HFVMTF - Cryostat and cryogenic specifications

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SC Cable Test Facility workshop

21st November 2022

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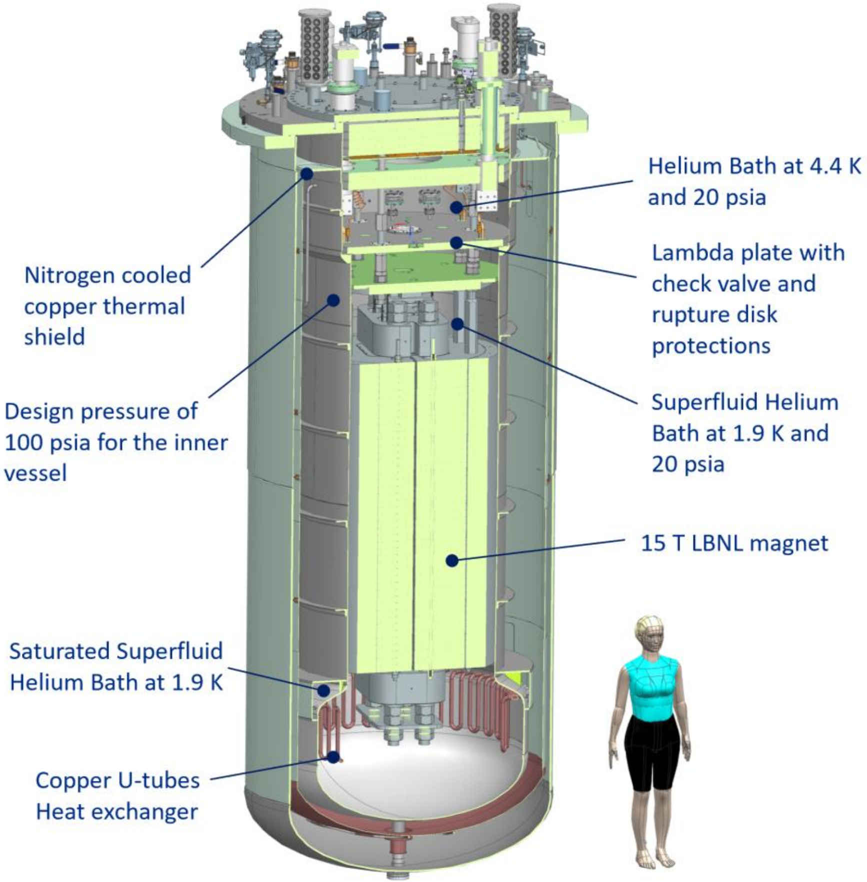
HFVMTF - Test Facility

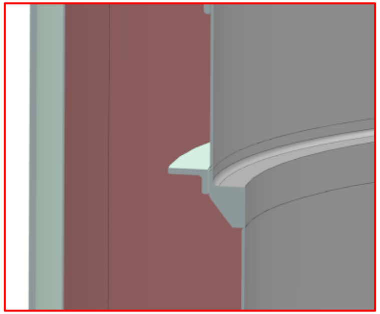
- New High Field Vertical Magnet Test Facility (HFVMTF) for testing superconducting cables in high magnetic field
- Similar test stand to EDIPO (PSI) and FRESCA2 (CERN)
- Double bath cryostat for a **1.3 m diameter and 3 m long magnet** in the superfluid bath
- **20 tons magnet** maximum
- Operation pressure and temperature: **1.3 bara and 1.9 K**
- Cryostat **ASME certified** (Section VIII Div. 1)
- MAWP of **6.89 bara**

