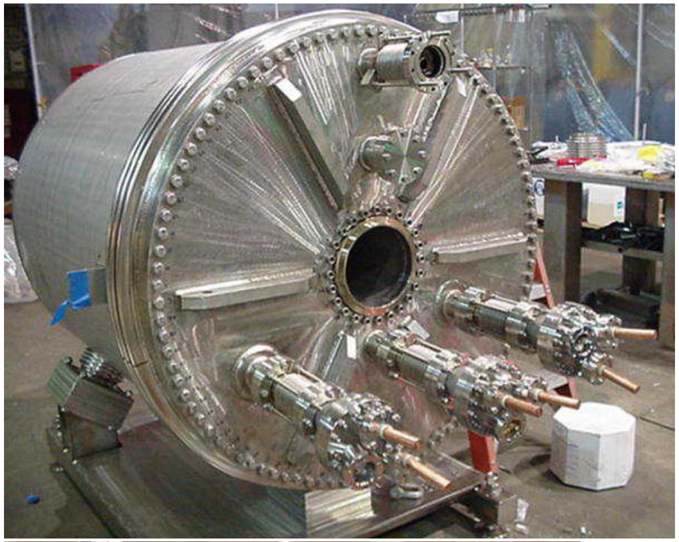
MERIT 15-T Pulsed Solenoid Magnet



K.T. McDonald
Princeton U.

MERIT Safety Review

CERN, 30 March 2007

CERN/MERIT Web Page:

http://proj-hiptarget.web.cern.ch/proj-hiptarget/

Princeton/MERIT Web Page:

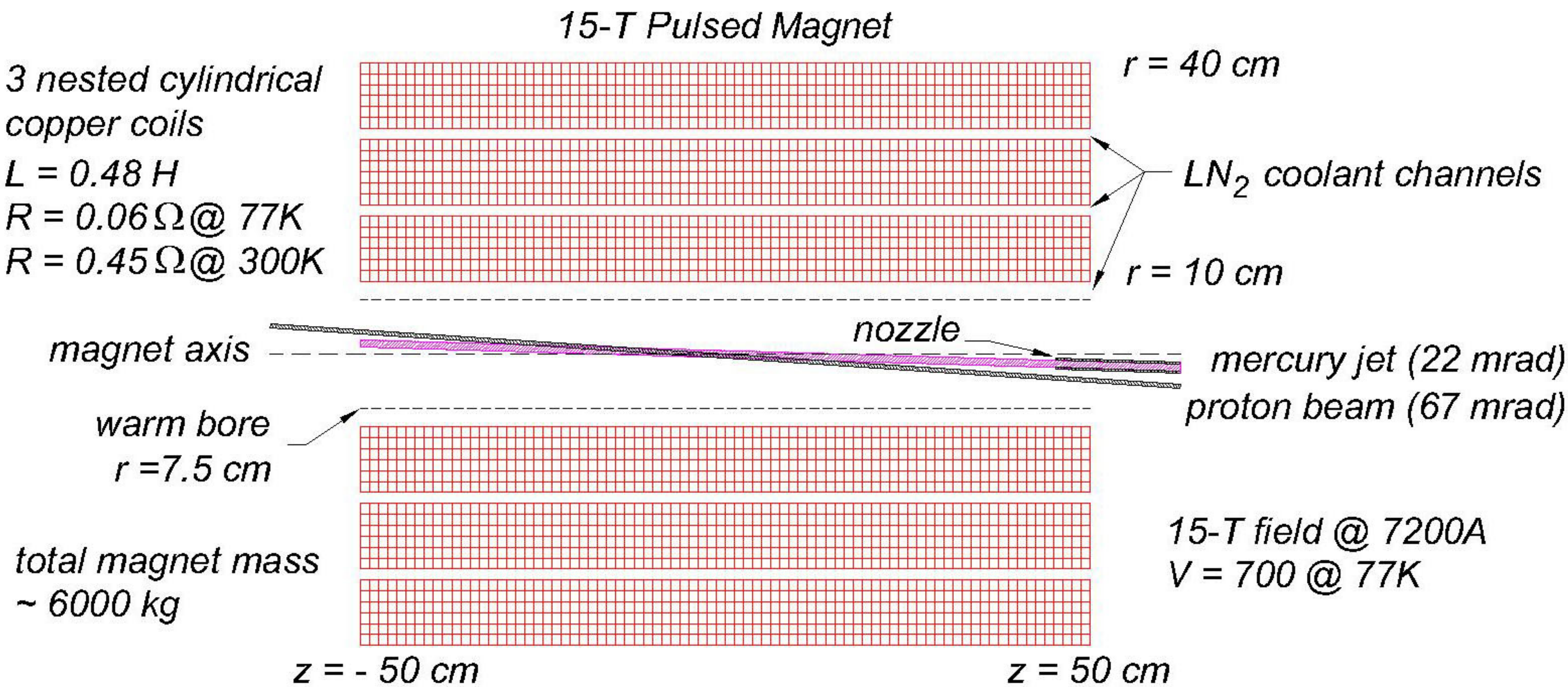
http://puhep1.princeton.edu/mumu/target/

MIT/MERIT Web Page:

http://psfcwww2.psfc.mit.edu/people/titus/#BNL%20Memos

Magnet Parameters

176-page Design Report: http://proj-hiptarget.web.cern.ch/proj-hiptarget/doc/MERITsolenoidDesignReport_May06.pdf



To produce 15-T field, need $I = 7200$ A.

When pre-cooled to 77k by LN_2, peak voltage is 700 V, peak power is 5 MW.

To minimize activation of LN_2, flush magnet before pulsing with 5-bar N_2 gas.

Magnet cryostat designed for 15 bar (for option to cool via He gas).

Magnet Design, Fabrication and Commissioning

2000-2001: Conceptual design of magnet by Bob Weggel (BNL).

http://www.hep.princeton.edu/˜mcdonald/mumu/target/weggel/chicago_020902.pdf

2001-2002: Mechanical design by Peter Titus (MIT).

Sept 2002: Magnet design review at BNL.

http://www.hep.princeton.edu/˜mcdonald/mumu/target/MIT/desrev_090602.pdf

Nov 2003: Contract for magnet fabrication awarded to CVIP (PA), with subcontract to Everson-Tesla for the coil fabrication.

Nov 2003: CERN "Safety Hearing".

http://www.hep.princeton.edu/˜mcdonald/mumu/target/CERN/safety/pilcher_minutes_tis_dec2003.pdf

Apr 2004: MERIT Experiment proposed to CERN (approved as nToF11, Apr 2005).

http://www.hep.princeton.edu/˜mcdonald/mumu/target/cern_proposal.pdf

Jan 2006: Magnet completed by CVIP, delivered to MIT.

Feb 2006: Magnet safety review at CERN.

http://noyac3.psfc.mit.edu/bnlpulsed/CERNSafety06.pdf

Mar 2006: Commissioning of magnet at MIT: 16 pulses including one at 15 T.

http://noyac3.psfc.mit.edu/bnlpulsed/testresults.pdf

Mar 2007: Integration tests of magnet + mercury loop at MIT: 14 pulses, 4 at 15 T.

