Lessons Learned from the Cool-down of a Superconducting Magnet using a Thermal-siphon Cooling-loop

M. A. Green, G. Bollen, S. S. Chouhan, C. Magsig
D. Morrissey, S. Schwarz, and A. F. Zeller

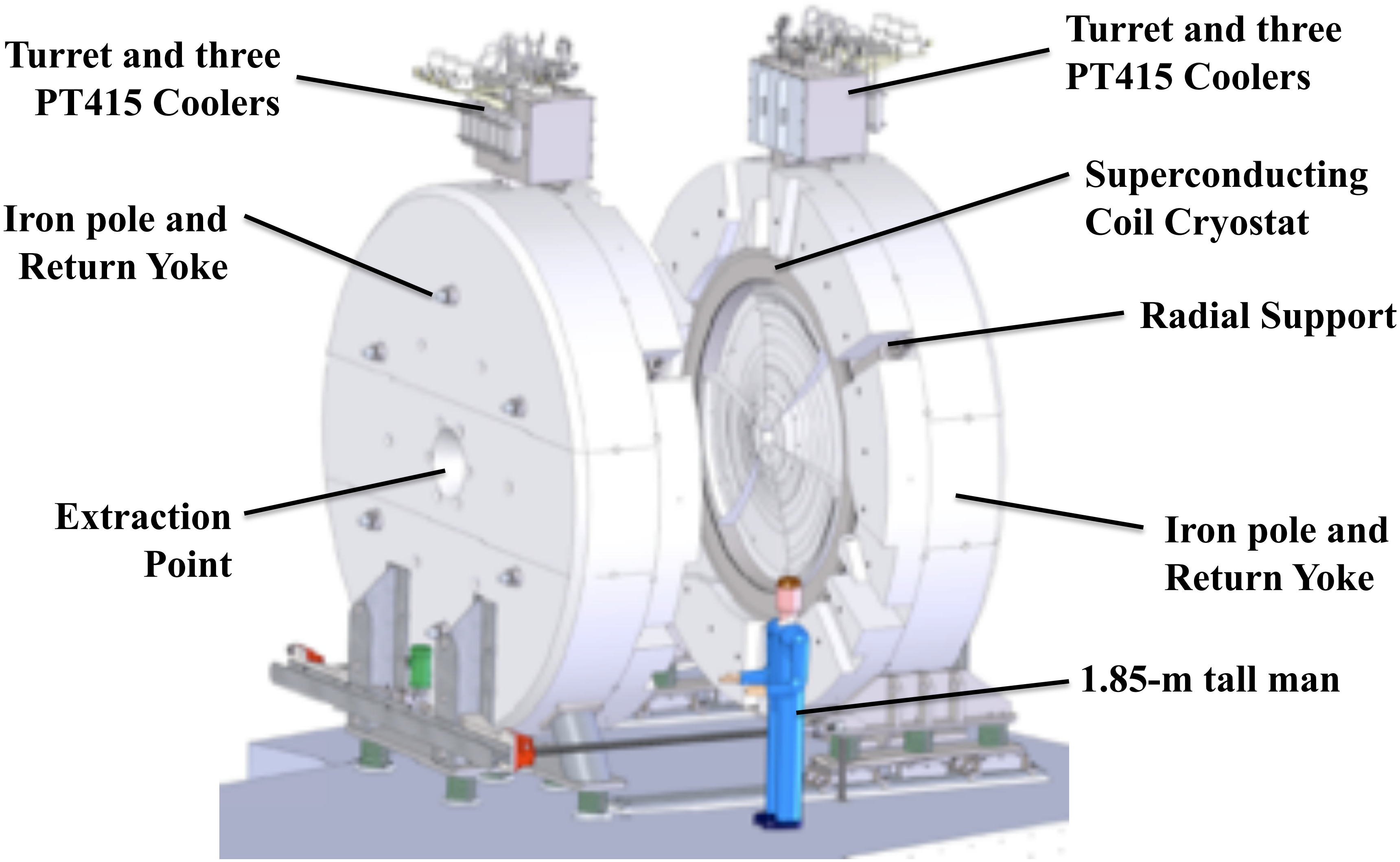
Michigan State University
East Lansing MI 48824, USA

CEC-ICMC 2015

The MSU Cyclotron Gas Stopper Magnet

- The cyclotron gas-stopper is a system for reducing the momentum of rare ions from 10 to 50 MeV/c to ~10 keV/c. Helium gas slows the heavy nuclei down while the ions are bent by a magnetic field so that they can be collected and extracted at the center of the magnet. The magnet has a horizontal axis.
- The magnet is an iron dominated 2.0 T sector pole dipole to focus the ion beam as deceleration occurs.
- The coils are cold, while the 167 ton magnet iron poles and return yoke are warm. The poles and return yoke are split to allow access to the beam chamber.

