DEVEL0PMENTS OF ADVANCED & ENERGY SAVING THERMAL ISOLATIONS FOR CRYOGENIC APPLICATIONS

Quan-Sheng Shu, Retired Senior Scientist
Jonathan Demko, LeTourneau University
James Fesmire, NASA Kennedy Space Center

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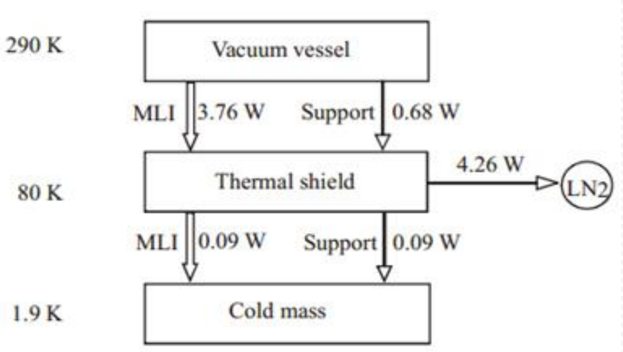
Contents (with Introduction & Conclusion)

Thermal Isolation – Crucial to All Cryogenic Applications

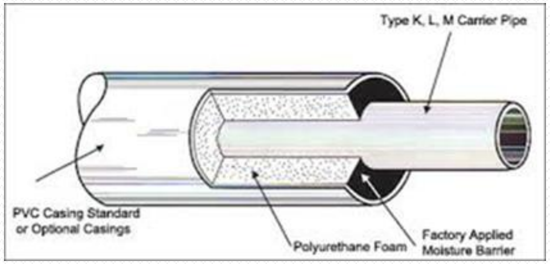
- Refrigerator cools cold mass – Thermal isolation minimizes heat leaks into cold mass
- Huge cooling power consumption needed: e.g. LHC, 27 kilometer, multi-hundred tons of Liquid He
- Extremely long cryogen holding time in Space, years
- Advanced and Energy saving Thermal Isolation is Crucial to keep cold mass at the operational Temperature
- Low conductive **support** **-** Equally important to thermal **insulation**
- Novel **heat switches** – alternation
- High vacuum is basic (Not discussed here)

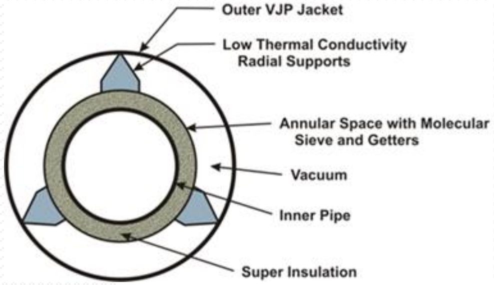


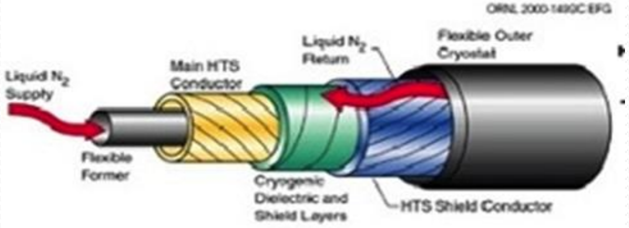
Thermal Isolation for LN2, LH2 Transfer Lines

- **Foamed Pipe**
  - Foam materials
  - Foaming methods: Tiles, spray, in situ foamed
- **Aerogel-based: twice better**
- **Vacuum Jacketed**

  about 40 times better
  - Vacuum- convection
  - Low conduction support: G-10 etc.
  - less cross section and small contact areas
- **+ MLI – reduce radiation**
  - 2-3 order better, also for LH2
- **High Tc SC Cable**
- **Special Transfer Line**







Thermal Isolation for LHe Transfer Lines

- **Latent heat-20.6J/g at 4.2K**

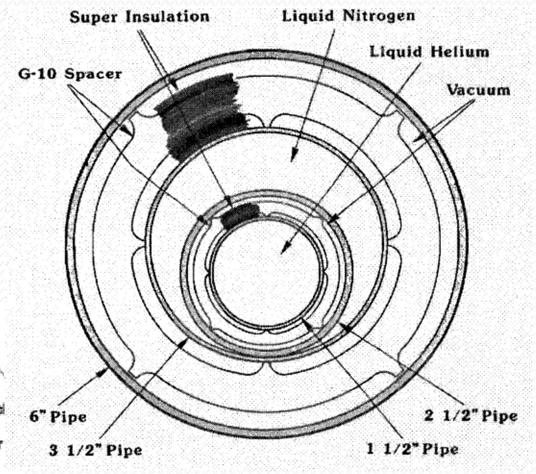
  Various high efficient LHe transfer lines: designed, tested, utilized. 27km in LHC etc.
- **Annual screens**