Safety Issues

Feb 06 Safety Review at CERN:

Some of the Postulated of Safety Issues:

Magnetic Field Hazard 6m to the 5 gauss line
Feromagnetic Material Projectiles
Joint Failure
- Excessive motion
- Omission of a Force Component

Insulation Failure, Arcing
Leaks Oxygen Deficiency Hazards
- He/LN2 Cryostat Leak
  - Mechanical Seal Failure
  - Bellows Crack
  - Ceramaseal Break
  - Lead Gland Nut Leak

Over Pressure
- Hotter than expected Magnet
- Loss of Vacuum in Jacket
- Vacuum Jacket Volume Pressurization
- Quick charge of LN2 with warm cryostat

Failure of Bore Heater
Thermal Shock
- Quick charge of LN2 with warm cryostat – The inner magnet segments were thermally shocked at Everson-Tesla

Accident
- Fire - Avoid Flammable Materials
- Seismic

- Successful operation of the magnet at MIT during Mar 06 and Mar 07 confirms that most safety issues have been addressed.

  March 2006 test summary:

  http://noyac3.psfc.mit.edu/bnlpulsed/testresults.pdf

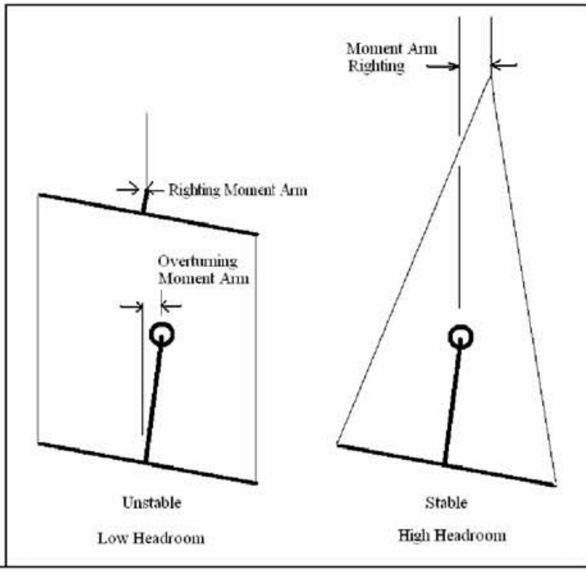
  Materials and Manufacturers' Certifications available in a loose-leaf binder.

  Concerns considered here:

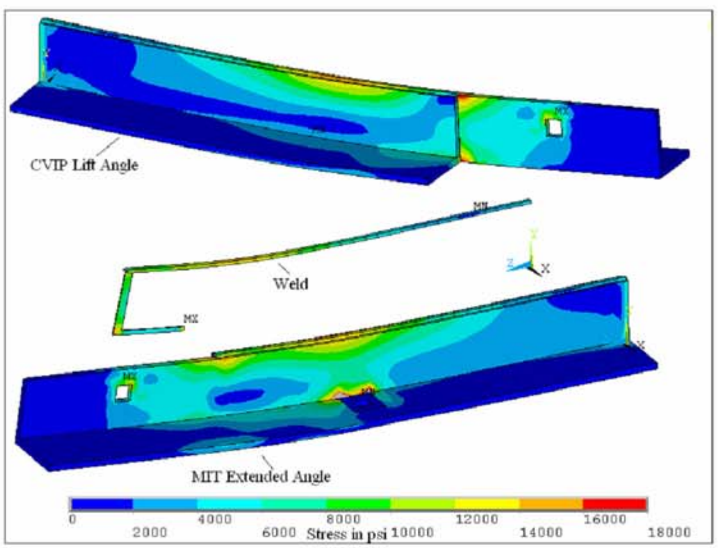
- Magnet hoisting.
- Magnet leads.
- Magnet fringe field.
- Cryostat leaks when cold.
- Endplate thermal insulation.
- Ice buildup on magnet connections.
- Liquefaction of oxygen.
- LN_2 filling and draining.

Magnet Hoisting

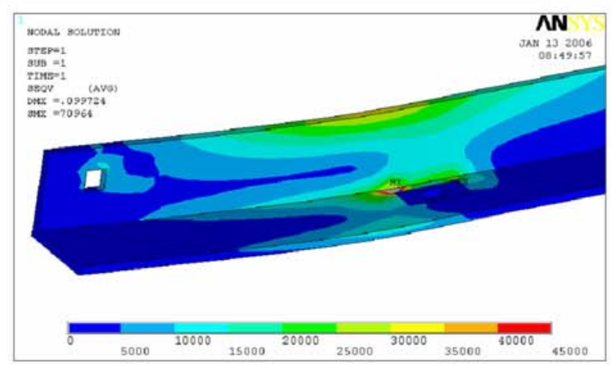
The initial lifting rig was unstable. This can be seen in the diagram below. The triangular sling arrangement is planned for use. In order for the headroom to be acceptable, the spreaders supplied by CVIP had to be extended by about 7 inches. .



Magnet lowered into place in front of PTF split pair magnet.



5 millitorr minimum,

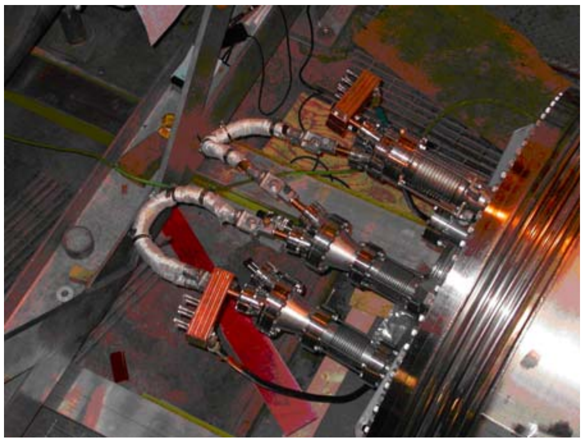


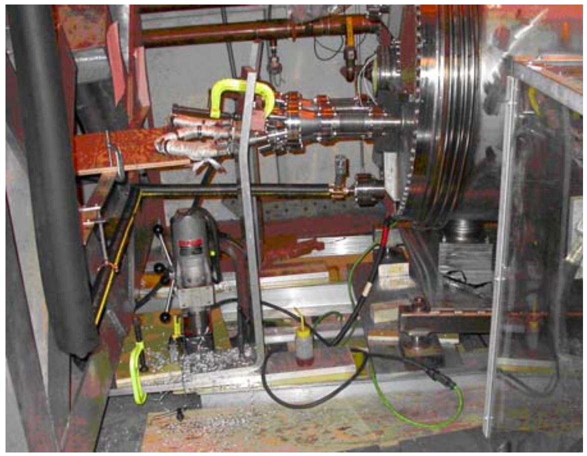
Extension I-beams welded at MIT. May needed to be bolted to satisfy CERN safety.

