Cryogenic behavior of the magnet

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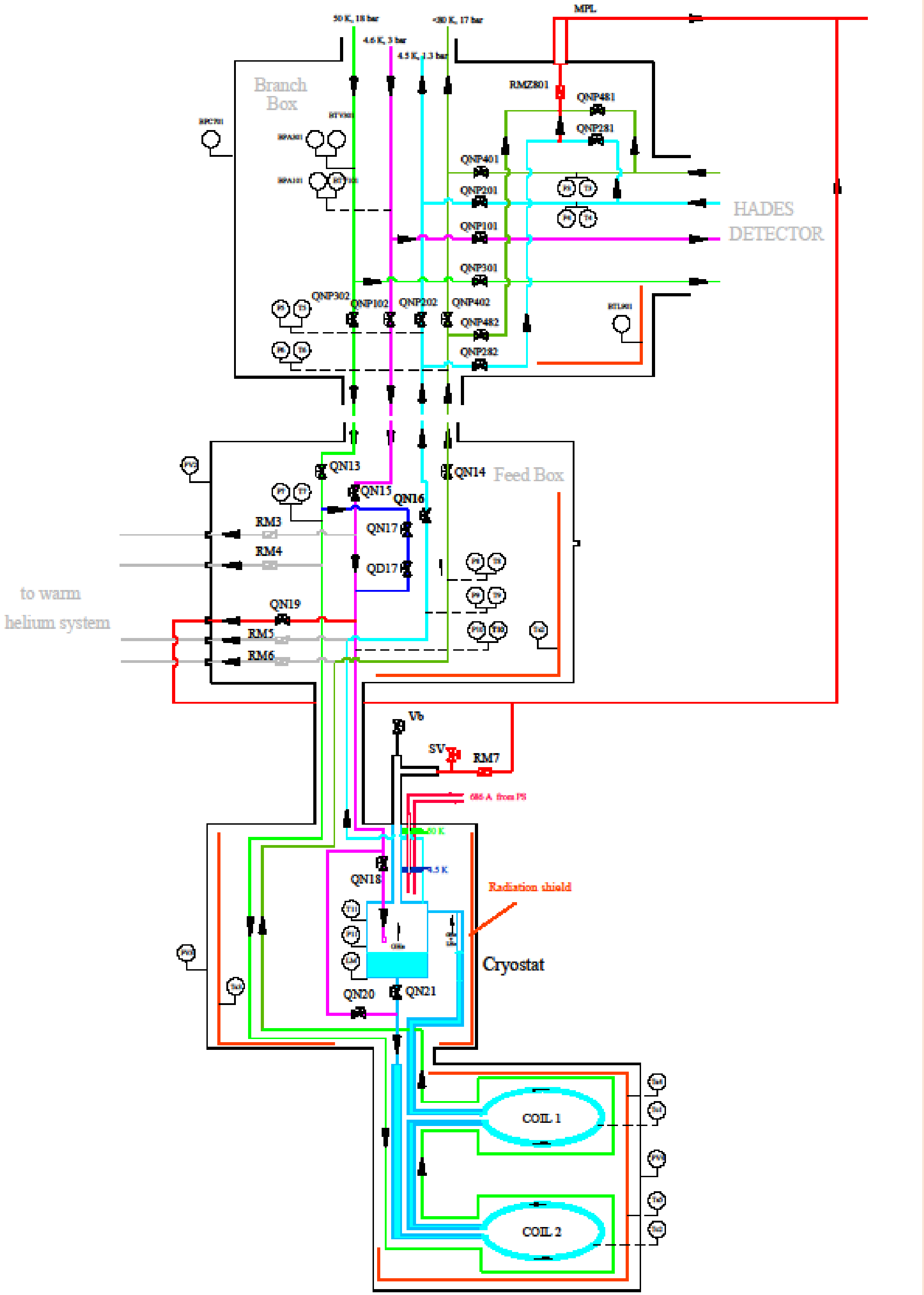
The cryogenic scheme of the CBM magnet

The total cryogenic diagram of the CBM magnet is shown.

It contain:
- The cryostat of the magnet
- The Feed Box
- The Branch Box
- The 25 m of the transfer line

Since May 2018 there is not principal change here.
The additional QD17 valve was added to exclude possible leakage from QN17 valve.



Cooling down of the magnet

Three stages of the cooling down:

- from 295 K to ~ 200 K (50% of internal energy)
- from ~200 K to ~80 K (90 % of internal energy)
- from 80 K to 4.5 K

From 295 K to 200 K

At the beginning some time will be spent for vacuum pumping. After 2-3 days (typically Saturday and Sunday) it will be $10^{-2} \div 10^{-3}$ Pa. Water leaves the material walls for about two days.

Total stored energy in one coil is ~ 160 MJ, about 50% in this stage.