  Multi temperature screens intercept heat load at high T levels
- **Unique design: spacers**

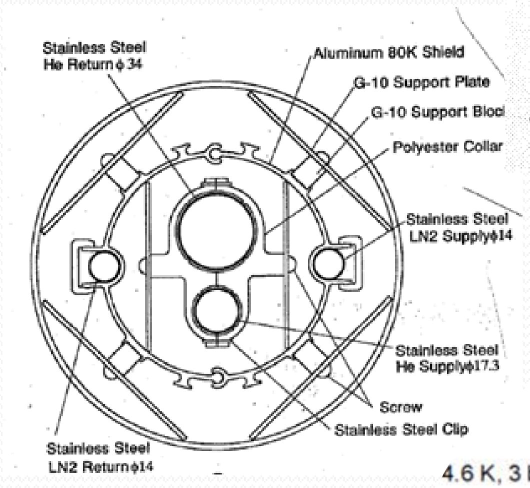
  Low conduction materials, less cross section and small contacts
- **Combine multi-transfer lines in one vacuum pipe**

  Cost, save space, construction, operation
- **Optimize the MLI layers**

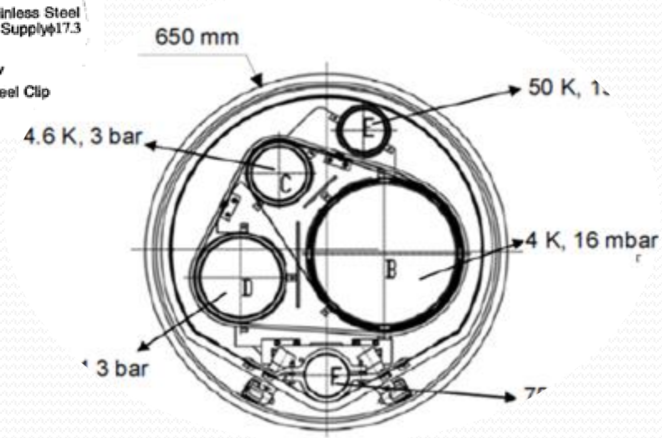
  ~77K: 30-40 layers, ~10K: 10-20 layers



Fermilab double line , ~6.5km

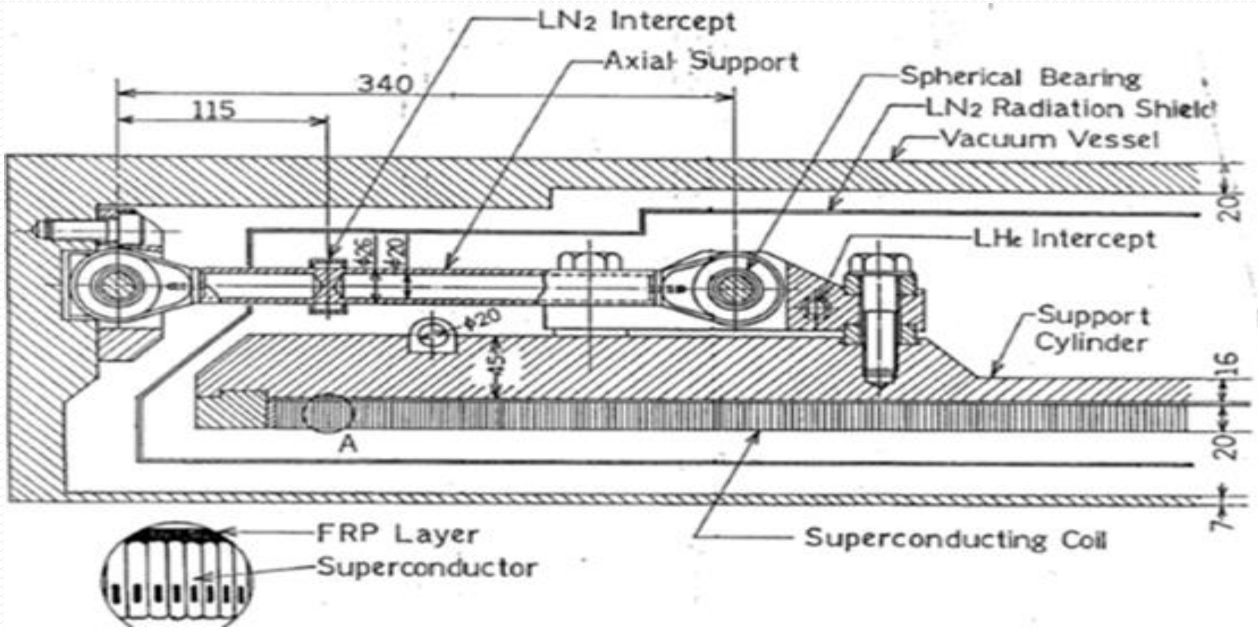


KEK Multi-lines 150 mm



CERN LHC, 650 mm

Support System for Thin Solenoid Magnets with Very Large Toroid Warm Bore



- Cold mass must be supported in a Stable and Stiff fashion
- Magnet: OD 3.3m, ID 2.8m, L 5m
- Field 1.5T, Cold mass 5.5 ton, Total weight 13 ton,
- Axial H force 100 ton on SC coil
- 0.25W per axial support, 0.3W radial
- 6 axial members all on one end, Inconel 718 OD 26mm ID 20mm
- 12 Inconel rods on each end
- Thermally intercepted at 77K and 4.4K: heat flux and hot spots
- Spherical bearing on both ends
- LN2 cooled shields

