The Results of the MICE Spectrometer Magnet 1 Test

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Topics to be Discussed

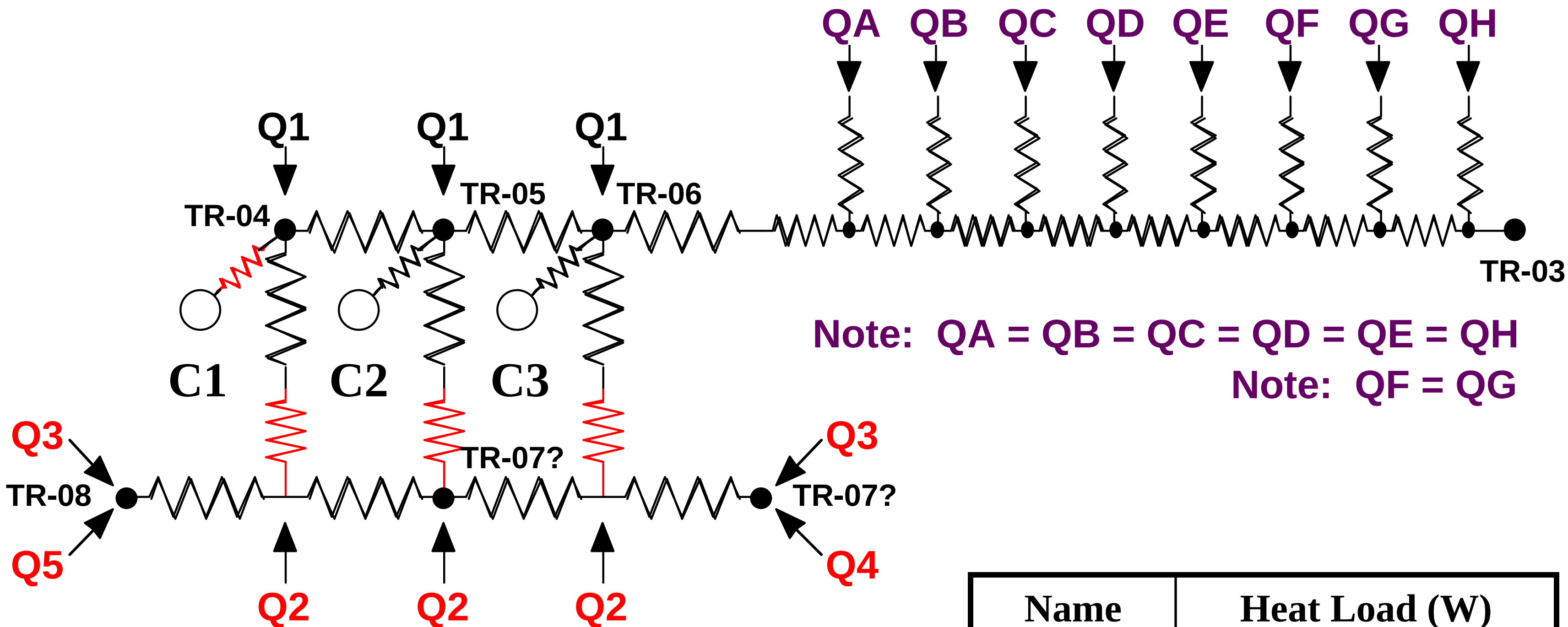
- Why is the test of Magnet 1 important?
- Pictures of Magnet 1
- The Cooler Arrangement for Magnet 1
- The Results of the Magnet 1 Test
- What went wrong with Magnet 1?
- Where did LBNL go from here?
- Concluding Comments

Why is the test of Magnet 1 important?

The magnet 1 test results are a clue as to what happened with magnet 2.

- The equipment within the turret was supposed to be the same for both magnets. This includes, the Cu leads, the copper plate that connects the leads to the coolers, and the connection from the copper plate to the 6061 Al tubes that connect with the Al shield.
- The major difference within the turret is that one cooler had no grease in the joint between the 1st stage and the sleeve around the joint.
- With no current in the magnet, the temperatures along the copper plate ranged from 55 K to 62 K versus 66 K to 81 K for magnet 2.

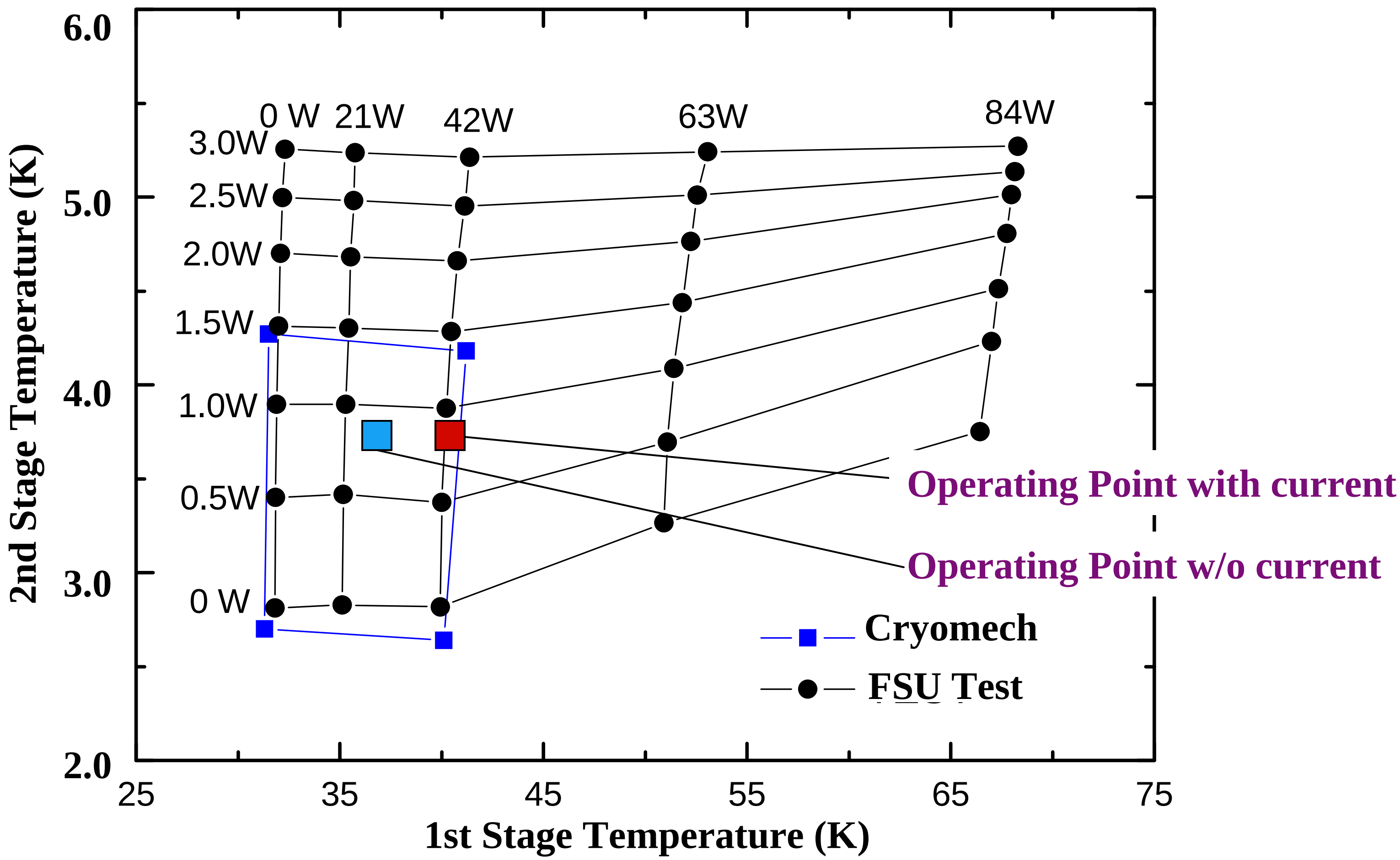
Theoretical Heat Load Diagram for Stage 1