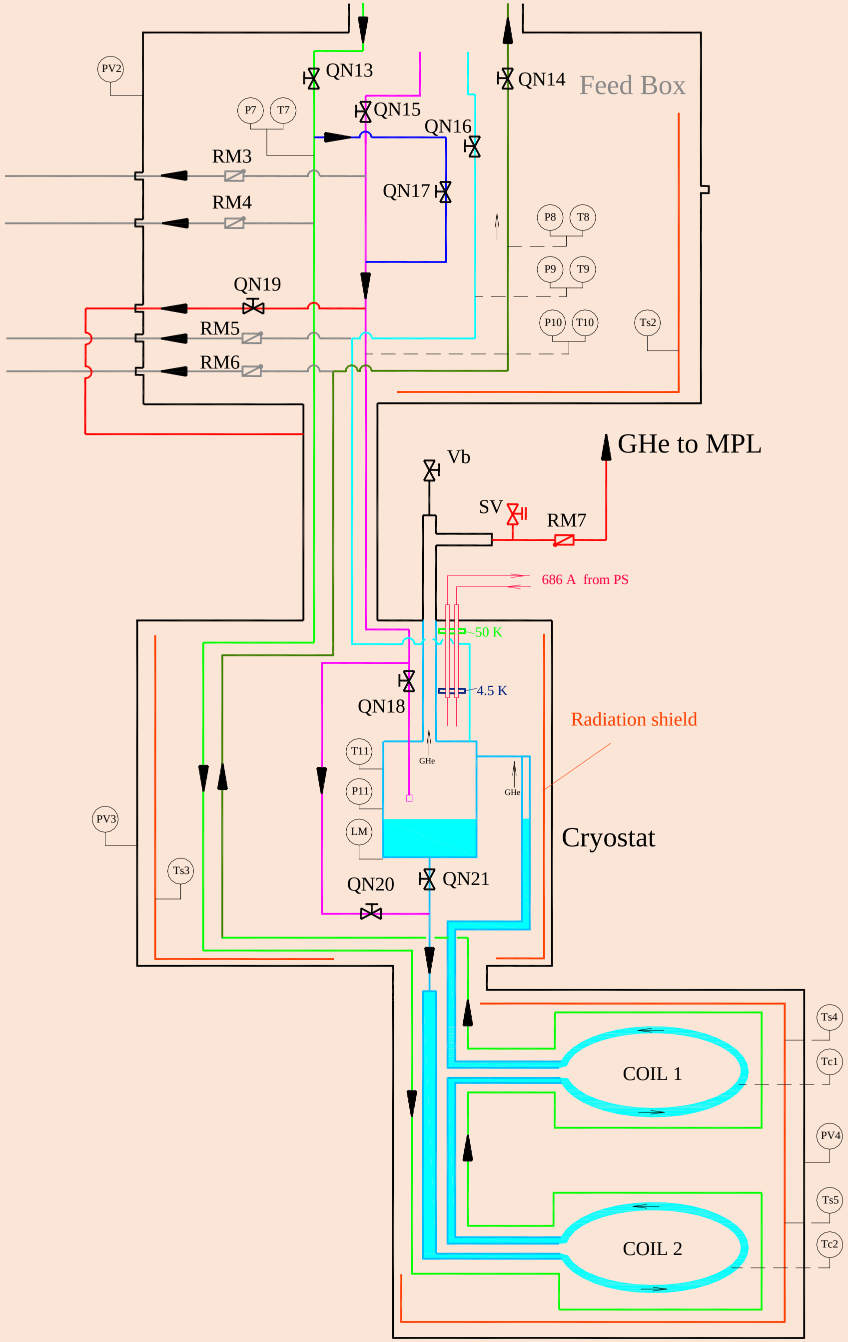
For cooling rate 1 K/h the power needed is ~450 W for two coils.

The radiation shields should be cooled first. The flow rate should be low for condensing water in the FB vicinity. QN17 is the control valve.

They will give from 150 W to ~50 W cooling power.