Connection of Magnet Leads to Power Supply Cables/Bus

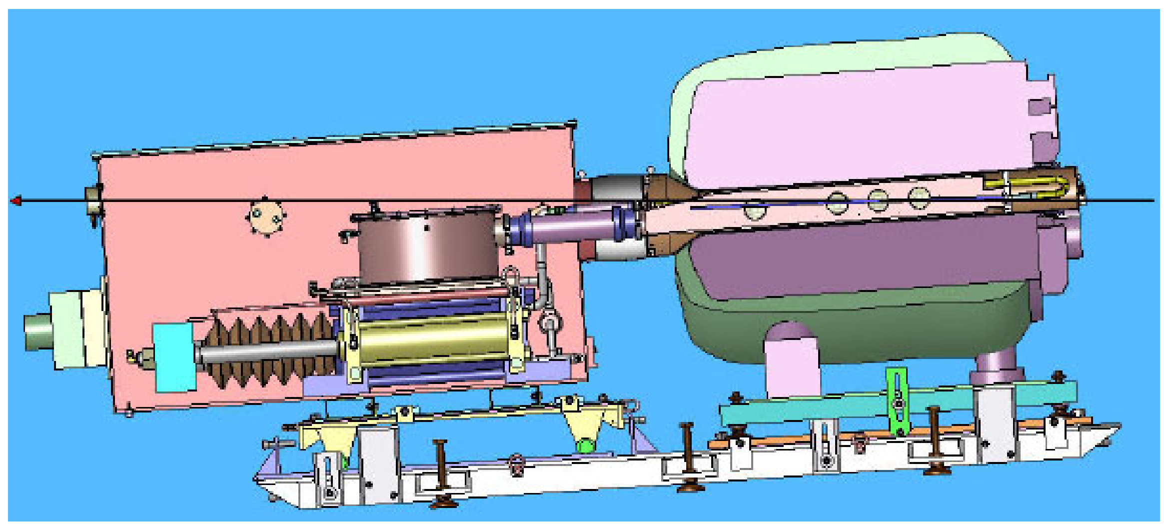
Magnet leads connected to Al bus bars at MIT.

Magnet leads will be connected to copper cables at CERN.





Desirable to have strain relief of connections supported off the magnet stand, so that magnet + baseplate can be either horizontal or at 4° while connected.



Current/Field Traces from Magnet Test Pulses at MIT

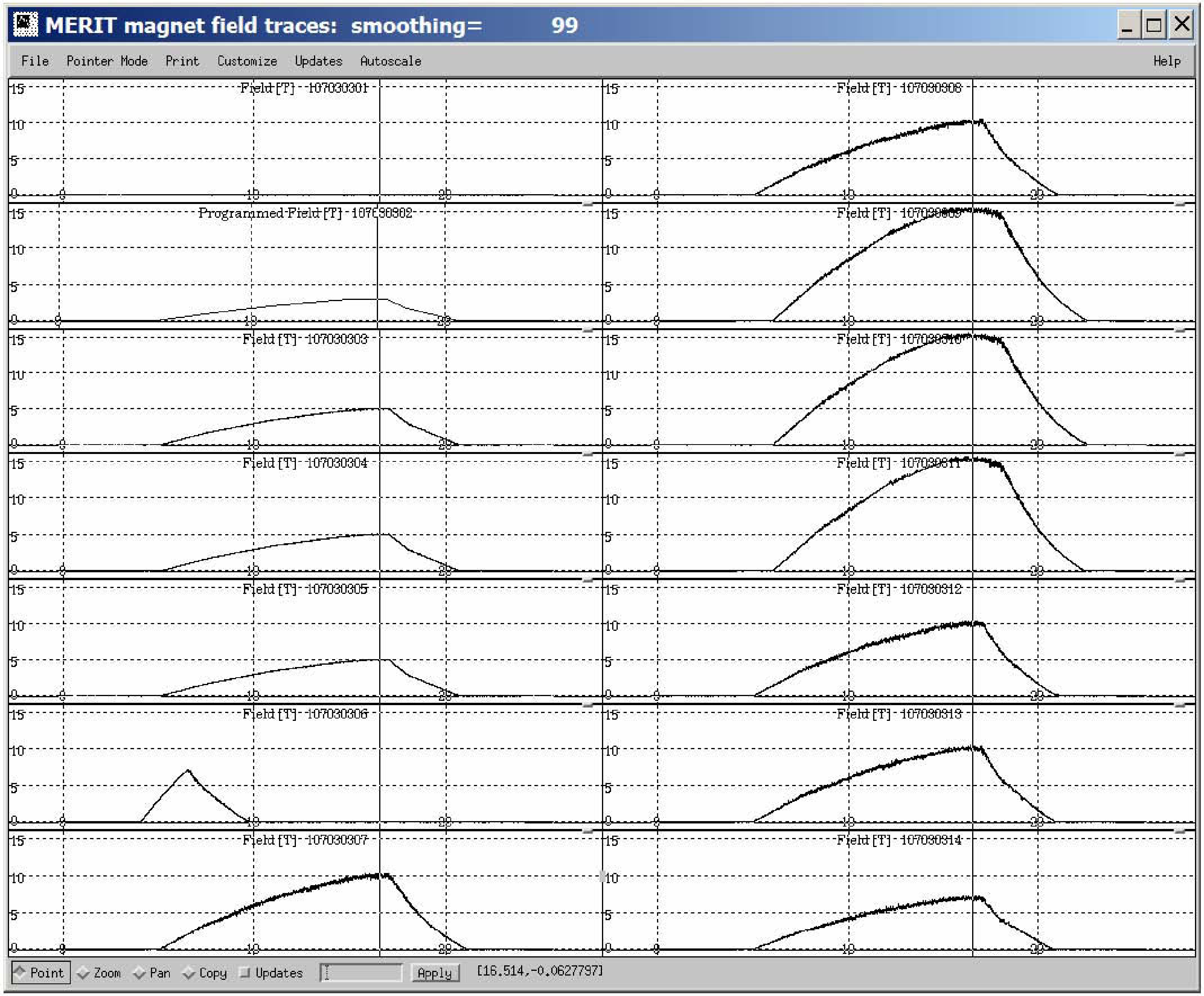
March 2006: 16 pulses, 1 @ 15 T.

March 2007: 14 pulses, 4 @ 15 T.