- QA and QF are based on having current in the copper leads. Q1 is per cooler and is the drop-in cooler tube, neck tubes and wires. Q2 is the shield heat load for a strip 0.3 m wide. Q3 is the cold mass and shield support heat loads. Q4 and Q5 are the remainder of the Shield heat loads. The total theoretical heat load is about 119 W with current in the leads and 74 W without current in the leads.

Name	Heat Load (W)
QA	14
QF	3
Q1	3.1
Q2	1.0
Q3	2.4
Q4	6.0
Q5	6.0

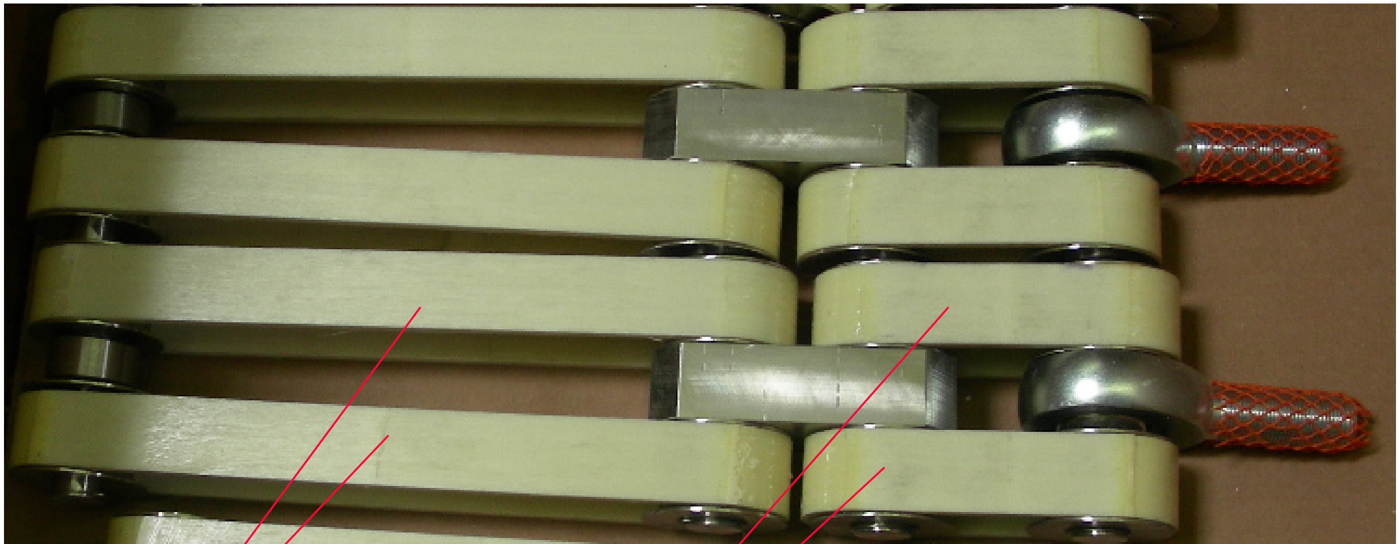
Cooler Operation Based on Calculated Heat Loads



The heat load into the first stage of the coolers was not zero. The heat load was about 0.3 W per cooler. Based on the temperature the total heat load was from 55 to 60 W per cooler, or the ΔT across the joint is too high. Stage 2 cooling has only a small effect on the stage 1 temperature (~2 K).