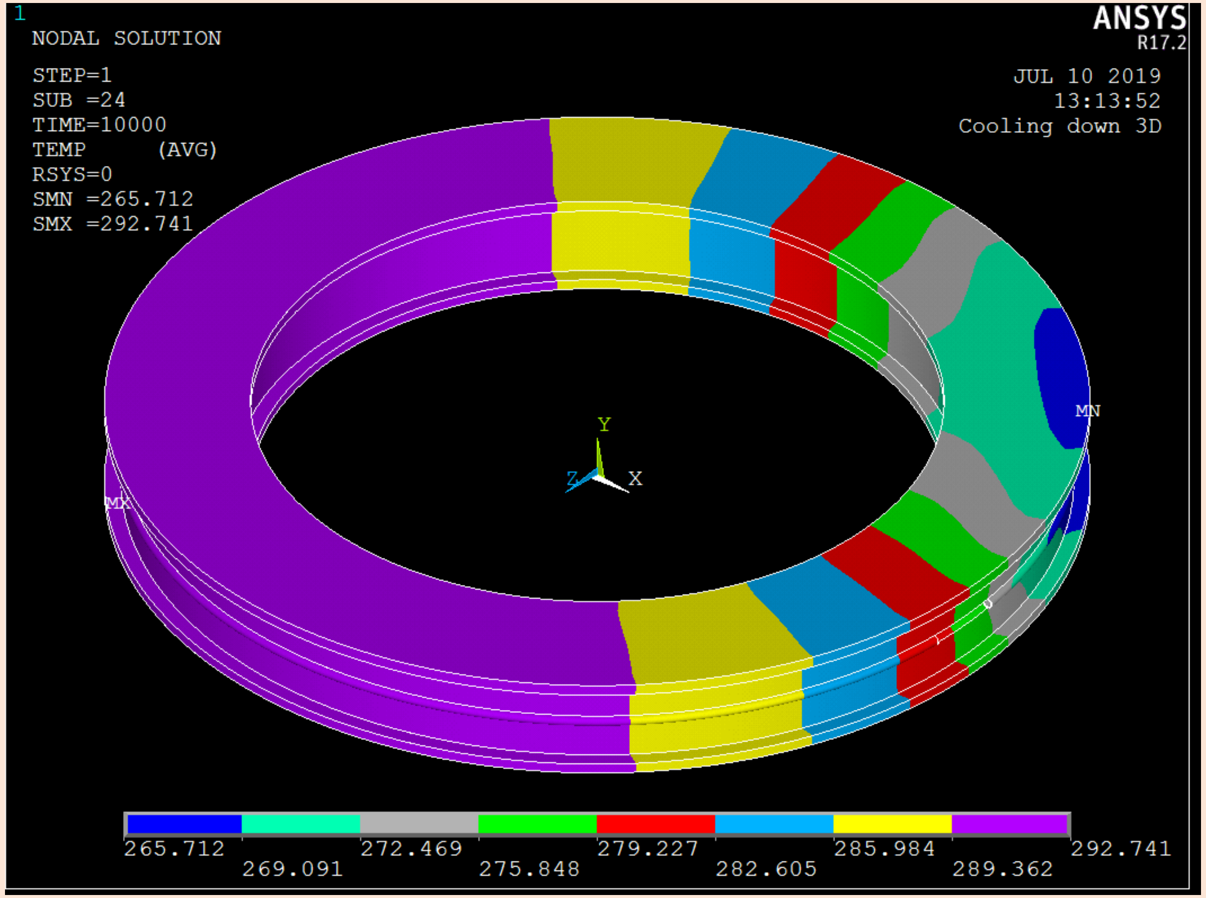
The magnet is cooled by 50 K helium of slow rate, about 0.4 g/s. Gas enthalpy is working.

Proposal to control temperature difference on the magnet during the cooling down.



Cooling by 50 K helium flow

The cooling was applied to the short length of the helium tube to demonstrate the thermal conducting properties of the coil.



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13:13:52
Cooling down 3D
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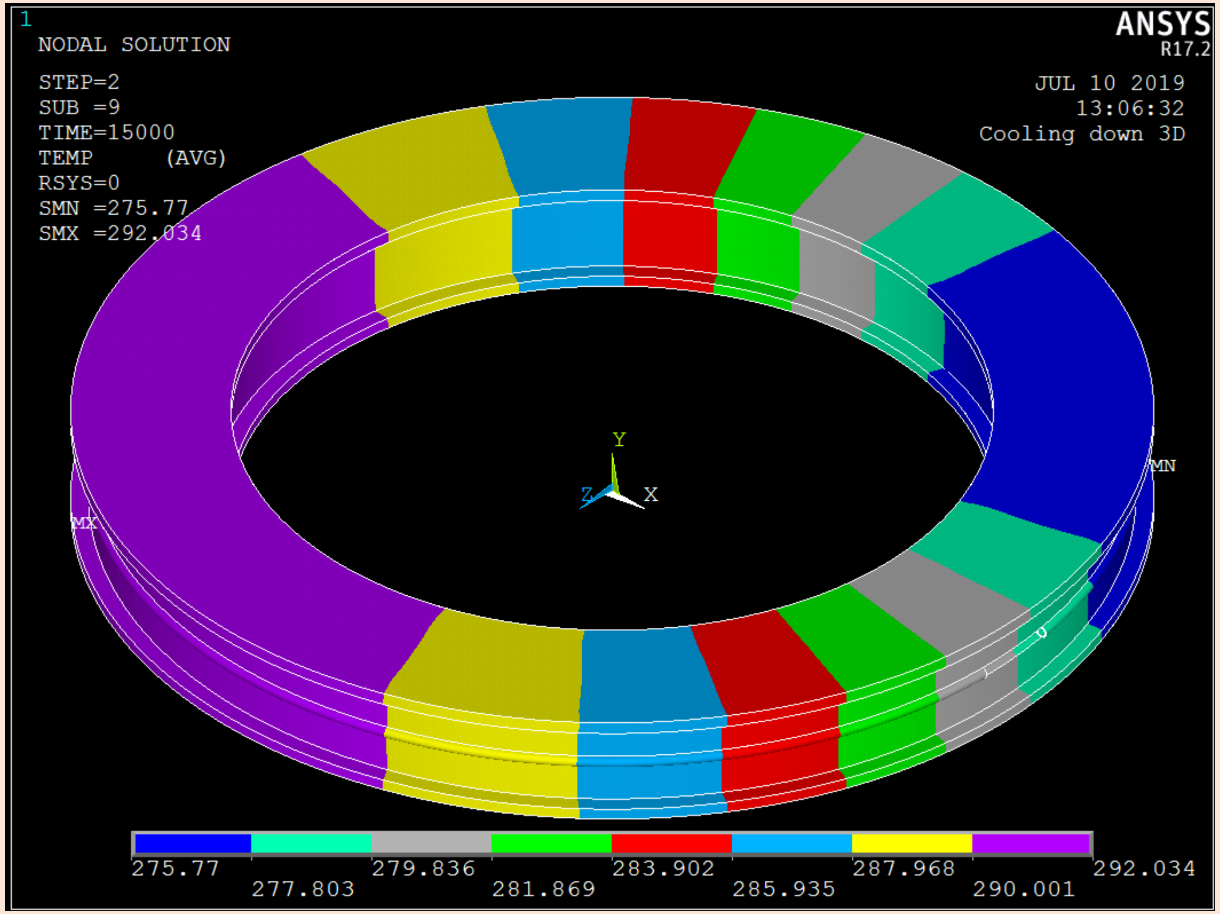
After 10000 seconds (2.8 hours)