Gas Stopper Magnet split to expose the Coils



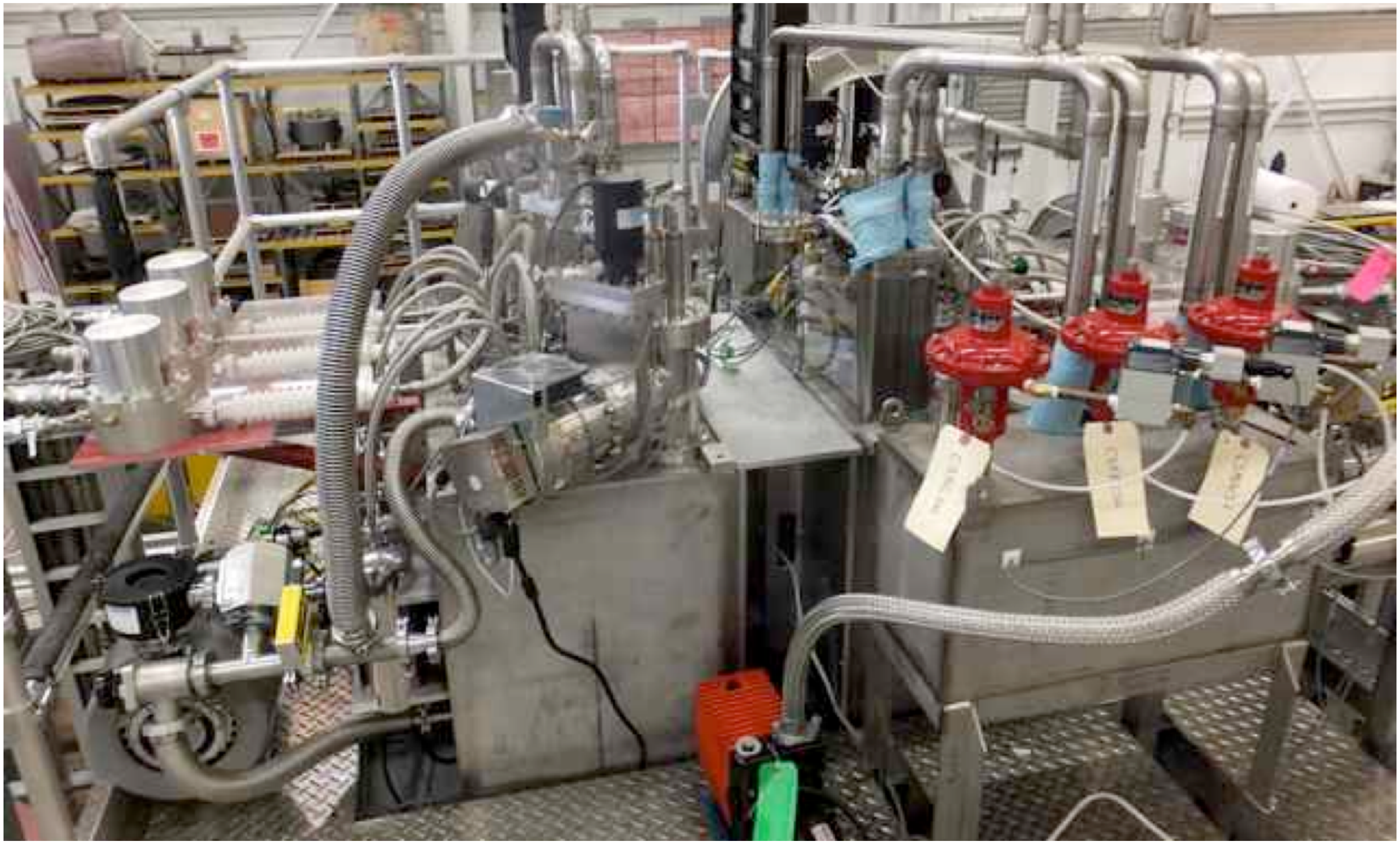
Gas Stopper Magnet Magnet Parameters

Table 1. Cyclotron gas-stopper magnet physical and electrical parameters.

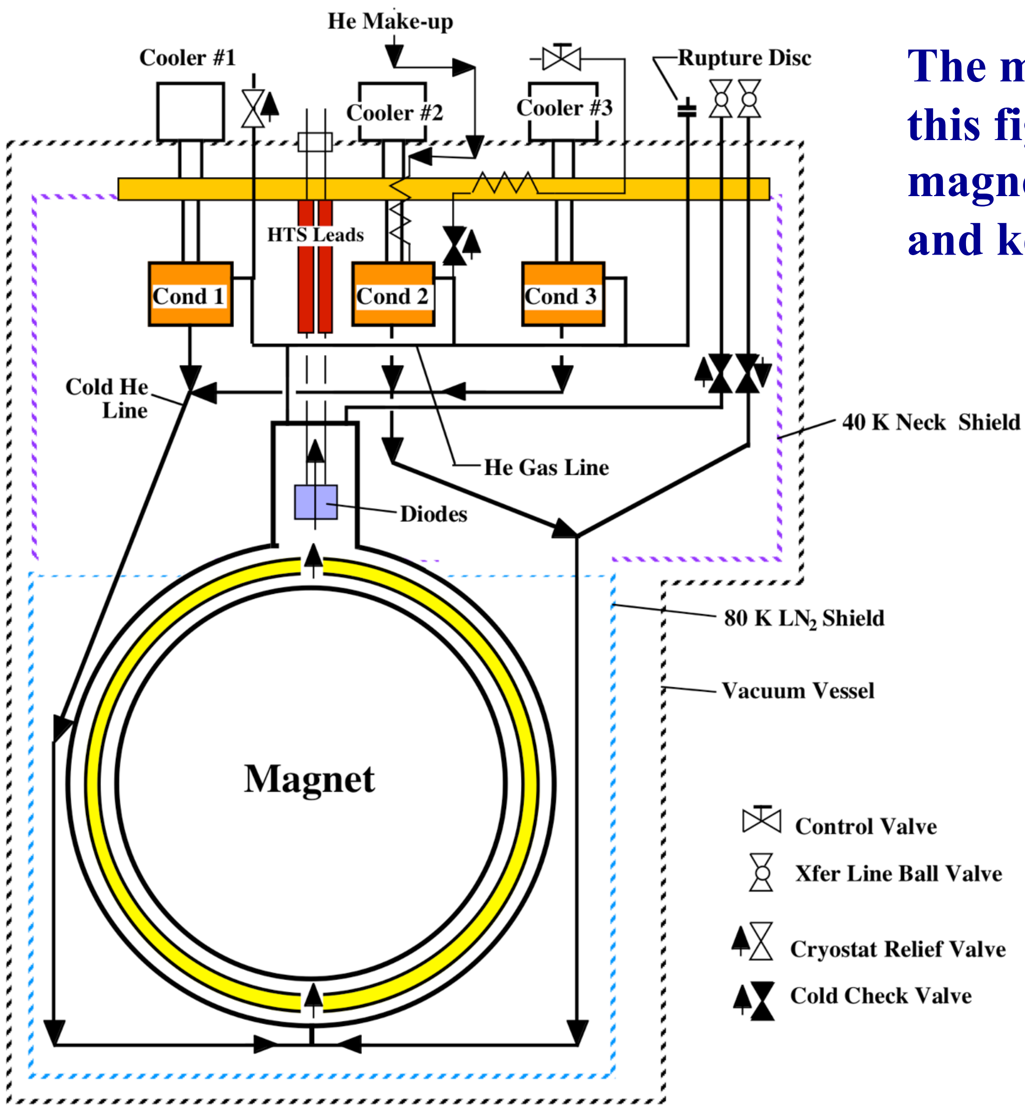
Parameter	Value
Iron Pole Radius (m)	1,10
Return Iron Outer Radius (m)	2.00
Average Pole Gap (mm)	180
Magnet Iron Mass (tons)	~167
Magnet Cold Mass per Coil (kg)	~1240
Number of coil turns	1767
Coil Cross-section R/Z (mm)	80/80
Coil Design Peak Current I_D (A)*	200
Coil Current Density at I_D (A mm^{-2})	54.9
Peak Induction in Coil at I_D (T)	2.05
Magnet Stored Energy E_D at I_D (MJ)	3.56
Self Inductance based on E_D (H)	178