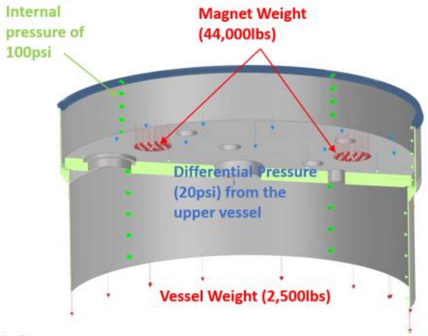


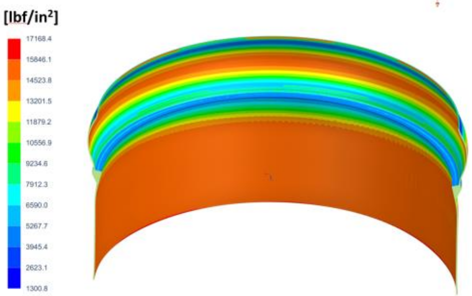
HFVMTF Cryostat

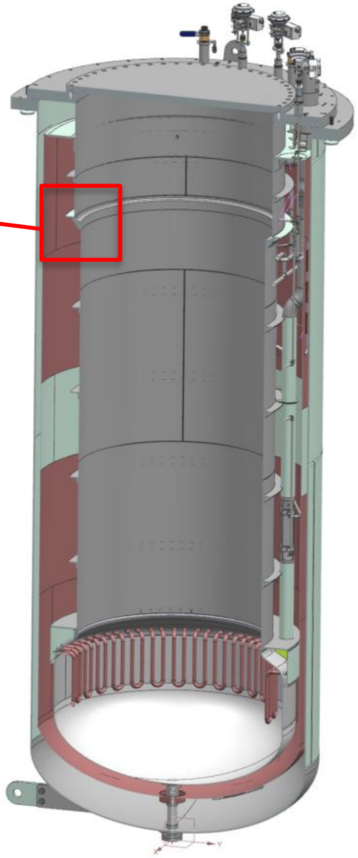
HFVMTF – Cryostat Design

- Ability is designing the **helium and vacuum vessel** made with 304L stainless-steel
- The two most complicated parts of this design are: the **lambda ring** and the **2K Heat exchanger**
- Lambda ring requirements:
  - Should sustain **25 metric tons** (weight of the magnet + mechanical supports)
  - An additional **1.3 bar** (vacuum on the lower part) pressure difference should be considered
  - A **minimum deflection of 0.13 mm** is needed to guaranty the seal between the upper and lower bath (spring energized seal)
  - **FEA** performed by Ability as been compared to an internal FEA to verify the design





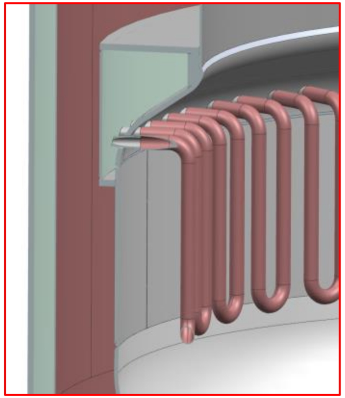


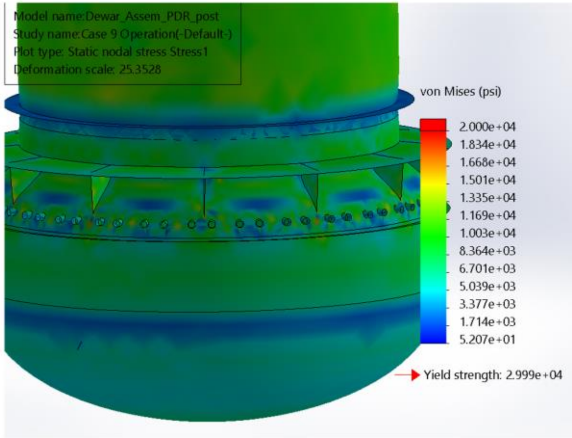


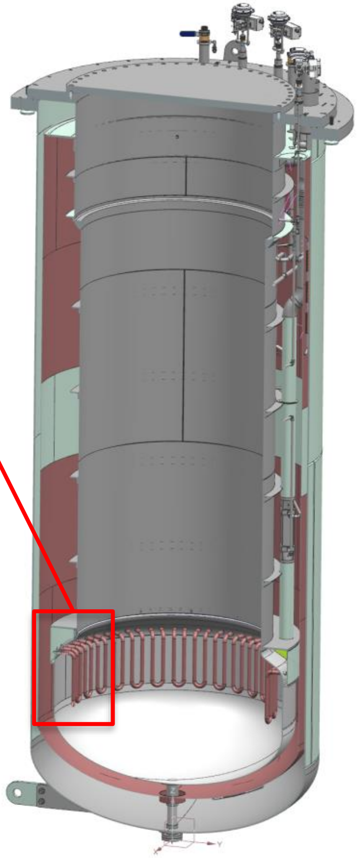
HFVMTF Cryostat

HFVMTF – Cryostat Design

- 2K Heat Exchanger:
  - **30 copper U-tubes** (similar design to Fresca2)
  - U-tubes brazed to the stainless-steel nozzles
  - Specific shape of the 2K saturated vessel to comply with the ASME code (different design than Fresca2)
  - 12 gussets were added to minimize the stress on the wall of the vessel
  - Sufficient flow path
  - The liquid level probe reaches the bottom of the 2K saturated vessel (not the copper tubes)