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Cooling down 3D
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After 15000 seconds (4.2 hours)

The magnet has good thermal conductivity. The control of the temperature difference to be < ~ 20 K can be realized by decreasing the He flow.

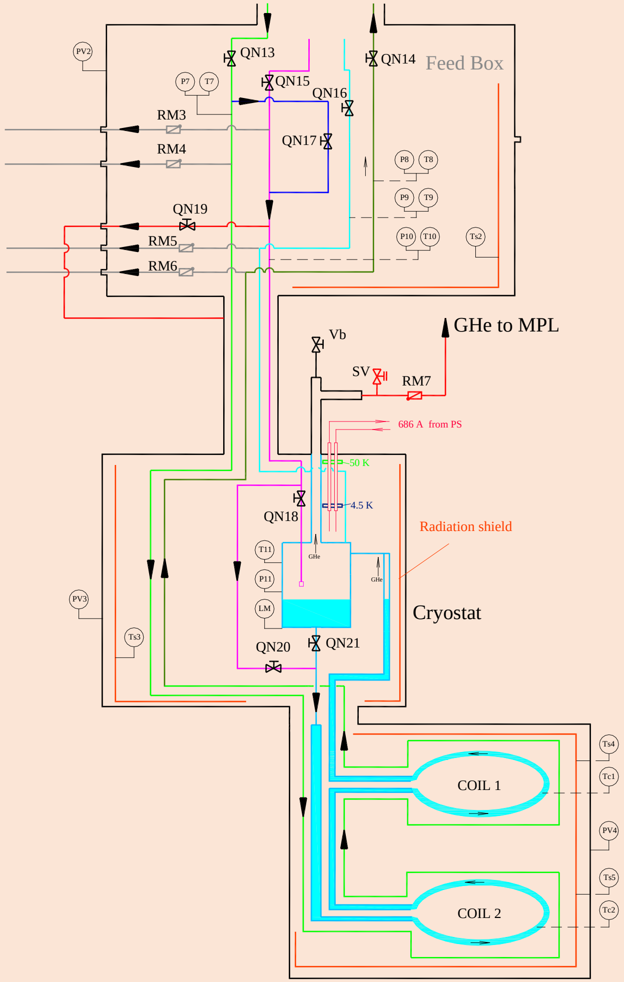
From 200 K to 80 K

About 45% of the initial stored energy will be extracted in this stage.

The cryogenic diagram is the same

The magnet is cooled by 50 K helium of increasing flow rate, about 1 g/s. Close to 80 K the flow rate will increased higher.

The temperature difference is controlled on the magnet.



Cooling down from ~80 K to 4.5 K

About 10% of the stored energy will be extracted in this stage, about 16 MJ for one coil.

The cooling scheme is changed like on the diagram.