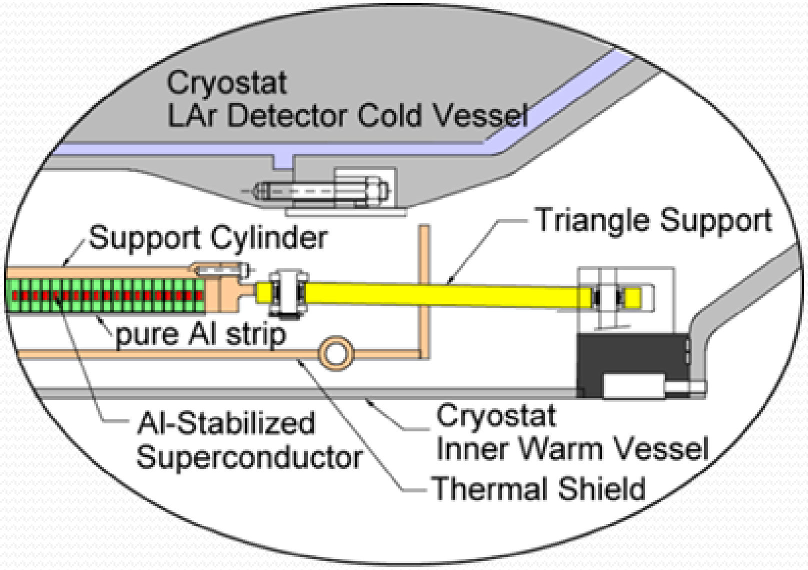
Support System for Thin Solenoid Magnets with Very Large Toroid Warm Bore