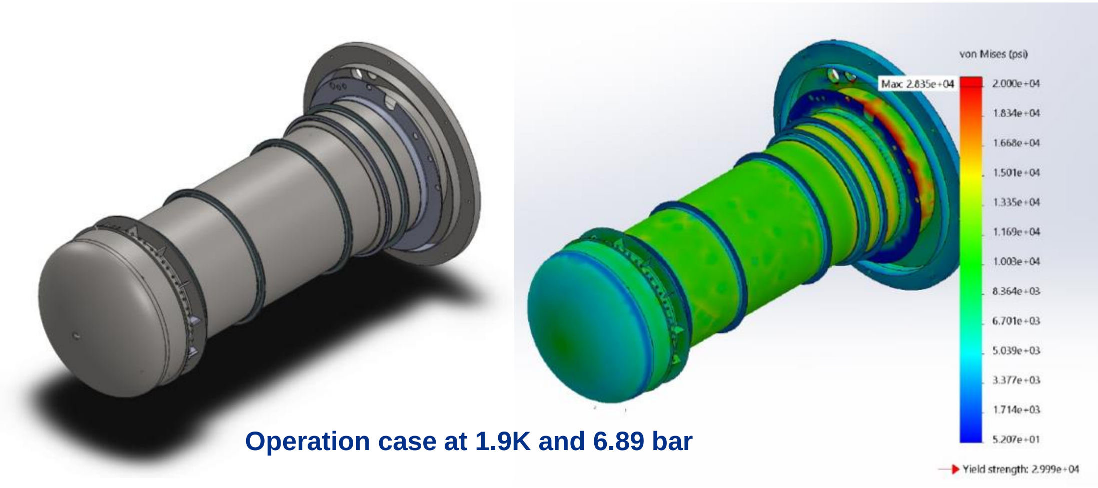




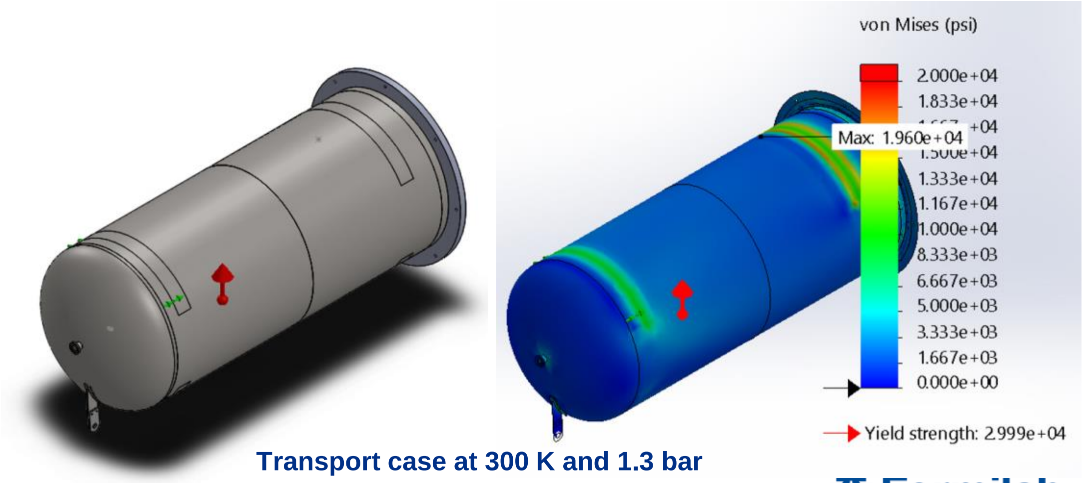
HFVMTF Cryostat

HFVMTF – Cryostat Design

- Cryostat only supported by the top flange (+ shipping support for transportation)
- Multiple FEA cases are performed by Ability to certified the vacuum and helium vessel
- **Operation case** (cryostat vertical) at 1.9 K and 6.89 bara
- **Transportation case** (cryostat horizontal) with an acceleration of 5 g vertical and 2 g horizontal
- Fast cool down of the thermal shield also verified by FEA