Pictures of Magnet 1

Cold Mass Supports for the Magnet



Low T Bands

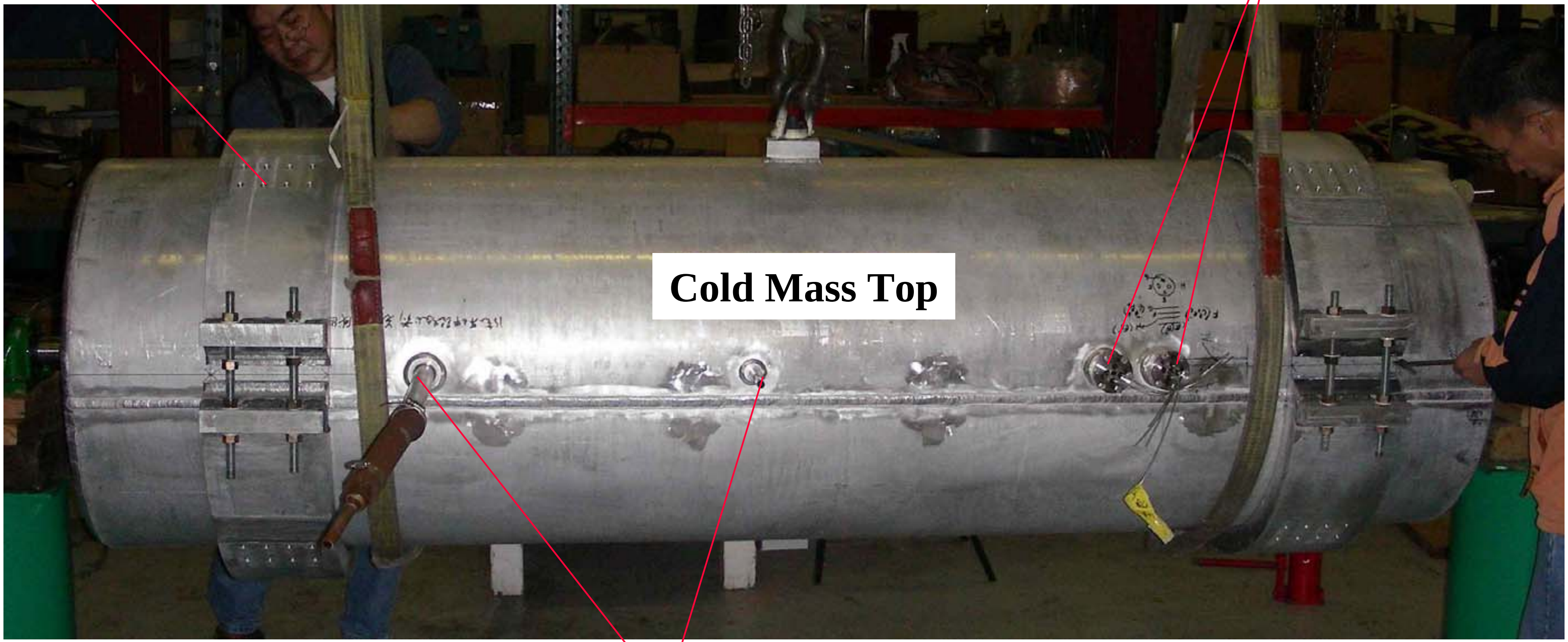
High T Bands

Support Band Assembly

Cold Mass Assembly for Magnet 1 after Welding and Vacuum Leak Check

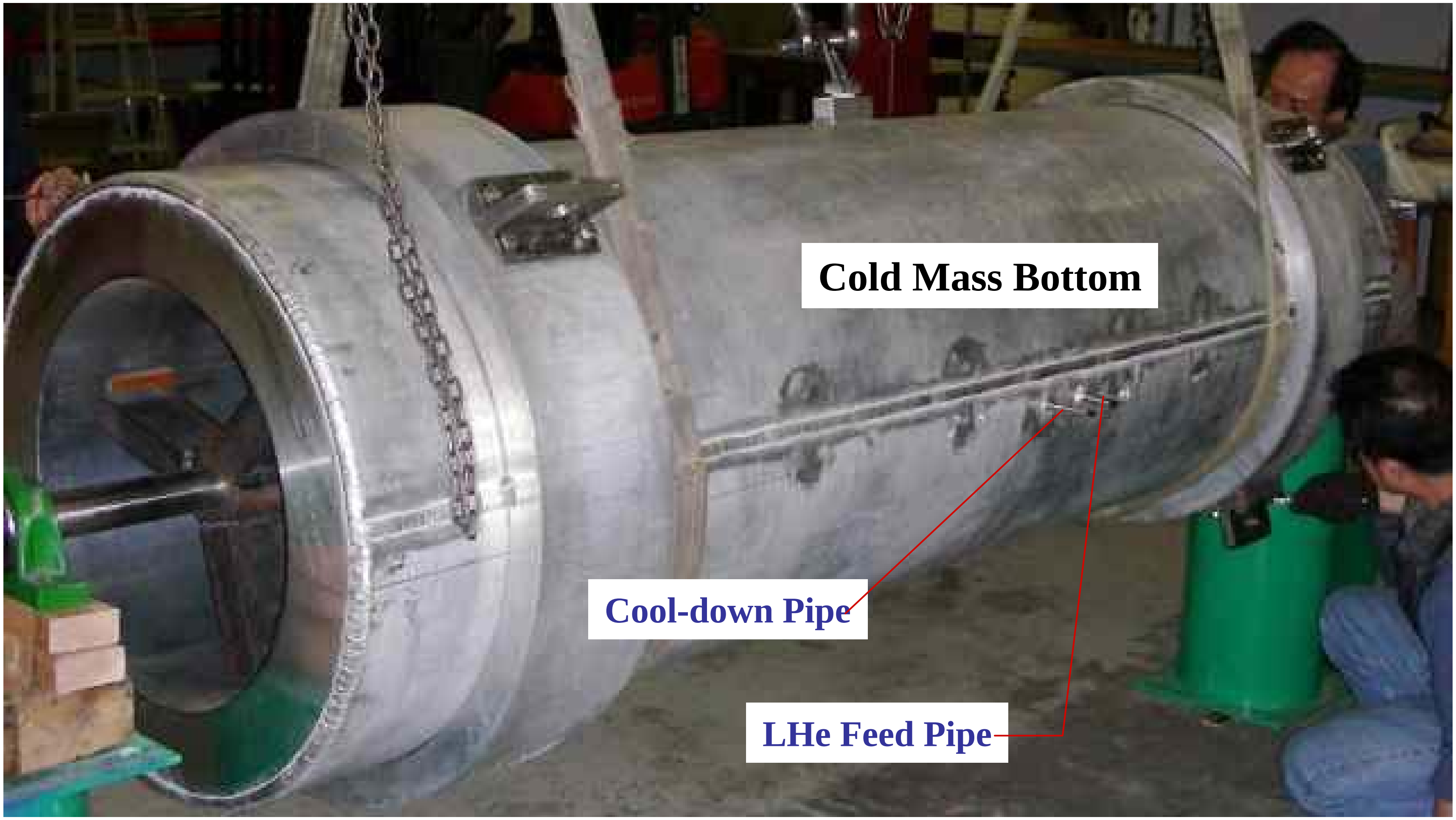
Band for Cold Mass Supports

Magnet Lead Ports



Cryogenic Service Ports

Cold Mass Assembly for Magnet 1 after Welding and Vacuum Leak Check

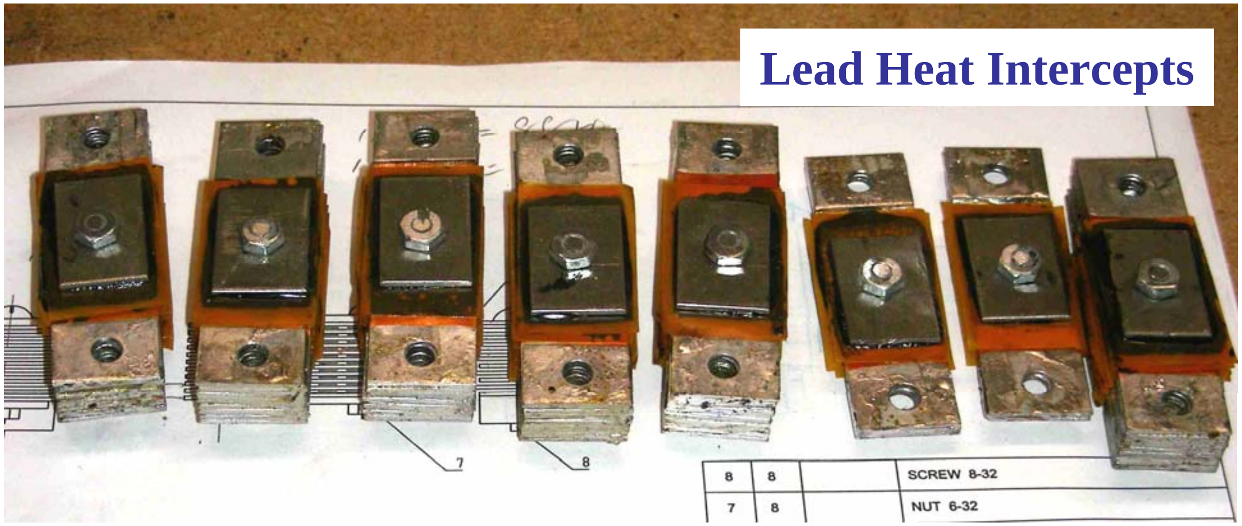


Support of the Cold Mass and Shield

Shield Support from End (1 of 8)