The two magnet coils are cooled using six PT415 two-stage coolers. The same six PT415 two-stage coolers can cool down the magnet.

Top of the Magnets Cryostats and Coolers



Magnet Thermal Siphon Cooling Circuit

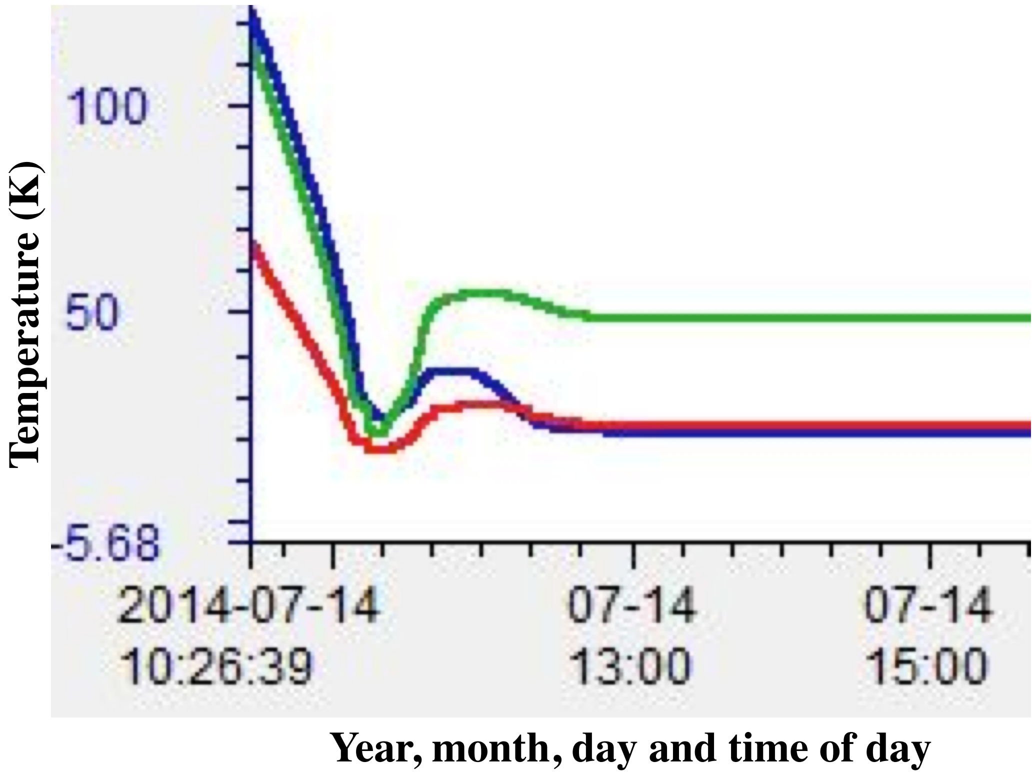


The magnet cooling circuit shown in this figure is designed to cool-down the magnet, liquefy helium in the cryostat, and keep the magnet cold at 4 K.

The condenser heat exchanger has warm helium from the magnet fed to the top of the condenser. Cold helium leaves the bottom of the condenser and goes to the bottom of the magnet cryostat to cool the magnet and it helium vessel.

This cooling circuit permits one to cool the magnet with a central refrigerator, as will as with the coolers.