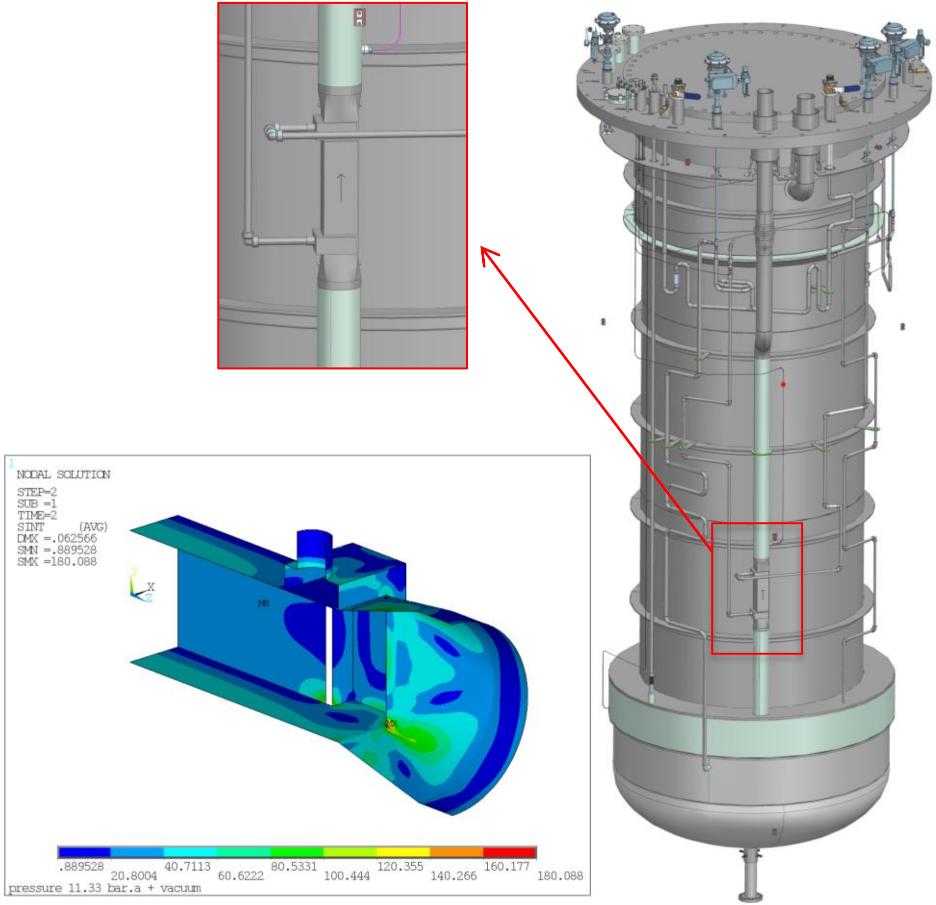
Operation case at 1.9K and 6.89 bar



Transport case at 300 K and 1.3 bar

HFVMTF – Cryostat Design

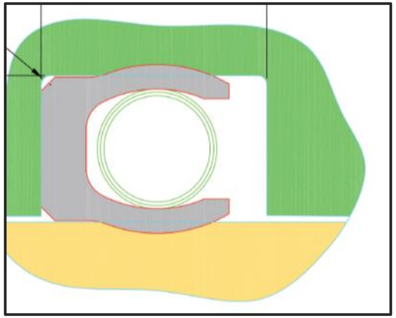
- **Joule-Thomson Heat Exchanger** manufactured by **DATE** (3 g/s)
- JT Heat Exchanger is also **ASME certified** (FEA performed by DATE)
- Pressure and temperature sensors (TVO) at the inlet and outlet of the low and high-pressure side of the JT Heat exchanger
- **Thermo-acoustic analysis** of the pressure conduit
- **Flexibility analysis** of the Helium and Nitrogen pipes done by Ability (Thermo-contraction)
- LN2 to cool down the thermal shield (fast cool down)



