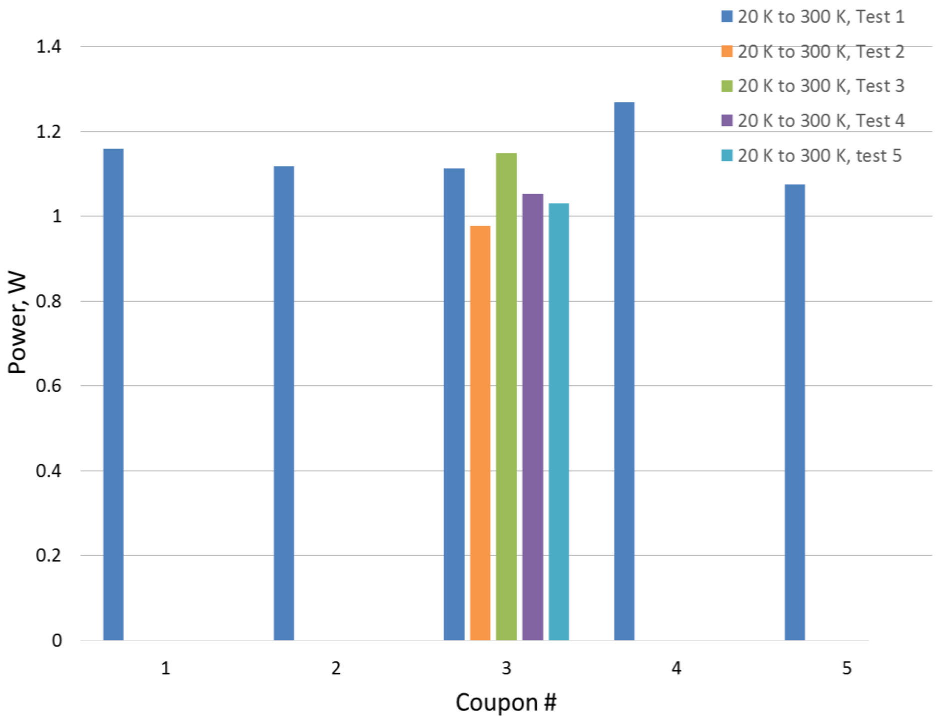
Coupons to FSU for Phase 1

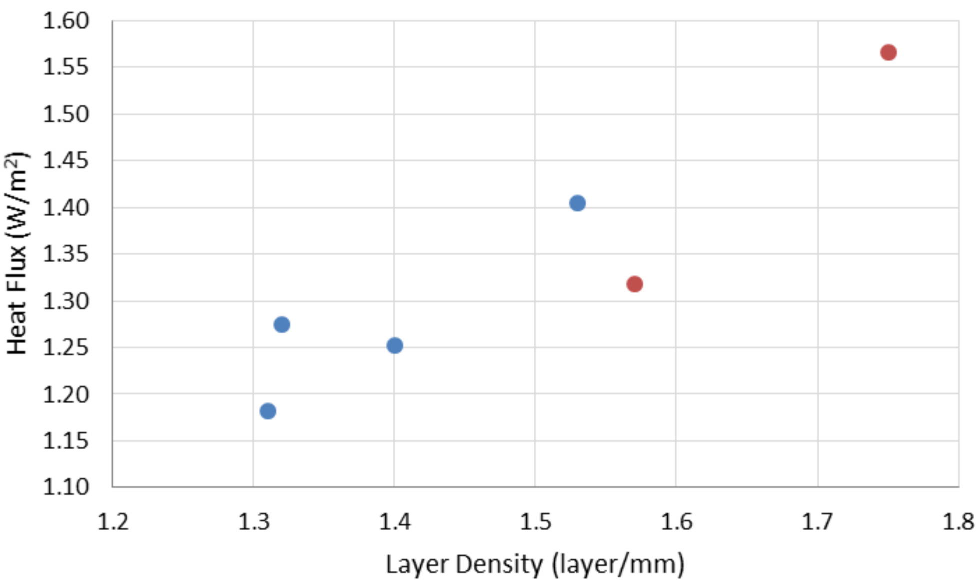
Cut out of previously procured MLI blankets for Multilayer Insulation Mitigation Experiment (MIME)

- Six coupons fabricated in 2010 by Sierra Lobo
  - 25 layers
  - Designed for SMiRF LH2 calorimeter
  - 60” wide, 96” long
- MIME stopped when CPST started and the old SMiRF liquid hydrogen calorimeter had too many problems to fix
- MLI blankets were stored in “bonded” storage since then
  - All coupons have since been used by IFUSI in one way or another
  - Added cover sheets to ease in handling
  - Added tapered ends for tighter radius
  - Left instrumentation in blankets (preventing damage from removal)