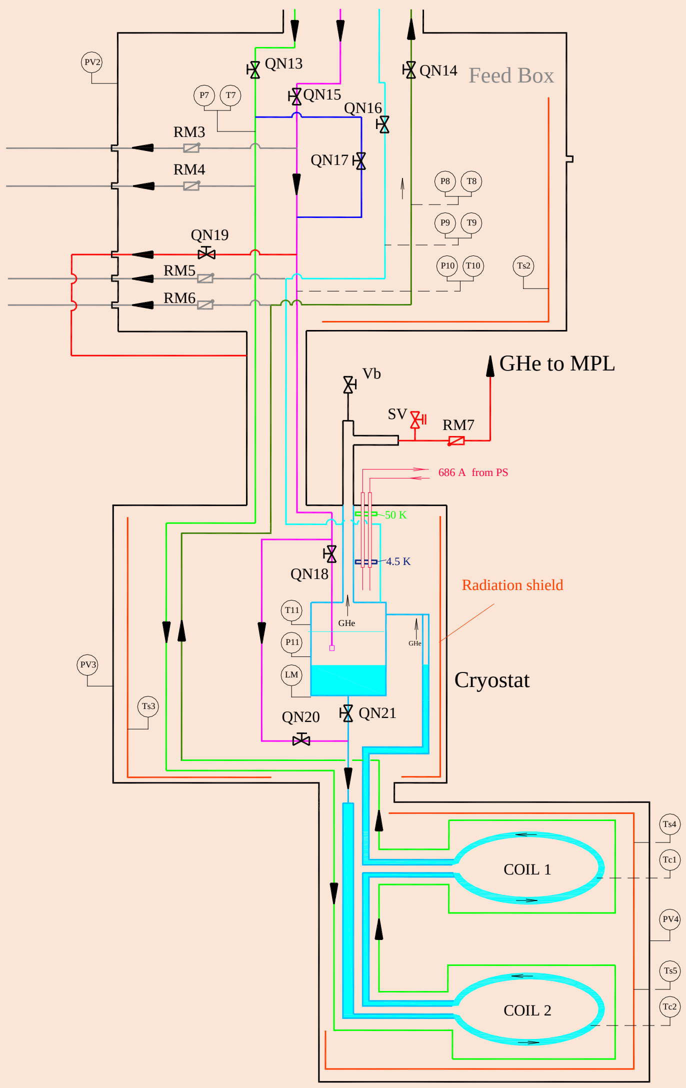
The 4.6 K will be used for cooling in this stage.

At 1.5 g/s mass flow rate it will take about 35 hours in this stage.

After reaching the 5 K temperatures, the cooling diagram becomes as for ordinal operation.

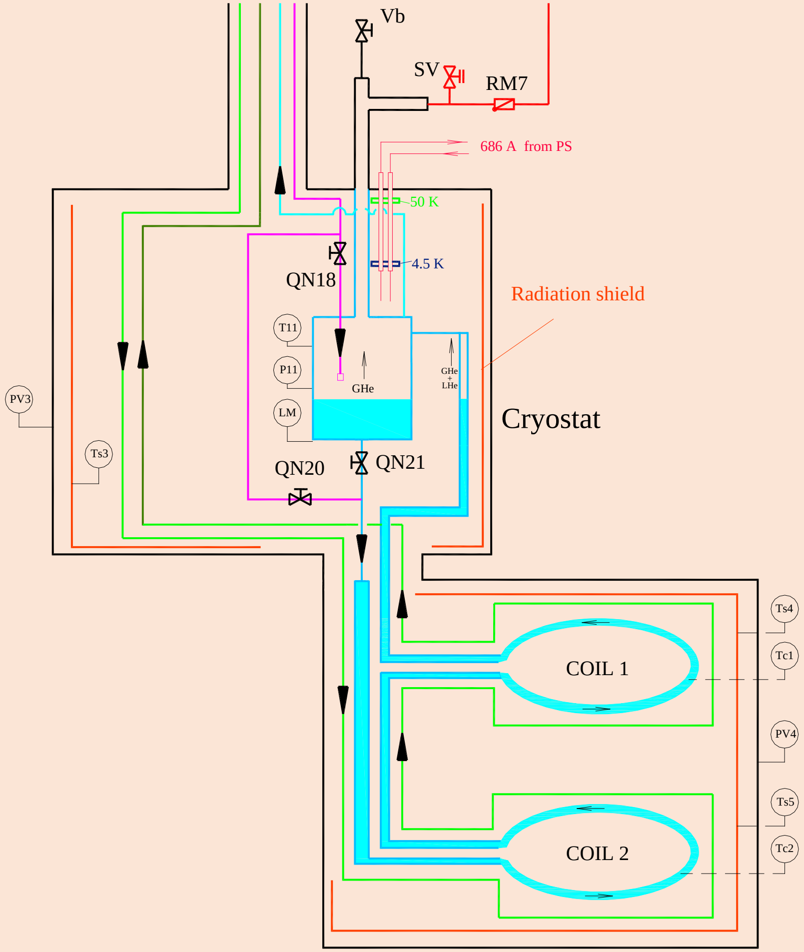
Total time for cooling the magnet is ~ 8 days.

Cooling from 100 K to 4.5 K



Operation at 4.5 K temperatures

The coils are cooled by the closed loop of helium on the thermosyphon principle.
The HTS current leads should be cooled by 50 K and 4.5 K gaseous helium.
The liquid helium level will be measured by installed LHe level meter.
One of the possible scenarios of LHe level controlling is to operate at insufficient flow of helium by controlling of QN18 valve, i.e. 1.5 g/s instead of demanded 1.7 g/s of flow rate. When the LHe level becomes too low then the QN18 will be opened to supply 1.8 g/s rate until demanded level of helium in the cryostat