Cooler Connection Pipes and Superconducting Lead Connections

Copper and HTS Lead Connections

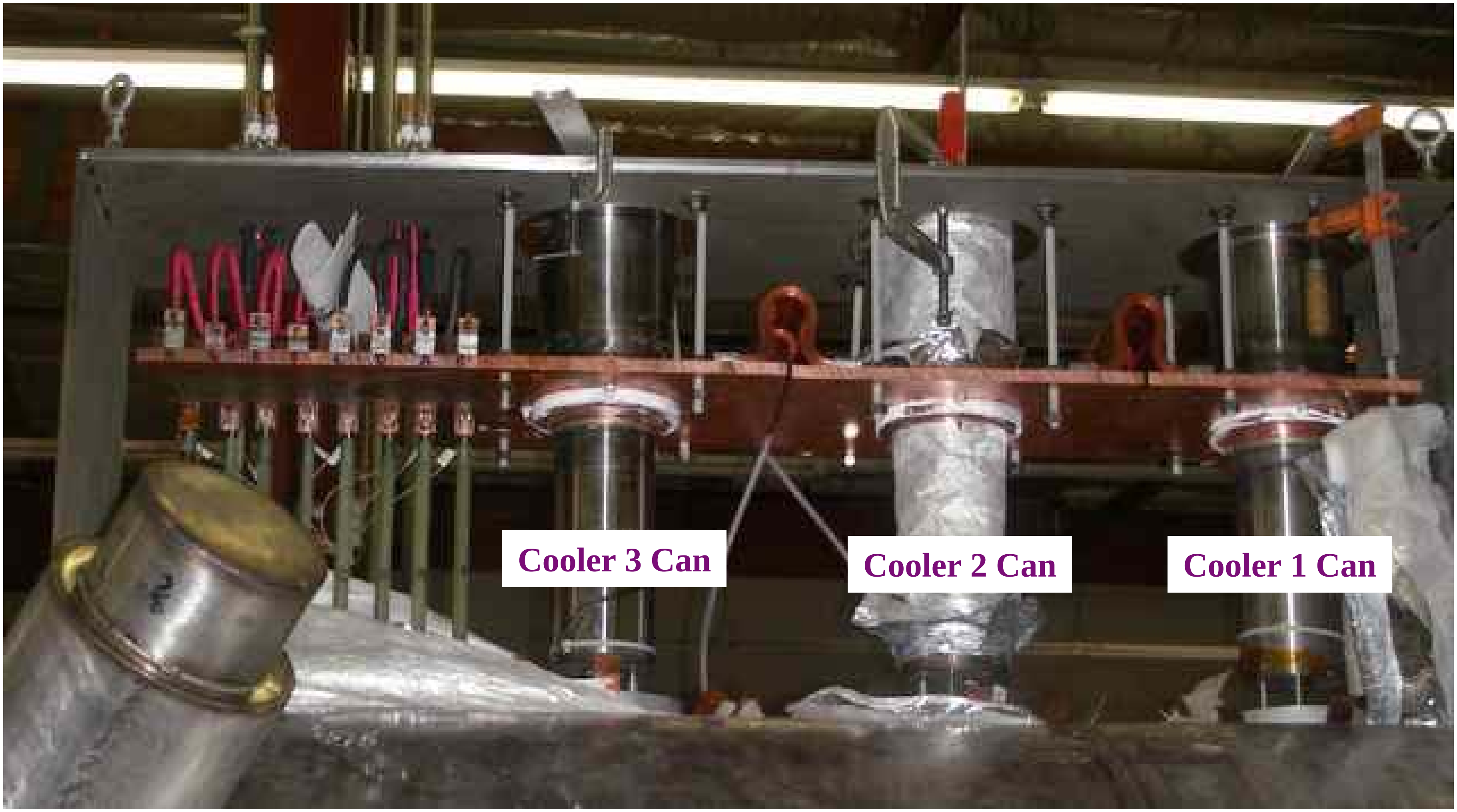


Lead Heat Intercepts

Cu to HTS Lead Connections

Connection of the Cooler Copper Plates

Magnet 1 Turret with Cooler Cans & Leads



Insulation of the Shield End

Spectrometer Solenoid 1 Test Setup

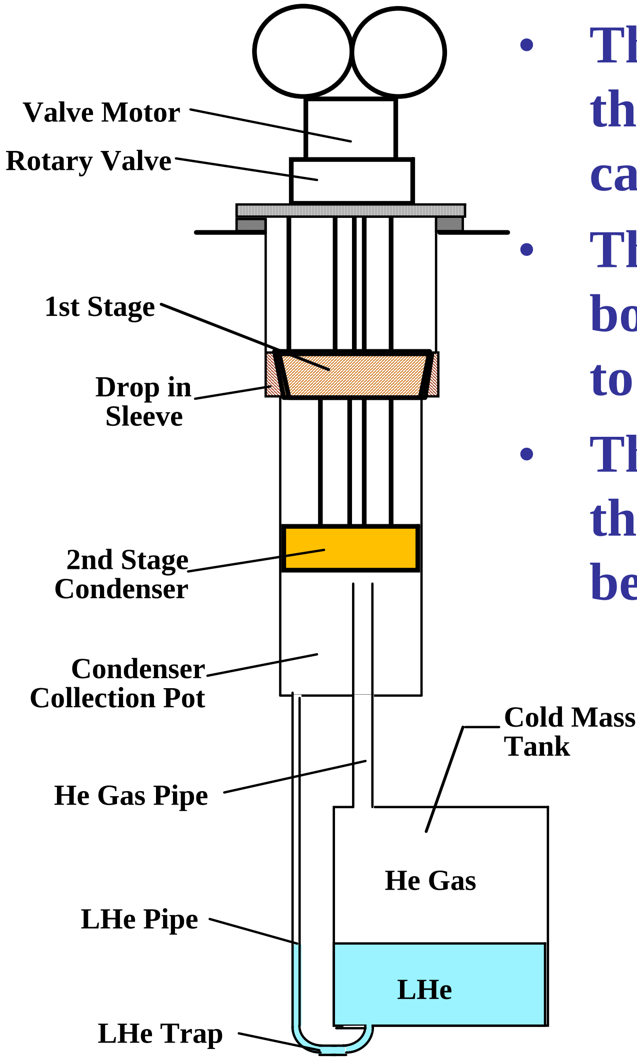
- Magnet Length = 2.7 m
- Magnet Diameter = 1.4 m
- Cold Mass = ~5000 kg
- Magnet Height = ~3.1 m
- Number of leads = 8
- The spectrometer magnet may be the largest magnet cooled with 4.2 K coolers.

The Magnet Cool Down and the Cooler Connection to the Magnet Cold Mass

The Magnet 1 Cool Down to 4 K