The Dip in the Temperature 1.5 hours after the start of the Cool-down



T Sensor on Condenser 1 (red)
T Sensor on Condenser 2 (blue)
T Sensor on Condenser 3 (green)

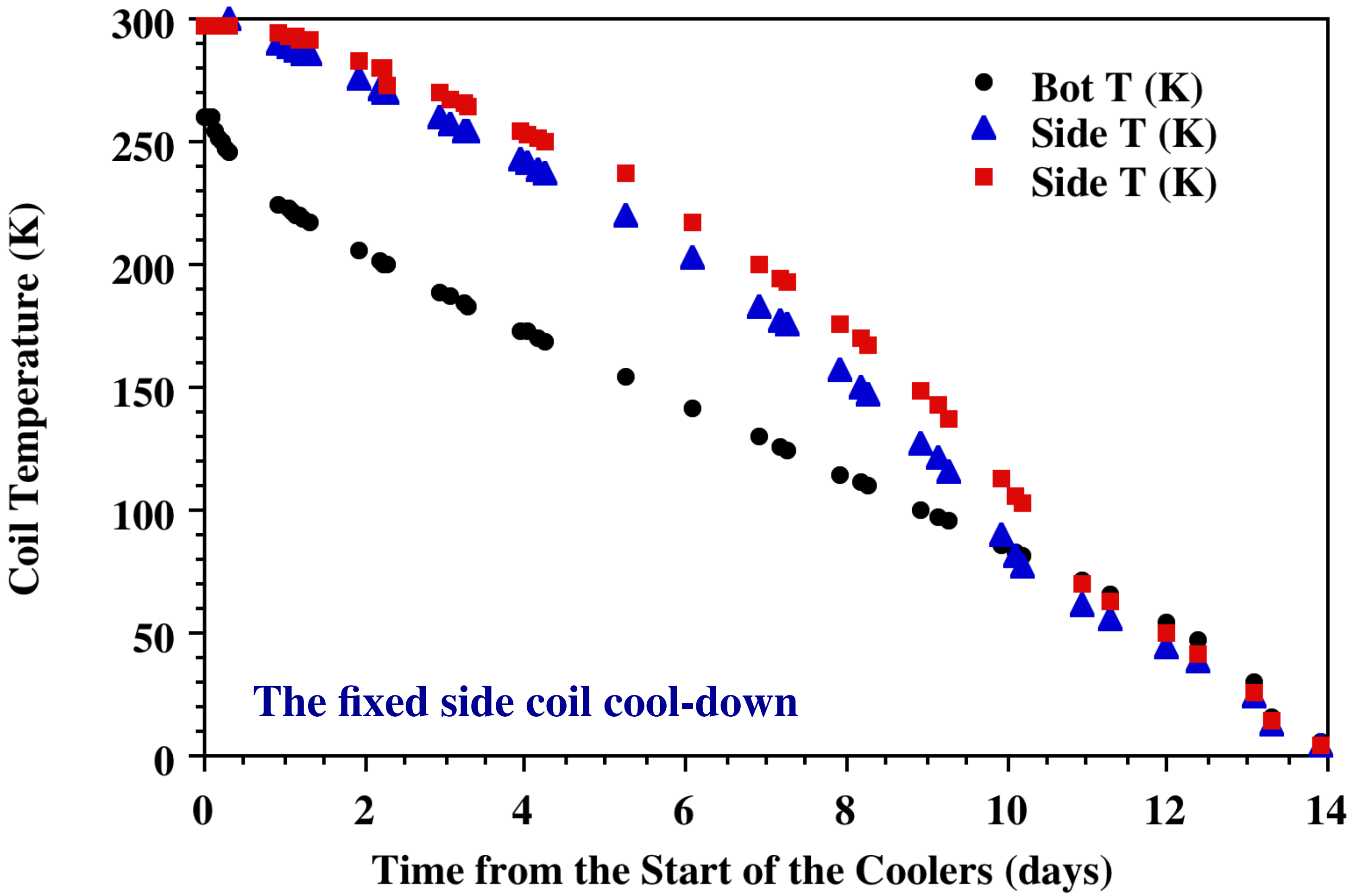
The temperature dip suggests the flow has started in the cryogenic cooling circuit.

The green sensor suggests that the cooler on condenser 3 is working much harder than the other two coolers.

A reason for a cooler not to work hard is a constriction in the helium flow to the low temperature sensor.

