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# AMS Magnet
# Cryogenic System Overview

Steve Harrison
Scientific Magnetics

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- Helium cooling and superfluid helium
- Magnet layout
- Cool down, filling, and pump down
- Steady state cooling system
- Current leads
- Quench and quench recovery
- Burst discs
- Valves

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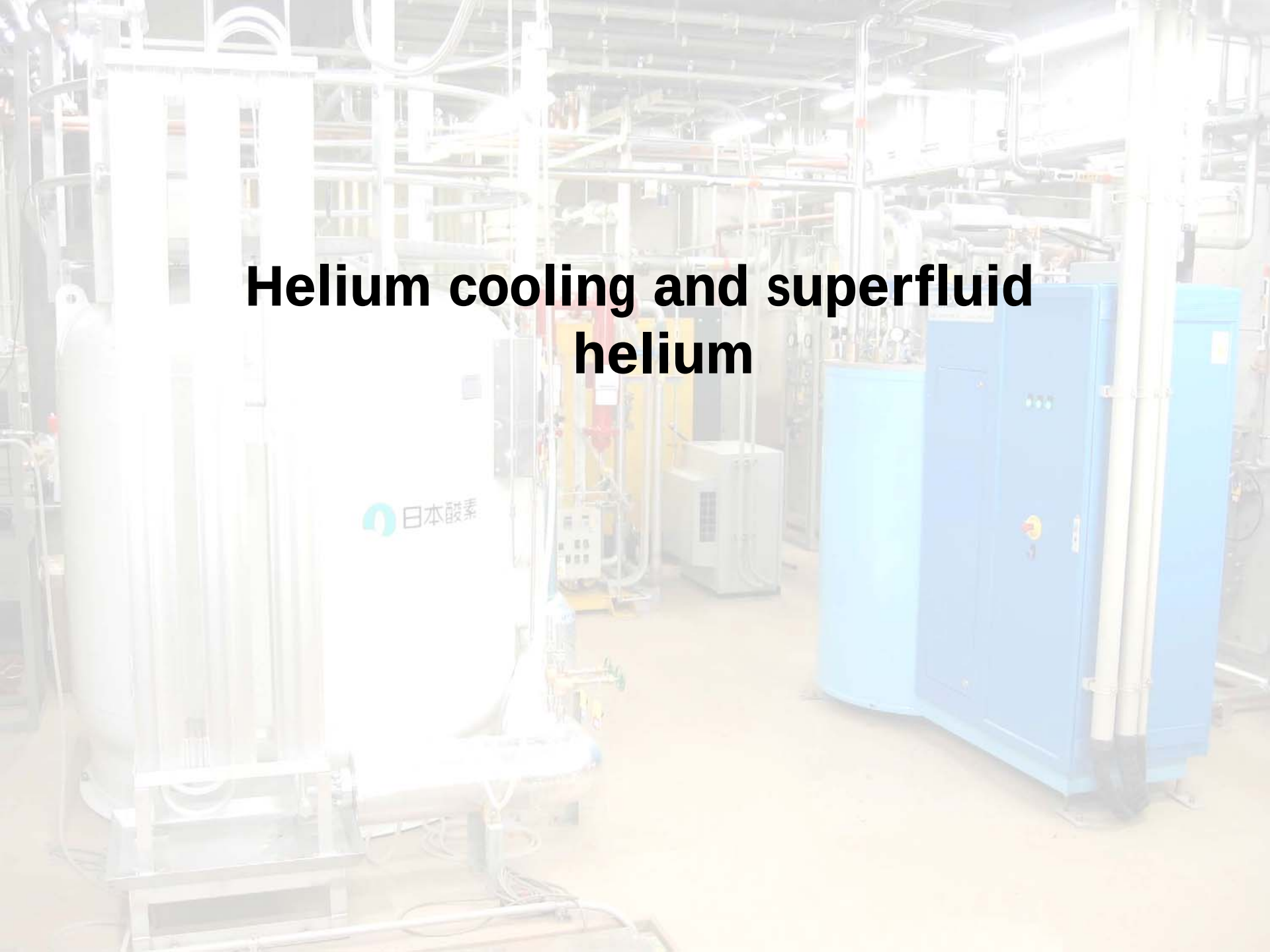
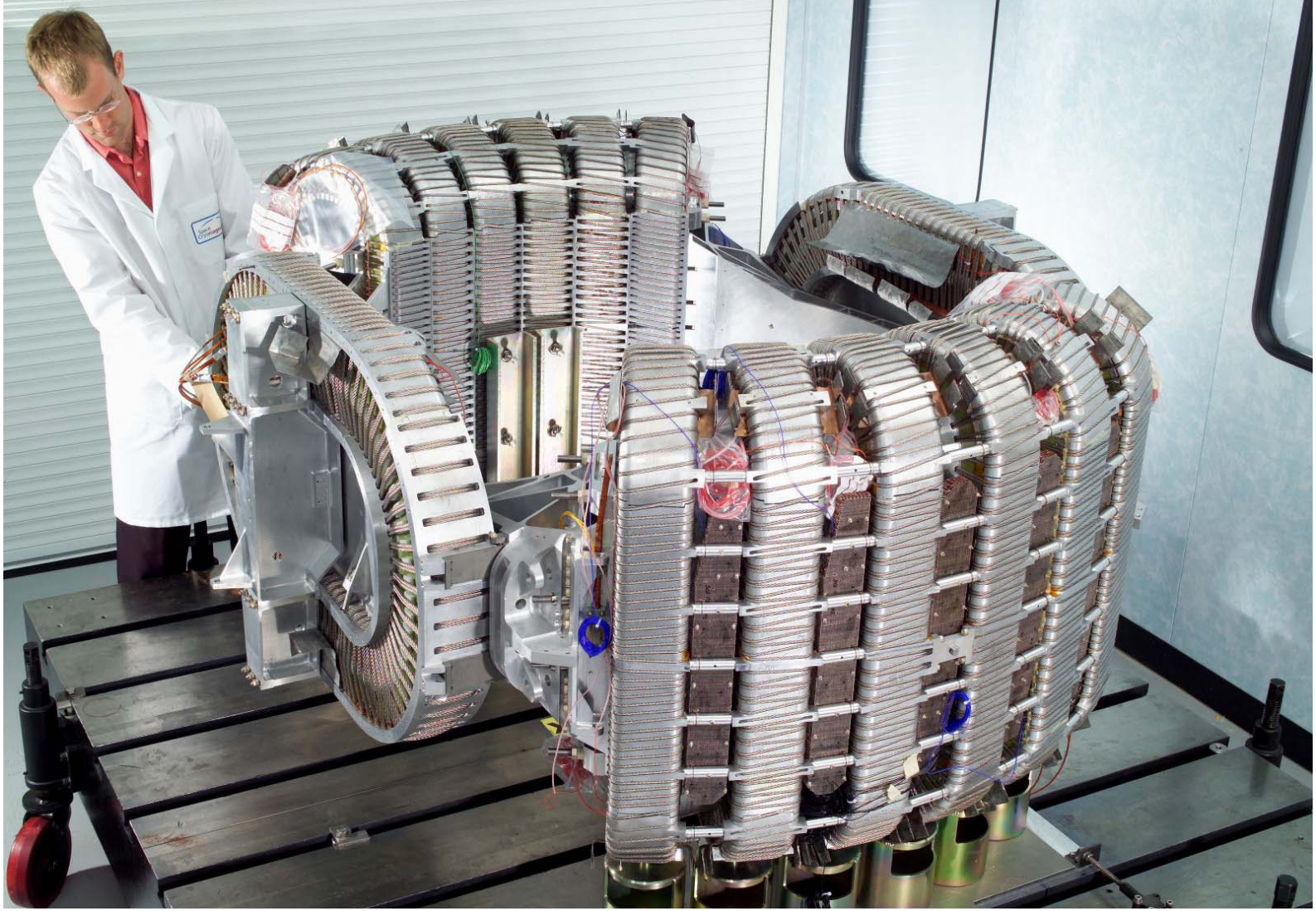



# Helium cooling and superfluid helium



The AMS magnet has 14 coils. These have to be maintained at a temperature below 4.0 K to be superconducting.

A superconducting coil can produce a high magnetic field for minimal weight and power consumption.

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To keep the coils at this temperature we use liquid helium:

- The only coolant which is still liquid at this temperature;
- Widely used all over the world in MRI and scientific systems.

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In common with several other cryogenic missions (IRAS, COBE, SHOOT, ISO, GP-B, Herschel)
AMS uses helium in the superfluid phase (below 2.17 K).

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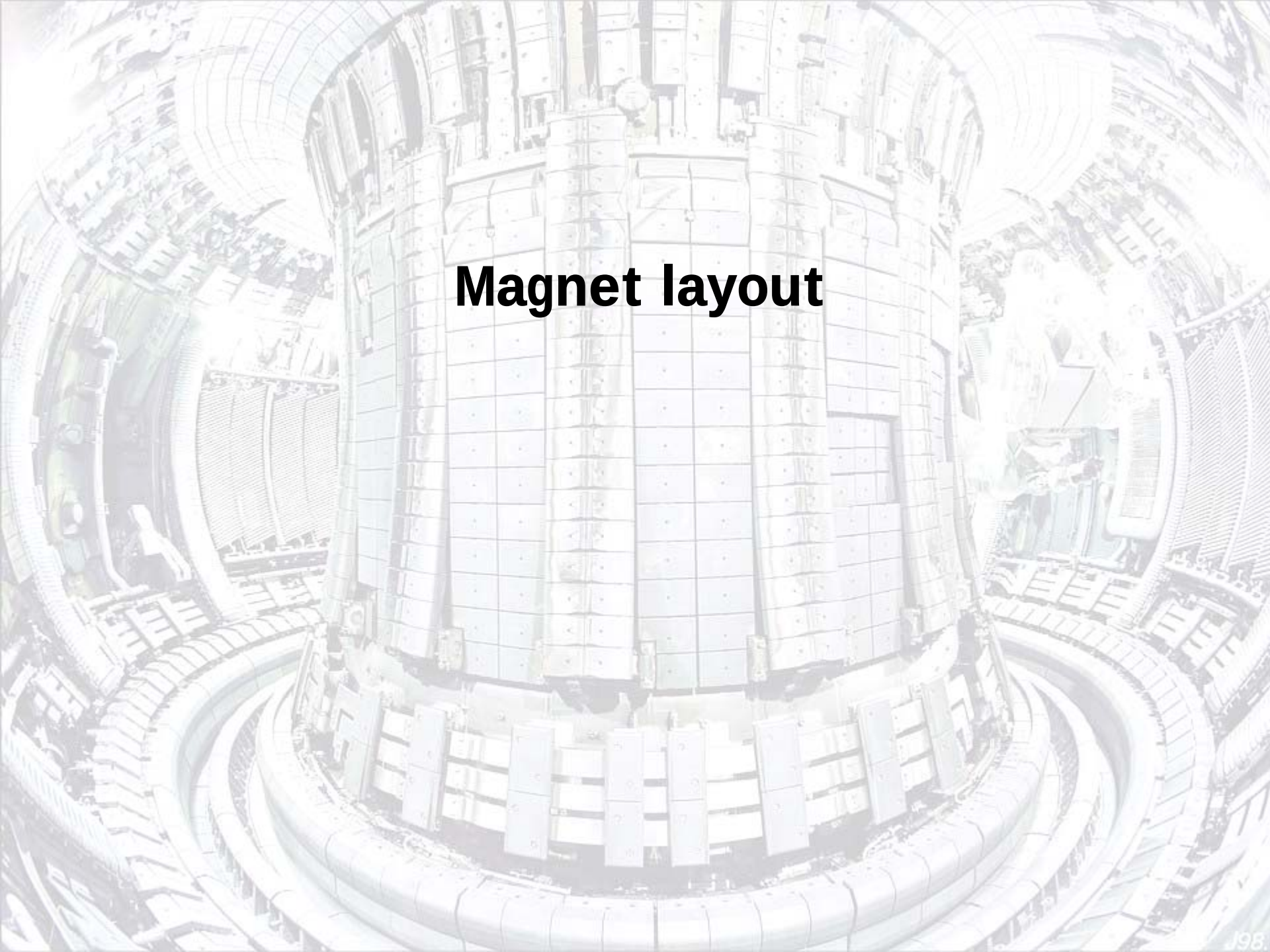
With superfluid helium we have extremely high thermal conductivity and heat capacity, giving good thermal stability.

Superfluid helium exhibits the “mechanocaloric effect”, which can be used for zero-gravity phase separation, and for pumping helium for use as a coolant.

# Magnet layout



The AMS helium vessel is toroidal (shown here during a cleaning process).

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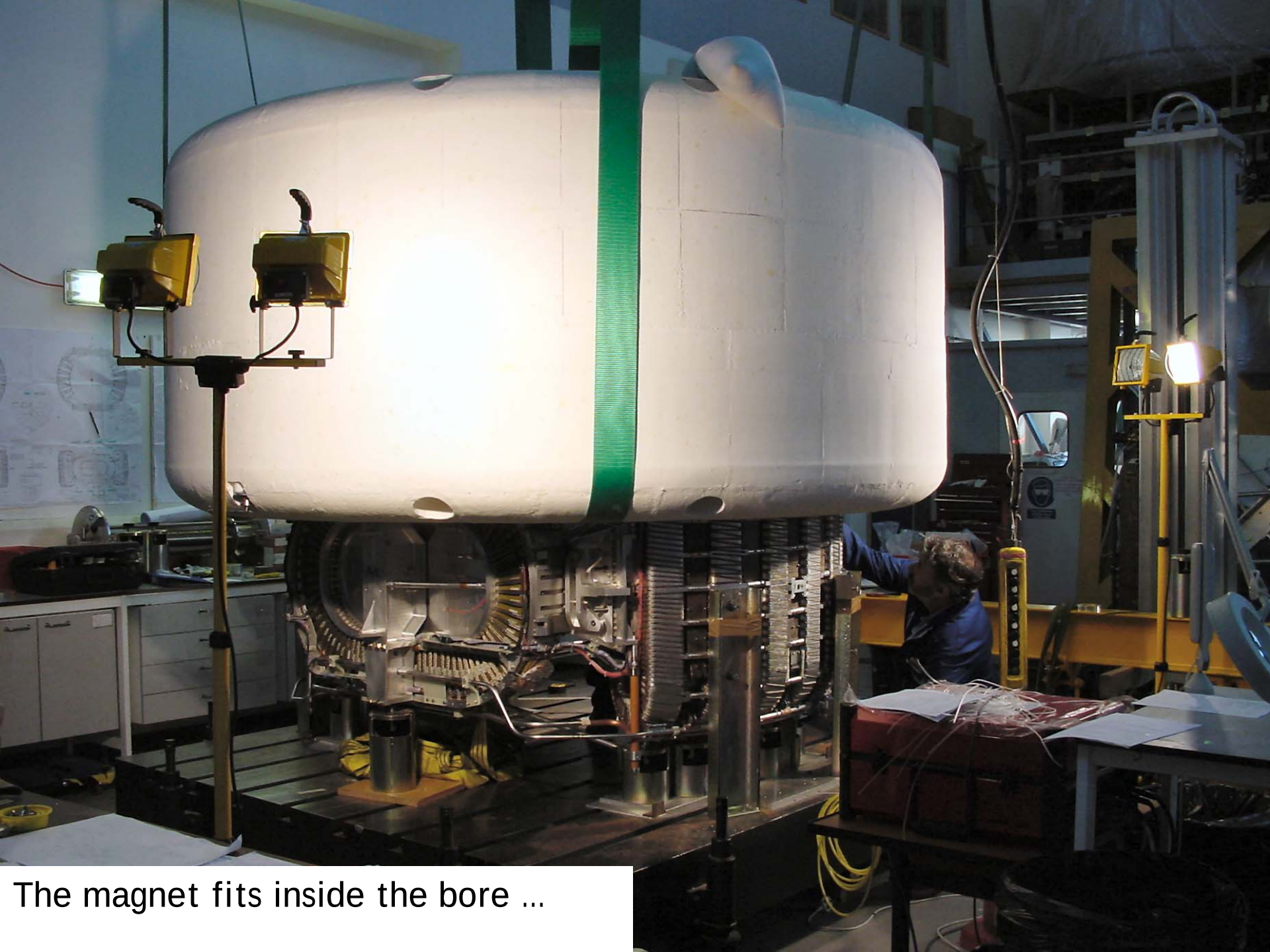
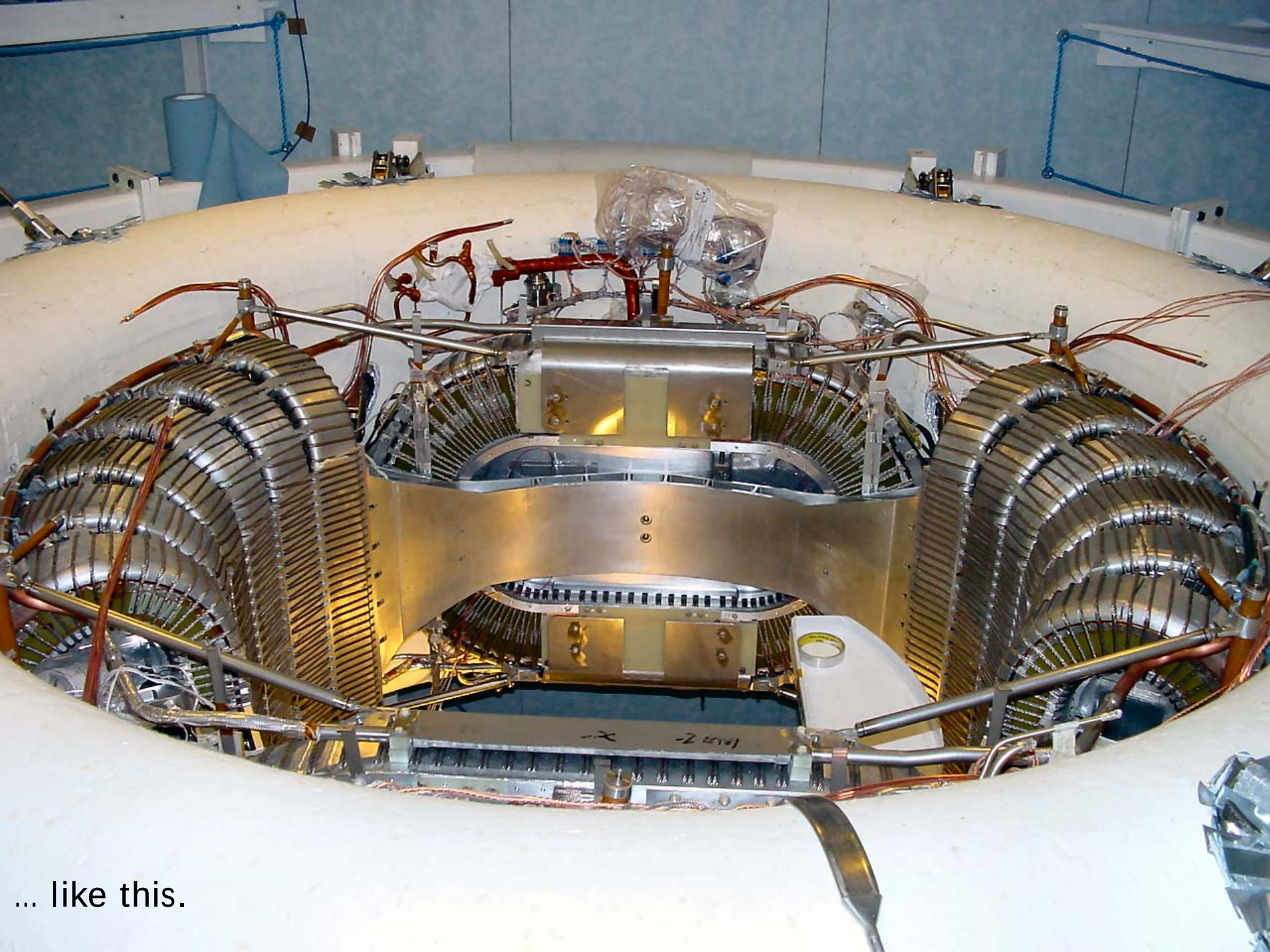
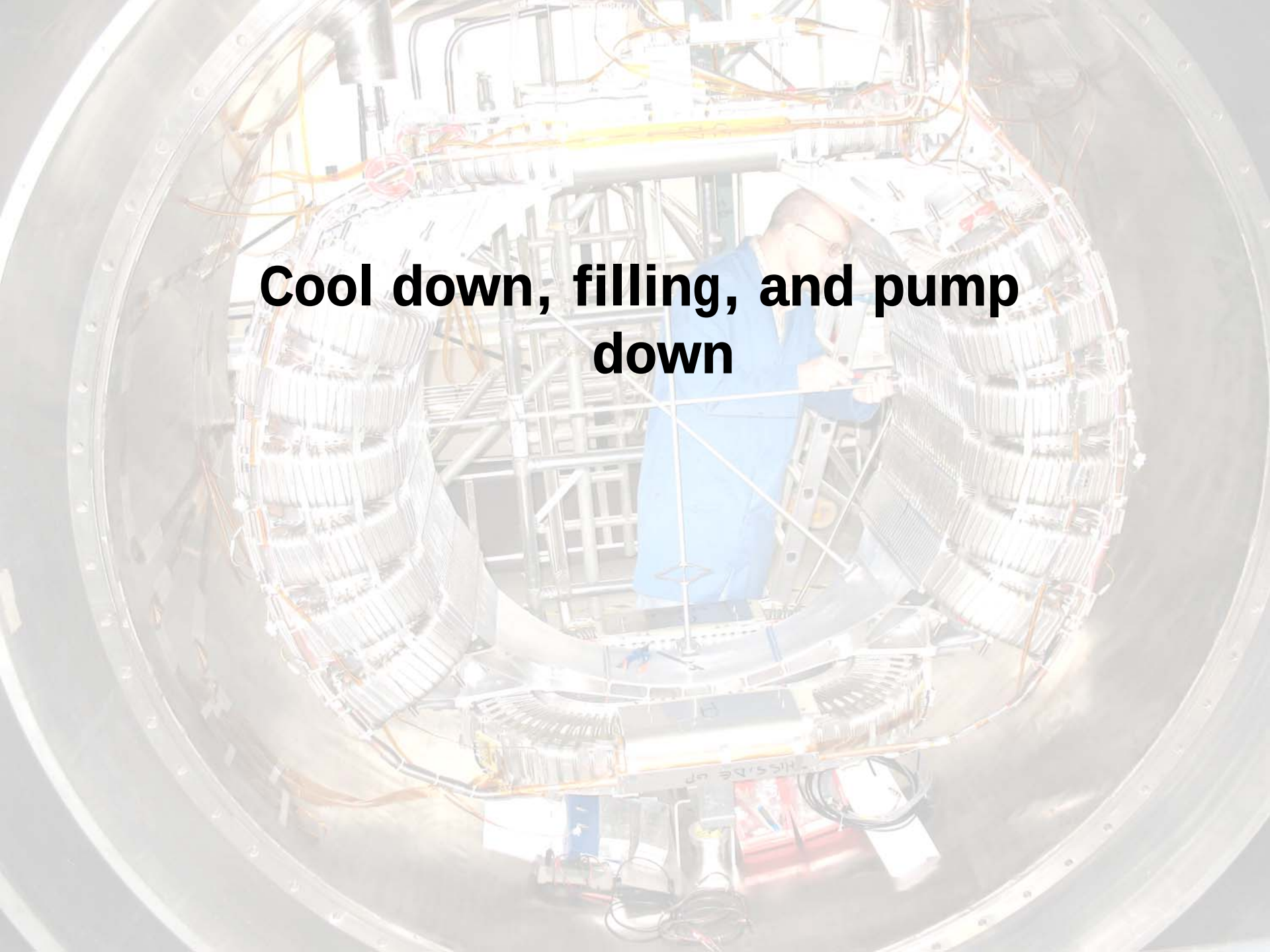