- The magnet was pre-cooled with LN_2. The cool down to 4.2 K was finished with LHe. Both magnets had to be cooled down slowly at first to control stress in the welds between the cover plate and the mandrel.
- With the 1st magnet, LN_2 was allowed to collect in the magnet He tank. The tank was then purged with He gas and pumped to get rid of the LN_2. During the cool down, the magnet resistance was not measured.

Cooler Arrangement for Magnet 1

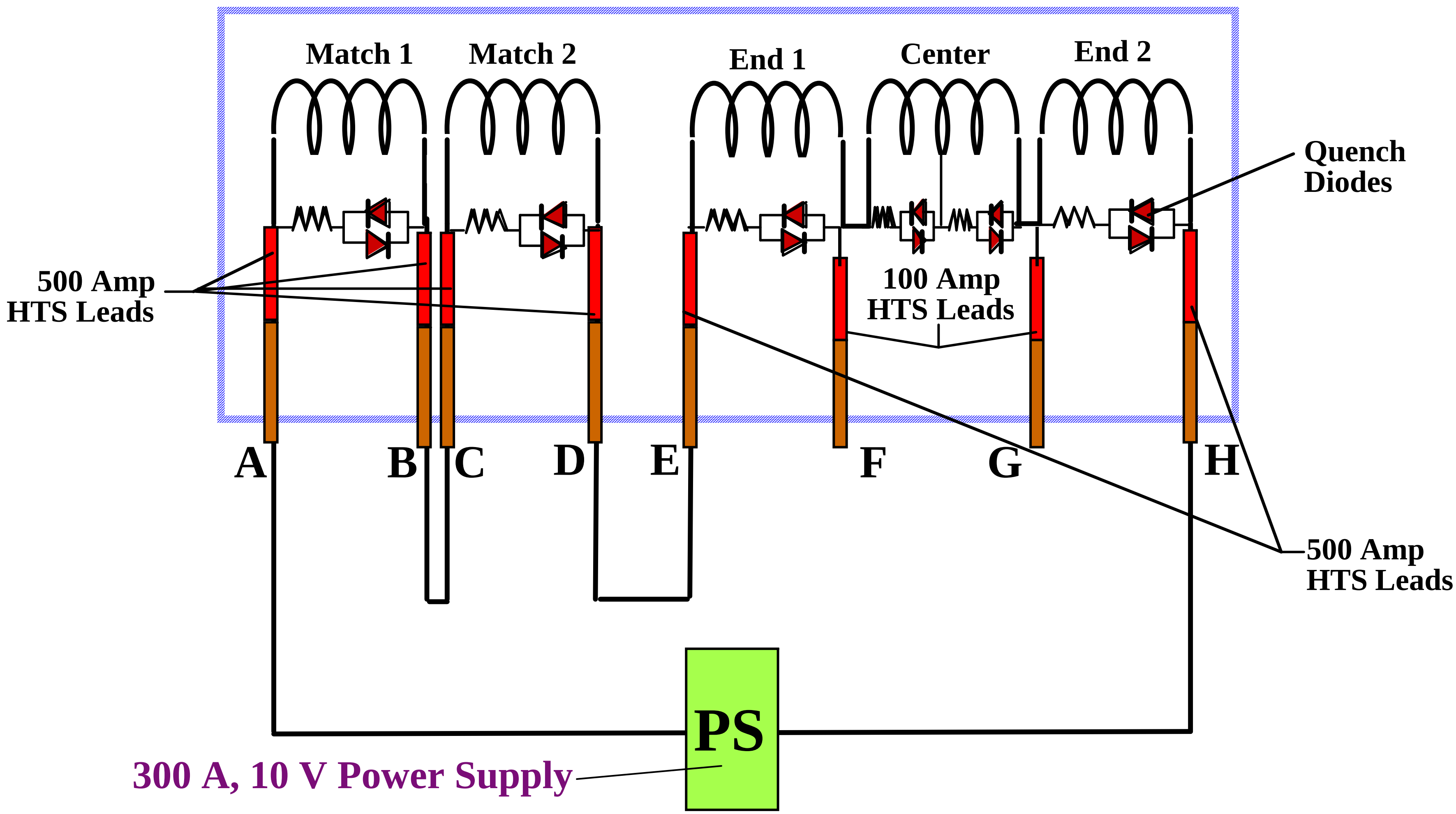


Arrangement B

- The condenser is 8 cm above the floor of the condenser can.
- The LHe tube feeds from the bottom of the condenser can to the bottom of the magnet.
- The He gas tube feeds from the top of the magnet to just below the condenser.