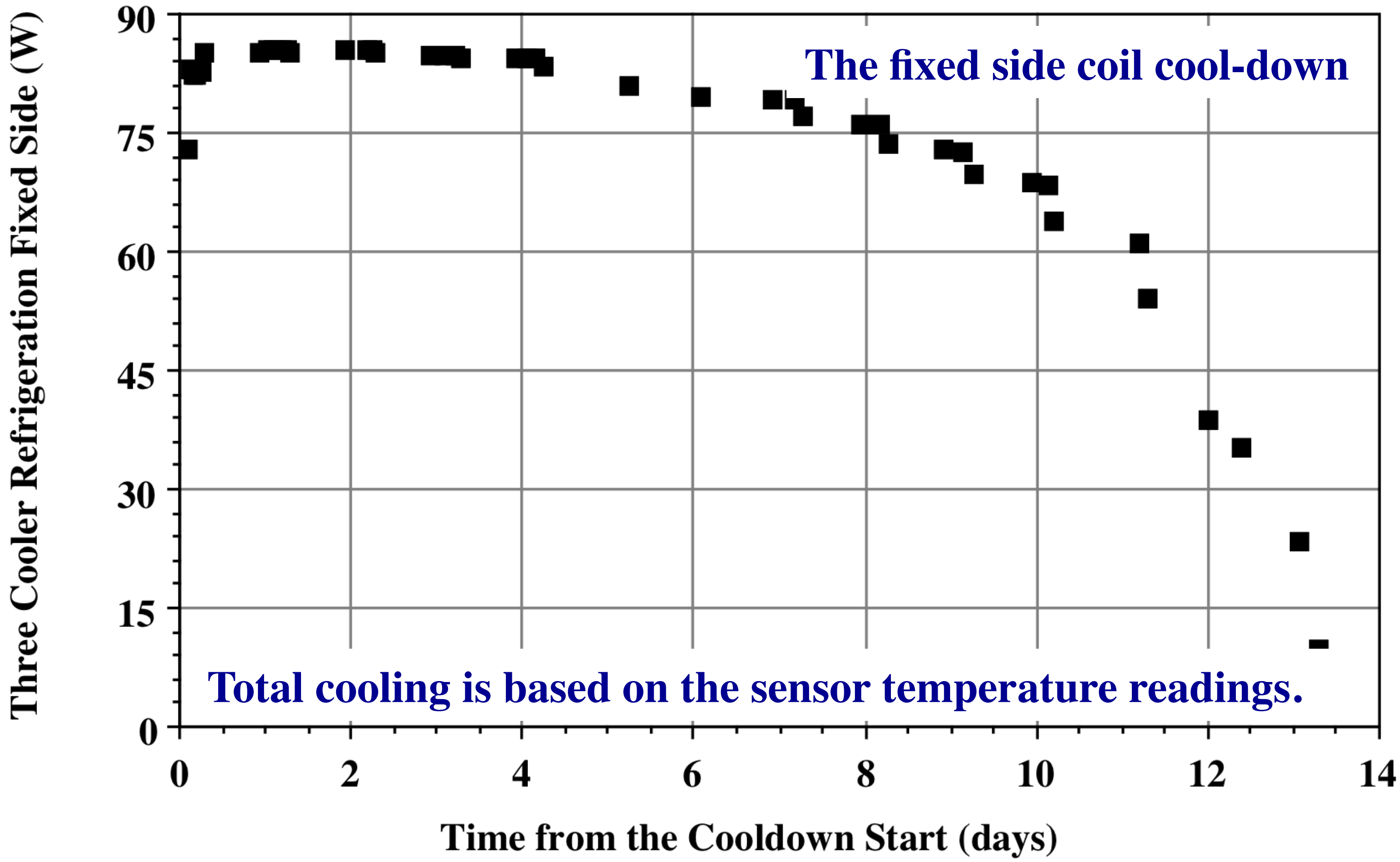
An improperly calibrated sensor is another possibility.

The magnet Temperature versus Time



The magnet cool-down took 13.5 to 14 days.

The Cooling from 3 Coolers versus Time



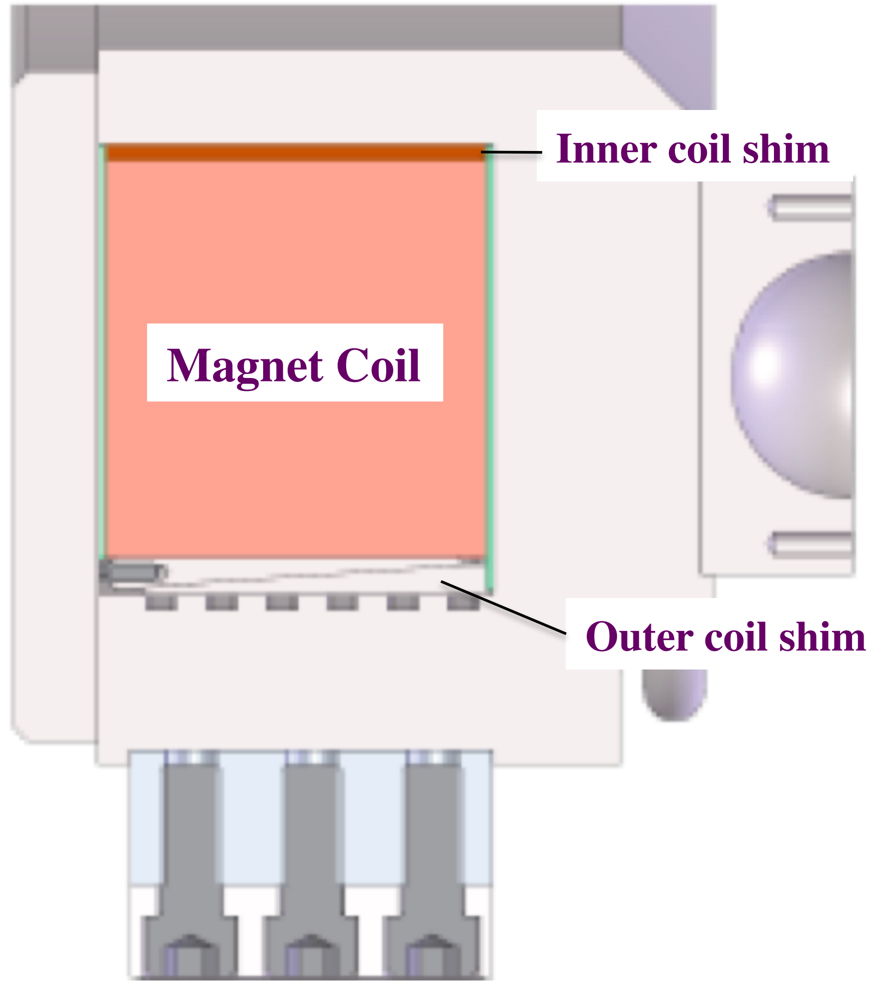
When one integrates the cooling over time, one find that the energy removed is 81 percent of the 104 MJ of thermal energy in 1240 kg of coil and cryostat. It is likely that one or more sensors is reading the wrong temperature.