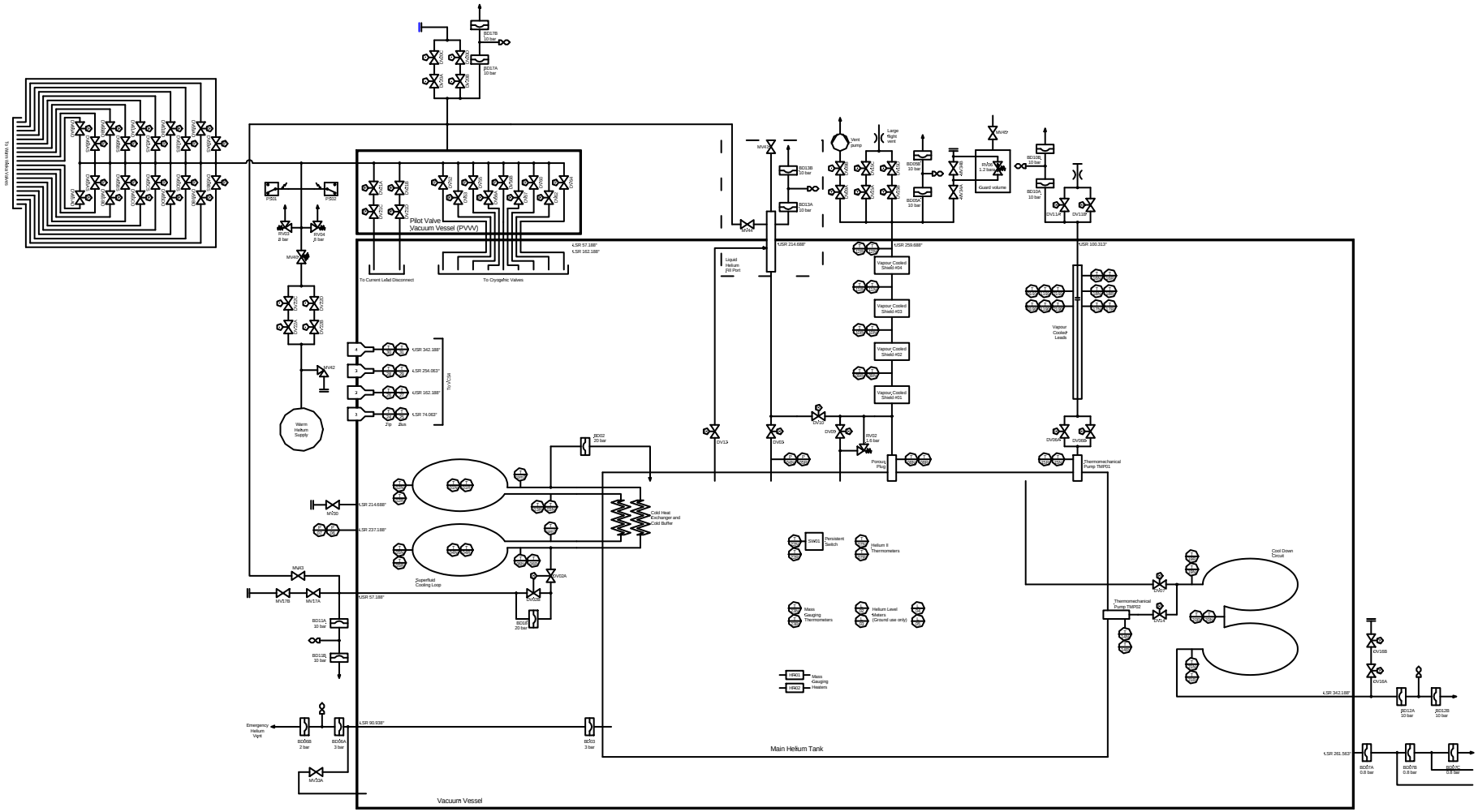
The magnet fits inside the bore …



… like this.



# Cool down, filling, and pump down




The whole of the magnet cryogenic system is shown on the process and instrumentation diagram (P&ID).

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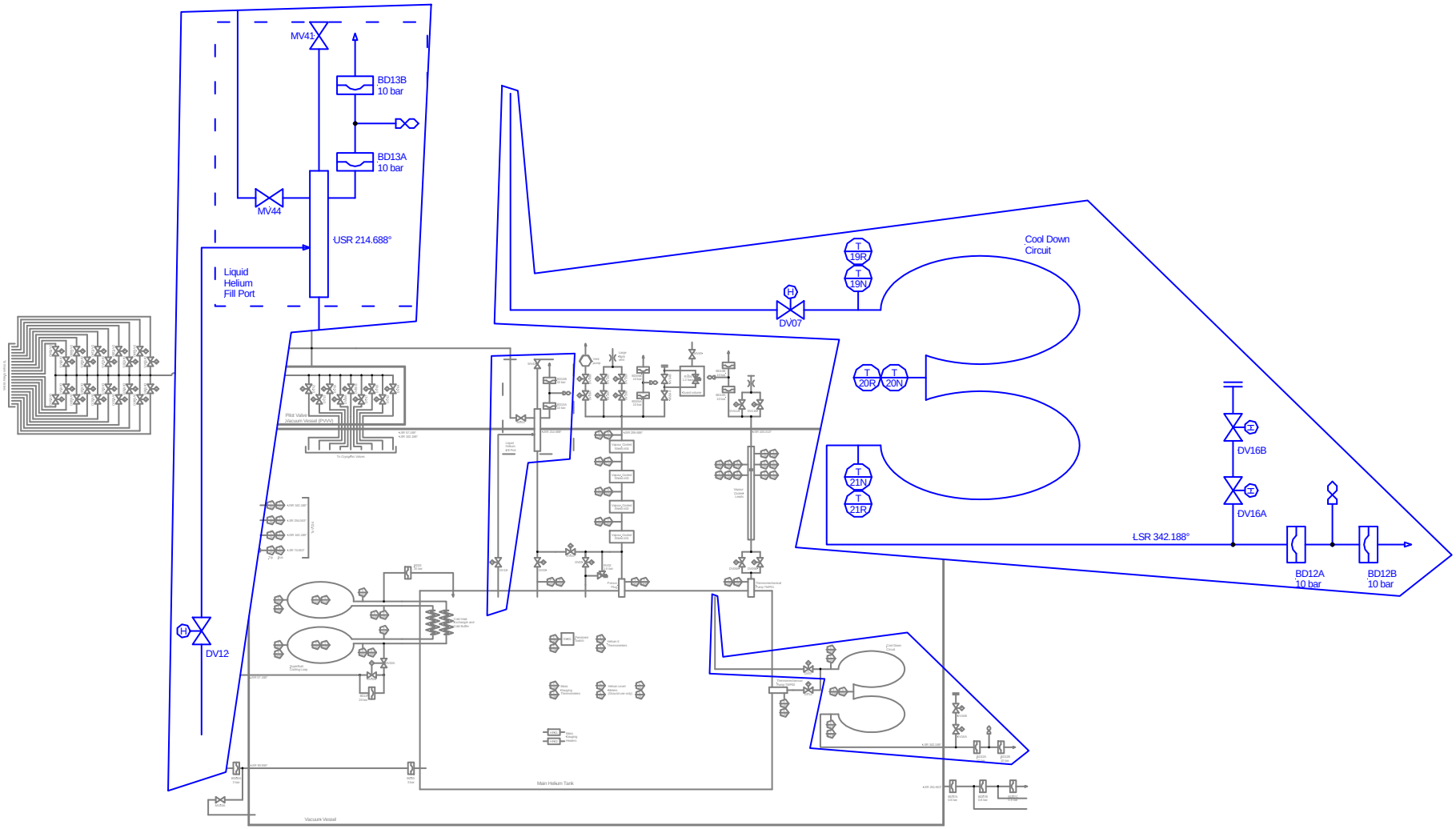


Cool down to 4.2 K.

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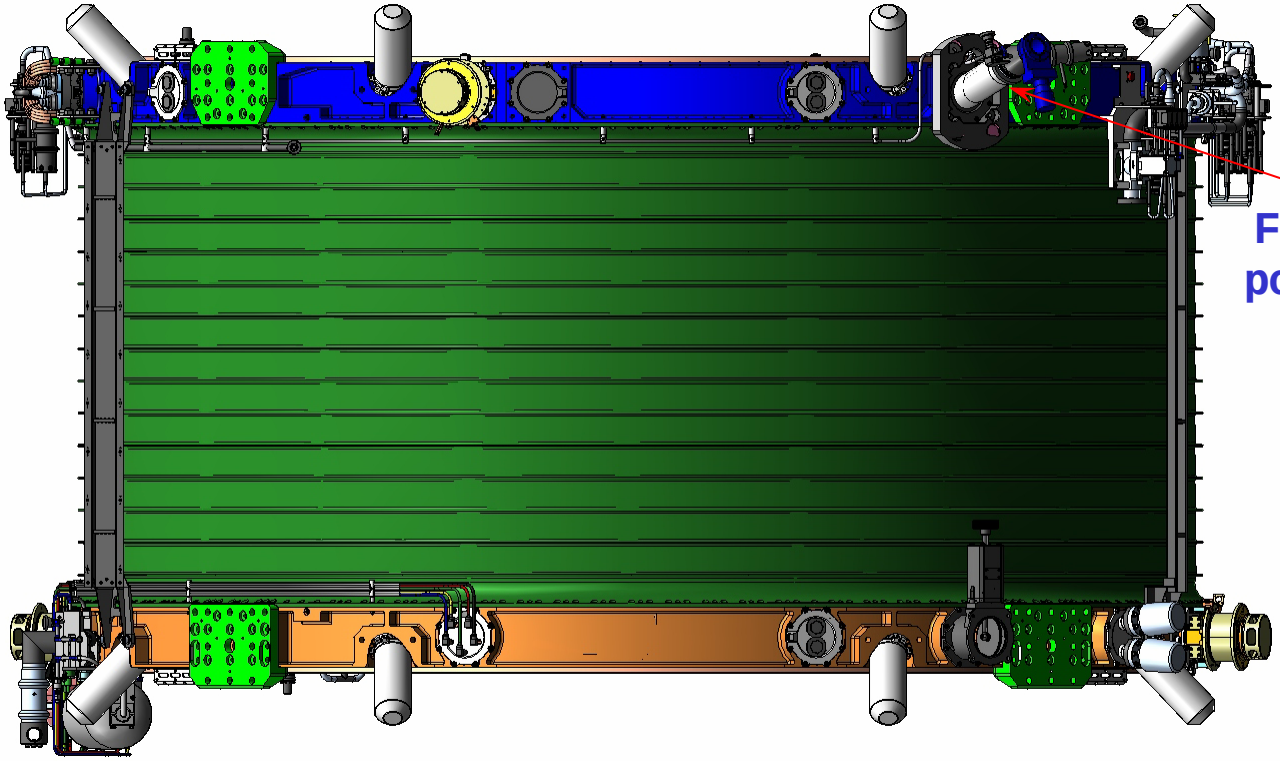

After evacuating the vacuum vessel, helium gas is supplied from the CGSE to the magnet fill port. The temperature is steadily reduced from room temperature to 80 K over a period of days. This cools the magnet without subjecting it to thermal stress.

Once below 80 K, the supply is switched to liquid helium at 4.2 K and the helium vessel is filled.

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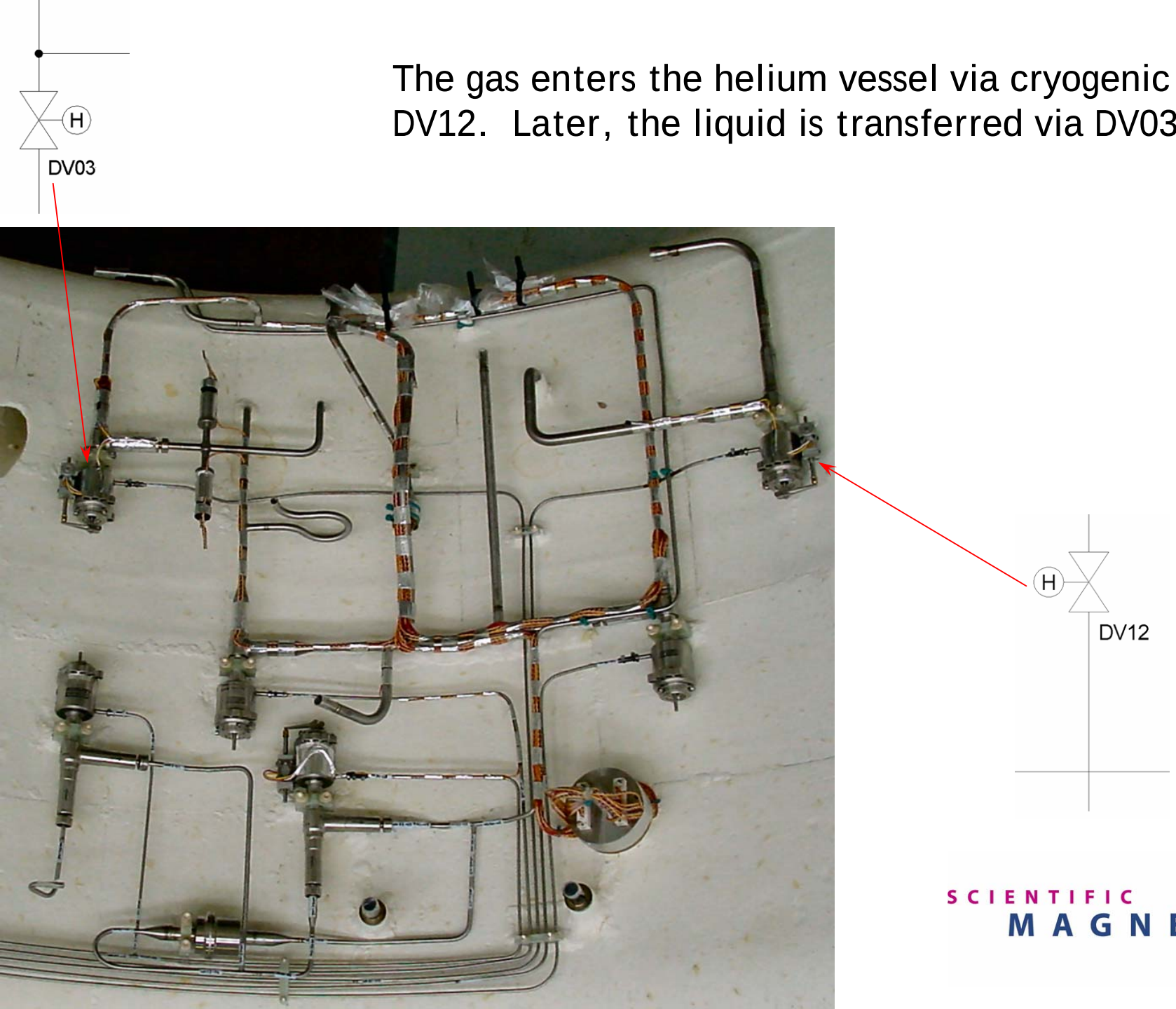
The gas enters the helium vessel via cryogenic valve DV12. Later, the liquid is transferred via DV03.

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The two larger “dipole” coils are cooled via copper heat shunts along the straight sections of the windings.

Heat shunts

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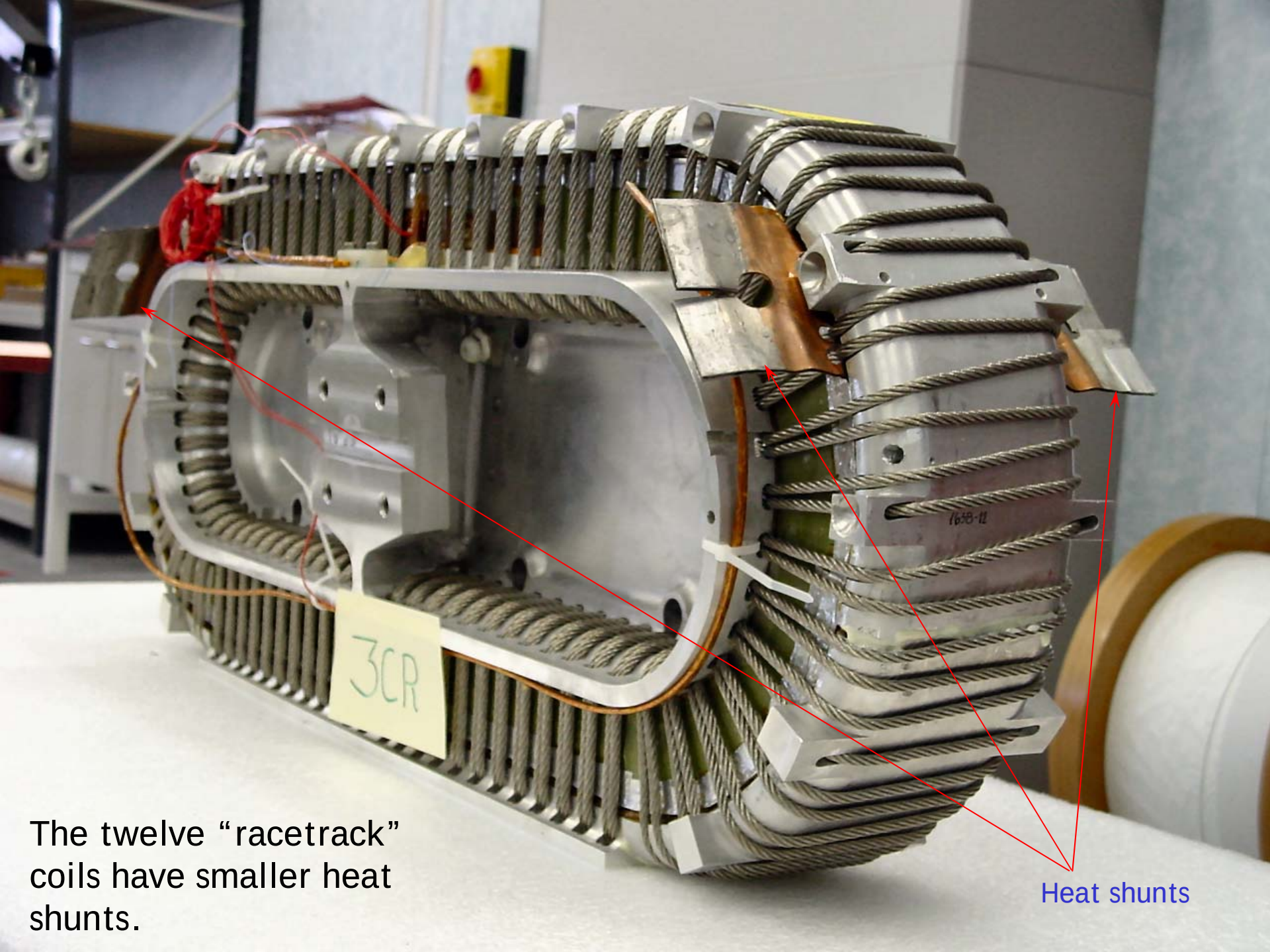
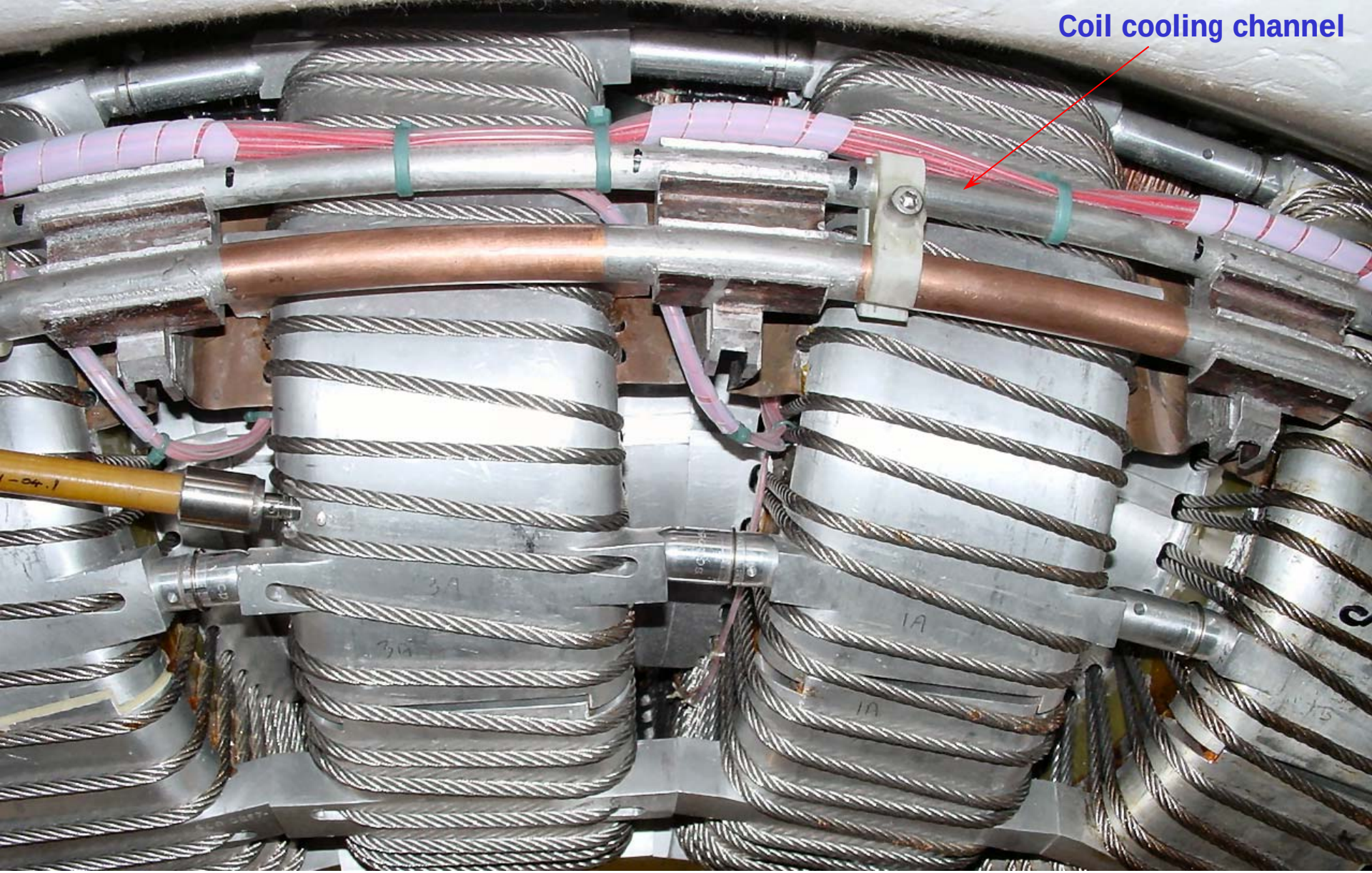



The twelve “racetrack” coils have smaller heat shunts.




The helium flows from the helium vessel through a cooling channel connected to the heat shunts on each of the coils.