Results of the Magnet 1 Test

How the Magnet is Connected while Training the Magnet



The Results of the Magnet One Test

- The 190 L cold mass helium tank was filled and the magnet was trained to 196 A (seventy percent of the design current).
- The shield temperature was too high by 20 K.
- Training was stopped when it was realized that the helium was being boiled-off at the rate of 6 to 8 liters per hour with the coolers on. The heat flow into the cold mass exceeded the cooling rate from 4.3 to 5.7 W. The first stage temperatures were reasonable despite a higher than expected heat load on the first stage. There appeared to be no net cooling of the cold mass.

1st Magnet Test Temperatures (magnet not at 4 K)

		Location	Temperature (K) July 08	Temperature (K) Aug 08
Si Diodes	TS-01	Outside Magnet Cold Mass	17.96	65.30
	TS-02	Outside 2nd Stage Can Cooler 1	6.41	3.37
	TS-03	Outside 2nd Stage Can Cooler 2	5.61	3.51
	TS-04	Outside 2nd Stage Can Cooler 3	6.13	4.03
Pt Resist	TR-03	Copper Far End of HTS Leads	60.89	60.28
	TR-04	Cooler 1 Copper near 1st Stage	62.37	61.36
	TR-05	Cooler 2 Copper near 1st Stage	55.10	55.44
	TR-06	Cooler 3 Copper near 1st Stage	56.30	55.62
	TR-07	Shield One End on the Top	92.32	93.71
	TR-08	Shield Other End near the Bore	106.95	108.81

1st stage heat loads are ~165 W, which is higher than predicted. The 1st stage temperatures are reasonable. ΔT between the coolers and shield is too high.

Cooling from the 2nd stage is not being transferred to the cold mass. The net boil-off from the helium tank was 6 to 8 L/hr (4.3 to 5.7 W).

This could be in error

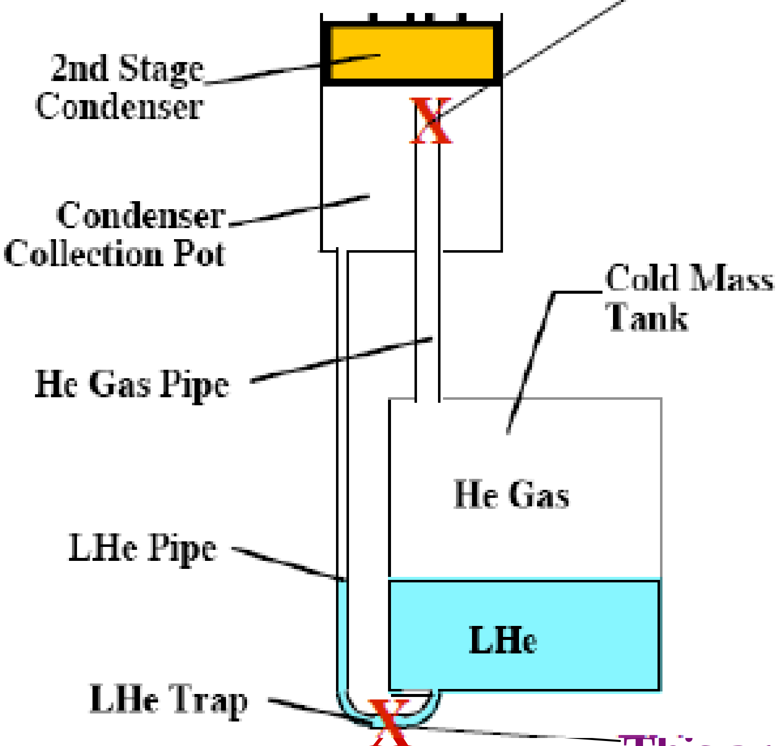
No grease in the joint?

What went wrong with Magnet 1?

Why is there no 4 K cooling on the cold mass?

- The pipe between the condenser and the cold mass helium tank was plugged with nitrogen ice.

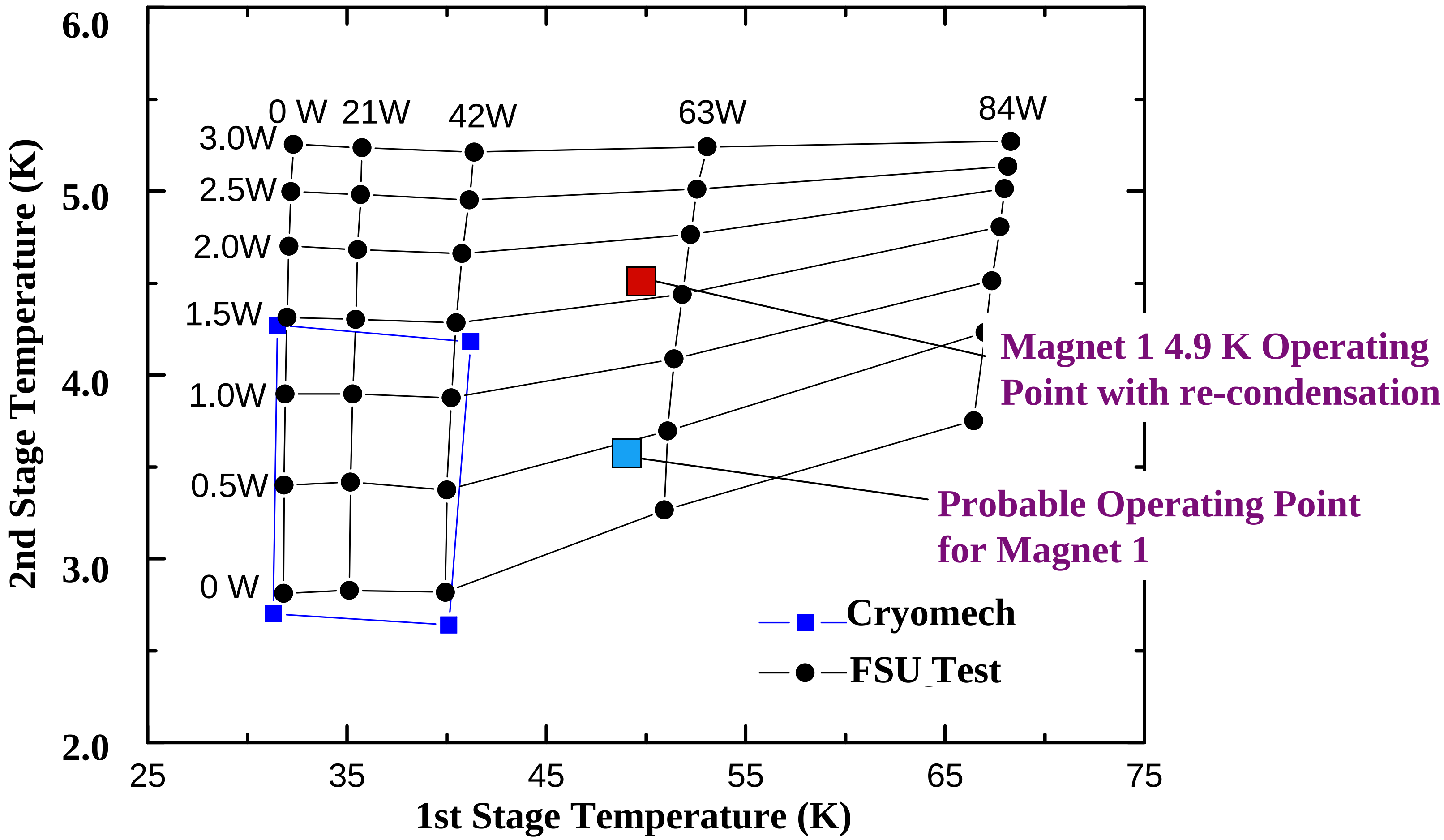
This area become plugged later.