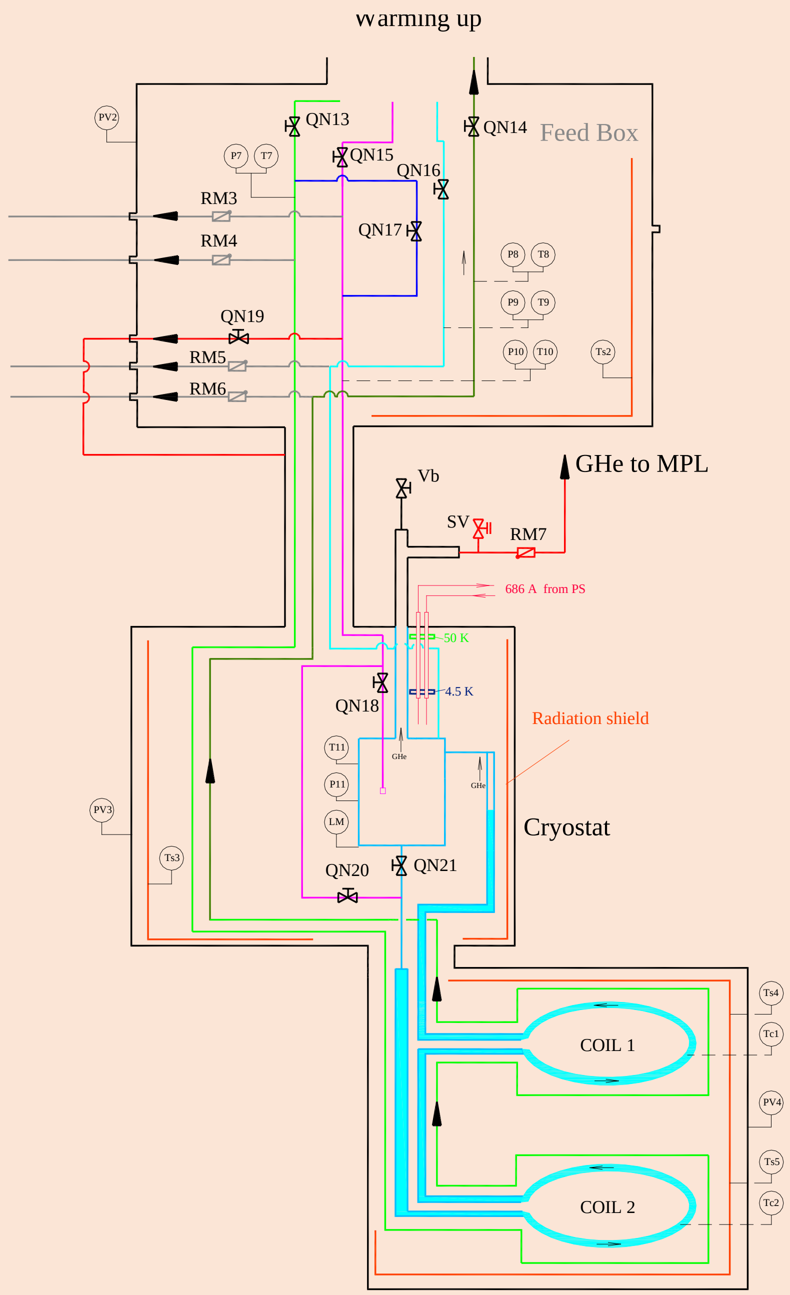


Warming up

This process will be conducted on the same principle as in the cooling down in the first and the second stages. The supply of 50 K helium should be shut. After increasing the lowest temperature in the cryogenic system beyond 27-28 K the vacuum pressure will be increased rapidly.

Some current may be input into the coils.

Additional power will come from heat transfer between the radiation shields and the magnet due to radiation and gases of vacuum volume. This power will be greater than from the proposed heaters.