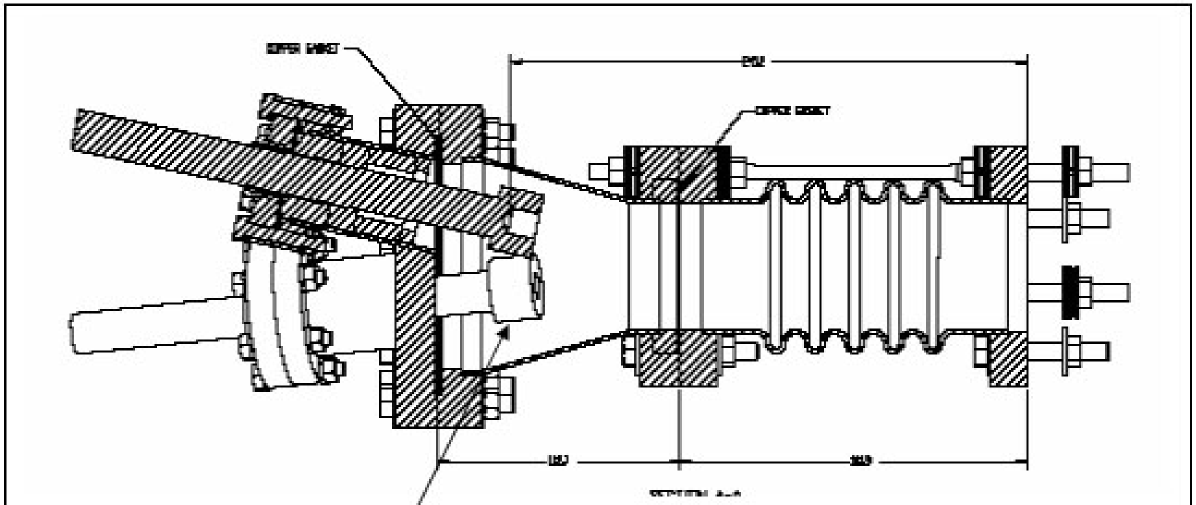
9-s ramp up,
4-s ramp down.

30 MJ heating, ⇒ 30K temperature rise.

March 2007 field traces:

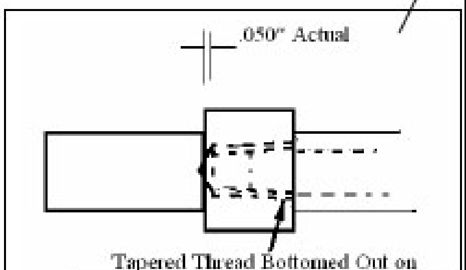


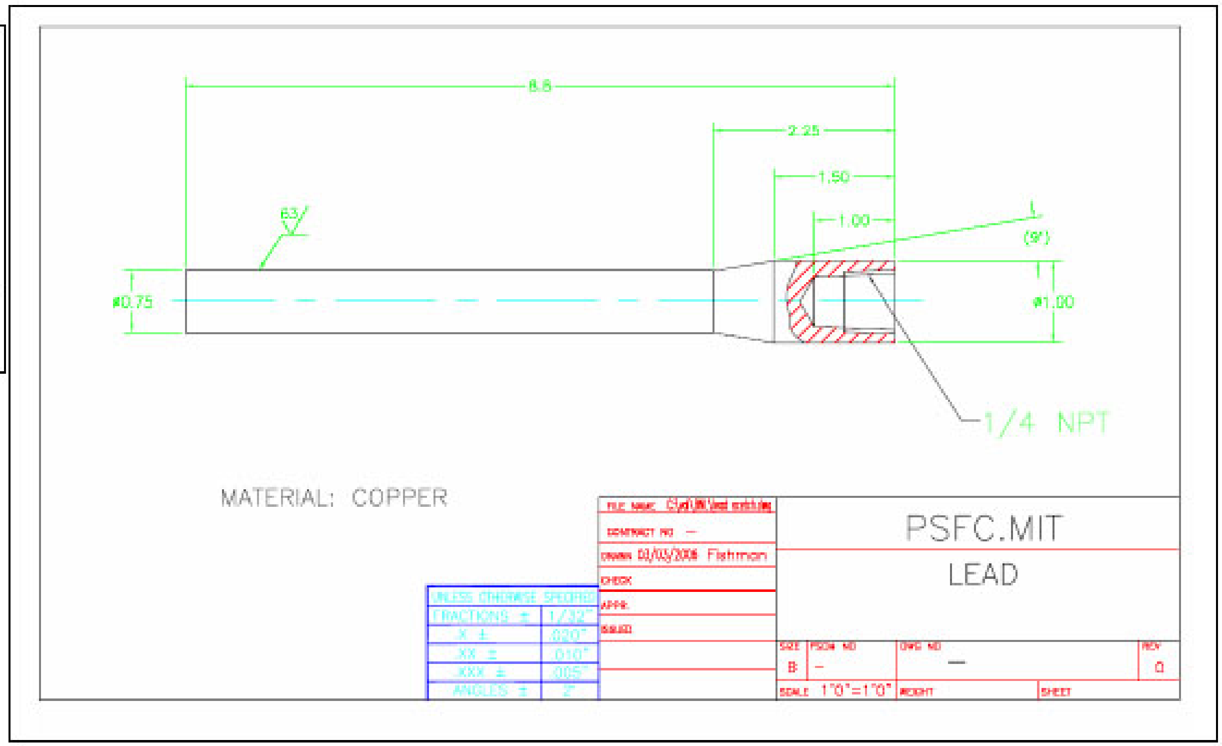
Magnet Leads Reworked, March 2006



Terminal bars need re-work for low current tests and replacement for high current tests

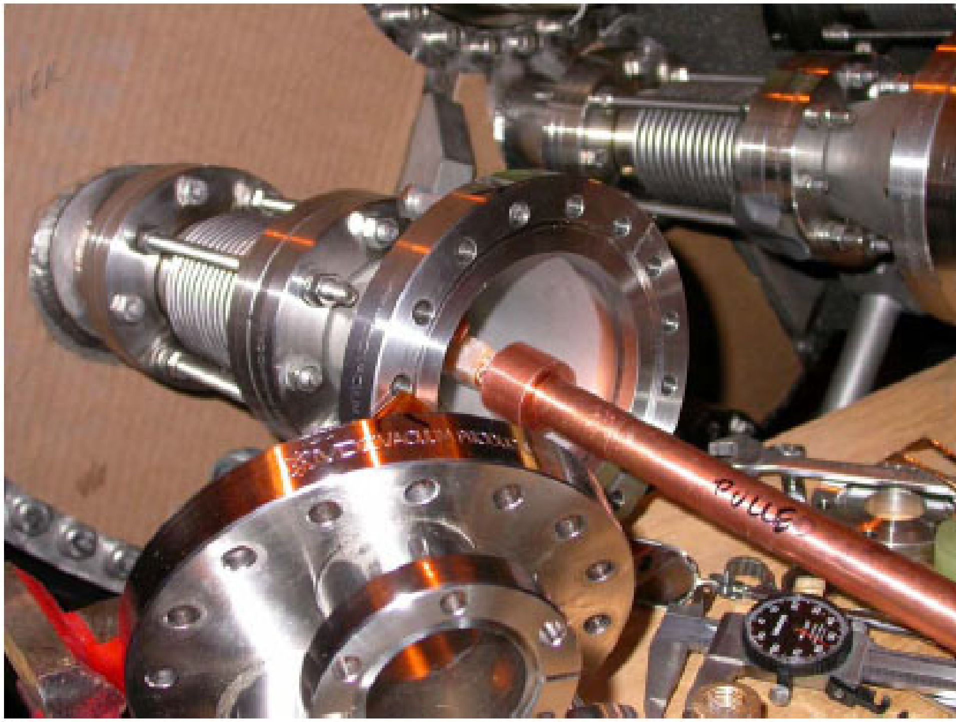
Ends will be wrapped in Kapton due to proximity of the female threaded sections and all threads are being brush silver plated.