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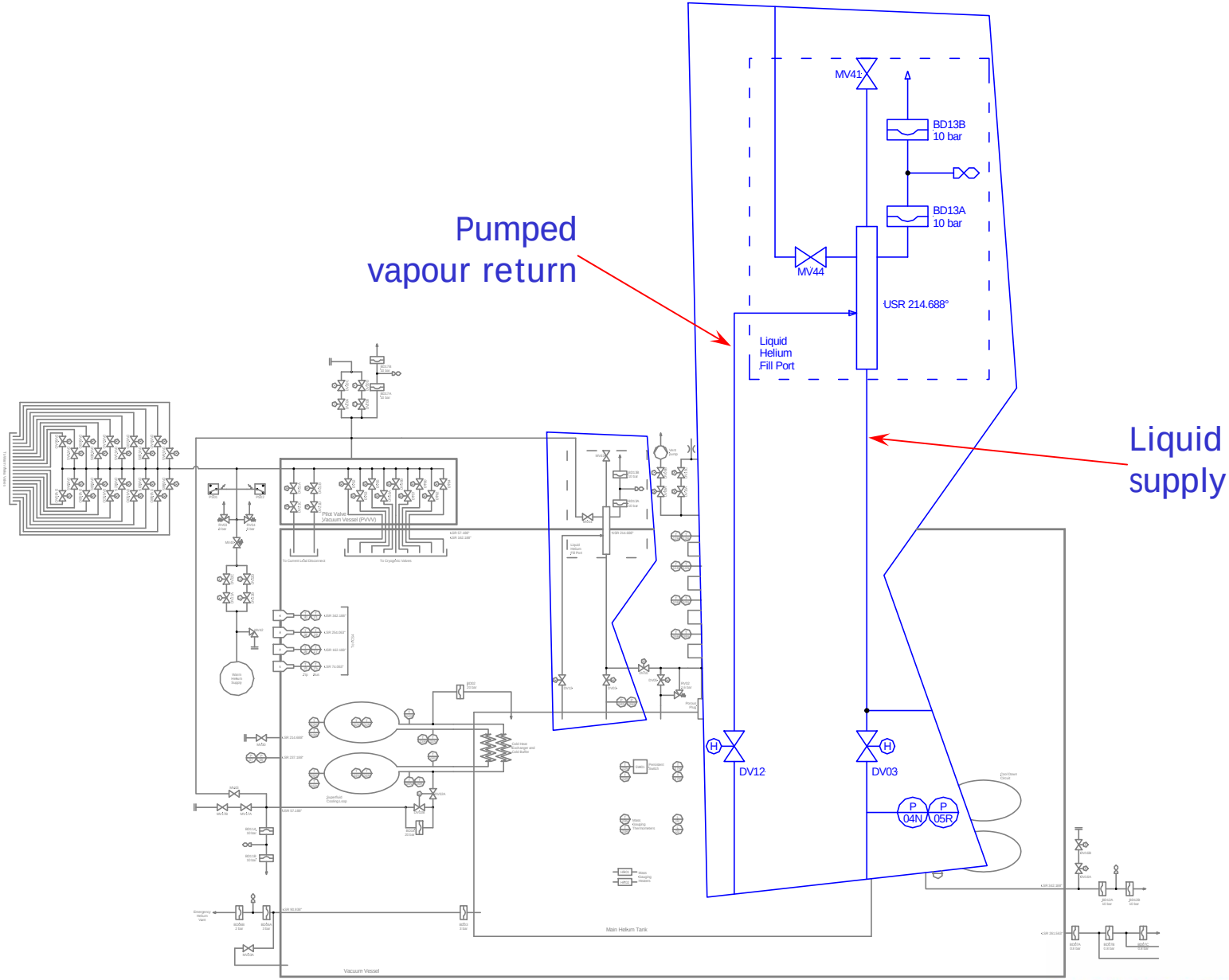


Pumping down from 4.2 K to 1.8 K.

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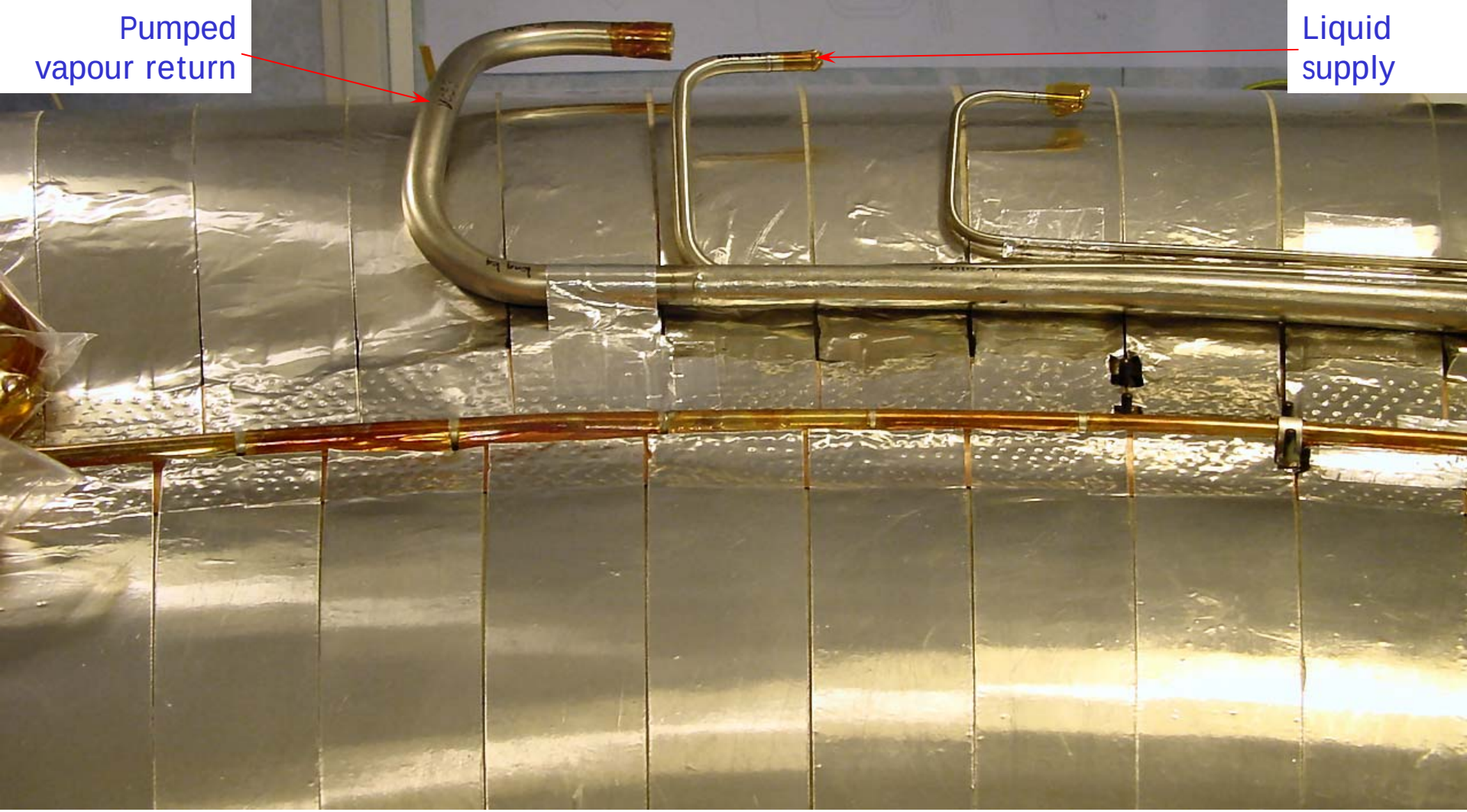


The CGSE supplies liquid helium and removes pumped vapour from the magnet cryostat via the fill port. The picture shows some of the pipework between the helium vessel and the fill port.

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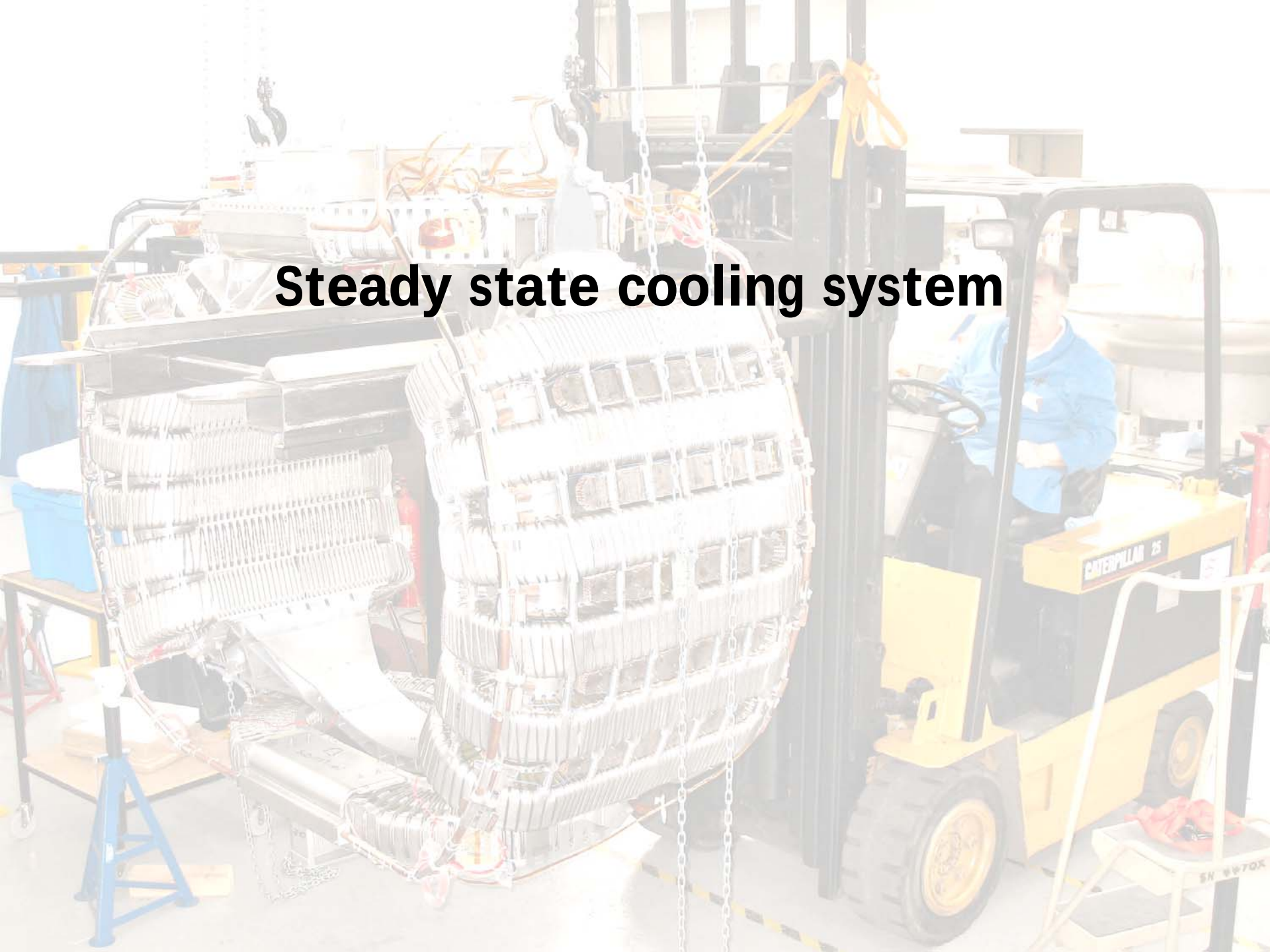
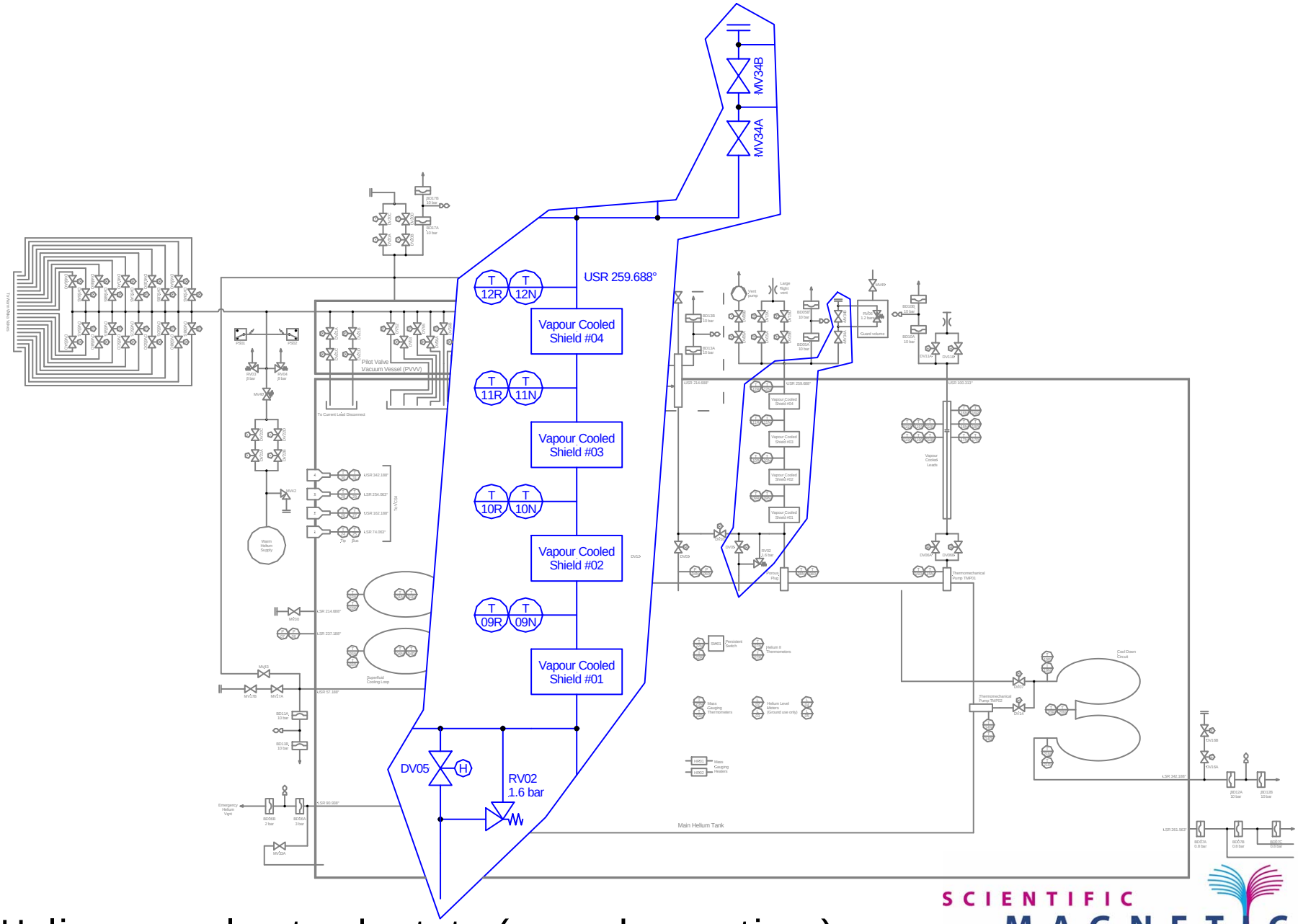
The CGSE includes large Roots pumps - similar to this one - for pumping the helium vapour.

# Steady state cooling system






# Helium vessel – steady state (ground operations)

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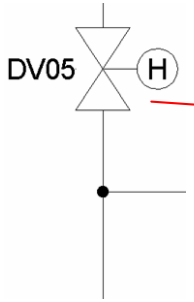


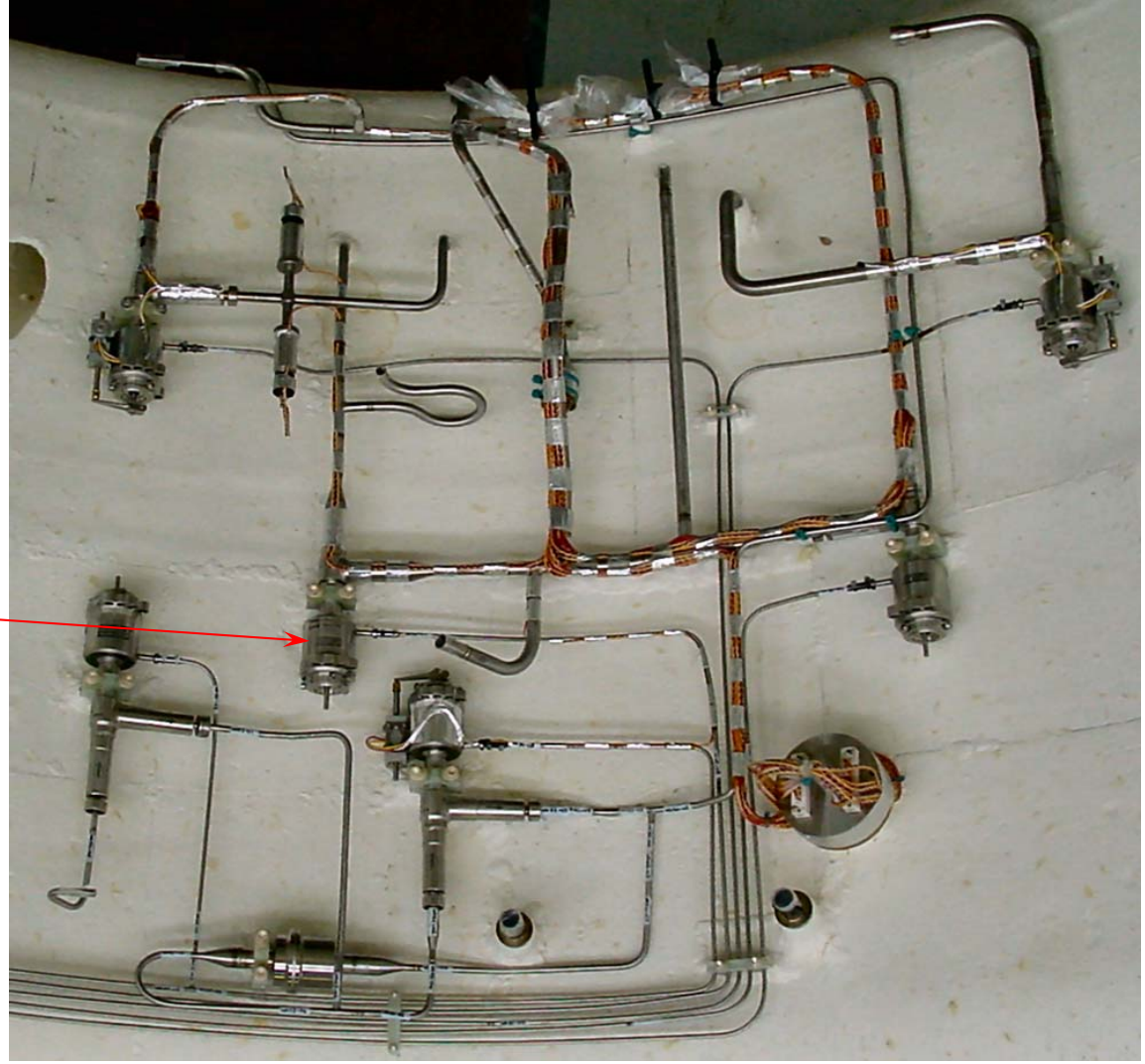

Heat leaking into the helium vessel and magnet boils some of the helium. The vapour leaves through cryogenic valve DV05.

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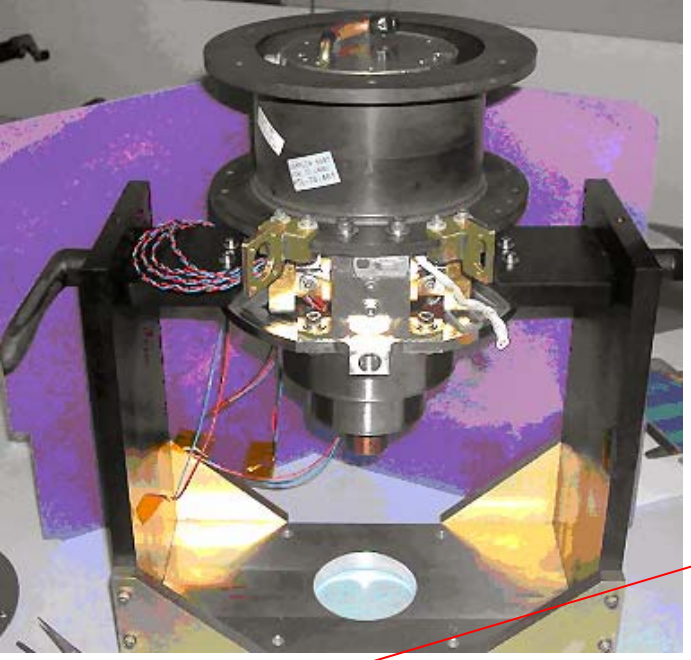
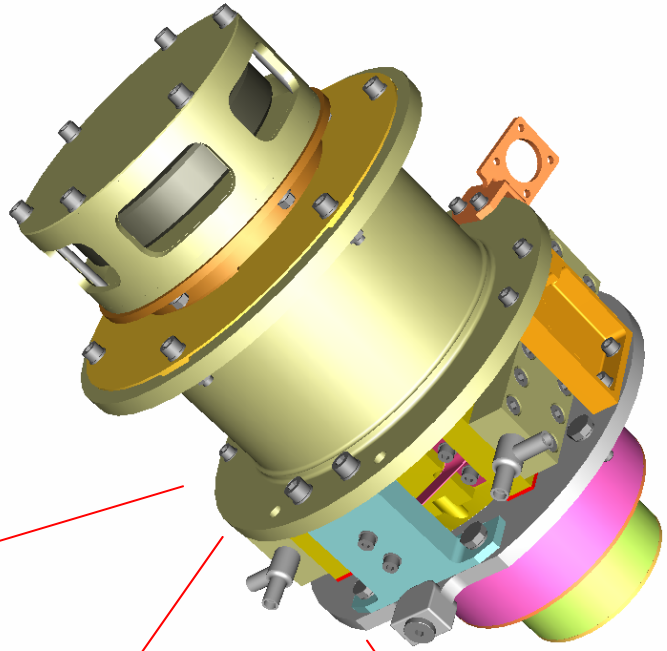
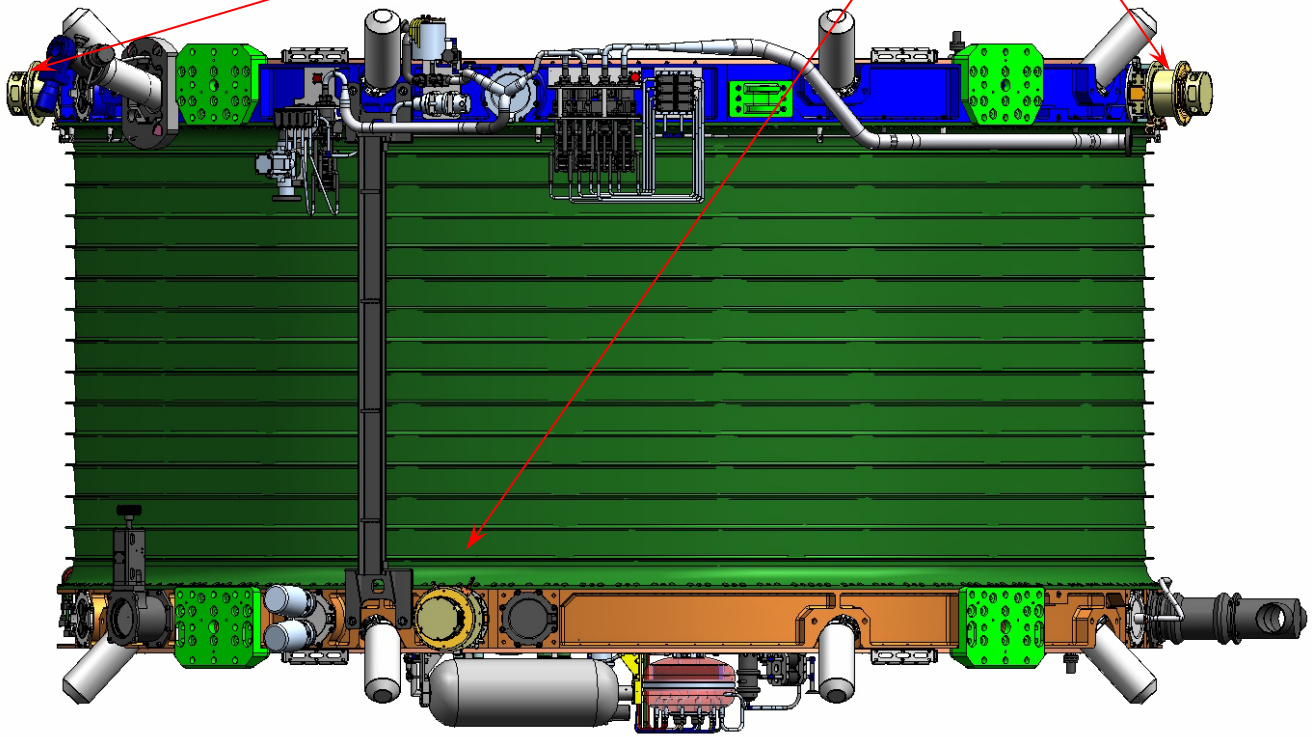
Between the helium vessel and the vacuum vessel, the helium gas is constrained to flow through four concentric vapour-cooled shields, removing incoming heat.