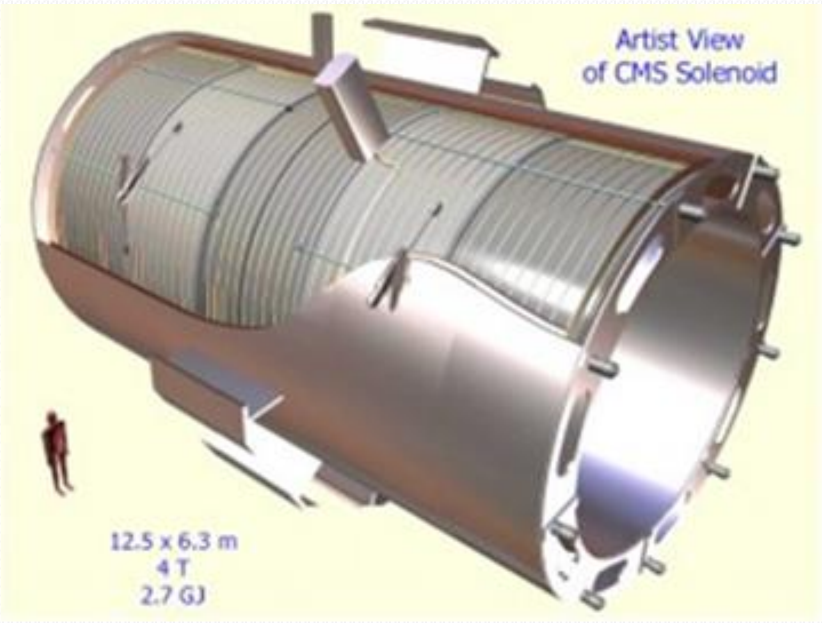
CERN ATLAS Detector Magnet

- **2T axial magnet field**
- **ID 2.3m L 5.3m, coil 5.5 ton**

CERN CMS Detector Magnet

- **4T axial magnet field**
- **ID 6 m, L 12.5 m, coil 5.5 ton**



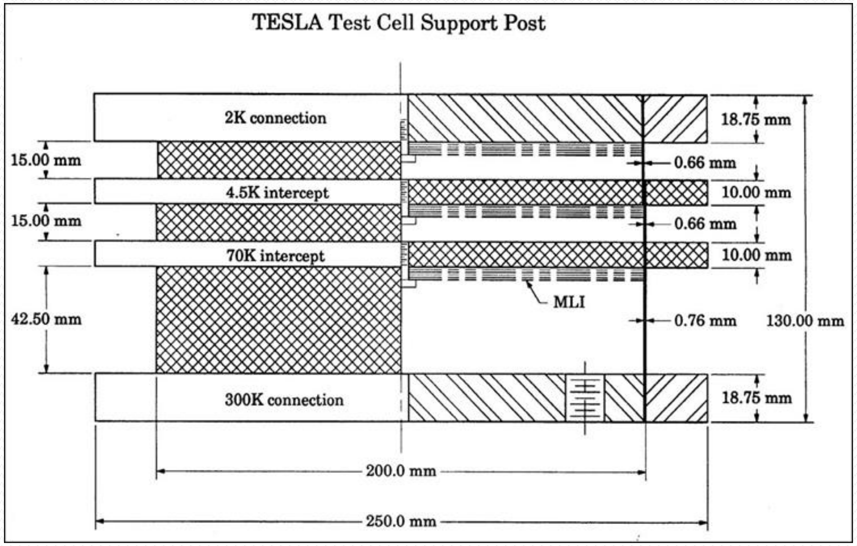


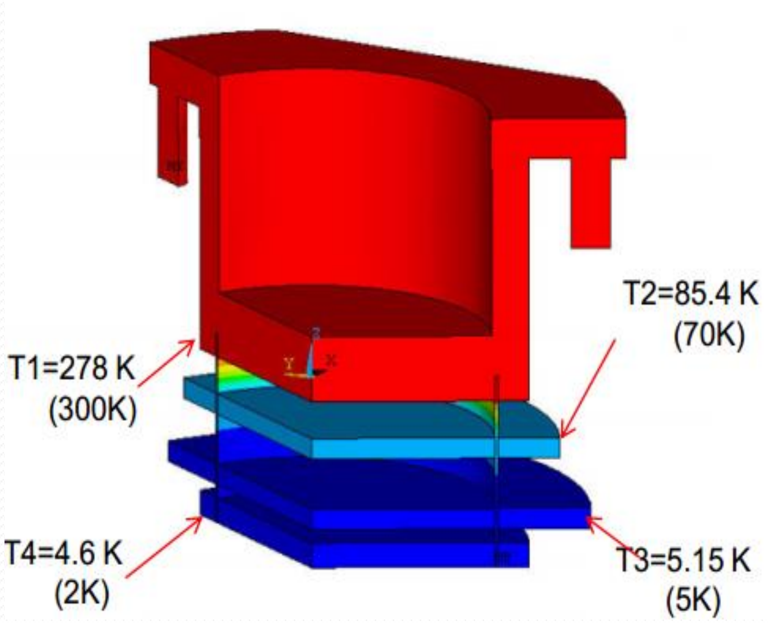
Support Post for Long Cylindrical Heavy Weight Cold Mass

International Collaboration
HERA, SSC, LHC, ILC (TESLA):

- Post Type Supports between 300K and 2K have been successfully developed and utilized.
- Minimize heat leak, withstanding the axial and radial loads.

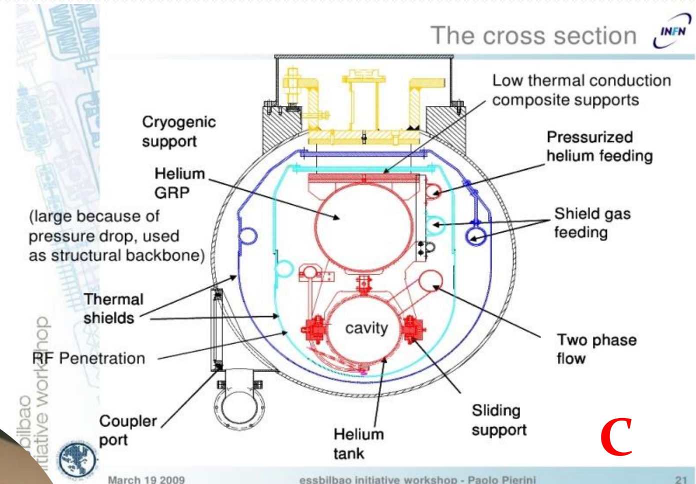
- Top and bottom stainless steel flanges, post column of fiber/epoxy
- Two heat intercept plate in aluminum alloy -shrink-fitted and glued to post at about 80K and 5K
- 80K to cold mass is 0.18W (0.09W by MLI and 0.09W by post support