Why is the cool-down time too long?

- Flow is restricted in the magnet coil cryostat because the cooling passages are too small.
- The shims in the magnet coil cryostat cause momentum jumps, which increase the cooling circuit pressure drop.
- The piping circuits into and out of each condenser are different lengths and diameters.
- The cooling model for the available cooling from the cooler was optimistic.
- The cryostat operating pressure is limited by the bellows in the piping. Otherwise the helium vessel is good for 1 MPa.

Gas Stopper Magnet Magnet Coil and Cryostat

Superconducting coil in its Helium Vessel. The inner shim is not shown.



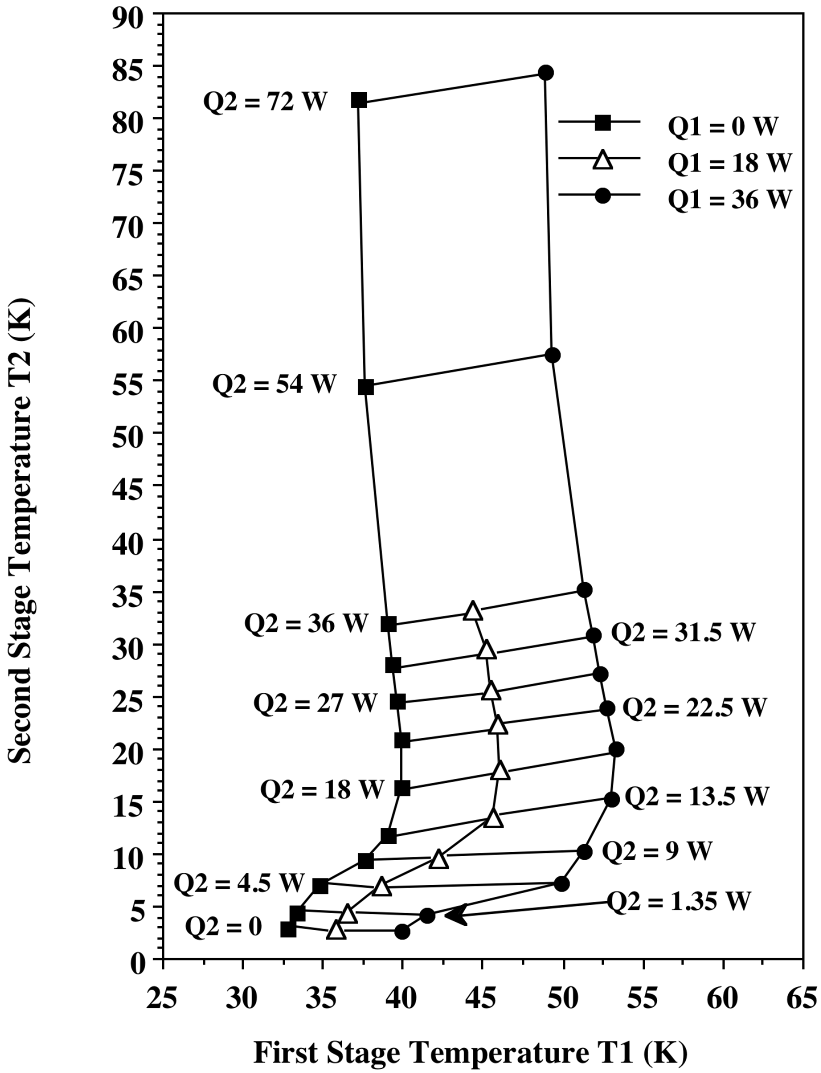
The Coil & Helium Vessel

Pipes into and out of the Condensers

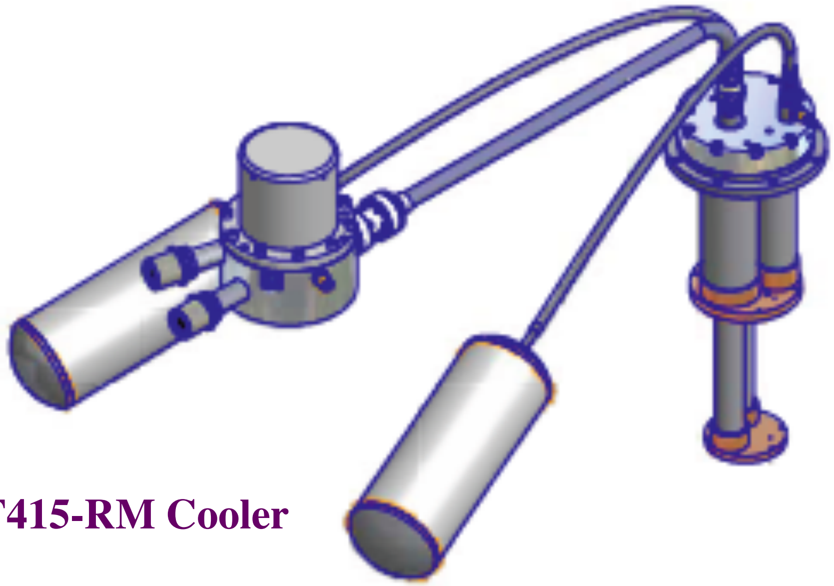
These pipes are not constricted very much.