The vapour-cooled shields are separated by superinsulation consisting of layers of aluminised Mylar and nylon netting.







The outer (fourth) vapour-cooled shield is also cooled by 4 Stirling cycle cryocoolers.

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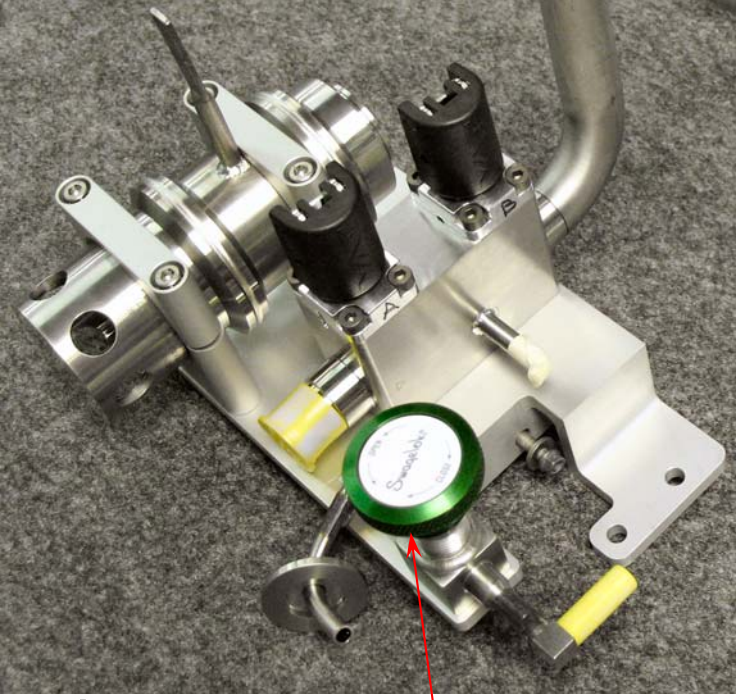
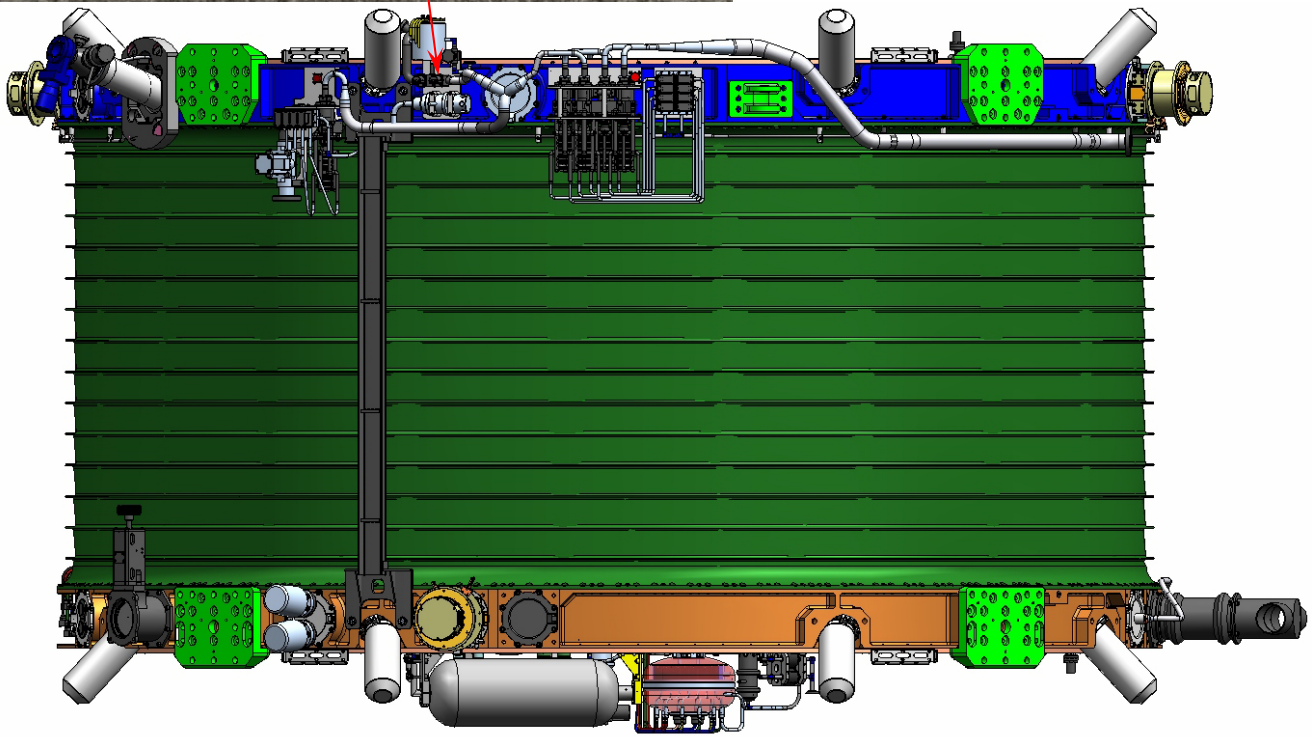


The helium leaves the vacuum vessel through a combination of valves and is collected by the CGSE.



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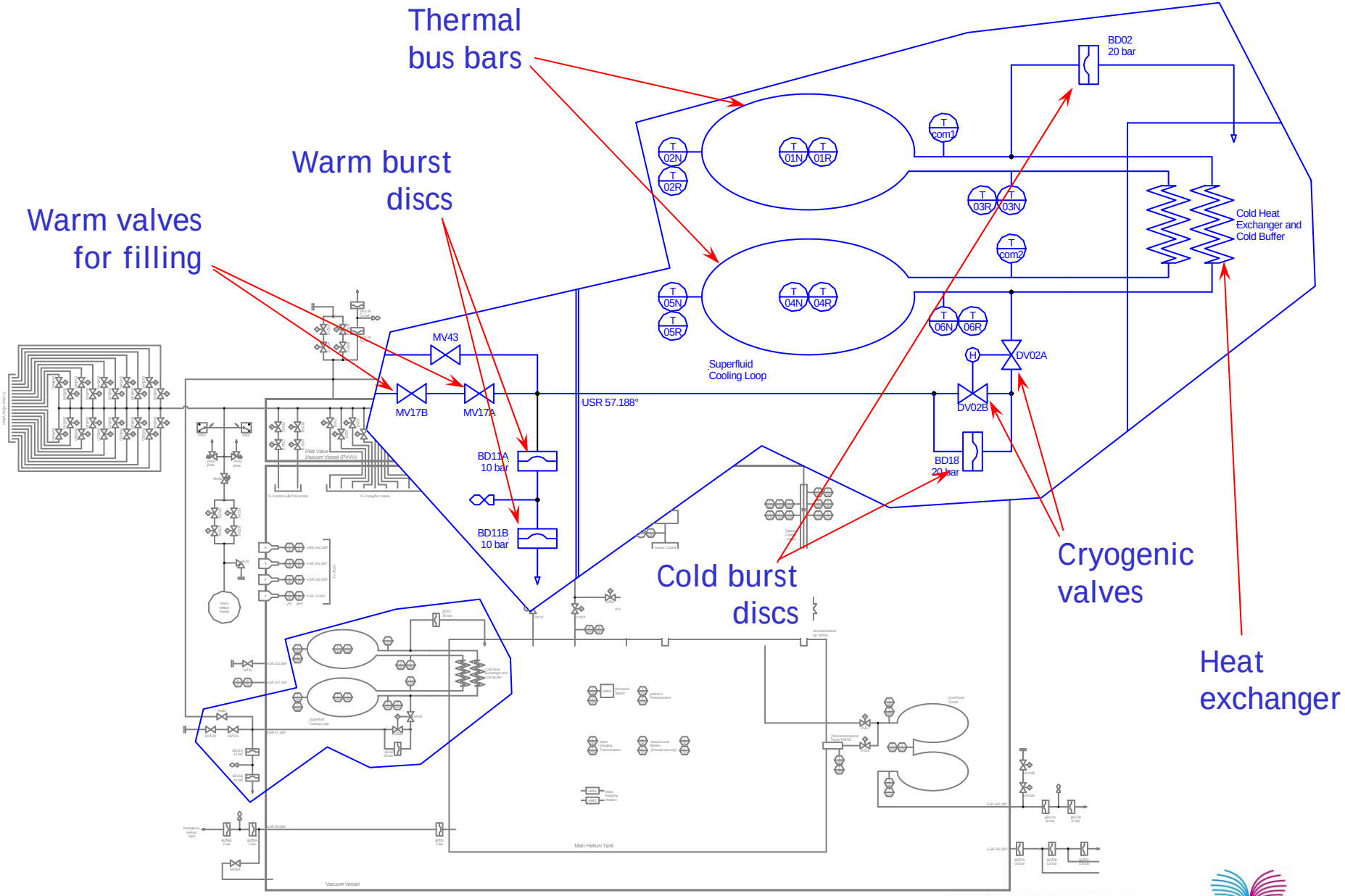


Steady state coil cooling system

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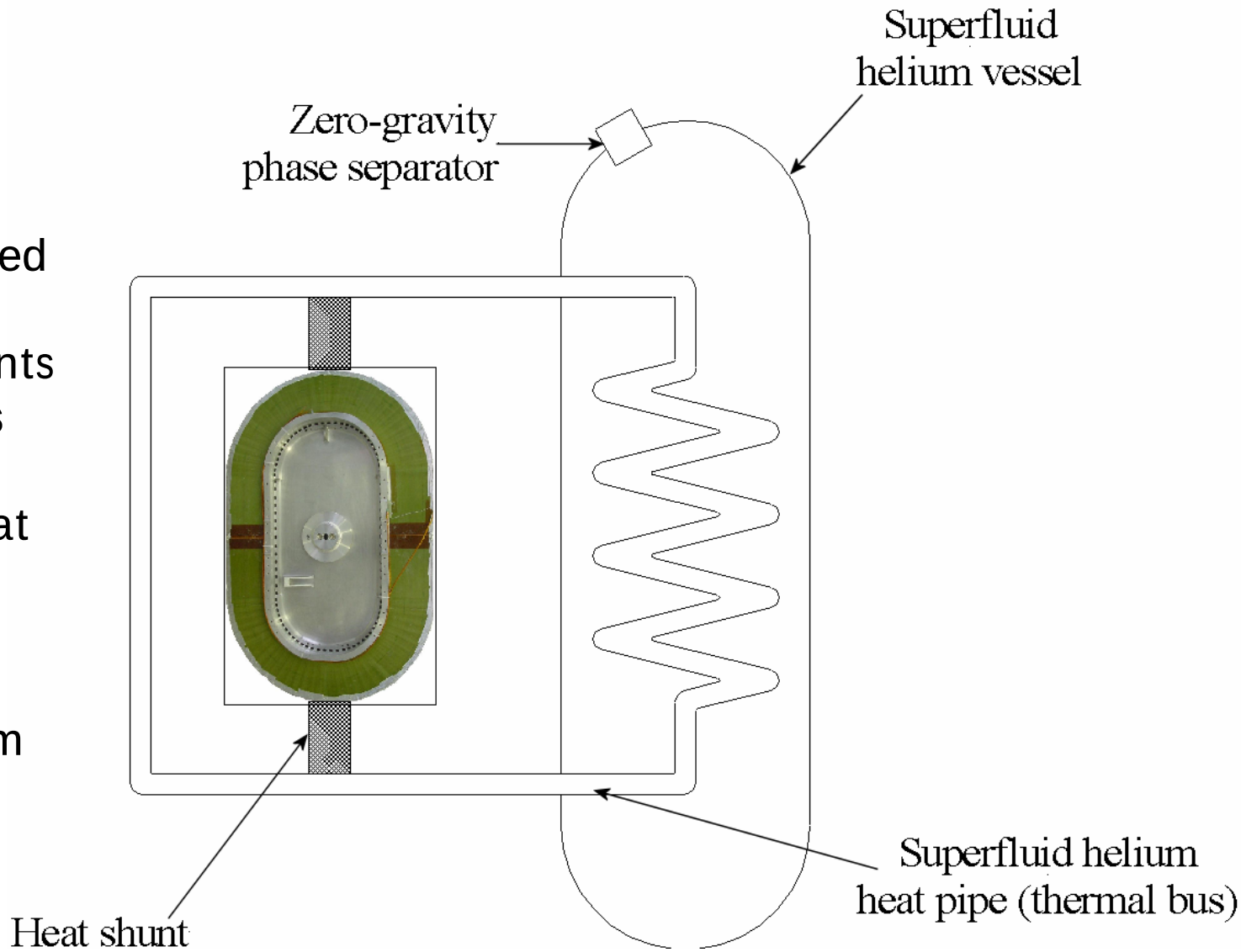
Heat from the coils is transferred through the copper heat shunts into thermal bus bars (superfluid helium filled heat pipes). It is dissipated by boiling in the superfluid helium vessel.

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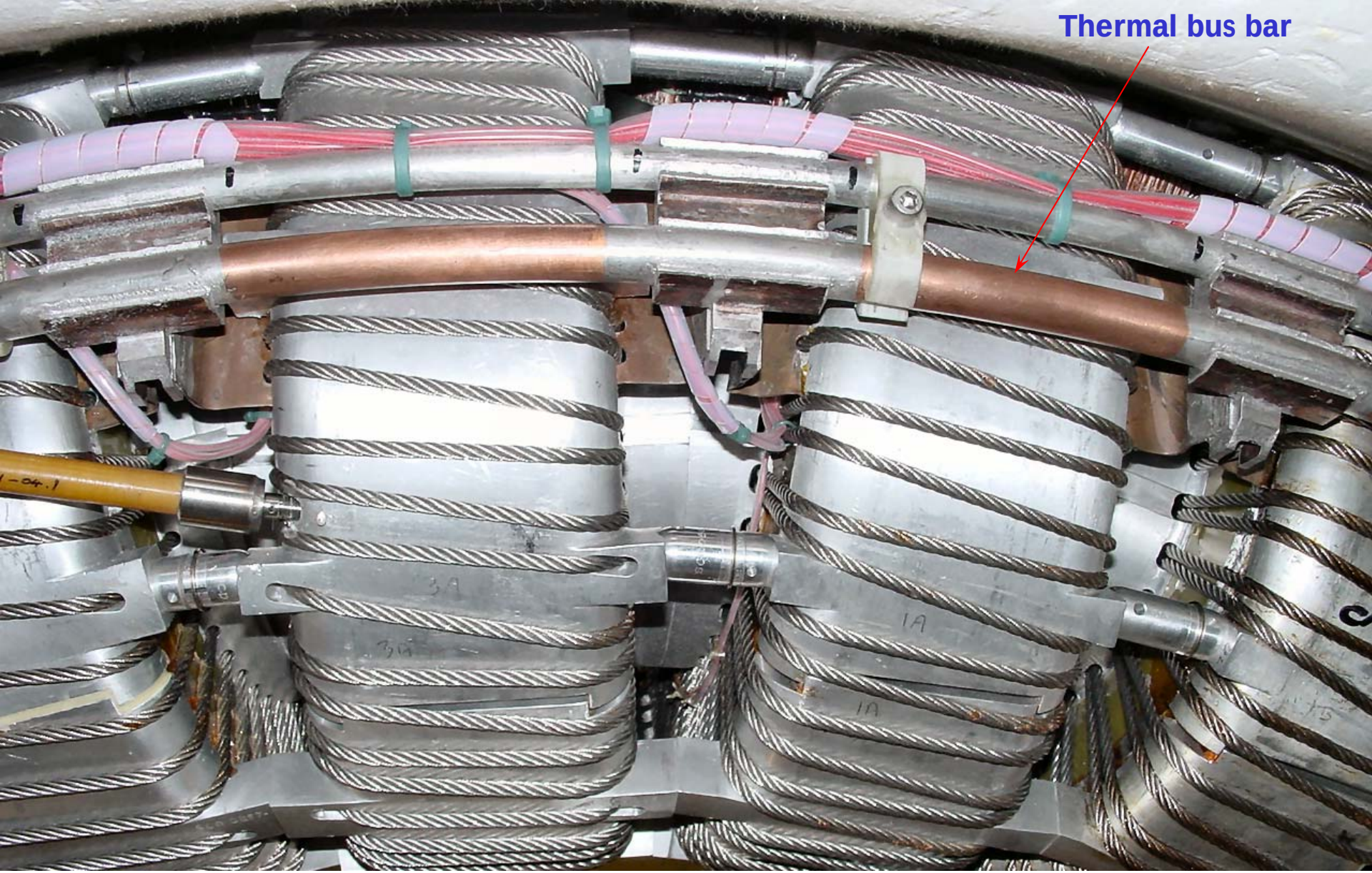


The thermal bus bars share their thermal connections to the coils with the cool down pipework.

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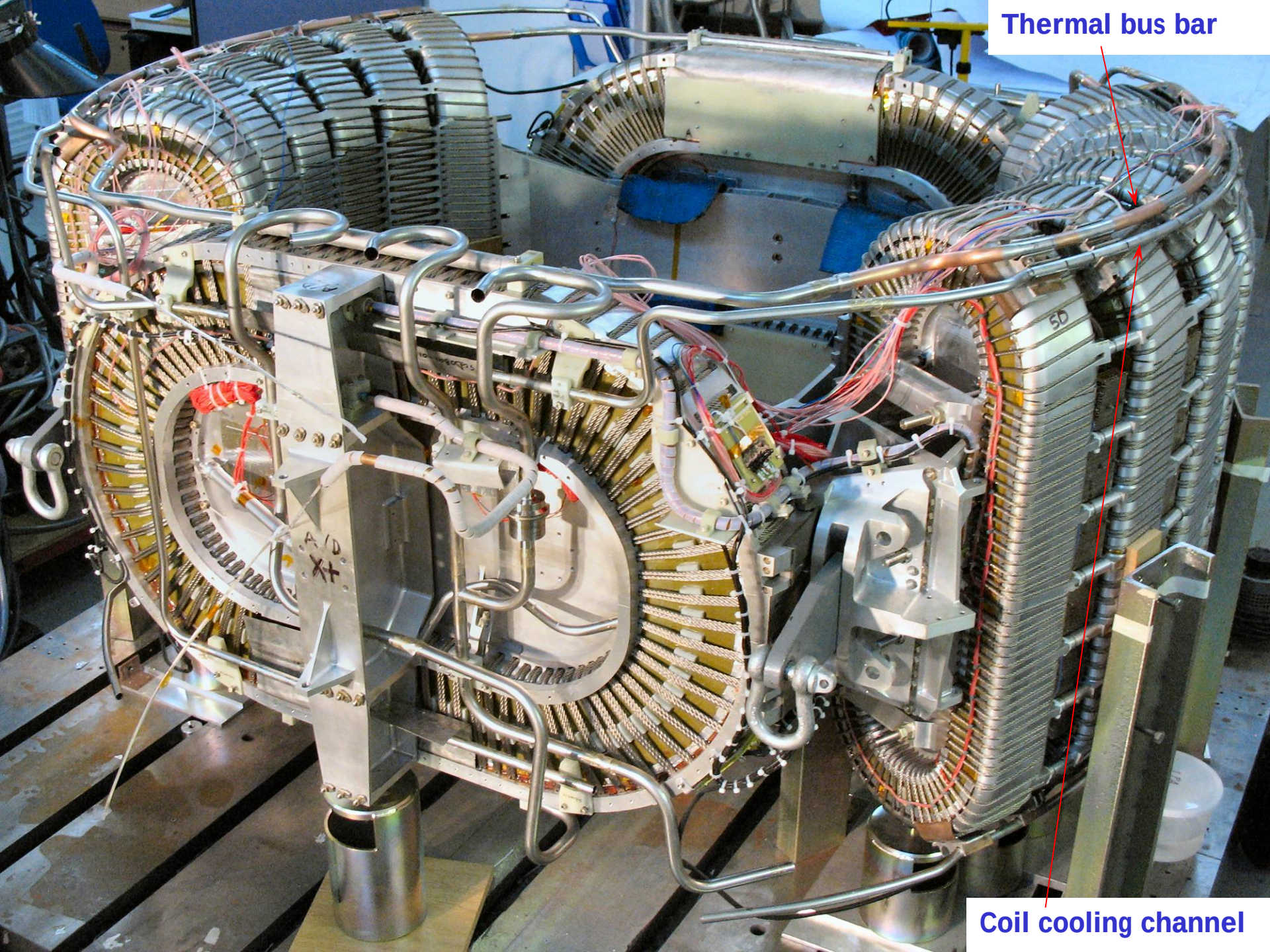
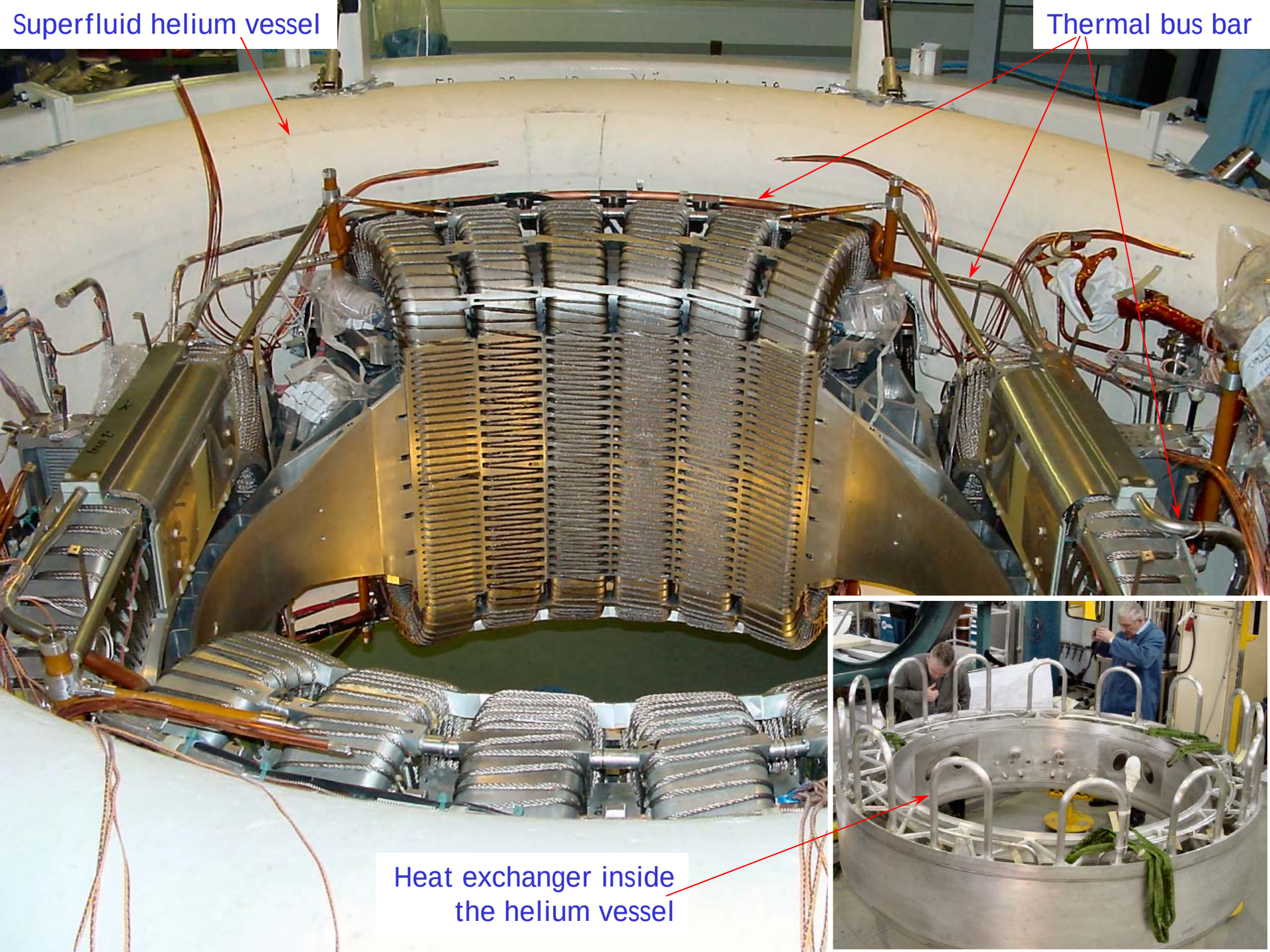
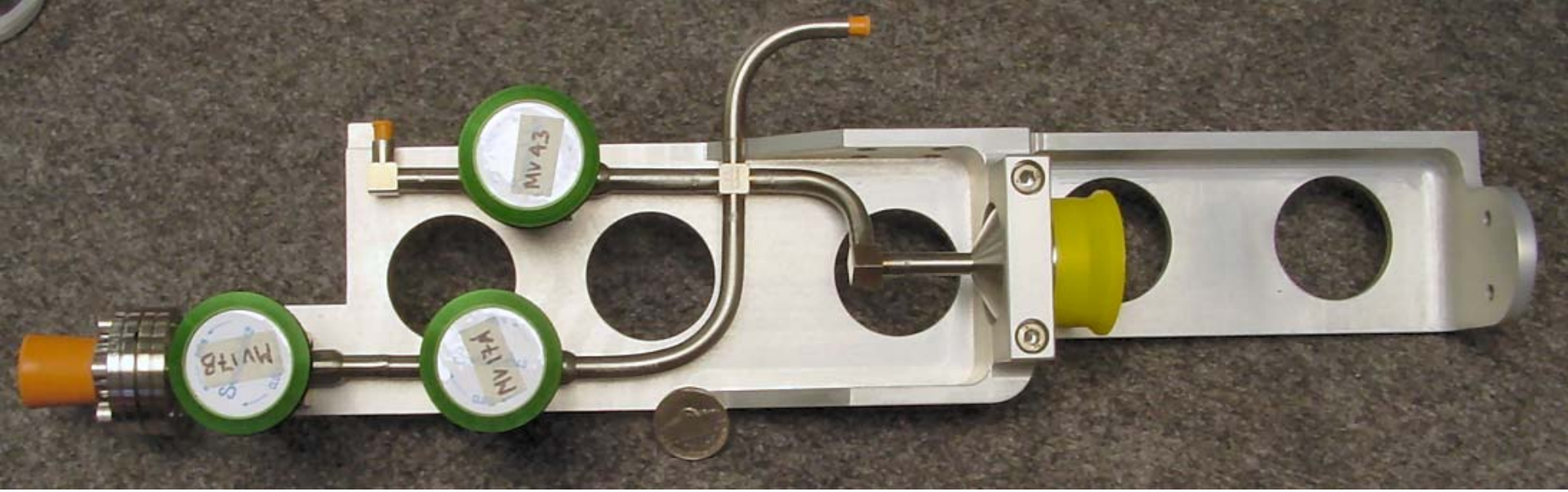