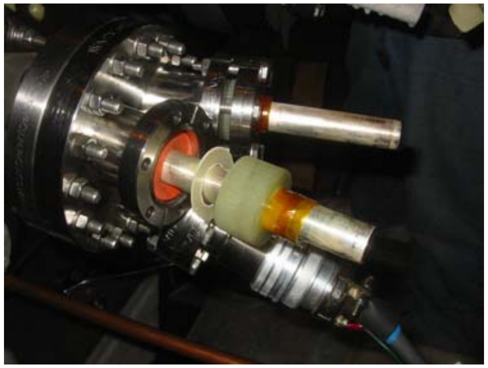
Magnet-Lead Rework, II

I – Peter Titus – stripped the thread of one of the copper bar extensions while attempting to tighten it. We decided to inspect and re-work all threaded connections s needed.



Magnet-Lead Gland Seal Rework, March 2007

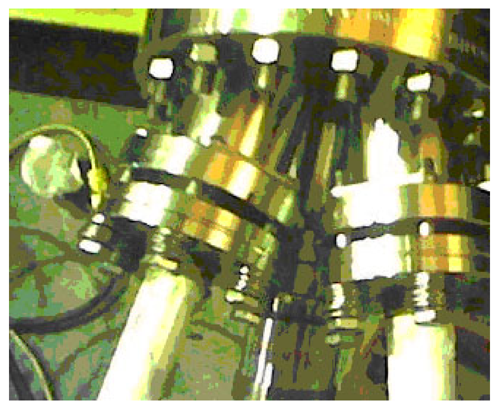
The gland seal of the copper leads is made via a stack of G-10 and silicone rubber.



Silicone rubber qualified at 77K in Feb 2006.

LN2 Dunk Test: Feb 9 2006 The gland for the power lead did not shatter – but it was rigid.

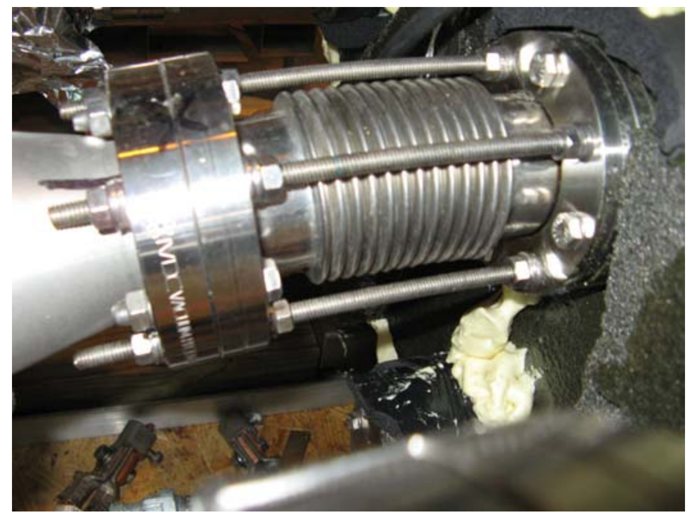
In March 2007 a 2nd silicone washer was added to each seal, and a Belleville washer stack added to provide compliance at both 77K and 300K.



Possible Bending of the Inner Coil Lead During Shipment

MIT, 3 March 2007:
The inner coil lead is already bent slightly.

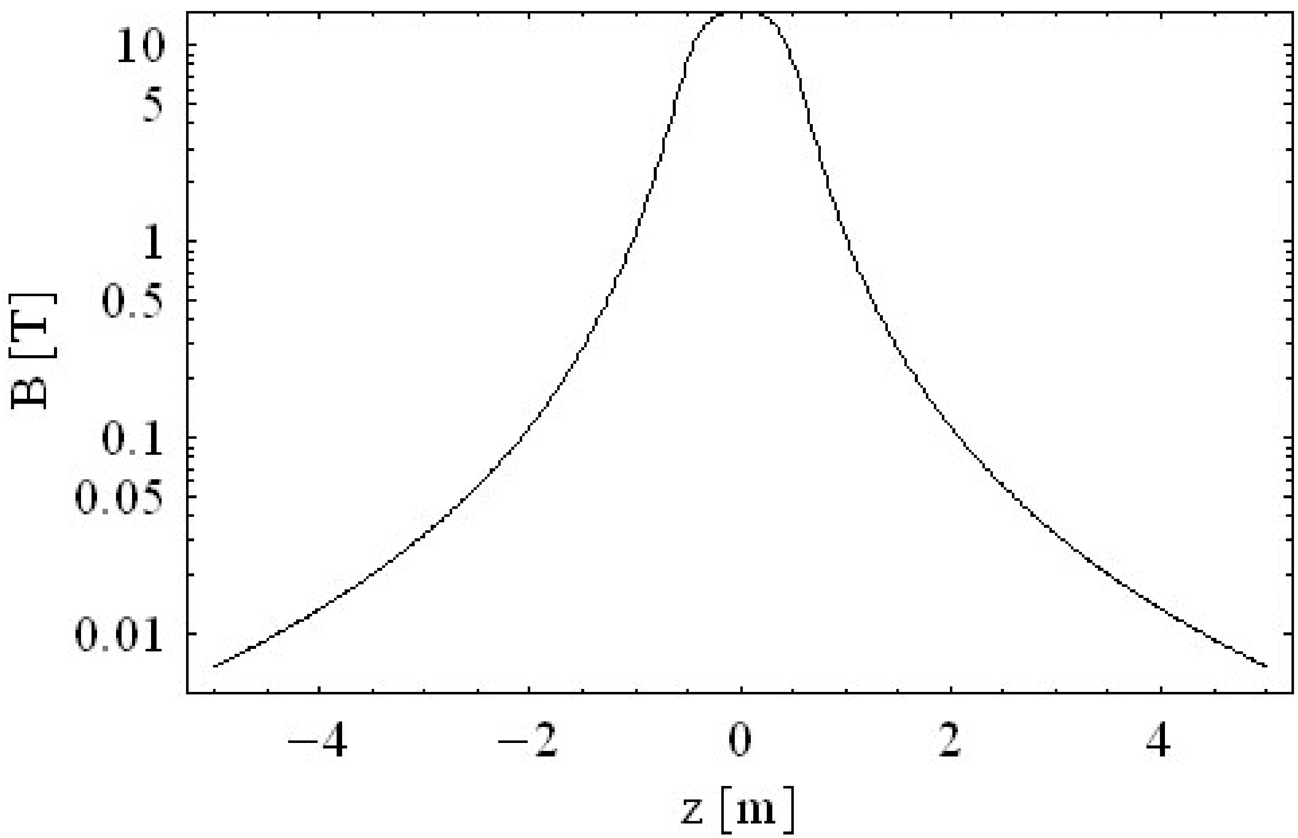
CERN, 21 March 2007:
The inner coil lead may be bent more now.
Caution: “fisheye” distortion in close-up photo.



Concern is a possible short of the copper leads to the stainless steel jacket.

We will verify the integrity of the leads with a “hi-pot” test @ 1000 V.