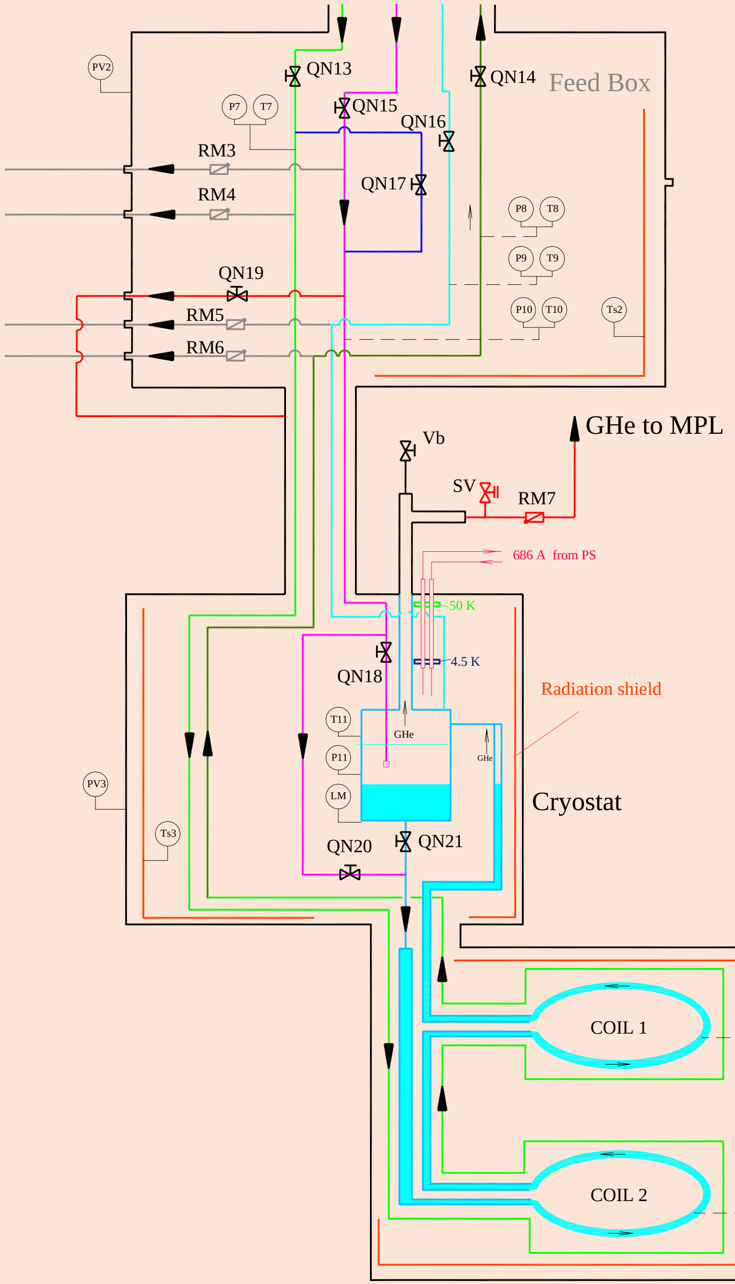


Quench recovery

If quench had occurred then the QN8 and QN9 valves in BB should be closed. The rising pressure in the cryostat will open RM7 valve to the multipurpose line. Liquid helium in the cryostat will not go down to the coils. The highest pressure in the system will be not more than 0.5 bar due to little amount of stored liquid helium in the system.

In the worse case of quench, when the stored energy is fully dissipated in one coil – this coil after a quench will be slowly cooled from ~ 90 K to ~ 50 K due to heat transfer between the winding and the heavy LHe case. After this the cooling down procedure will go as in the third stage of cooling down the magnet.

Cooling from 100 K to 4.5 K



Safety analysis 1. Pressure rise during the quench.

Very high pressure may be in the cryostat in case of a quench or any break of insulating vacuum when air or even helium may leak inside the vacuum volume. It will lead to very high heat flux to the coils and the cryostat.

In the current design only 3 l of LHe are in the coils. In the LHe cryostat volume ~ 180 l.

Typical value of the heat flux is 10 kW/m^2.

This factors determines the mass flow rate of helium – G to be evacuated from the system.

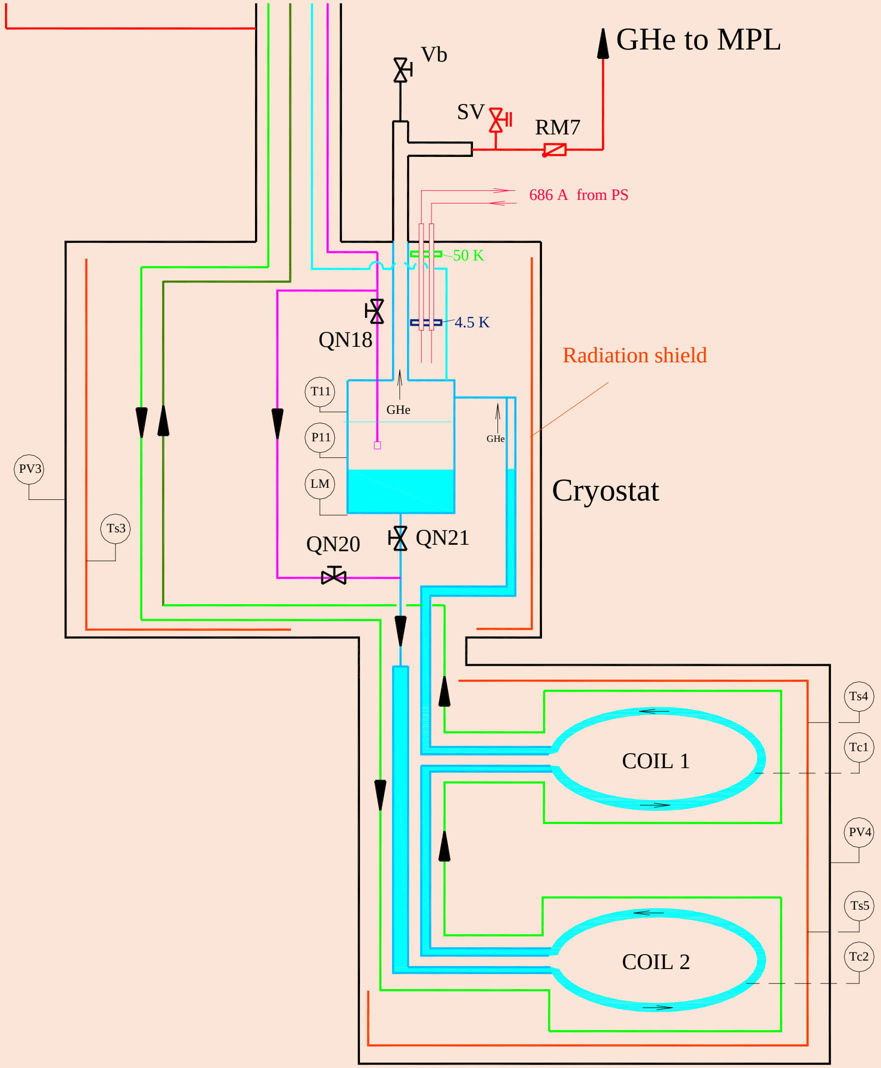
For the coils G = 0.3 kg/s, tube diameter is