- After the magnet warmed up to 70 K, N_2 migrated to the area around the condenser plugging the gas pipe as well. The 2nd cold head temperature dropped to 3 to 3.5 K with no net cooling

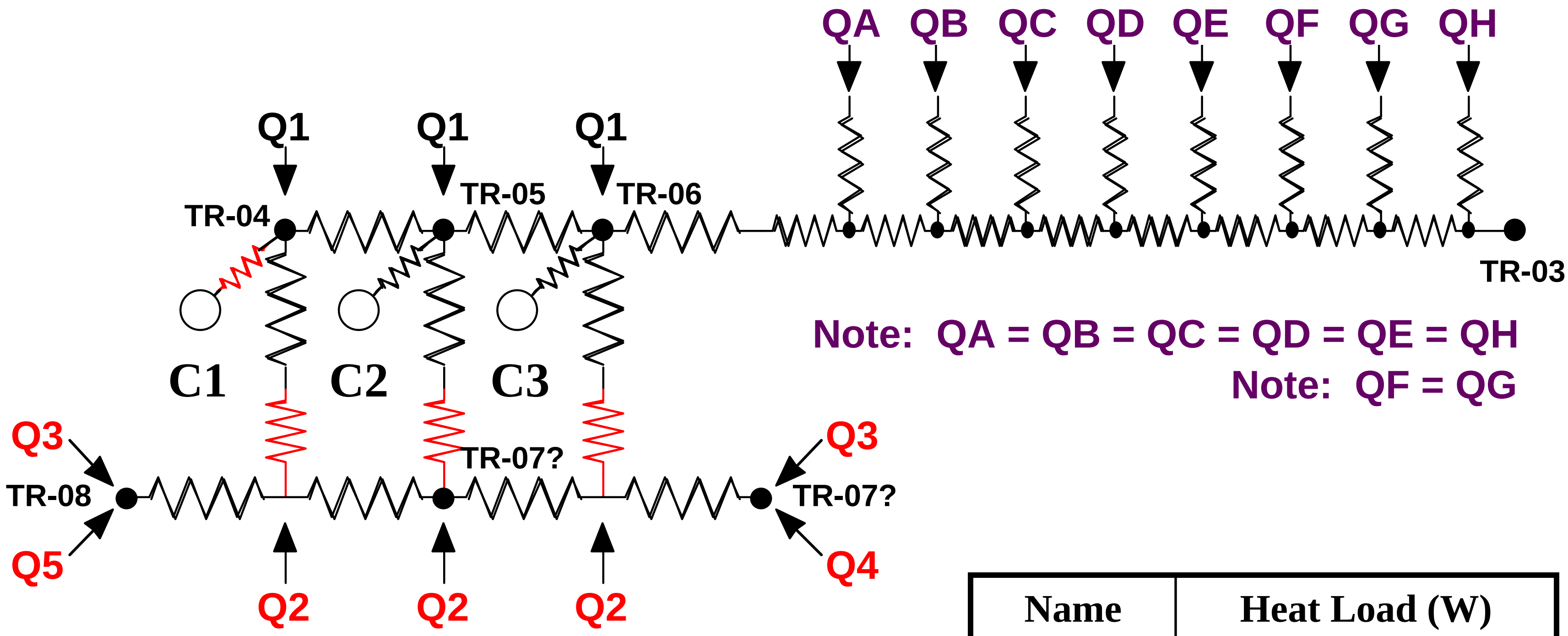
This area became plugged during the cool down.

Does the stage 2 refrigeration affect the cooler stage 1 temperature? No, not much.



The heat load into the first stage of the coolers was not zero. The heat load was about 0.4 W per cooler. Based on the temperature the total heat load was from 55 to 60 W per cooler, or the ΔT across the joint is too high. Stage 2 cooling has only a small effect on the stage 1 temperature (~2 K). Note: there is no current in the leads.