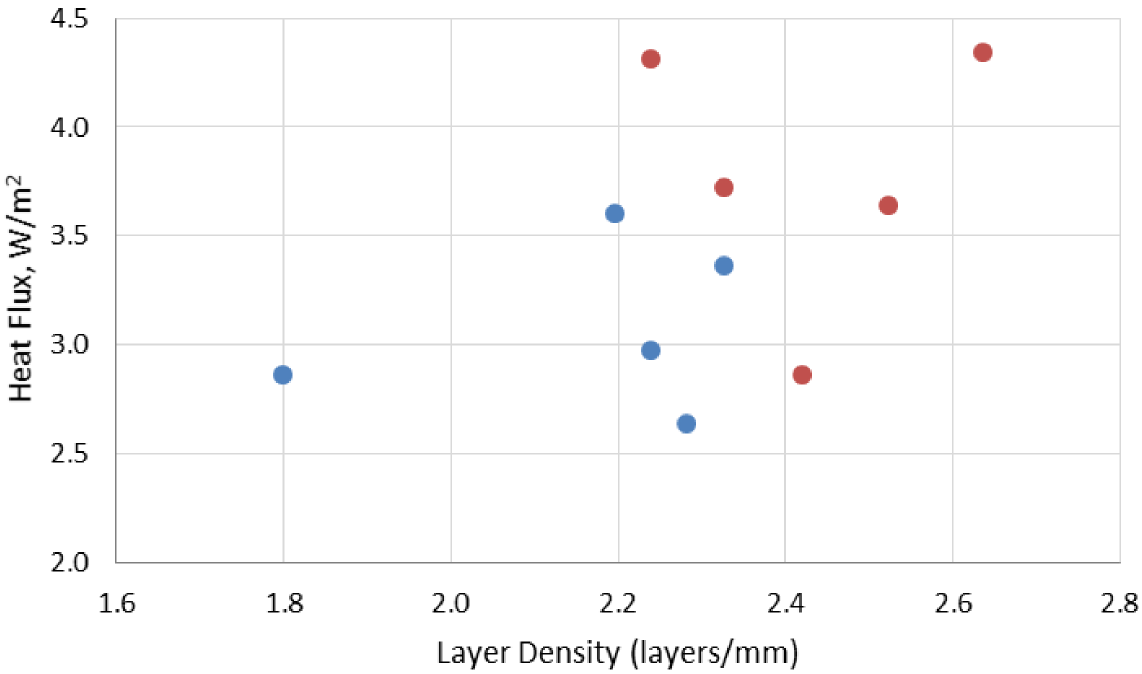


Results – Phase 1





Results – Phase 2



ASTM E 2586

- For samples sizes less than 12, the standard deviation can be estimated by the range divide by a constant, d_2 (provided in the standard, for n = 5, d_2 = 2.326)
  - Adjusted standard deviation: 0.083 W
- Z-score: how many standard deviations the individual tests are from the mean

$$Z_i = \frac{(Q_i - \bar{Q})}{s}$$

300 K to 20 K testing	MLI 1	MLI 2	MLI 3	MLI 4	MLI 5
	1.159	1.118	1.113	1.268	1.075
Z-score	0.15	-0.34	-0.40	1.46	-0.86
Z-score (trad s)	0.19	-0.43	-0.51	1.83	-1.08

- Estimated Standard Errors
  - Mean:
    - Note: 0.017 W is 1.5% of the average

$$se(\bar{Q}) = \frac{s}{\sqrt{n}} = 0.017$$

  - Standard Deviation:
    - C_4(n=5) = 0.939986
    - 0.083 – 0.066 = 0.017 < 0.028