This pipe is constricted

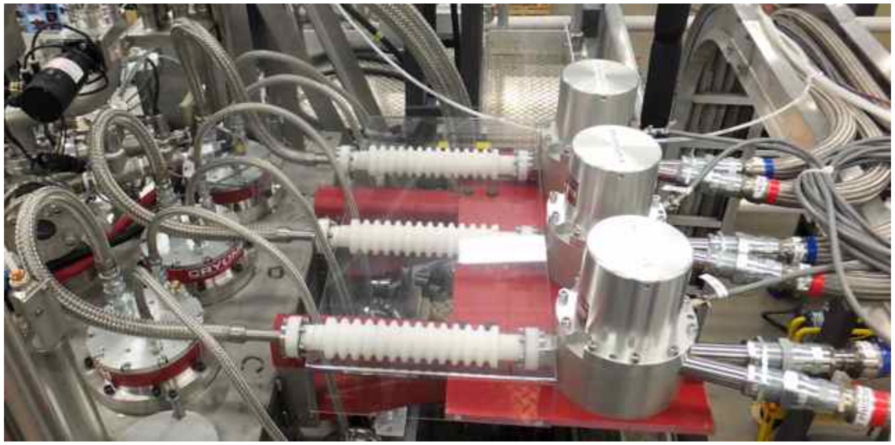
Cooling Parameters for a PT415-RM Cooler