Possible Load Diagram for Stage 1 for Magnet 1



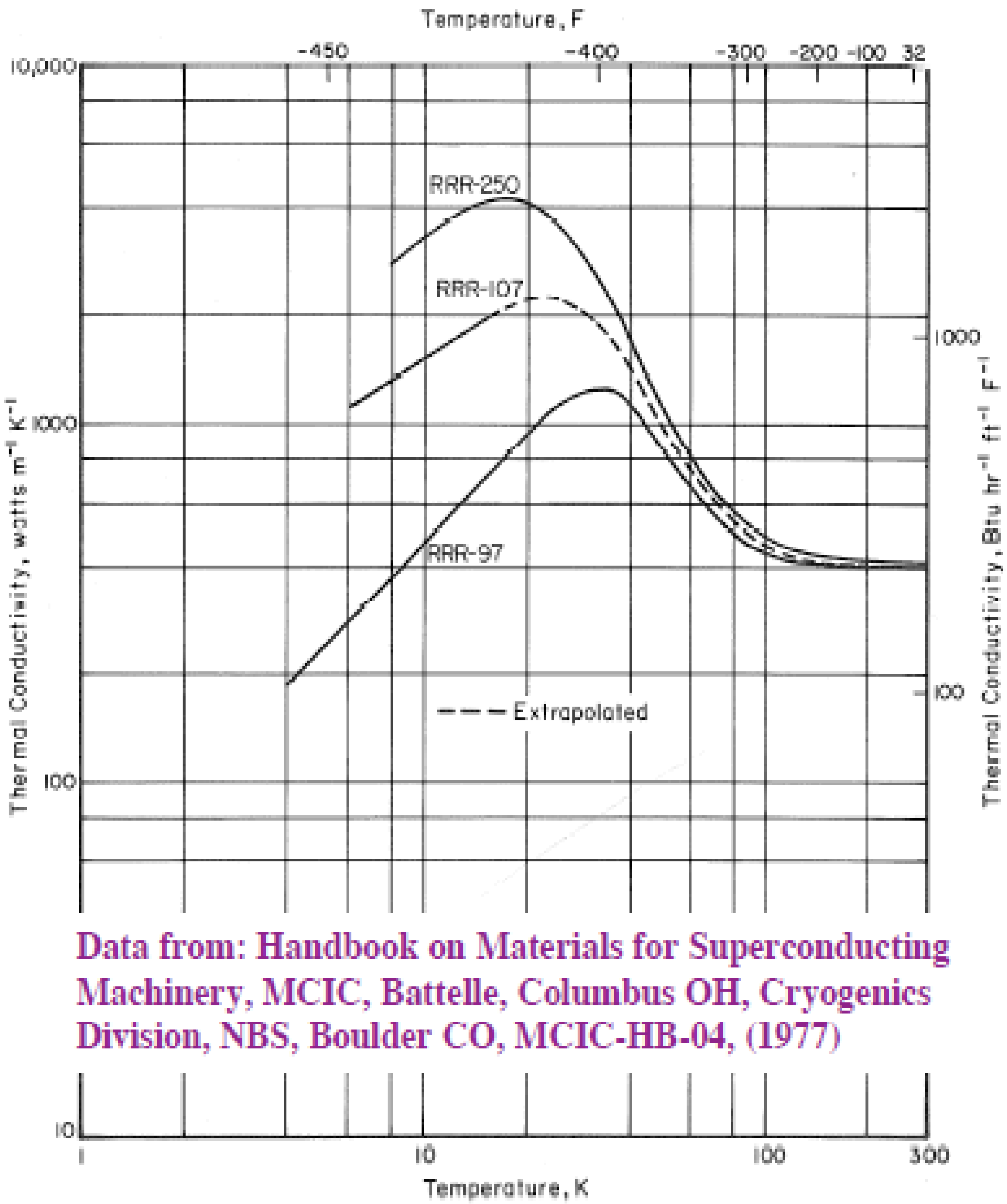
- QA and QF are based on having current in the copper leads. Q1 is per cooler and is the drop-in cooler tube, neck tubes and wires. Q2 is the shield heat load for a strip 0.3 m wide. Q3 is the cold mass and shield support heat loads. Q4 and Q5 are the remainder of the Shield heat loads. The total theoretical heat load is about 175 W with current in the leads and ~138 W without current in the leads.

Name	Heat Load (W)
QA	18
QF	4.0
Q1	3.1
Q2	3.0
Q3	2.4
Q4	18.0
Q5	18.0

Why are the temperatures much lower for Magnet 1 than for Magnet 2?

- The heat load into the cooler first stage is probably lower for magnet 1 than magnet 2. The apparent heat leak in magnet 1 ranges from 165 to 180 W based on the cooler 1st stage temperature. The heat leak in magnet 2 could be as high as 280 W.
- Since the temperature at the leads and the cooler 1st stage region is lower, the thermal conductivity of the copper is higher.
- The ΔT within the joint between the stage 1 sleeve and the 1st stage could be a factor.

Thermal Conductivity of Copper and Aluminum



Data from: Handbook on Materials for Superconducting Machinery, MCIC, Battelle, Columbus OH, Cryogenics Division, NBS, Boulder CO, MCIC-HB-04, (1977)

- The thermal conductivity of OFHC copper nearly doubles when the temperature goes from 81 K to 55 K. The OFHC Cu must be well annealed so that its RRR is as high as possible. At 55 K, k = ~900 W m^{-1} K^{-1}.
- 1100-O aluminum exhibits the same sort of behavior as OFHC copper, but the effect of lowering the temperature is not as great as with OFHC copper. The 1100 aluminum must be well annealed. At 55 K, k = ~500 W m^{-1} K^{-1}.
- The thermal conductivity of 6061 aluminum goes down as the temperature goes down. This material is not very good for shields or shield interconnects. At 55 K, k = ~ 80 W m^{-1} K^{-1}.

Had the tubes been unplugged, would the coolers been able to keep magnet 1 cold?

- **The helium boil-off was not accurately measured. The rate of helium boil-off suggests a heat load of 4.3 W to 5.7 W at 4.3 K.**
- **At 4.3 K the net cooling provided by three coolers was about 4.0 W. To provide 4.3 W of net cooling the second stage temperature would be ~4.5 K. In order to provide 5.7 W of net cooling the second stage temperature would have to be ~4.9 K. For cooling at 4.2 K, the answer is no.**

Magnet 2 Changes that resulted From the Magnet 1 Test Data

Changes Made on Magnet 2

- The cold mass was fiducialized with respect to the outside of the cryostat.
- A liquid nitrogen tank was attached to the shield so that LN_2 could be used to pre-cool the shield before turning on the coolers.
- The connection from the shield to the coolers was improved by that addition of 1100-0 Al straps.
- The connection between the coolers and the cold mass was changed to eliminate the trap.
- The insulation around the cold mass was improved.
- The cool down procedure was changed.

Concluding Comments

- **The magnet 1 cold mass was not cooled by the coolers because nitrogen ice blocked the helium flow channels.**
- **Magnet 1 appeared to have an excessive heat load compared to theory.**
- **Despite the excessive heat load, the first stage temperature was in a reasonable range across the OFHC copper strip between the coolers and leads.**
- **The fact that the coolers produced only a small amount of cooling at 4.2 K, the 1st stage temperature was not affected by very much by the lower heat flow into the 2nd stage.**