$$se(s(Q)) = s\sqrt{1 - c_4^2} = 0.028$$

- Suggests data is statistically significant

Results

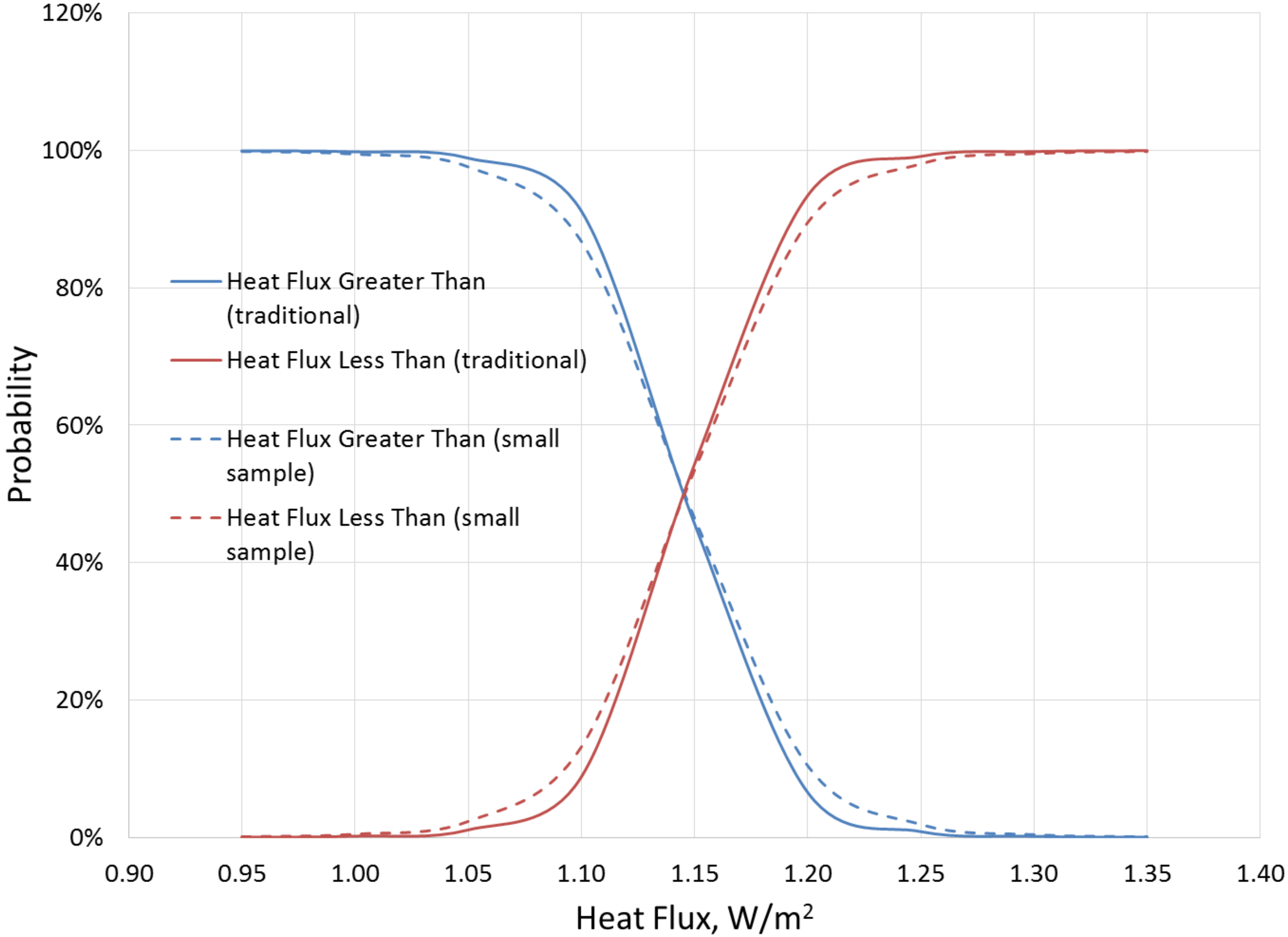
Test Series	Mean, W	Min, W	Max, W	St. Dev, W	Range, W	Uncertainty
20 K to 300 K, All Five	1.15	1.08	1.27	0.066	0.19	+/-8.4%
20 K to 300 K, Coupon 3	1.06	0.98	1.15	0.061	0.17	+/-8.0%
77K to 293K, First Five	2.40	2.05	2.80	0.27	0.75	+/- 15.6%
77 K to 293 K, Second Five	2.90	2.20	3.35	0.41	1.15	+/- 19.8%
77 K to 293 K, All ten	2.65	2.05	3.35	0.43	1.30	+/- 24.5%

Statistical Results

Test Series	Mean Standard Error, W	Mean SE as Percent of Mean	Calculated St. Dev, W	St. Dev Standard Error, W	St. Dev Calc – Meas, W	St. Error Greater?
20 K to 300 K, All Five	0.017	1.2%	0.083	0.023	0.017	YES
20 K to 300 K, Coupon 3	0.015	1.1%	0.074	0.021	0.013	YES
77K to 293K, First Five	0.064	2.7%	0.322	0.092	0.053	YES
77 K to 293 K, Second Five	0.099	3.4%	0.494	0.140	0.085	YES
77 K to 293 K, All ten	0.042	1.6%	0.422	0.099	-0.006	YES

All Data Sets are Statistically Significant!

Probabilities of Next Coupon



Equations (from Microsoft Excel)

- **Top curve**

=T.DIST((Q$_{avg}$ – Q)/(St.Dev/√j),j,TRUE)

- **Bottom curve**

=T.DIST.RT((Q$_{avg}$ – Q)/(St.Dev/√j),j)

$$t = \frac{(\dot{Q}_{avg} - \dot{Q})}{s/\sqrt{j}}$$

j = number of samples (5)

Repeatability Summary

- **25 layer systems repeatability around +/- 8%**
  - Phase 1A showed repeatability of +/- 8.4 %
  - Phase 1B showed repeatability of +/- 8.0%
  - Five coupons between 300 K and 20 K
  - Statistics line up with standard errors associated with small sample sizes, suggests that data is meaningful
  - Indicates that ir-repeatability mostly due to installation (layer density)
- **10 layer systems repeatability +/- 15 – 25%**
  - Similar layer density trend (though not nearly as distinct)
  - Installation technician played a role too
- **Indicates repeatability a function of number of layers**