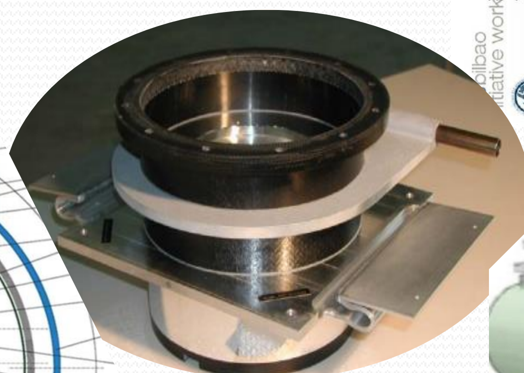


Support Post for Long Cylindrical Heavy Weight Cold Mass

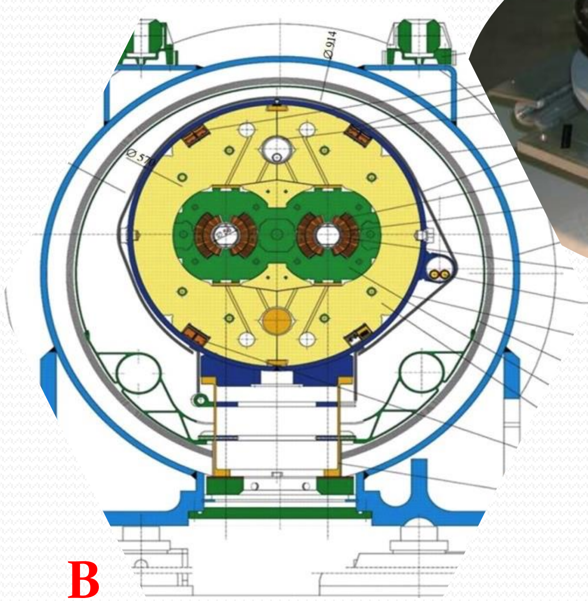
- A – LHC magnet post support
- B – LHC magnet on the post in the cryostat
- C – ILC/TSLA/XFEL cryostat
- D – ILC cavities upside down through Helium line hang to the post



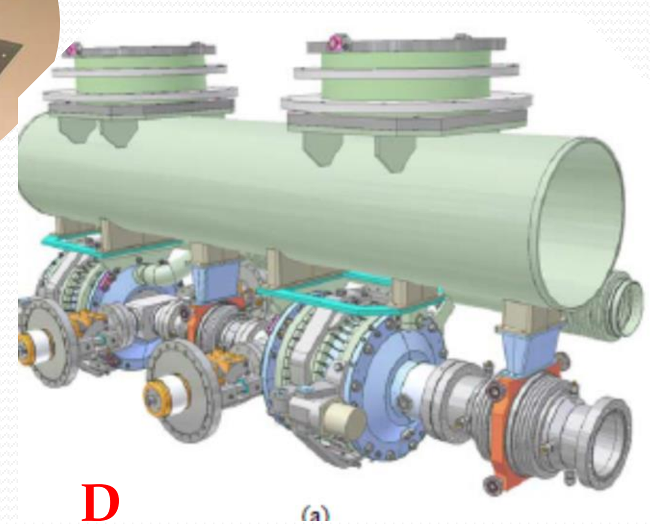
C



A



B

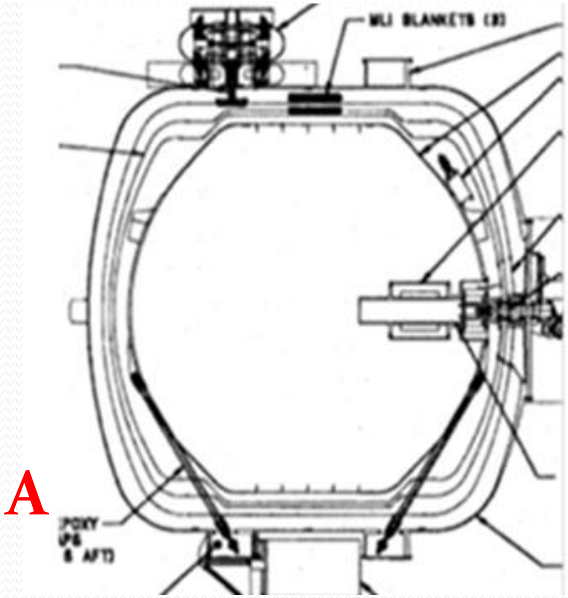


D

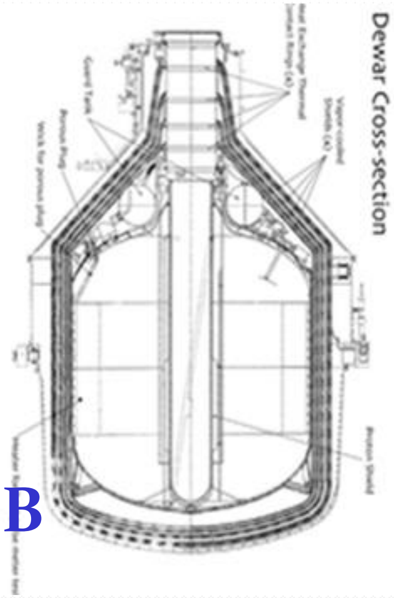
Other Advanced Support for Cryostats and Storage Tanks