Thermal bus bar
Coil cooling channel


Superfluid helium vessel
Thermal bus bar
Heat exchanger inside
the helium vessel




To fill the thermal bus bars, ambient temperature helium gas (clean and dry) is supplied from the CGSE at 1 bar during magnet cool down. It enters the magnet system through this combination of valves.

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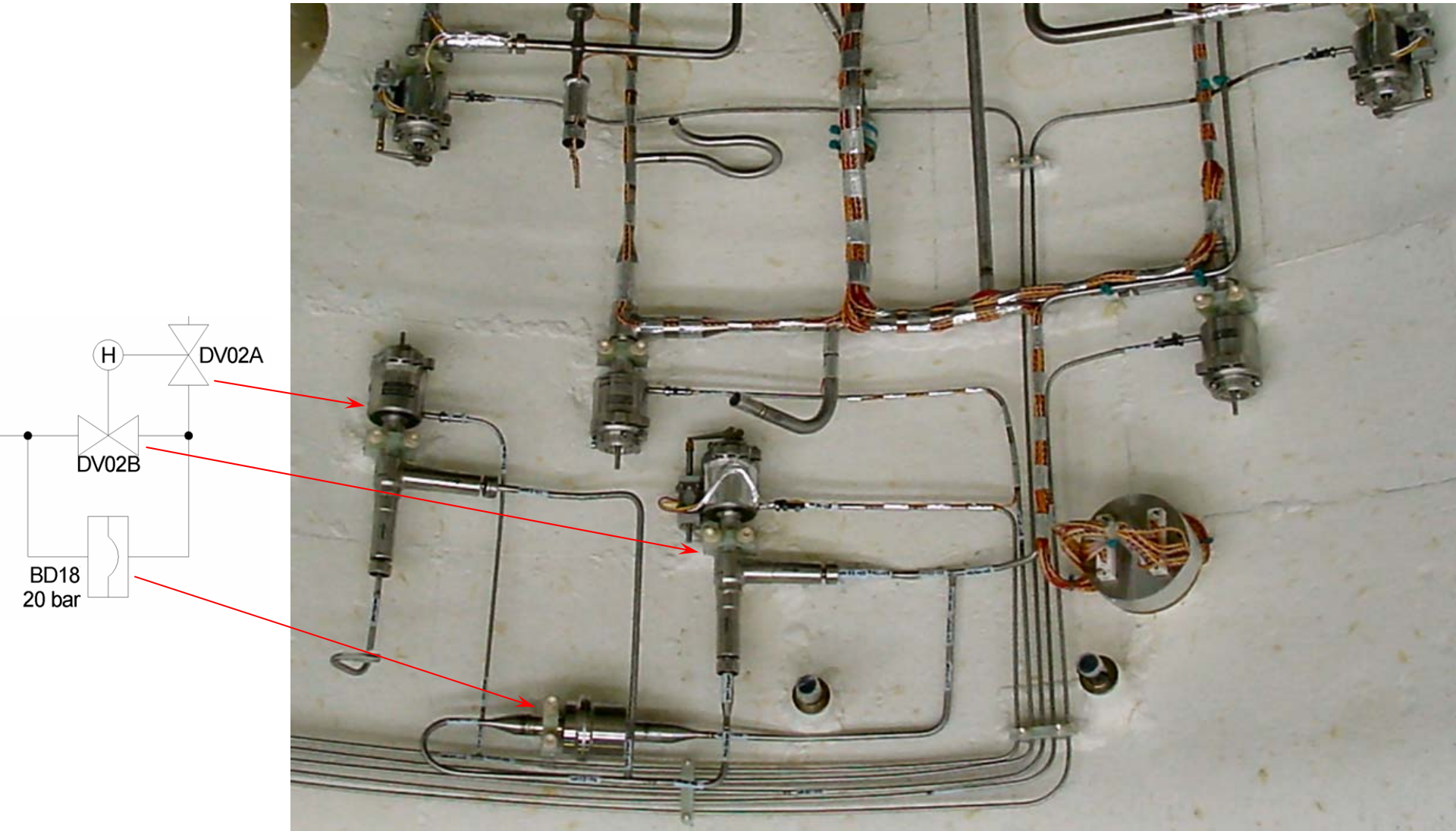
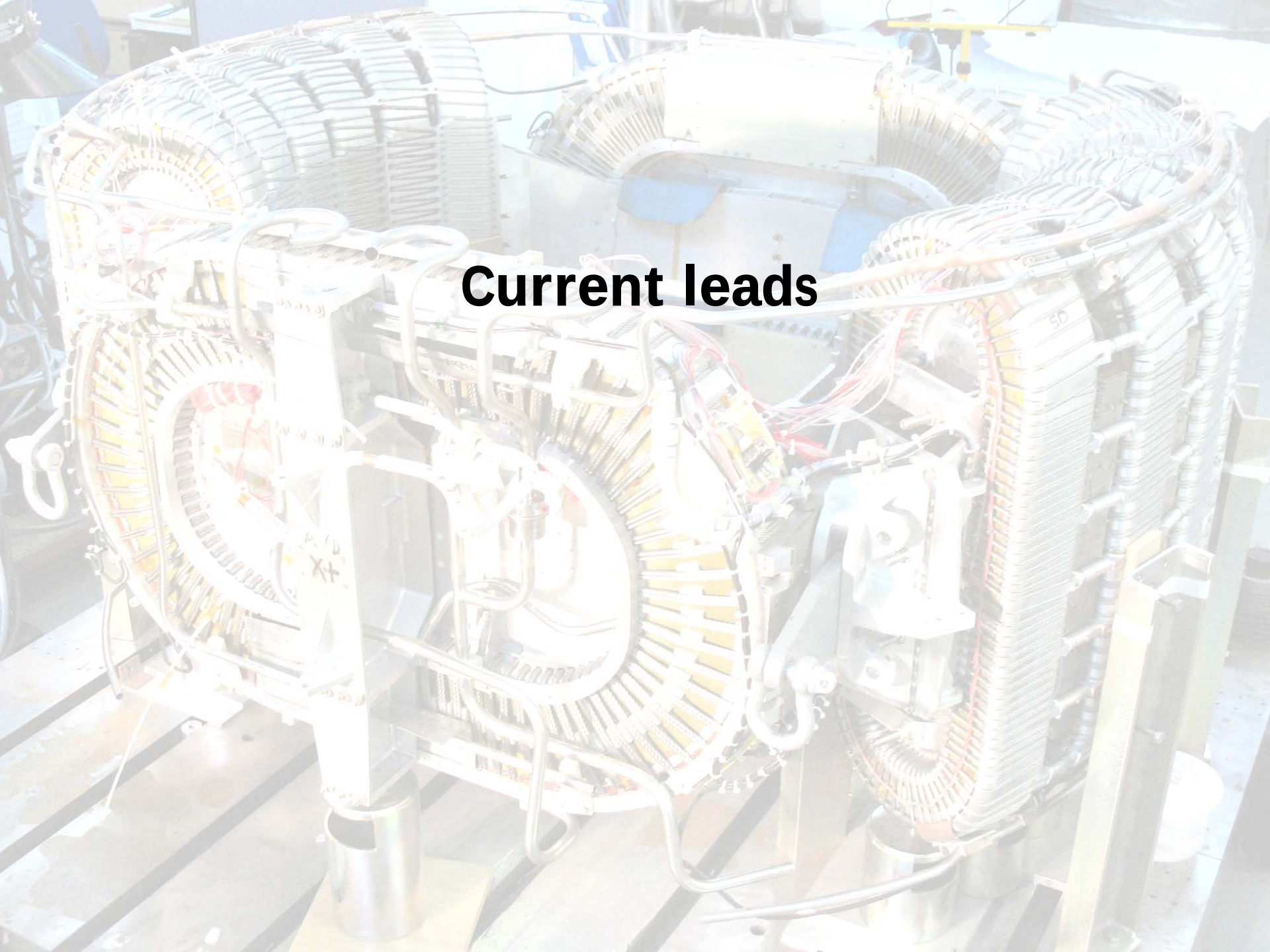
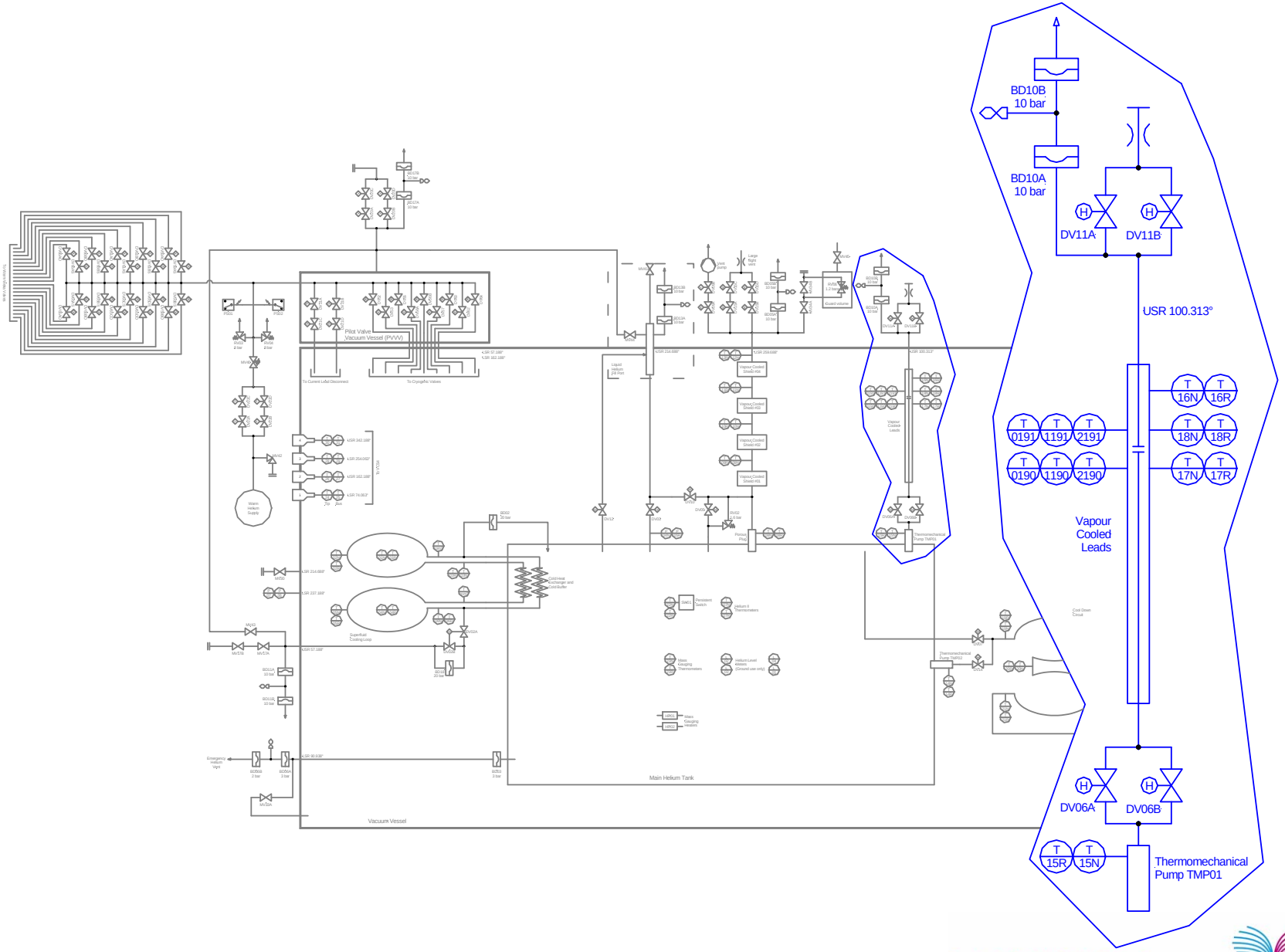
The gas is transferred to the coldest part of the system through a stainless steel pipe. It enters the thermal bus bars through a pair of cryogenic valves. Any potential trapped volumes are protected by burst discs.

As the magnet cools down, more helium is drawn in by condensation until the thermal bus bars are filled with helium at 1.8 K and around 0.5 bar.





# Current leads

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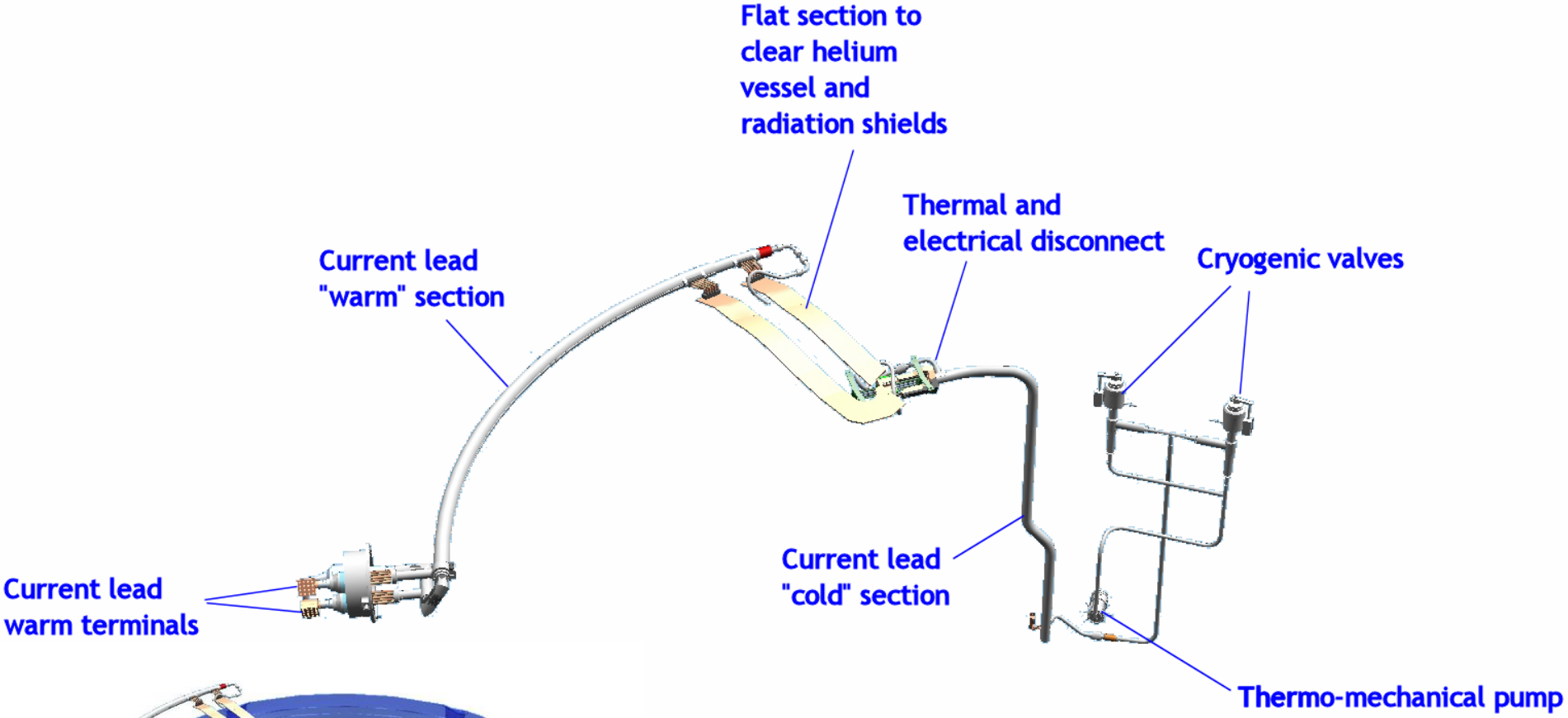


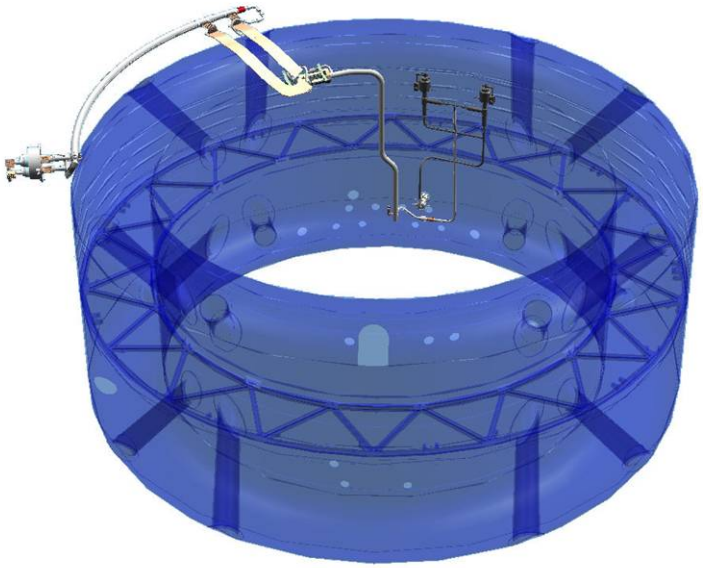

The current leads geometry is necessarily complicated to fit around the magnet coils and helium vessel.

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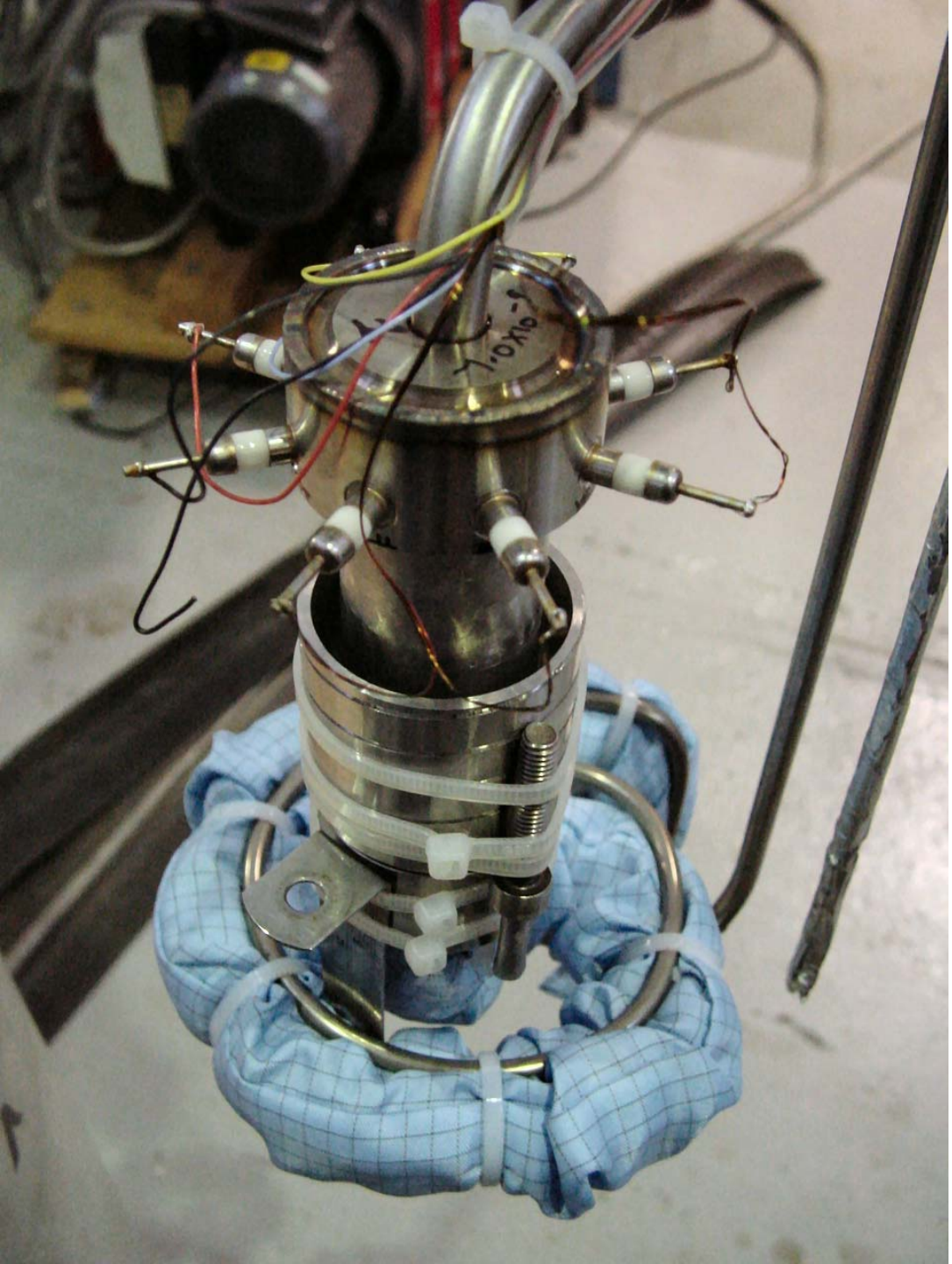

The current leads are cooled by helium pumped from the superfluid helium vessel by a thermo-mechanical pump.