d= 0.016 m. The result for the coil is

Δp = 1.4 bar. Helium will be evacuated after 1.2 s at given parameters.

For the cryostat: G = 1 kg/s, d = 0.03 m. The result for the cryostat is Δp = 0.04 bar.

$$\Delta p = \xi \frac{8G^2}{\pi^2 \rho \cdot Y^2} \cdot \frac{L}{d^5}$$



Safety analysis 2. Cooling down valves are fully opened.

Faulty full opening of cooling down valves may have some risk of destroying cold elements of the system including the coils.

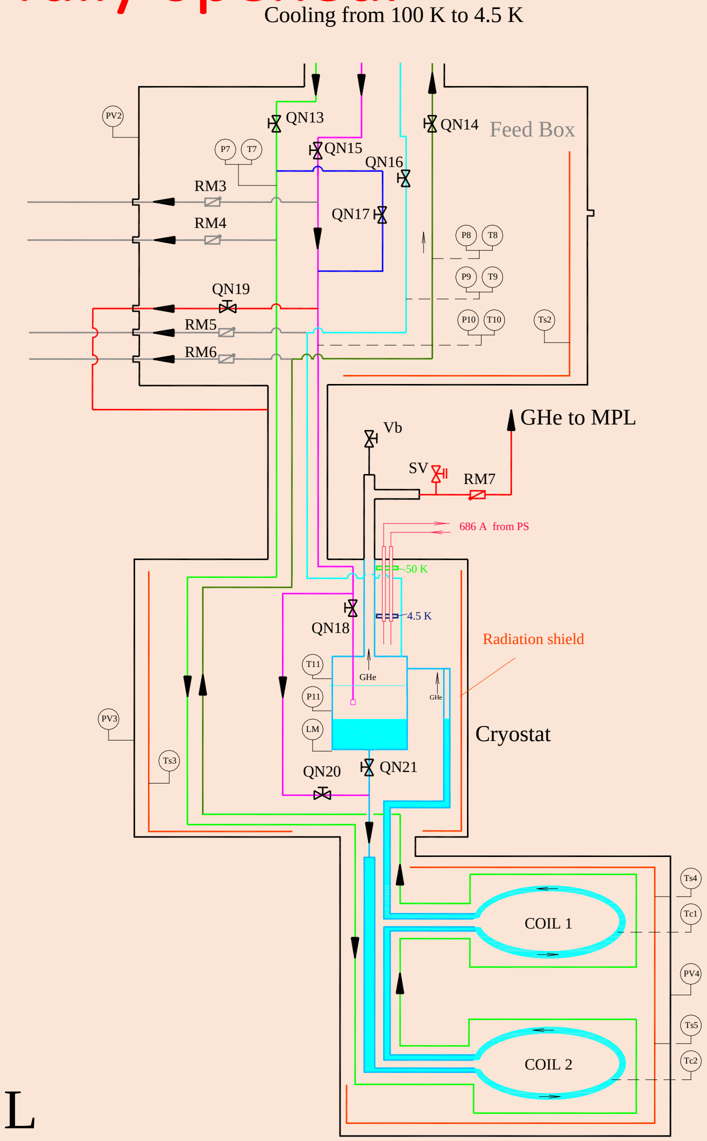
The by-pass lines intended for cooling down only can be designed with narrow tubes to restrict high mass flow rate.

These lines are placed around the QN17 and QN20 valves.

At 18 bar pressure, 6 mm of i.d. and 0.5 m of length (QN17), the mass flow rate of 50 K helium can be restricted to 0.02 kg/s. The cooling power in 50-100 K enthalpy is ~ 5 kW. Not high.

Δp = 0.06 bar for ordinal cooling down mass flow rate.

Conclusion: the narrow tube with 6 mm of internal diameter may be used in the design.



$$\Delta p = \xi \frac{8G^2}{\pi^2 \rho \cdot} \cdot \frac{L}{d^5}$$

Conclusions

- Cooling down of the magnet
- Operation at 4.5 K temperatures
- Warming up
- Quench recovery
- Some safety aspects were discussed