A - XRS CSS: **below 1K** by a demagnetization, fiberglass/epoxy tension strap supports, **4-intermadiate temperature screens**

B & C - Experimental cryostats and storage Dewar: Inner vessel supported mainly by its neck. multi-conducting shields fixed to the neck, cooled by neck and/or by the cold vapor bypass tubes

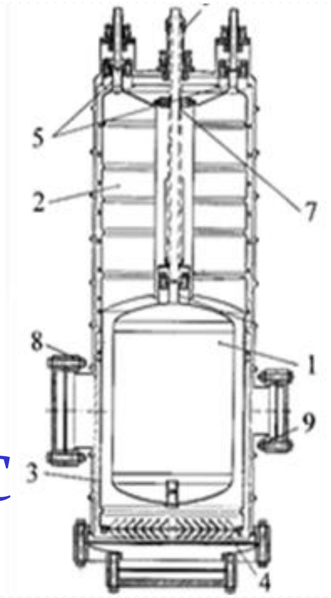


A



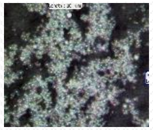
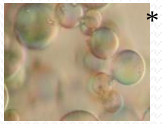
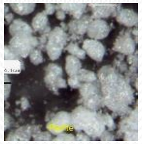
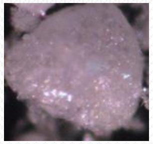
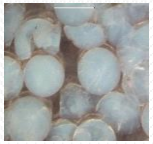
B

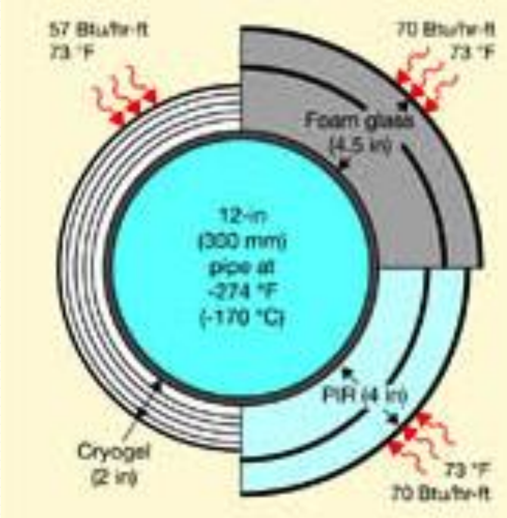
C



Foams, Glass Bubbles, and Aerogels

- **Sprayed foams and foamed still employed in storage tanks of LN2, LO2, LNG. For LH2 storage in special cases**
- **Glass bubbles - a cost efficient & high performance alternative in storage tank of any size developed by KSC CTL. Demonstrated in a 218,000L LH2 tank at Stennis Space Center, 50% less boiloff (losses)**
- **Investigation of the most comprehensive thermal insulation systems utilizing aerogel insulations has been performed by the KSC CTL.**
- **Microscope comparison of traditional perlite powder, glass bubbles and aerogel beads**
- **Aerogel has advantages: Reducing the thickness & performance is better than foams and perlites**
- **Aerogel blanket materials-commercially available**
- **Flexible aerogel - good candidate for**
  HTC SC cable (thermal + mechanical properties)

	10x	**100x**
Glass Bubbles ~65μm *zoom is 300x		 *
Perlite Powder ~600μm		
Aerogel Beads ~2000 μm		