A thermo-mechanical pump has no moving parts: it is actuated only by a heater.

The pump is primed by a surface tension device which ensures liquid helium is always available.

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Both the thermo-mechanical pump and the liquid acquisition system were developed by Scientific Magnetics specially for AMS. They were extensively tested and qualified using test equipment loaned from CERN.

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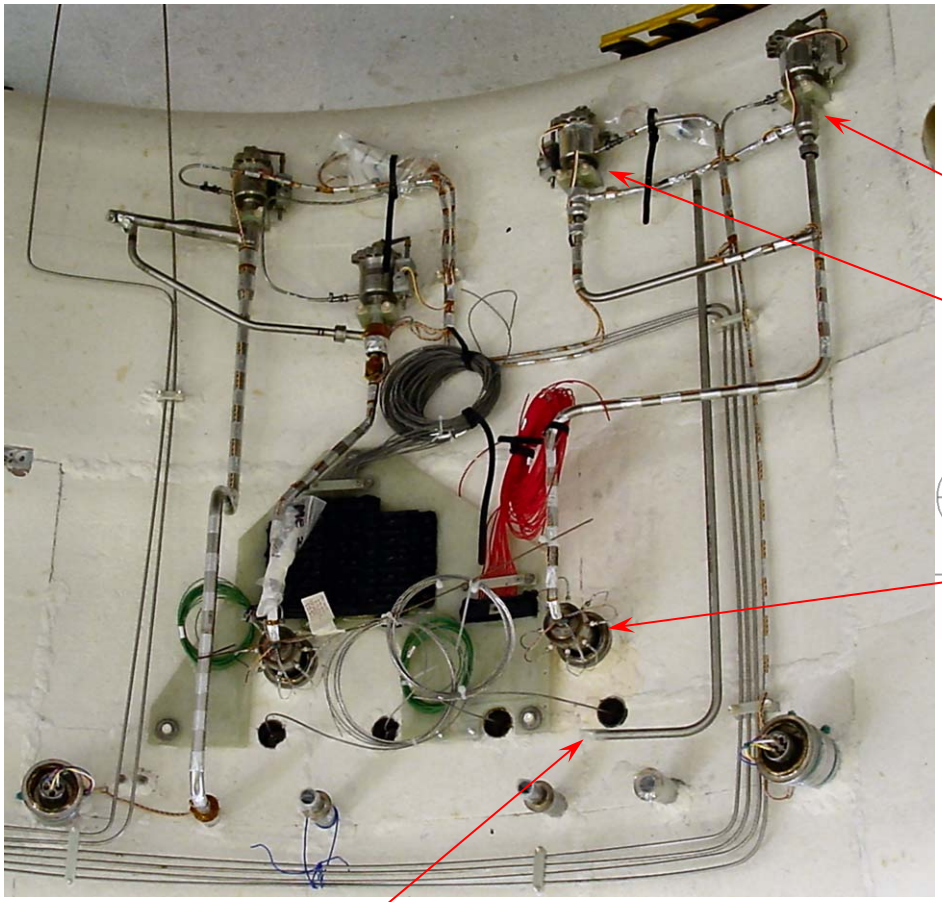
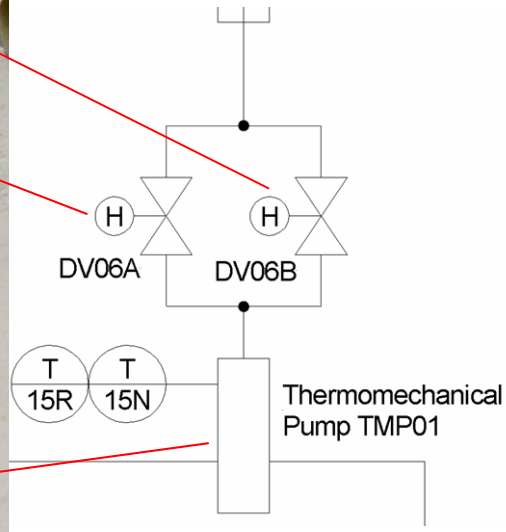
From the pump, the helium flows through two parallel cryogenic valves (for redundancy) and then enters the current leads.






To the current leads

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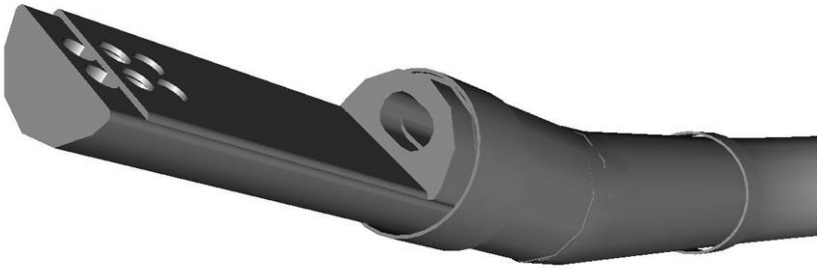

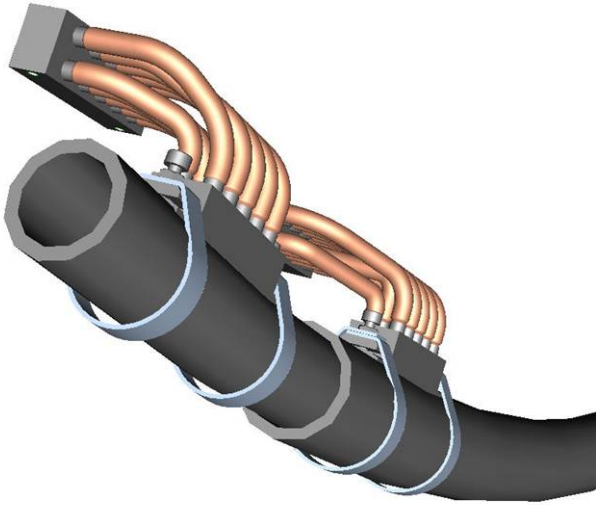

Only one of the leads is in contact with the helium: the other is cooled by clamping the leads together with insulation. The leads are coaxial at the warm end, and D-shaped at the cold end.

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Completed
“cold” section

Current
feedthrough into
the helium vessel

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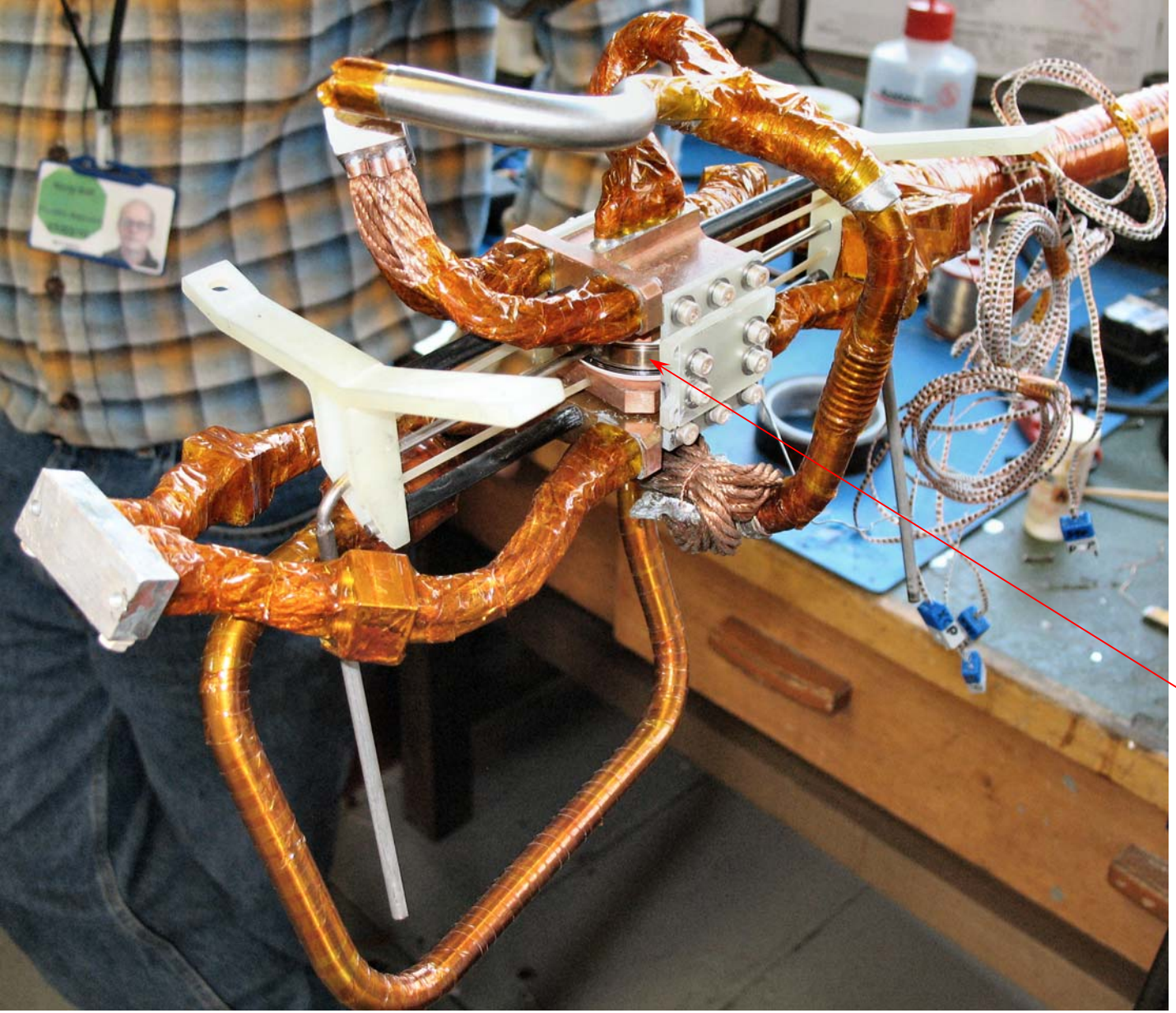
Cold section of the current lead installed between the helium vessel and the magnet




Bench assembly of the current leads disconnect.

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Connection to disconnect

Connection to vacuum vessel feedthrough

Warm end of the current leads.

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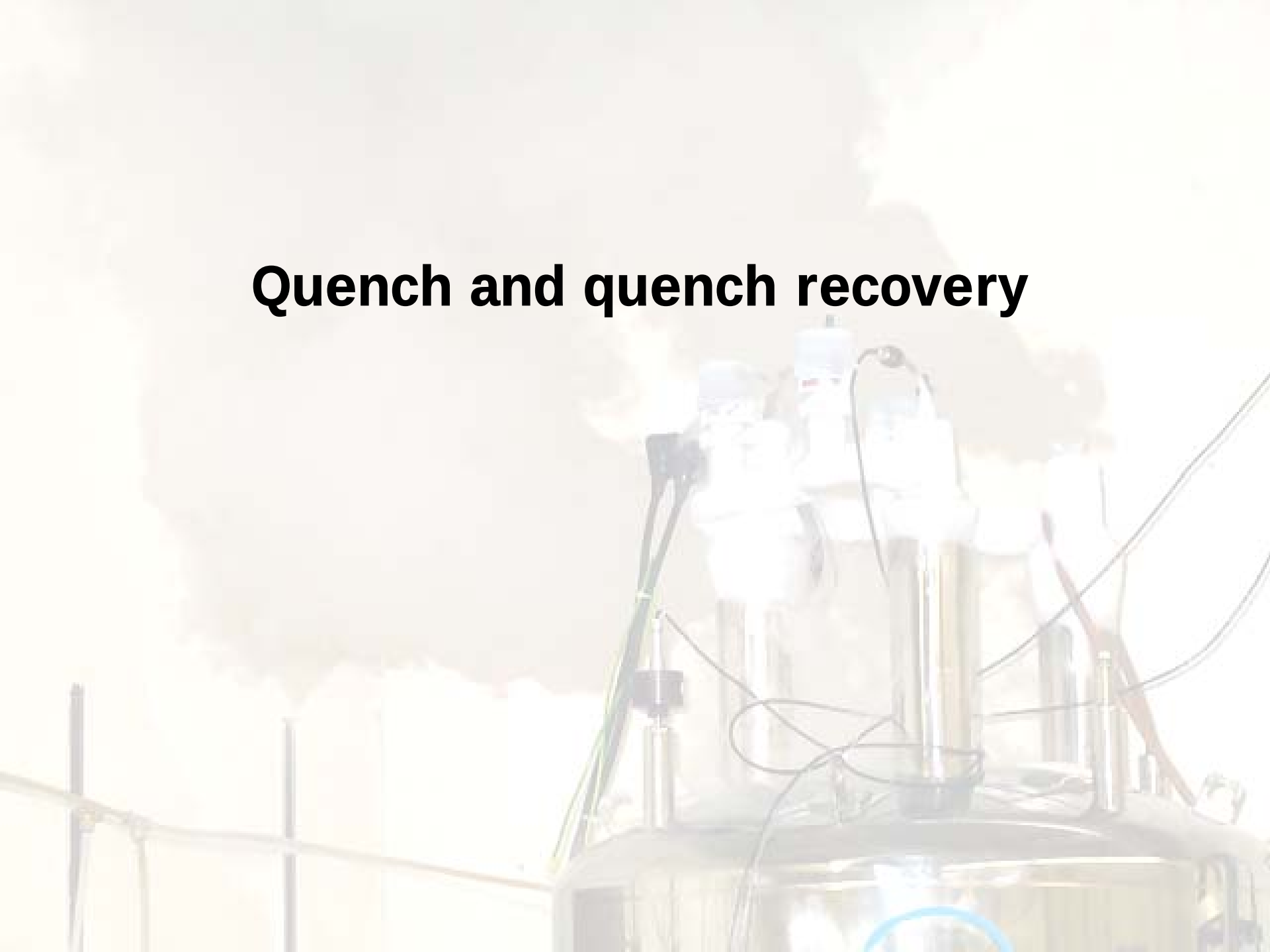
# Quench and quench recovery



Quenching of superconducting magnets is a well-known phenomenon whereby the superconductor suddenly becomes resistive. The energy stored in the magnetic field is dissipated as heat in the coils and helium.

Magnets do not generally quench except when run for the first time, when they often exhibit “training”, or quenching at successively higher currents.

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- The AMS magnet is not expected to quench until it runs out of helium at the end of its mission on the ISS.
- Even if it does quench, the indirectly-cooled design should mean that no helium is vented. This concept was demonstrated in single-coil and full magnet testing.
- After a quench, the magnet can be re-cooled using the helium in the helium vessel.

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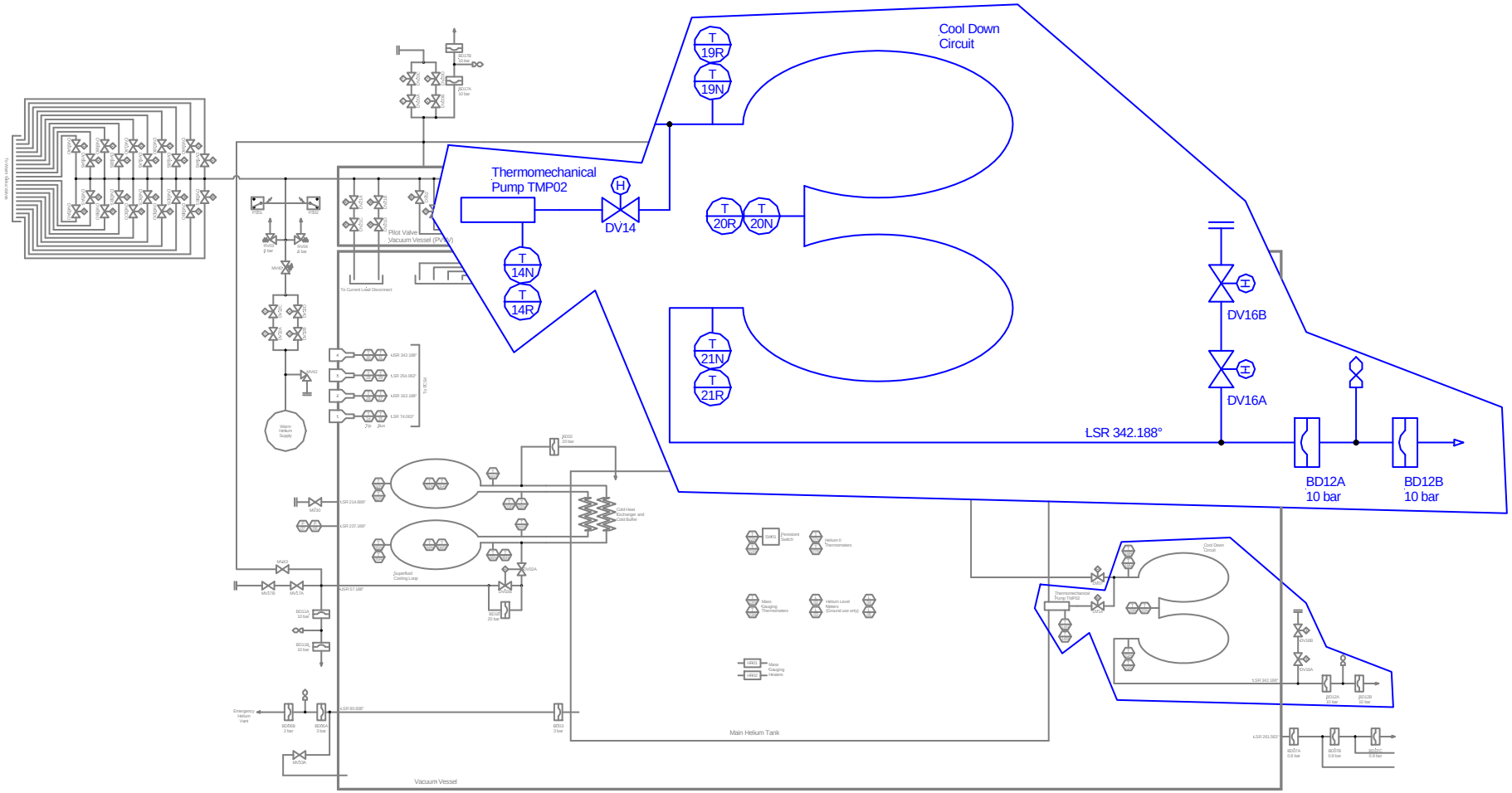


# Quench recovery

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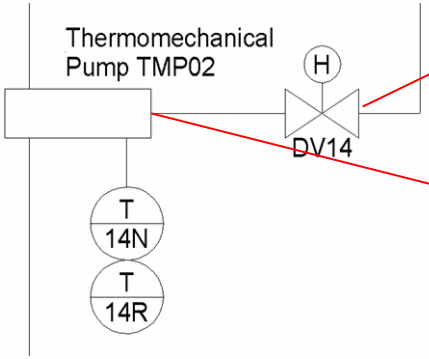
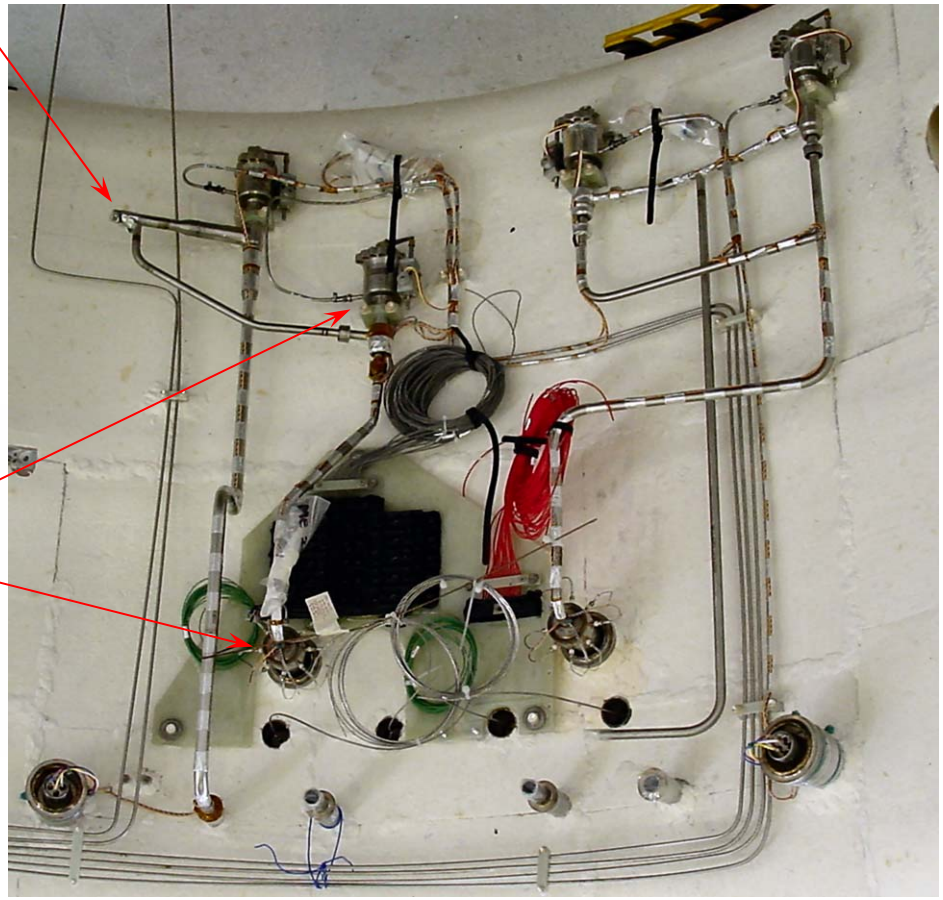
To the cool down circuit



To re-cool the magnet after a quench, a second thermo-mechanical pump is used to force helium around the magnet cooling channel.