Magnet Fringe Field



At full power, the field is above 100 G for ± 5 **m along the magnet axis.** *Therefore, the mercury loop was fabricated from stainless steel, and the stands from aluminum.*

If warm magnet up with, say, a 150-A power supply, the field is above 20 G for ± 2 **m along the magnet axis.**

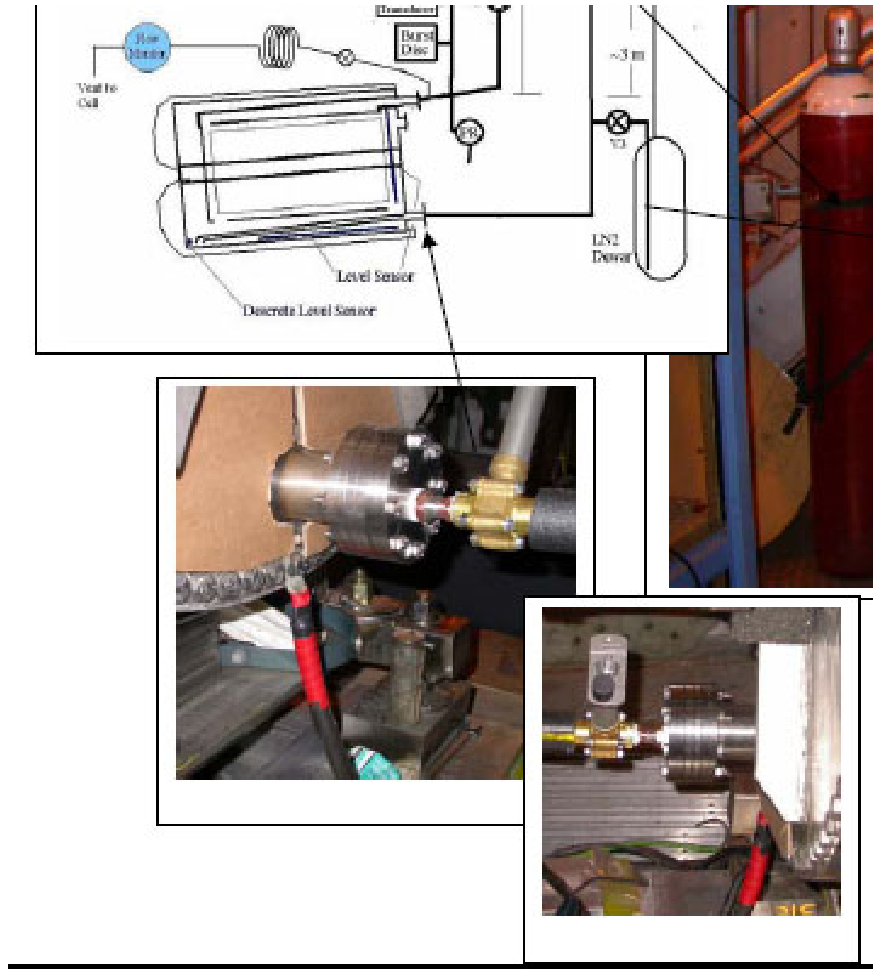
Measurements in Bldg 180 @ 150 A: 5 G at $r = 0,\ z = 2$ **m on axis;**
15 G at $r = 1.5,\ z = 0$ **m.**

Cryostat Leaks When Cold

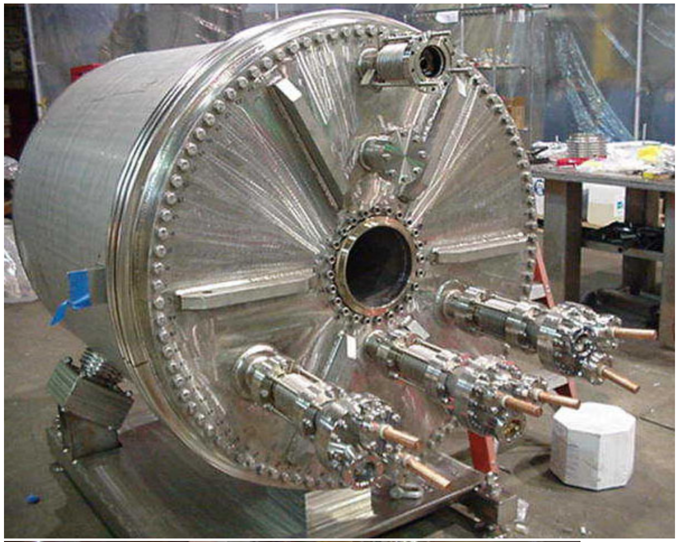
The cryostat was leak-tight at 15-bar pressure tests at room temperature, Jan-Feb 2006.

During the March 2007 tests, when the magnet was cold and the cryostat pressurized to 2 bar, there were significant leaks near the lowest Conflat flange, and the Conflat flange on the middle lead, as well as minor leaks around some of the gland seals.

- The leaks at the Conflat flanges were due to loose bolts.
- The leaks at the gland seals were mitigated by the rework described previously.
- The cryostat then held pressure at 6 bar (magnet @ $\approx$ 200K), and was shipped to CERN under 4-5 bar pressure.
- The magnet arrived at CERN on 19 March 2007, and was found to be at 5-bar pressure.
- Additional pressure tests, both at 77K and 300K will be conducted at CERN.