General Optimization of MLI Performance

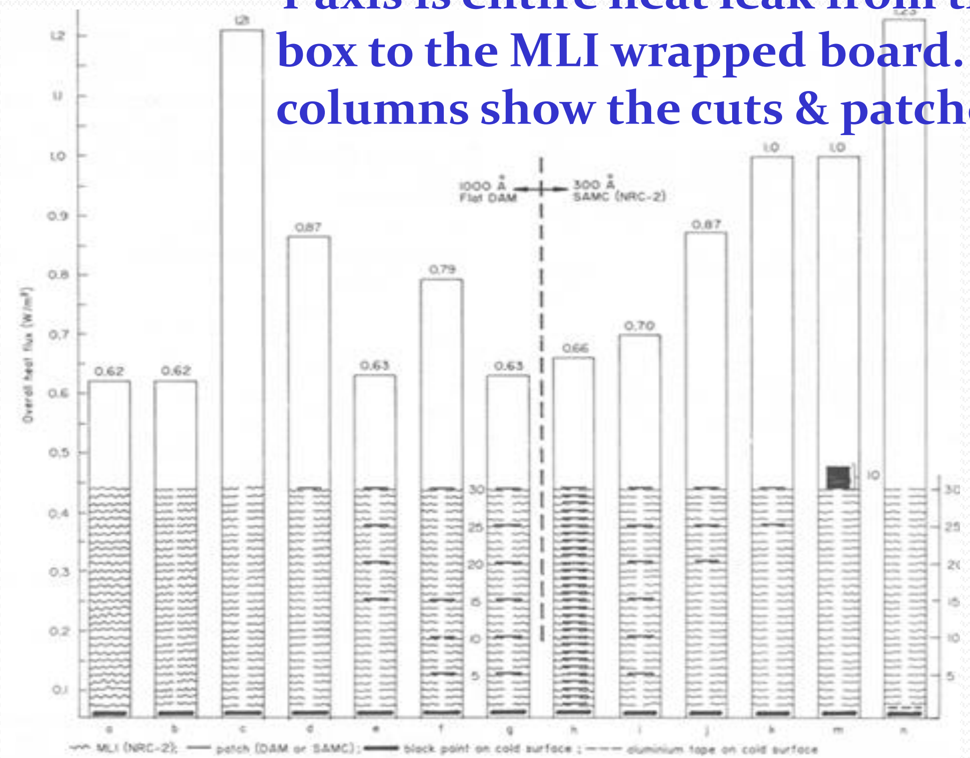
- Aluminum coated on double sides of the thin layer of Mylar or Kapton, Gold coatings in space applications
- Perforated Mylar or/and crinkled Mylar forms - achieve the best vacuum levels between layers
- Thin fiberglass layer between each Mylar - minimize contact thermal link, out gases. Self-pumping layer, not widely accepted
- Lightweight MLI to reduce self-compression
- Number of MLI layers - tradeoff among minimum heat leak, material cost, space availability
- 40-50 layers for LN2 level cold mass, and 60-80 for LHe level. For piping: 10-30 layers LN2; 30-40 LHe. (not include inter-T screens)
- Optimize the layer density to a giving particular structure has always been considered. Hence, add unnecessary number of MLI layers will be useless
- Intermediate T screens (shields) between several layer groups - Superior approaches to greatly reduce heat load to the cold mass
- A combination of aerogel blanket with MLI would sustain a certain degree of vacuum deterioration - demonstrated by KSC CTL

Thermal Degradation and Remedy of MLI with Penetrations

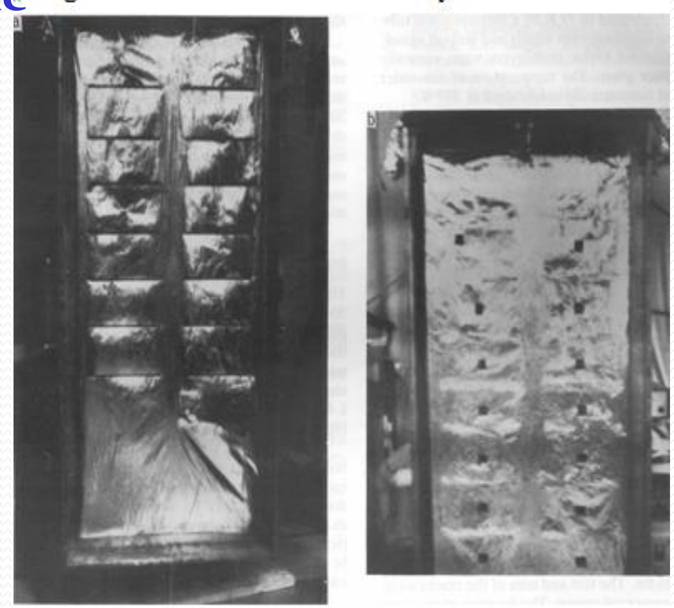
- Penetrations in real MLI systems inevitably occur: cold mass supports, power leads, RF power couplers, measuring instruments
- Around penetrations: gaps, cracks and overlaps in MLI system. Assembly joints and gaps between prewrapped MLI blankets
- Degradation of the thermal performance of MLI by cracks and slots much serious than thought
- Due to a 6 mm crack in a 90 layer MLI blanket, heat load was more than 200 times the value through a unit area without cracks
- A comprehensive studies to reduce the effects of cracks-gaps-holes in MLI by a Fermilab team. Heat load, T distributions & patches approaches to improve the thermal performance (compared with original MLI) have been tested
- Currently, a series of calorimeter testing coupled with thermal modeling by KSC CTL to further understand the complex heat transfer mechanism. Testing of various styles of integration of structures and fluid components into MLI blankets.