PT415-RM Cooler Extended Performance

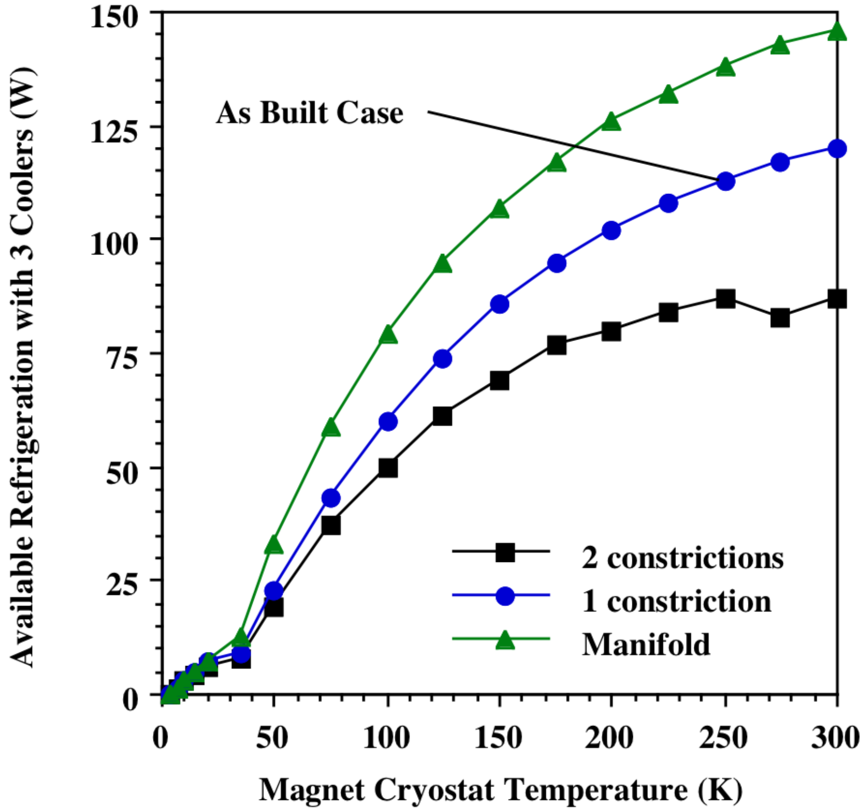


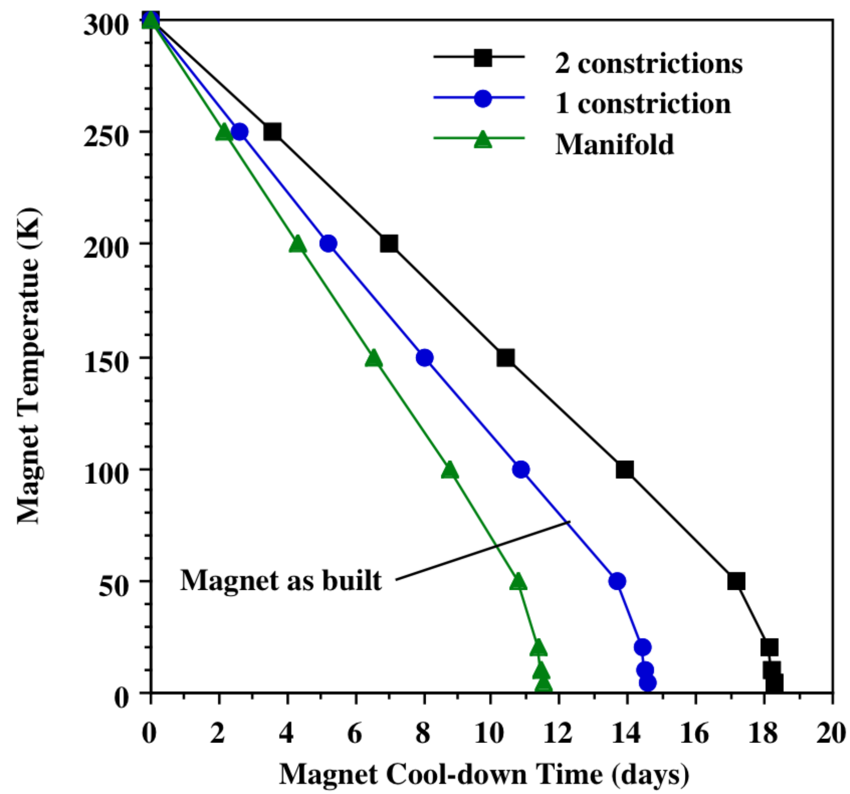
PT415-RM Cooler



Three PT415-RM Coolers at MSU

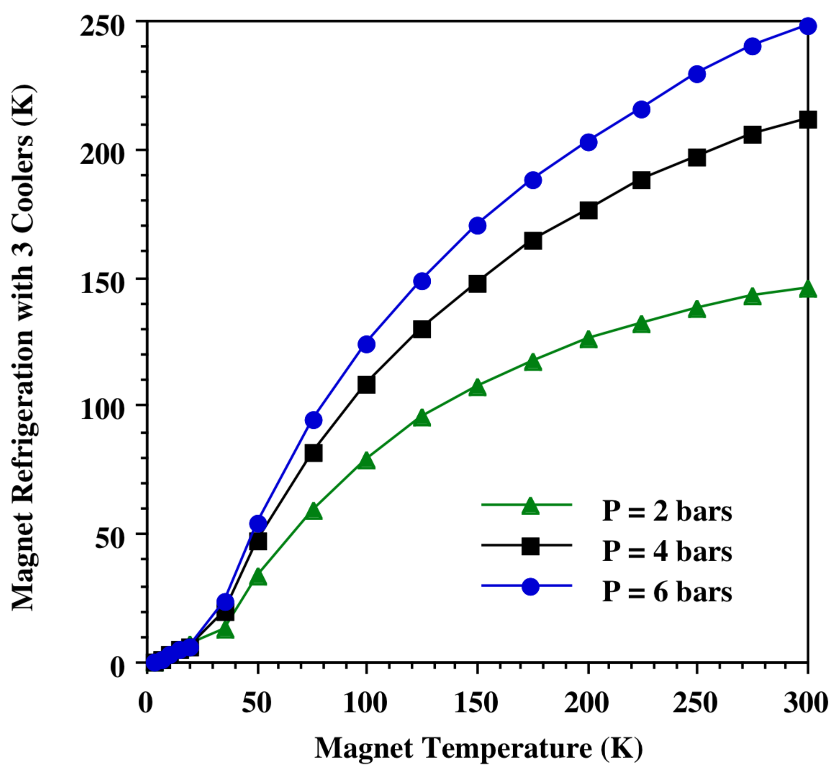
The Effect of Pipe Constrictions on Cool-down

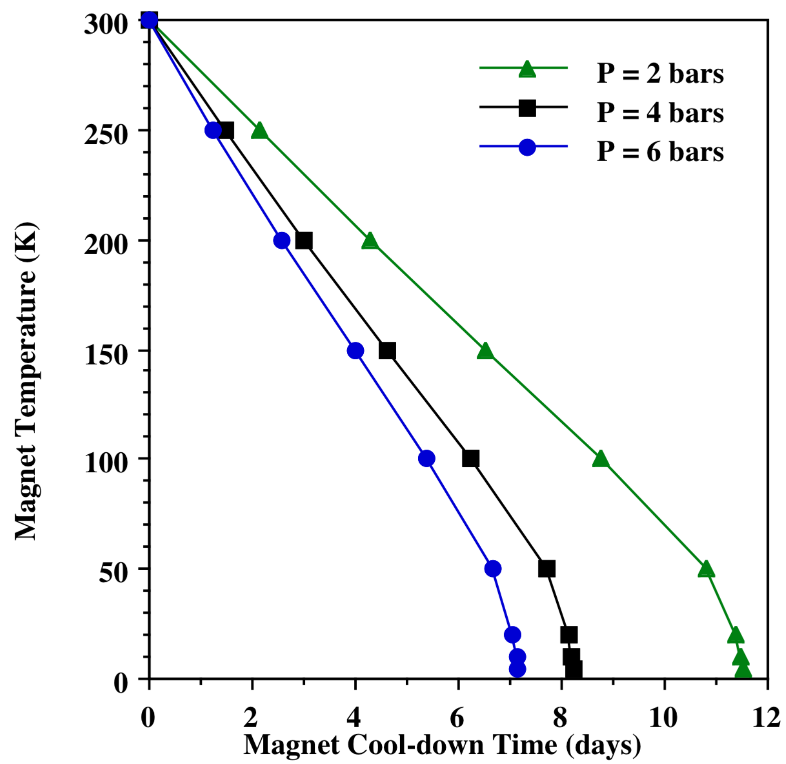




It is clear that there is only one real pipe constriction into the condensers.
The calculated cool-down time is close to the actual cool-down time.

The Effect of Cryostat Pressure on the Cool-down Time





The cryostat was designed for pressures above 1 MPa (10 bar absolute).
The bellows in piping from the condensers to the cryostat fail at 0.25 Mpa.

Concluding Comments

- **The cool-down of the MSU cyclotron gas-stopper magnet took almost 14 days instead of 4 days.**
- **There is a cooler cold head temperature dip just before the thermal-siphon cooling circuit flows.**
- **The primary reason for the increased cool-down time was the tightness of the magnet passages.**
- **The cooling circuit piping in and out of each condenser is different. As a result, the coolers don't remove the same amount of heat.**
- **The cryostat helium vessel pressure was limited to about 0.2 MPa by the bellows in the piping.**