Thermal Insulation

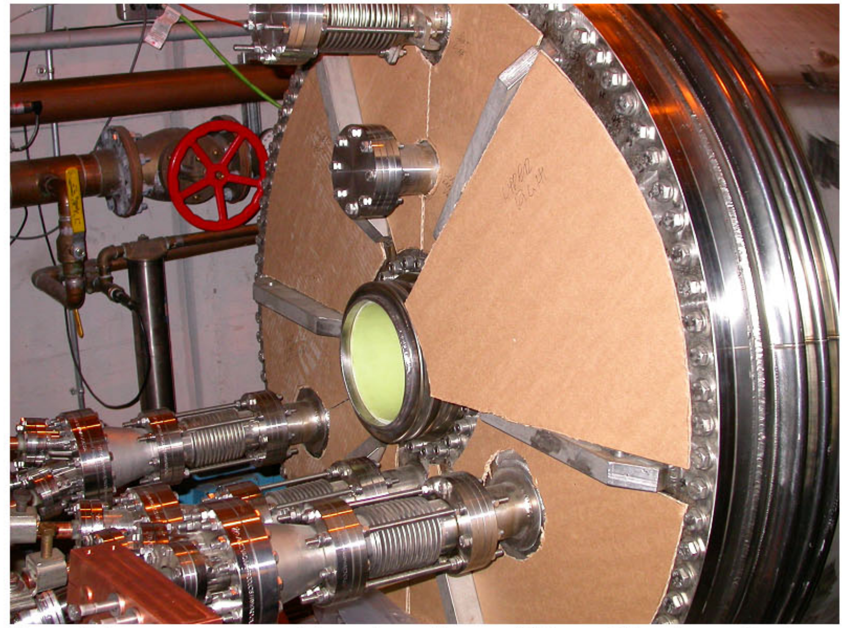


- Cryostat vacuum jacket does not cover the endplate.
- The 0.8-m-diameter bellows next to the endplate, as well as the magnet leads, are covered in Armaflex insulation. http://www.armaflex.com/
  Mold resistant AP/Armaflex Insulation is a flexible elastomeric thermal insulation and black in color. The expanded closed-cell structure of AP/Armaflex makes it an efficient insulation. It is manufactured without the use of CFC's, HFC's or HCFC's. It is also formaldehyde free, low VOCs, fiber free, dust free and resists mold and mildew.
- Most of the flat endplate is covered in rigid Pittsburg-Corning Foamglas (noncombustible), which is bonded to the endplate with Stycast, an adhesive from Lakeshore Cryotronics.
  http://www.foamglasinsulation.com/literature/FI201.pdf
  http://www.lakeshore.com/temp/acc/am_epoxyts.html
- Gaps in the Foamglas insulation are filled with a spray-foam insulation, Dow "Great Stuff". This material is "flammable" but "fireblocking".
  http://greatstuff.dow.com/greatstuff/pro/sds.htm
  http://greatstuff.dow.com/greatstuff/pro/slideshow.htm

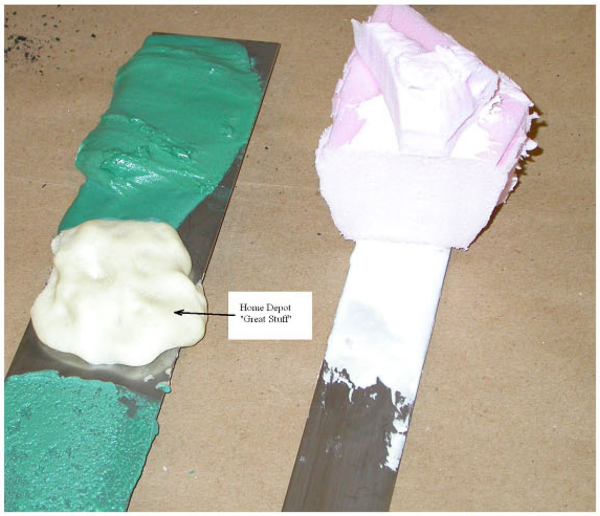
Thermal Insulation Tests, Feb 2006

Insulation Tests

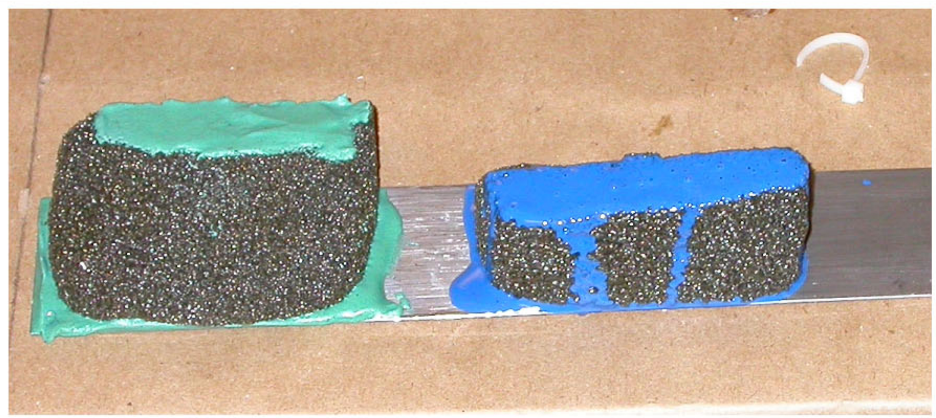
CTD materials slump badly on vertical surfaces – They would be almost impossible to apply to the cover. We plan to use Pittsburgh-Corning FoamGlas. It is a closed cell foam that survived dunk tests well. The cells have H2S, but are noncombustible. The dunk test produced little damage to the foam cell structure (as measured by a "smell" test).



Templates are prepared to cut sections of FoamGlas to apply to the cover.



"Great Stuff" Home insulation foam survived the dunk tests very well. The white CTD material, applied in a thick coat, lost its bond after a dunk test, but behaved well as an adhesive. "Great Stuff" is flammable