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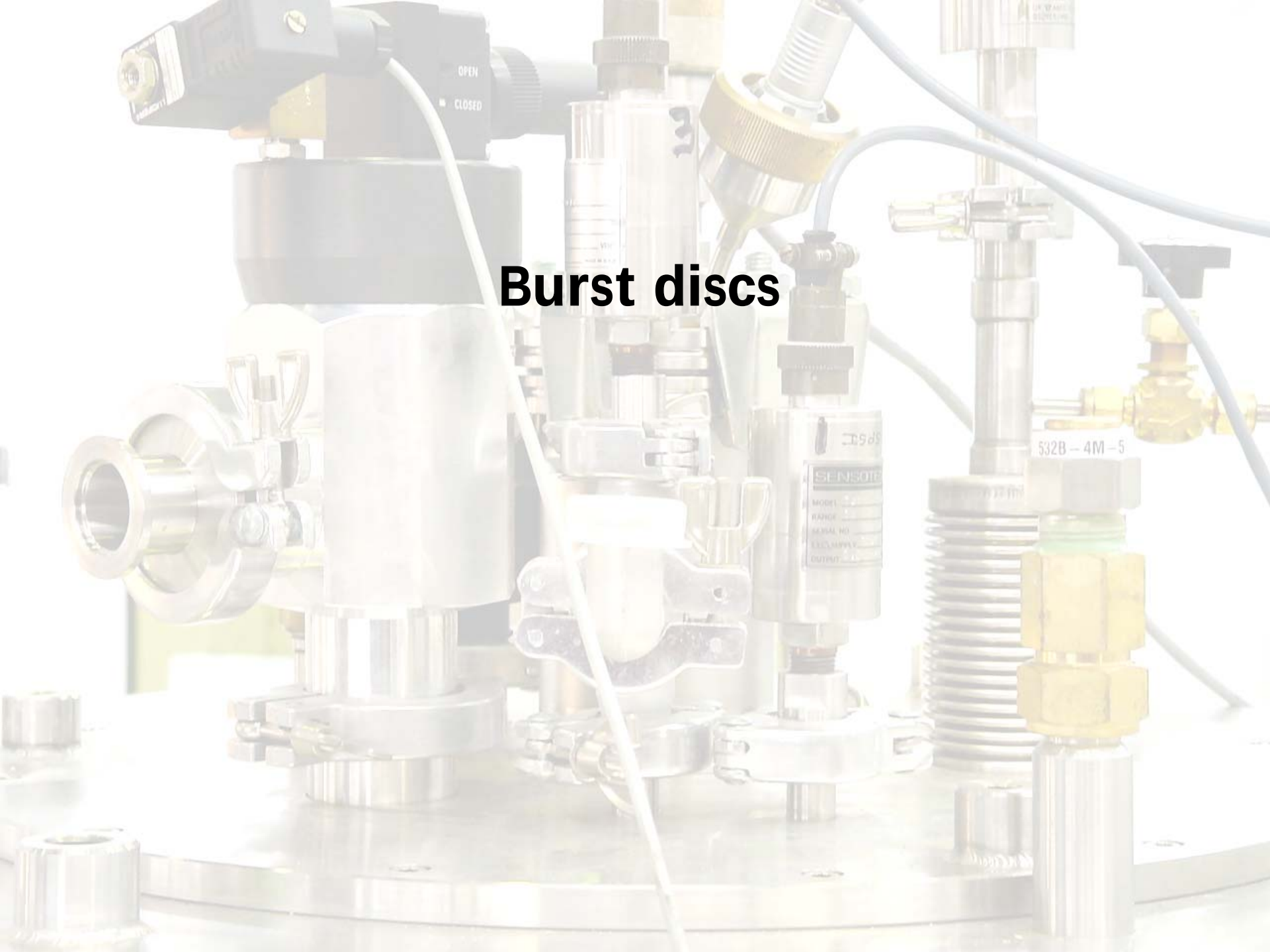
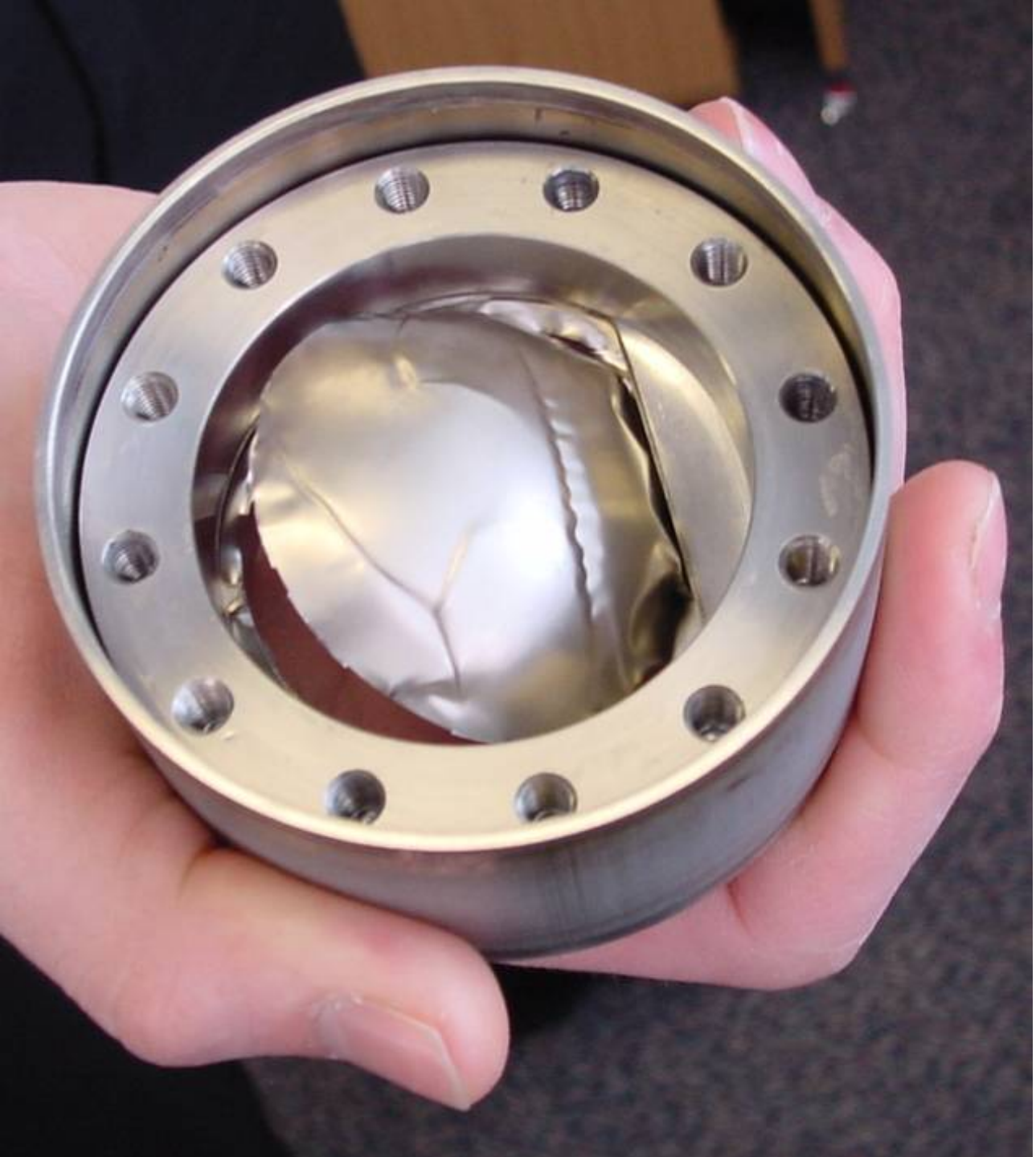
# Burst discs





All vessels and potential trapped volumes are protected with burst discs.

The design, qualification, and testing of the discs was agreed with the NASA safety panel and has been carried out accordingly.

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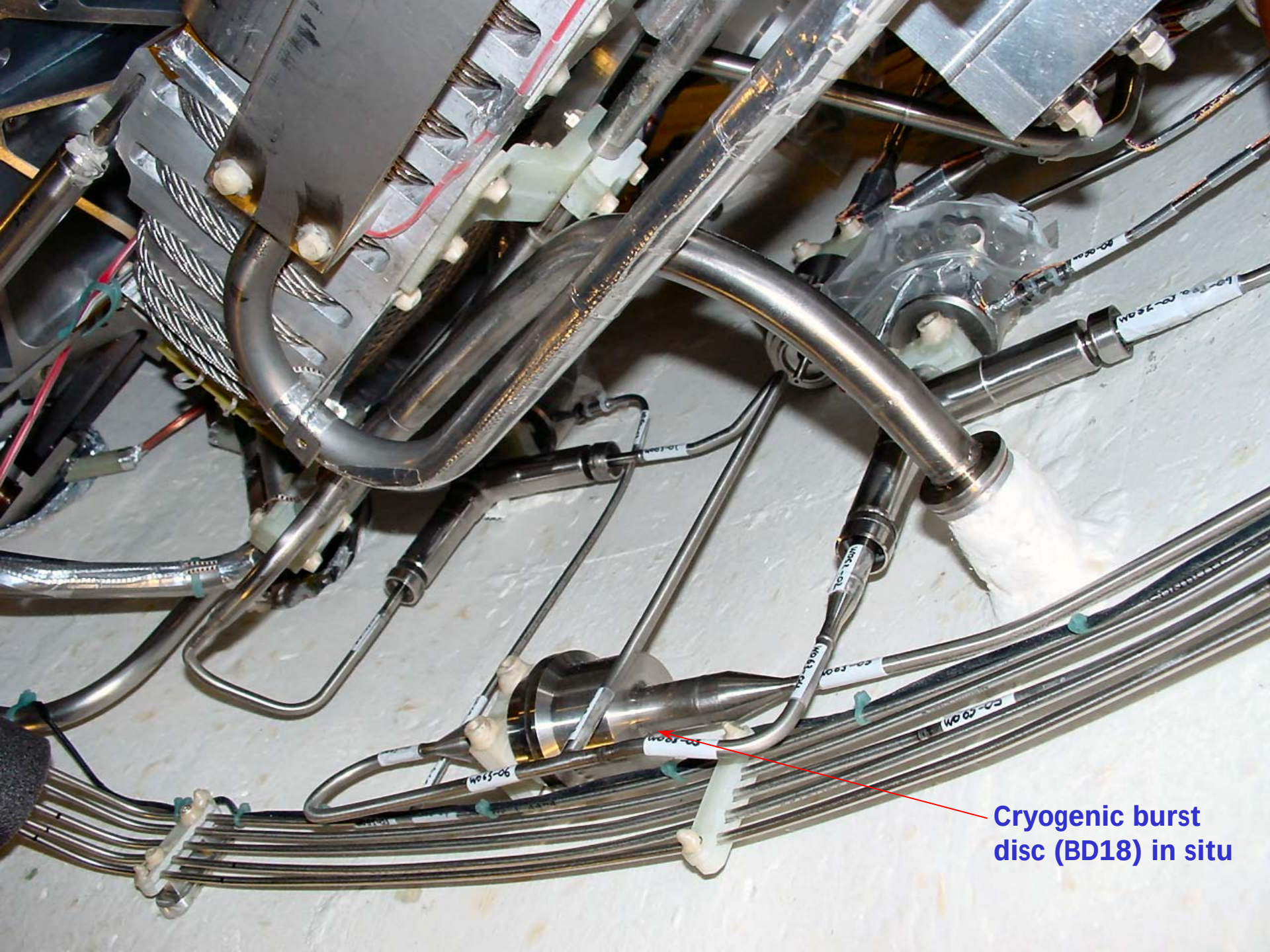
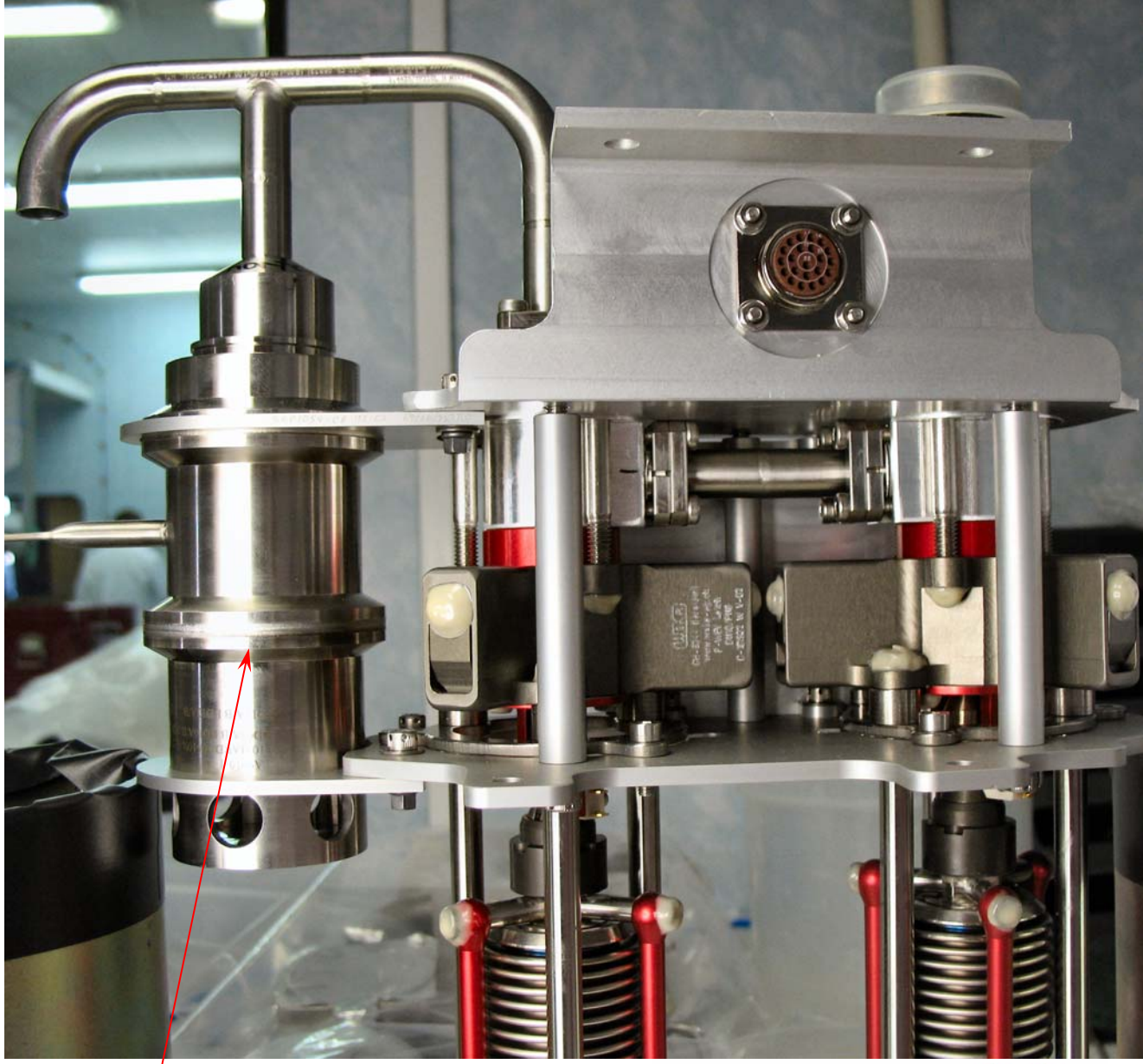

Cryogenic burst
disc (BD18) in situ

Details of venting and analysis are the subject of another presentation.



**Warm burst disc arrangement will be mounted outside the vacuum vessel**

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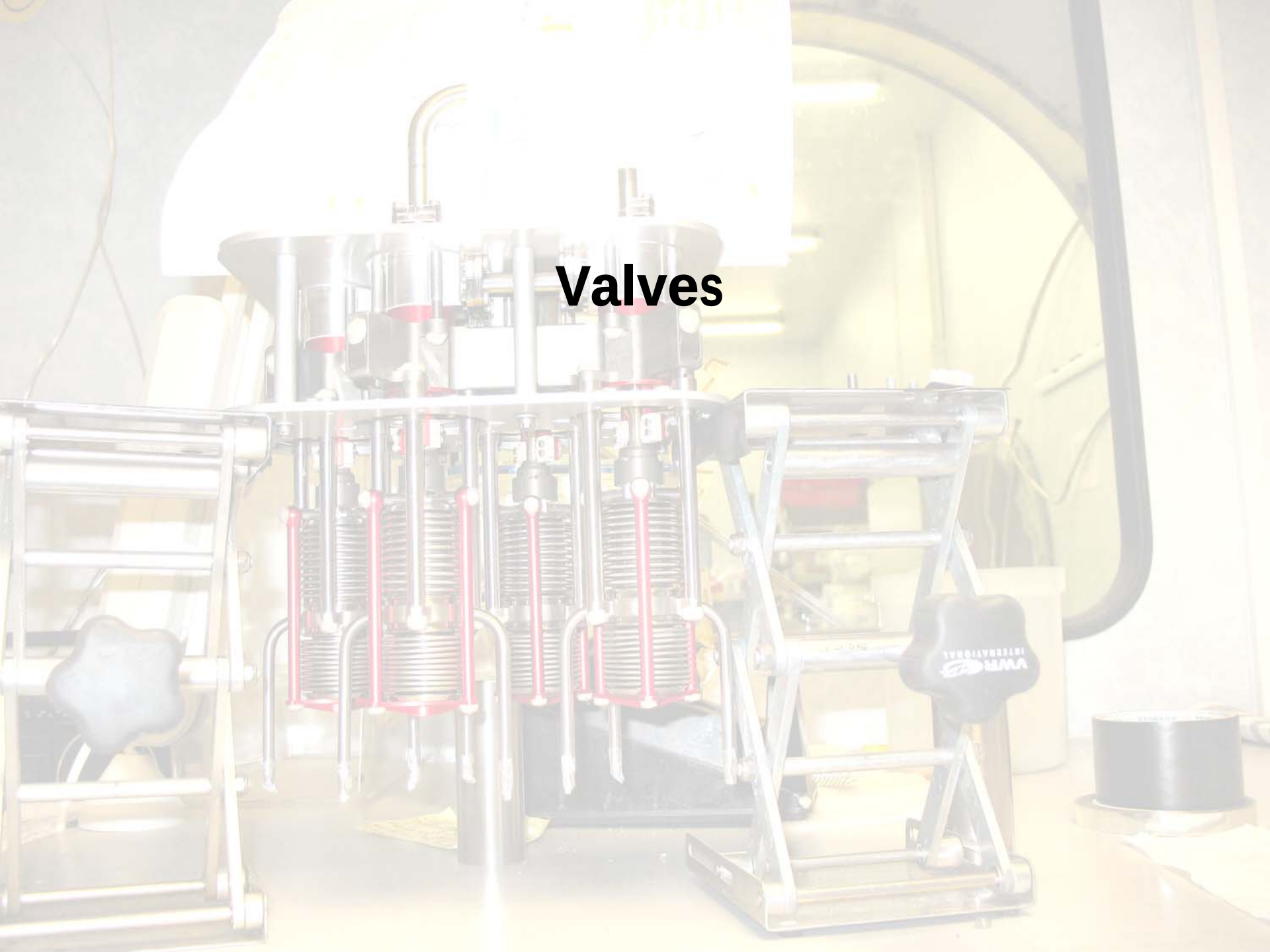
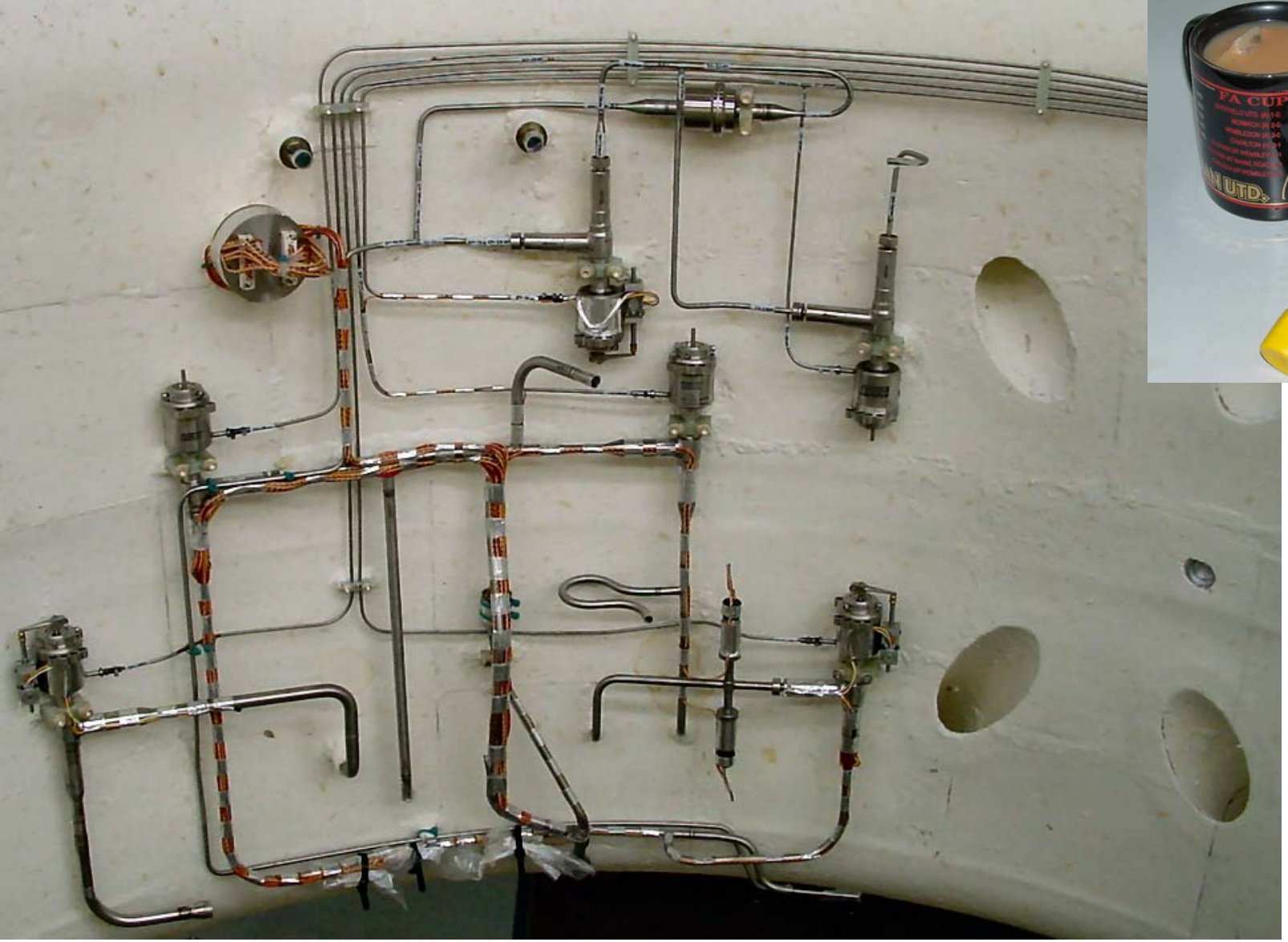
# Valves





Cryogenic valves are mounted from the bore of the helium vessel.

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The valves are bellows sealed, and normally closed. They are opened by helium gas pressure forcing a bellows to expand against the sealing spring.

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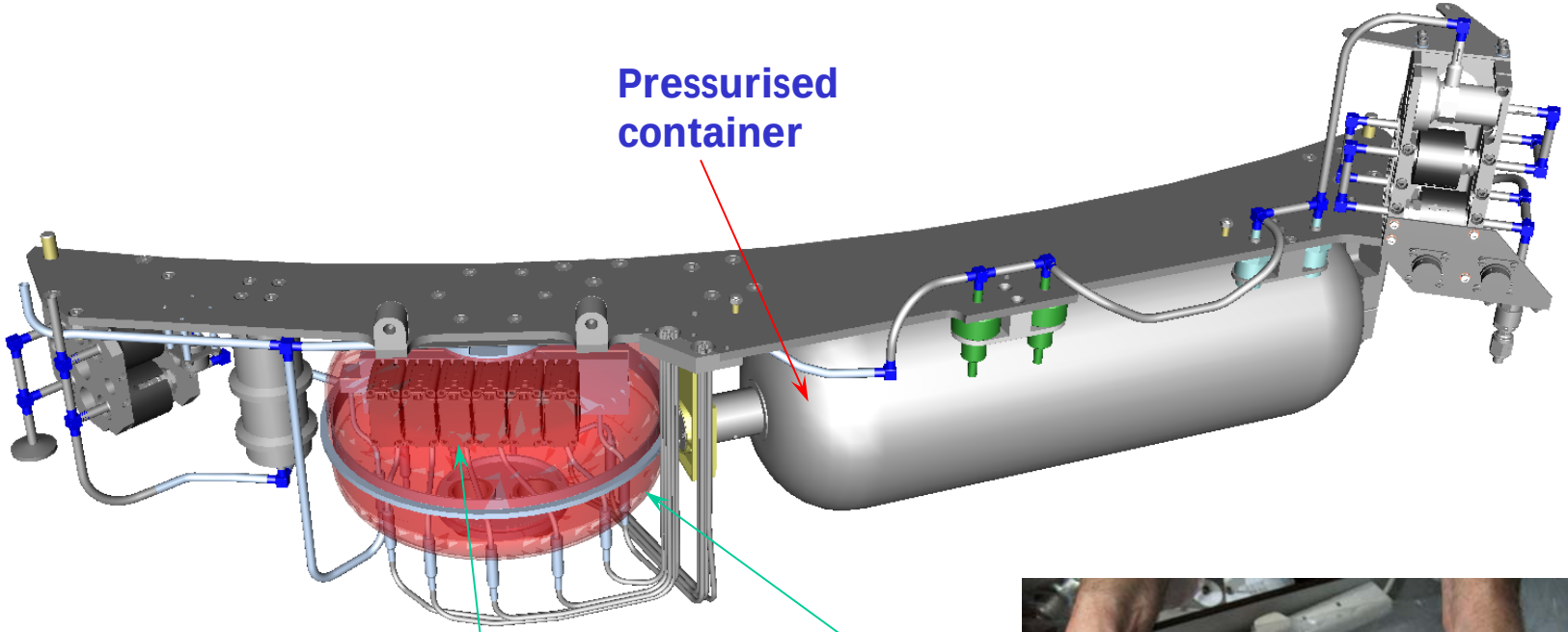
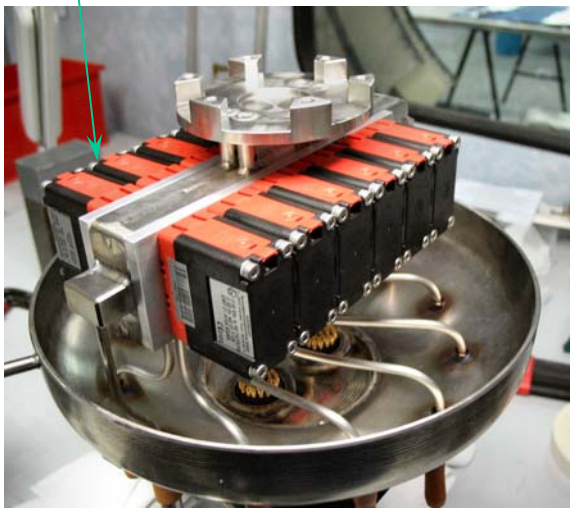



The helium gas is stored in a pressurised container, and flow to the cryogenic valves is controlled by pilot valves. To prevent air leakage into the actuation lines, the pilot valves are inside a pumped vacuum vessel (the pilot valve vacuum vessel or PVVV).