Thermal Degradation and Remedy of MLI with Penetrations

Y axis is entire heat leak from the box to the MLI wrapped board. The columns show the cuts & patches

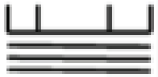
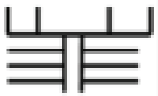
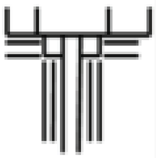
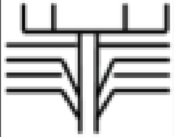


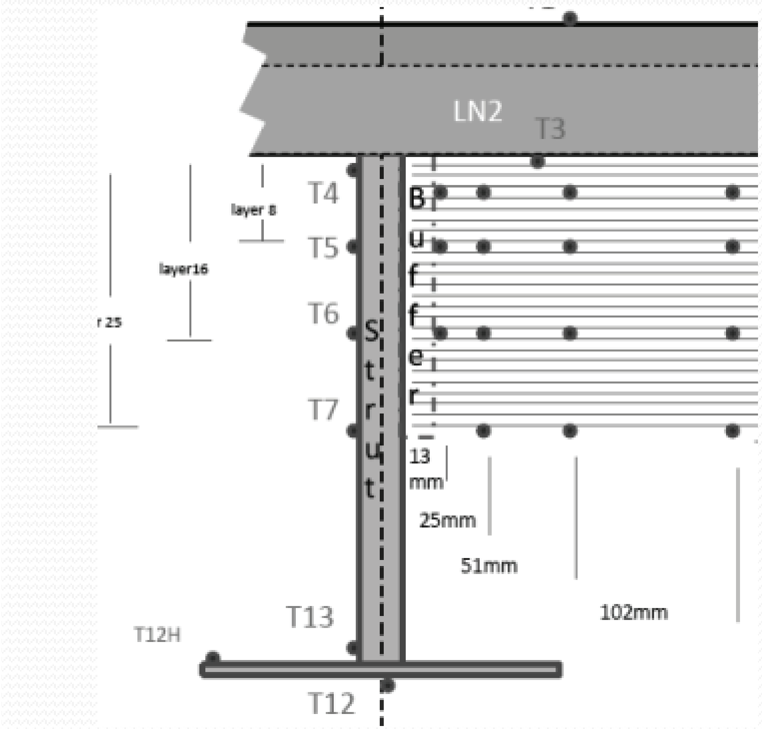
Graphic summary of heat flux results of patch study. a, No cracks; b, one-dimensional slits; c-m, runs 2 to 11; n, 0.09mm aluminum tape on cold surface, no patches (by Fermilab)



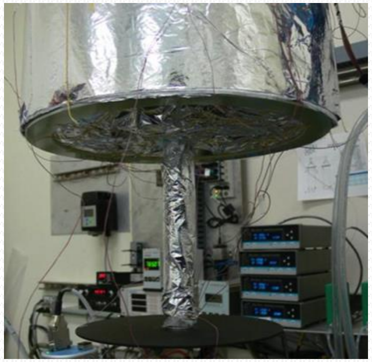
The central flat board cooled by LN2 or LHe in a box of 176x76 x15 (cm). The T-in, T-out is 4.2-77K or 77-300K. The assembly placed in a cylindrical cryostat. Boiling rate is measured.

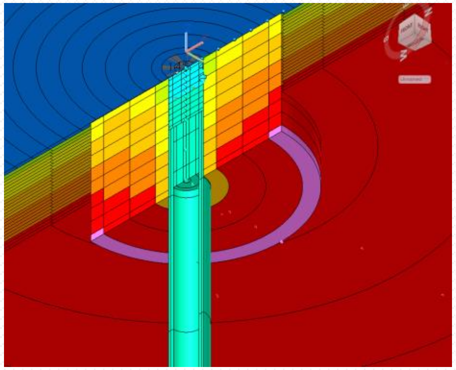
Thermal Degradation and Remedy of MLI with Penetrations

Test Description	Reason	Figure
No Penetration	Baseline	
No Integration a) Without gap b) With gap (a no buffer case)	Worst Case	
Isolated Penetration a) 1/2" Aerogel Blanket b) ½" Bead Pack c) 1" Aerogel Blanket d) ½" CryoLite e) 1" CryoLite	Isolate bulk insulation from penetration insulation	
Temperature Matched a) Lockheed b) Test #1	Best Case (assumes single warm temperature)	



To understand the complex heat transfer mechanism surrounding penetrations, a series of calorimeter testing coupled with thermal modeling by KSC CTL. Temp sensor location with struts and key test results of MLI penetrations study.





Novel Heat Switch of Managing Heat Load to Cold Mass

Many developments of novel heat switches, which can alternatively provide high thermal connection or full thermal isolation of the cold mass

- Magnetic levitation suspension post and bearing
- Shape memory alloys switches
- Quad-Redundant thermal switches
- Differential thermal expansion thermal switches
- He and gap-gap heat switches
- H2 and gap-gap heat switches
- Superconducting-normal switches
- Piezoelectric heat switches
- Cryogenic diode heat switches
- Mechanical demountable connections

CONCLUSION

- Various insulation materials, sophisticated cold mass supports, novel heat switches and high thermal efficient cryostats make it possible for both large scale SC projects and extremely long lifetime space instruments.
- Since thermal performance of thermal isolation are sensitive to the configurations/operational conditions, continuing R&D is required, as new challenging projects emerge from the horizon.
- The successful achievements based on the previous and existing investigations will present a strong guidance to the further efforts.