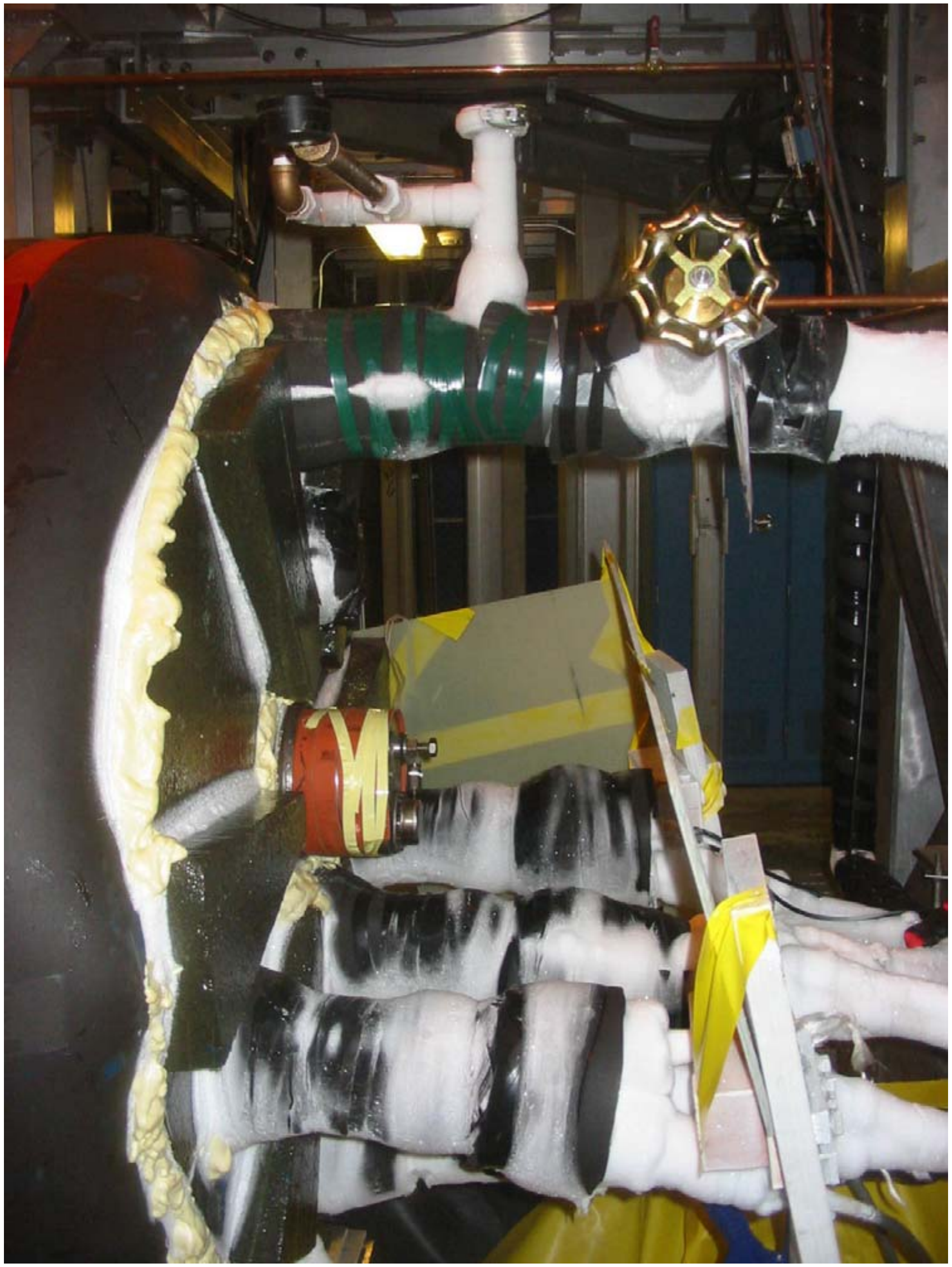


FoamGlas survived dunk tests well. Green is the CTD material. Blue is Stycast

Ice Buildup on Magnet Connections

After 1 day at 77K, the magnet leads showed noticeable ice building at MIT.

This issue can be mitigated (but perhaps not completely eliminated) by use of an additional layer of Armaflex insulation on the leads and endplate.



Oxygen Liquefaction

Oxygen liquefies at 90K (and freezes at 50K).

The Armaflex insulation on the magnet leads does not make a gas-tight bond to the stainless steel flanges and bellows, so oxygen can potentially come in contact with surfaces below 90K.

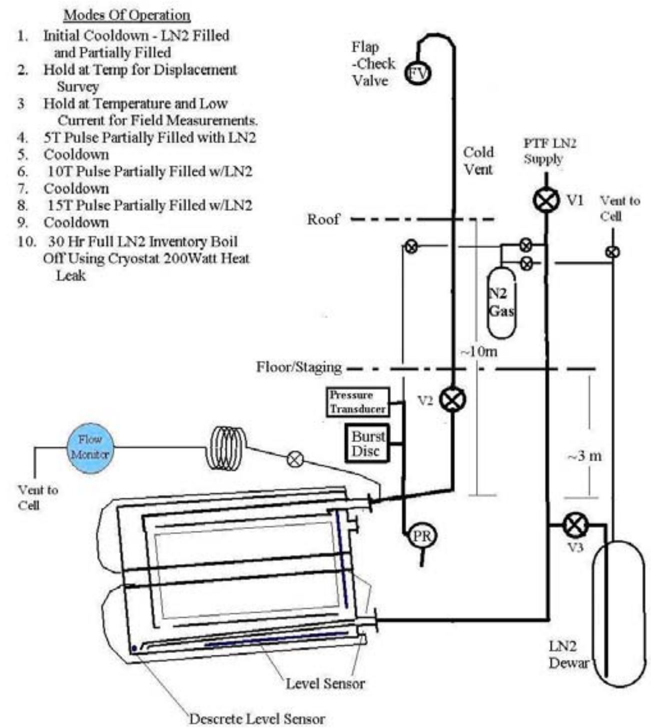
During tests in March 2006, small liquid drops from the magnet leads caused slightly increased, localized oxygen levels when they hit the floor and vaporized.

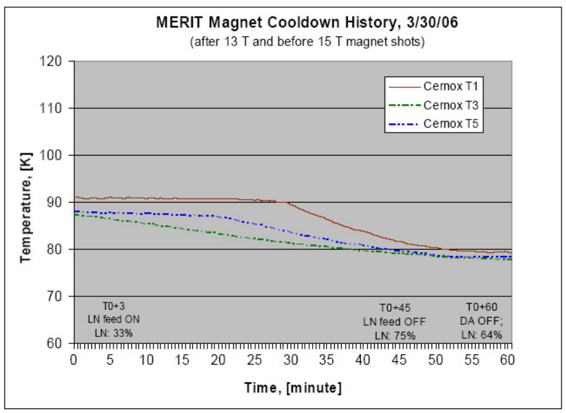
This issue is mitigated by ice building on the cold surfaces, which provides a conforming layer of insulation that the Armaflex does not.

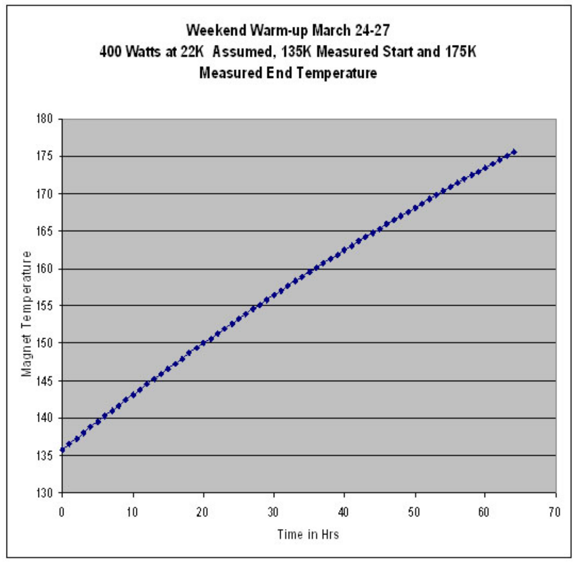
LN_2 Filling and Draining

The MERIT system tests at MIT were performed with a simplified cryogenic system that did not permit as rapid filling and draining ($\approx$ 10 min each) of the LN_2 as desired at CERN.

However, filling and draining proceeded smoothly on the longer times scales ($\approx$ 30-60 min) as were possible there.

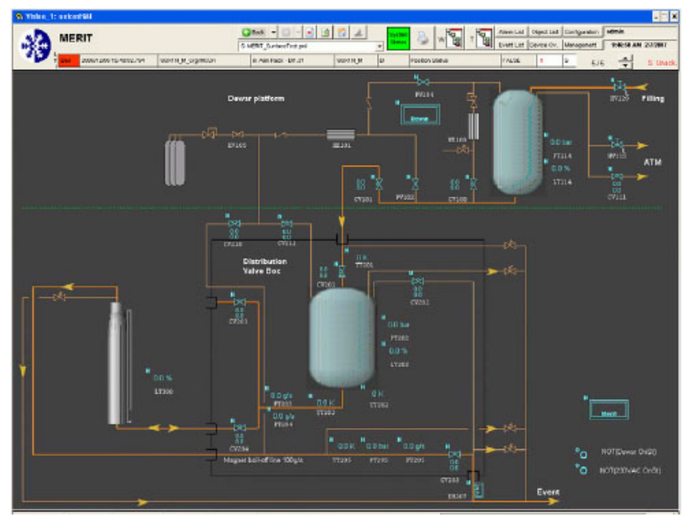






15K cooldown in 30 min.

3-day warmup $\Rightarrow$ 200 W heat leak.



Full tests of the MERIT cryogenic system as coupled to the 15-T magnet will be performed in Bldg 180 at CERN prior to installation of the equipment in the TT2 and TT2A tunnels.