PVVV

Pilot
valves



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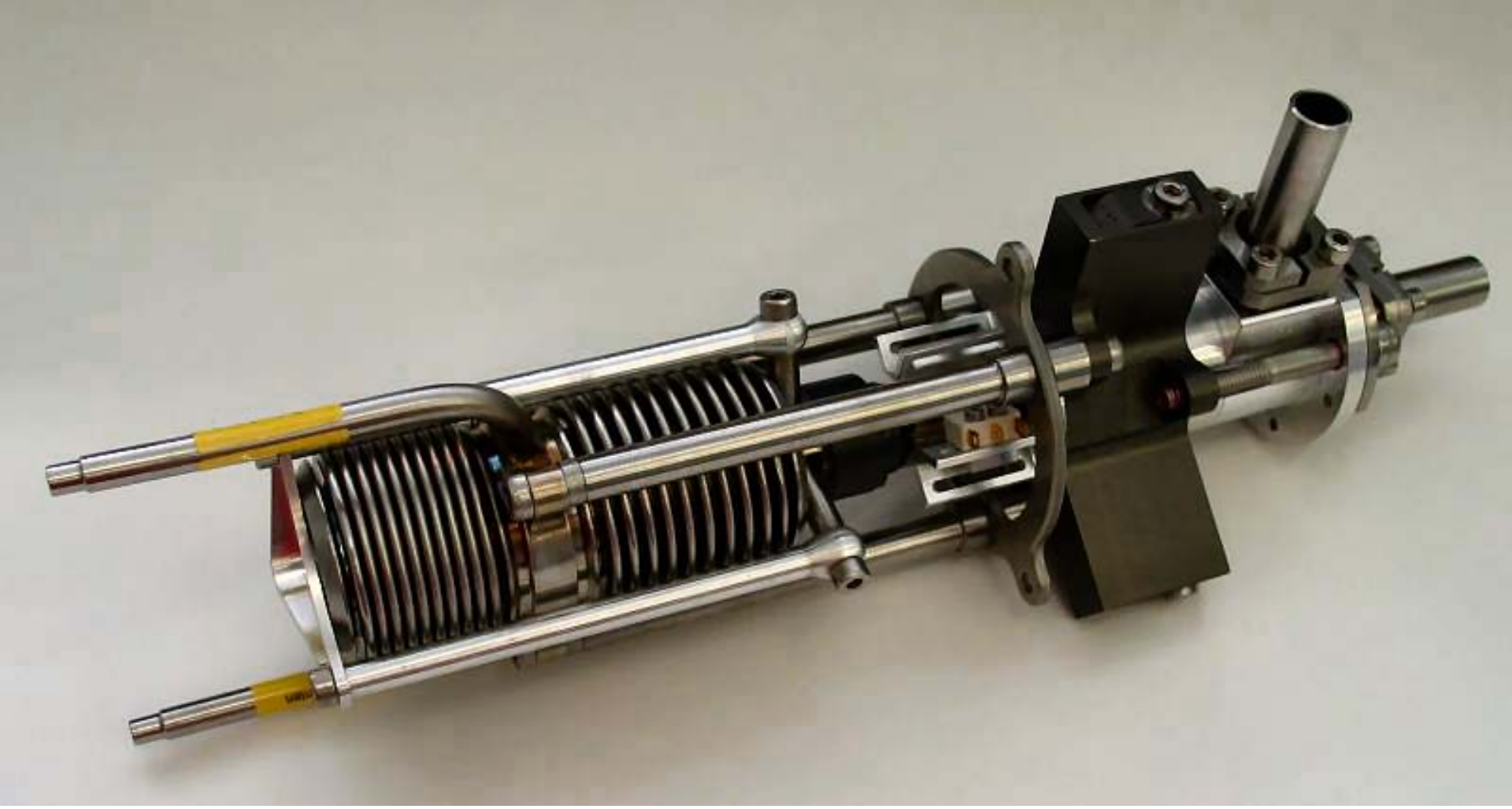

Most of the warm valves are bi-stable, with a spring-loaded mechanism to latch open or closed. Actuation again uses helium gas from the pressurised container.

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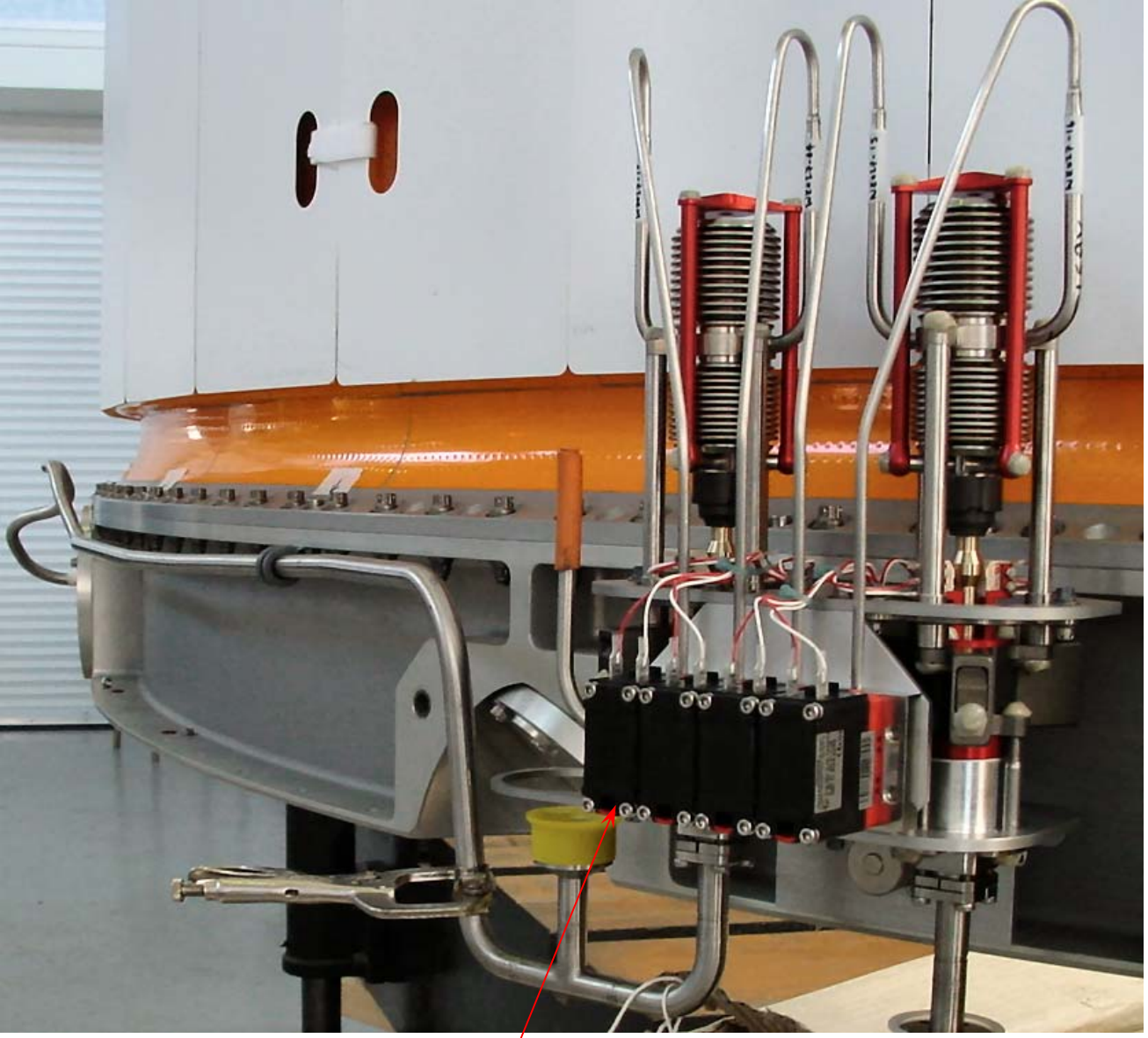

Pilot valves

Because the valves are at ambient temperature, the pilot valves do not have to operate in vacuum and can be mounted near the latching valves.

Two pilot valves are required per latching valve (one to open and one to shut).

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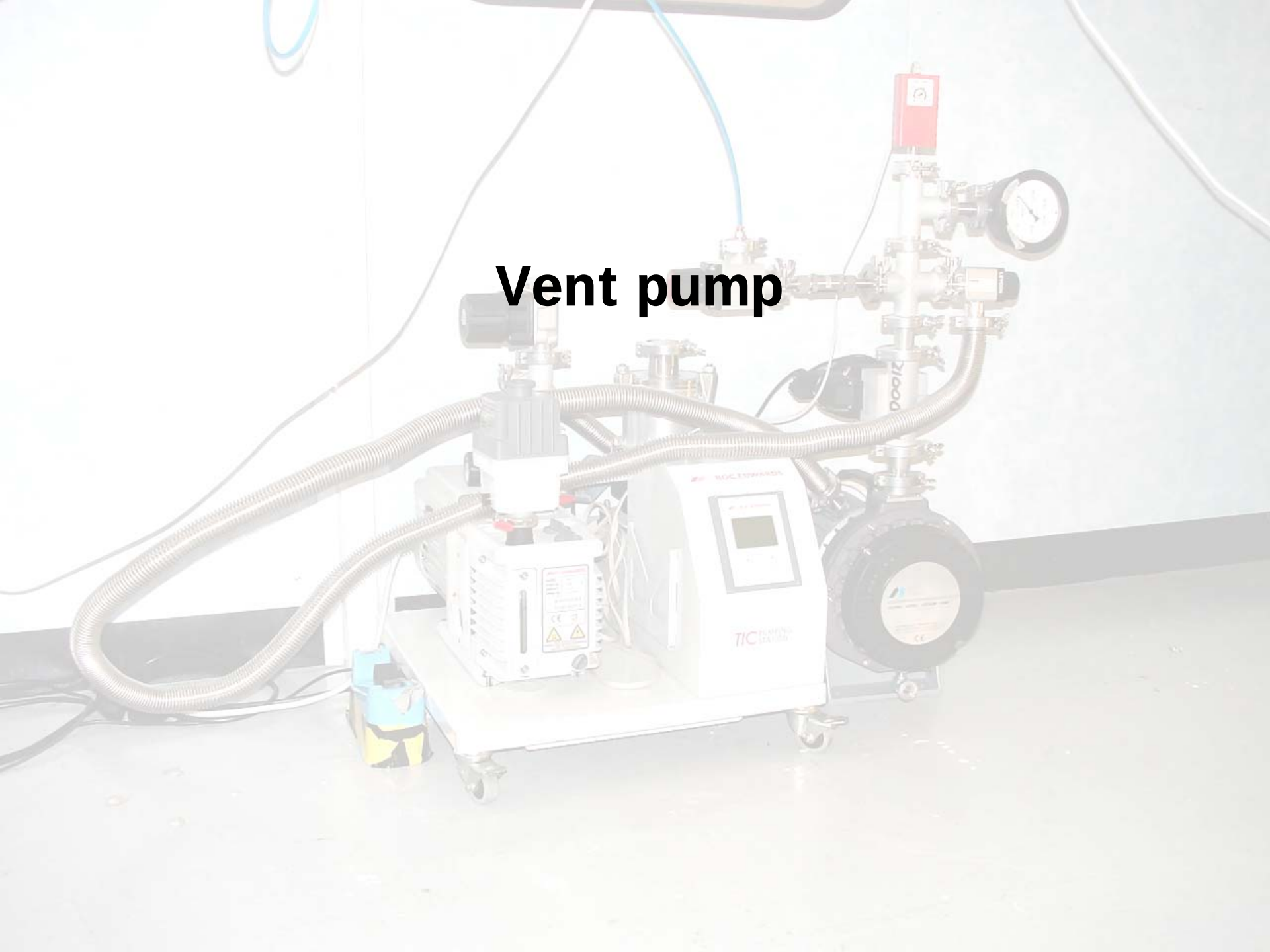
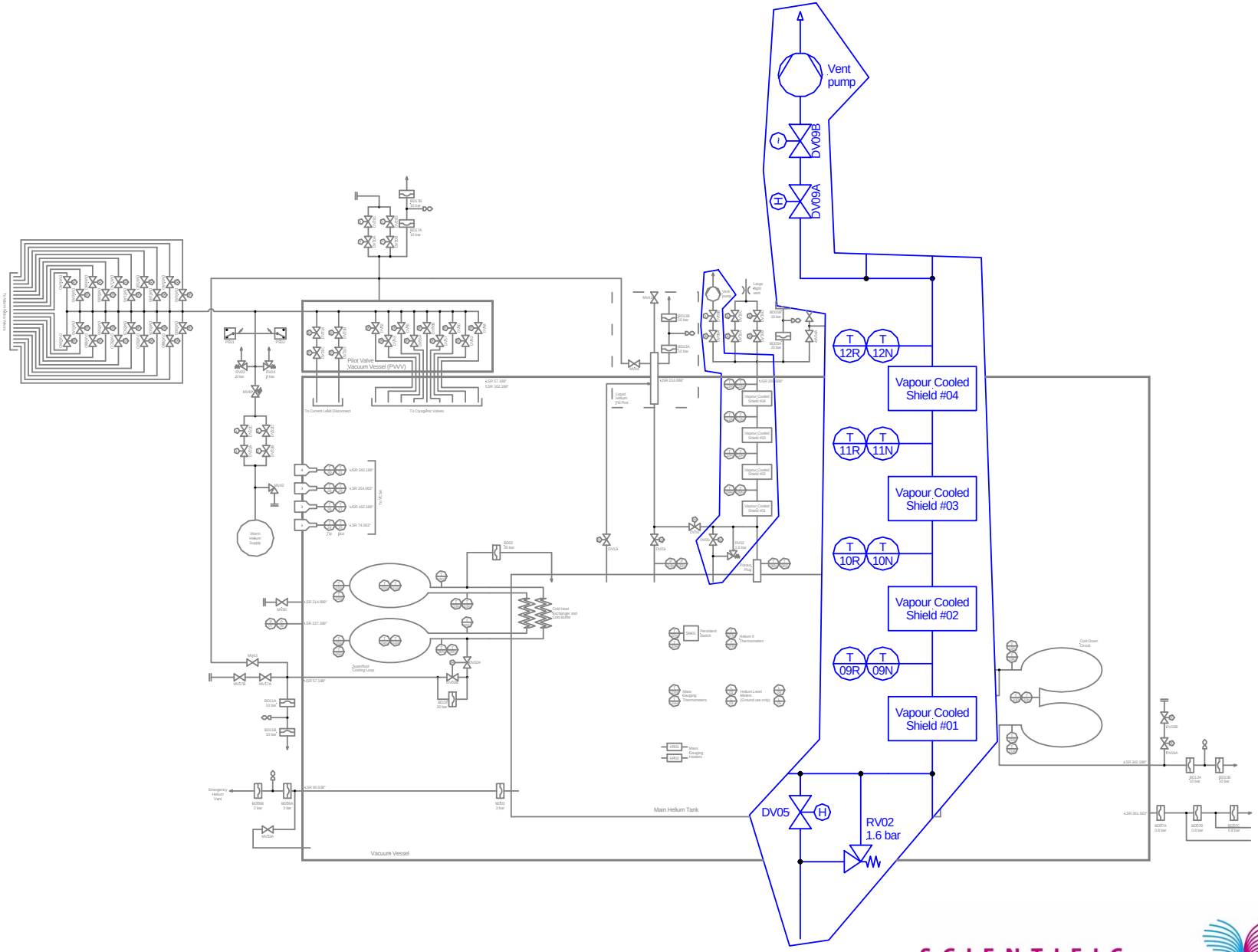
# Vent pump






# Helium vessel – using the vent pump (ground operations)

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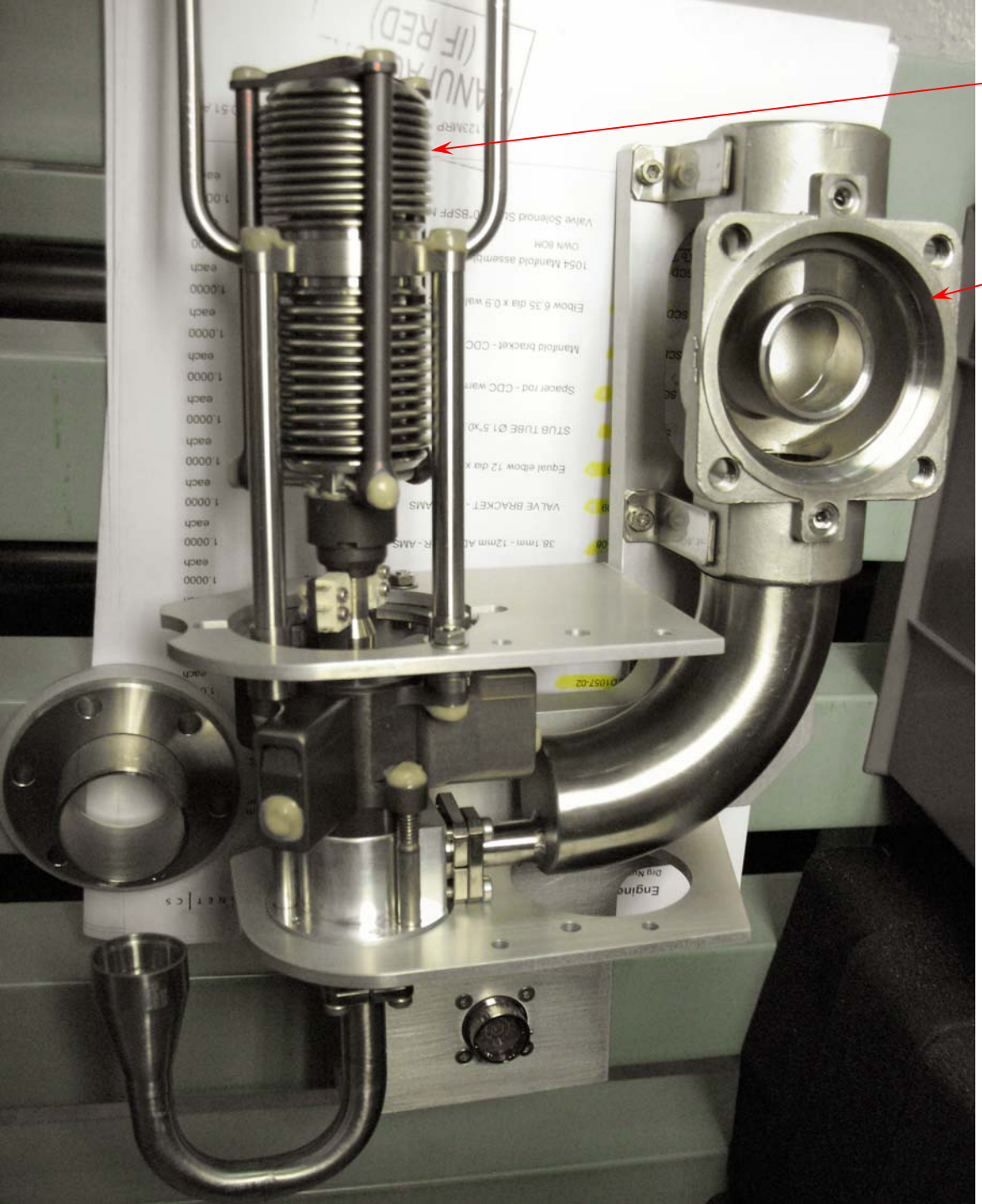


When the CGSE is not available, the helium vapour from the vapour-cooled shields can be diverted to leave the vacuum vessel via a latching valve and a solenoid valve.

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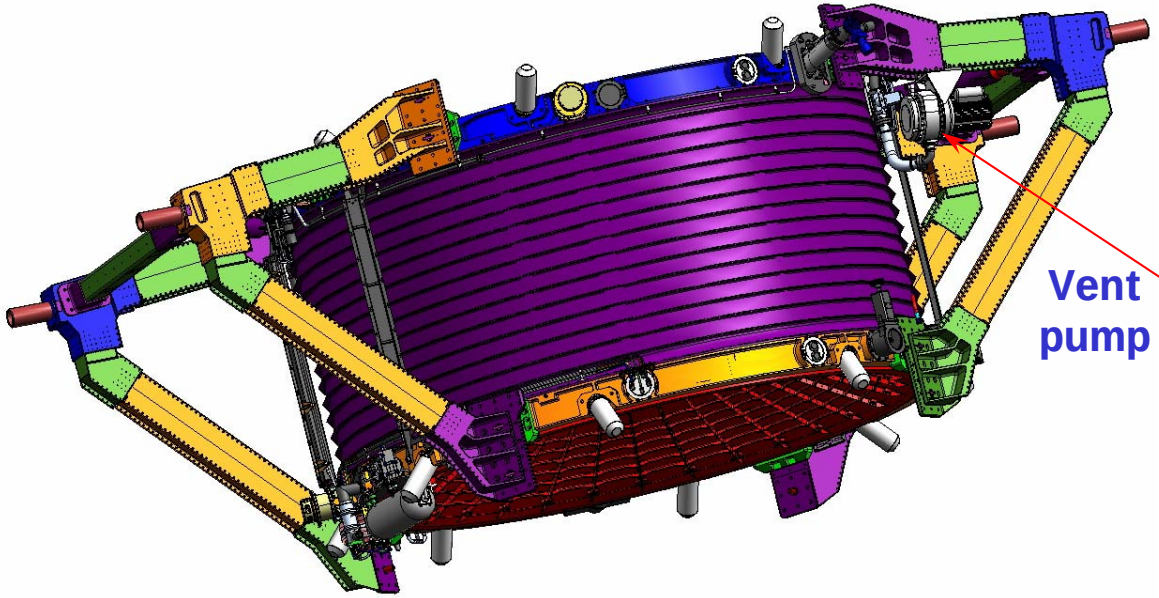

The vent pump is much smaller than the CGSE pumps, and will probably not be able to keep the helium pressure in the superfluid range indefinitely.

It is attached to the USS, so flies with the experiment, but is never used after launch.

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