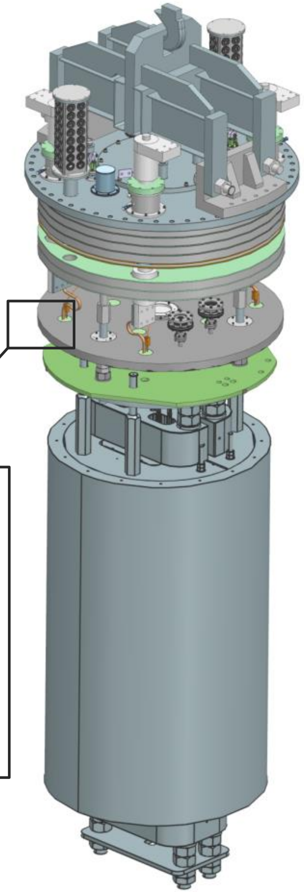
HFVMTF helium vessel

HFVMTF – Lambda/Top plate Design

- **Two Lambda/top plates** will be manufactured:
  - One for the **magnet test facility** (4 current leads)
  - One for the **cable testing facility** for fusion (2 current leads)
- Supports a **20 tons magnet** and **1.3 bar** pressure difference
- **50 mm thick** lambda plate made of 304L (same material as the vessel to comply with the ASME code)
- **Spring load energized seal** (8 tons minimum required to seal a minimum) made with:
  - Fluorolon 1000 PTFE for the seal jacket
  - Elgiloy spring (Cobalt-chromium-nickel alloy)



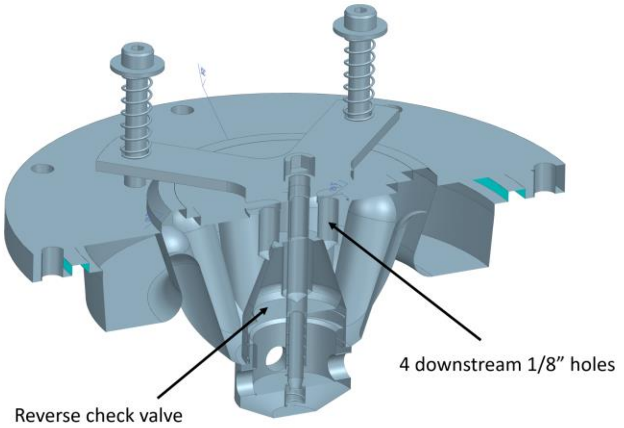
Energized spring seal

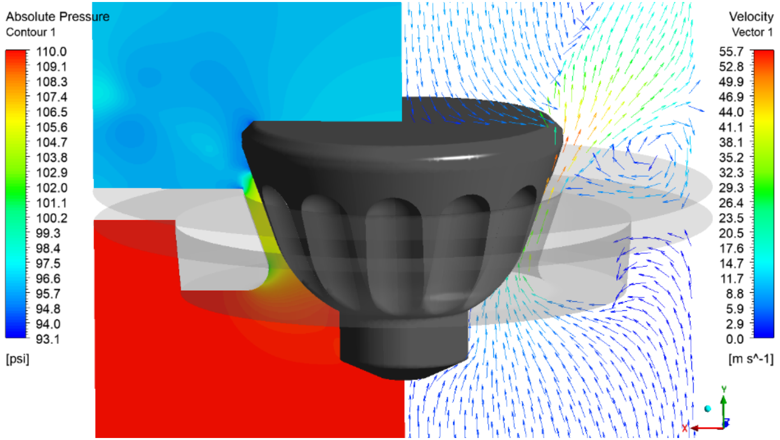


Lambda/top plate design

HFVMTF – Lambda plate Design and Safety

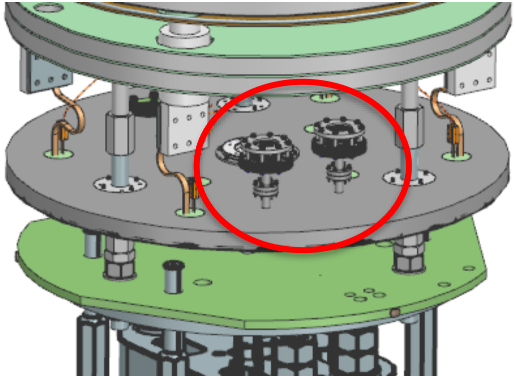
- The **BNL safety design** on the lambda plate composed of **two check valves**:
  - One large PTFE check valve to protect the lower bath during quench of the magnet
  - One small check valve (**reverse check valve**), inside the larger one to protect the upper vessel during the cool down between 4 K and 2 K
- Minimum pressure difference of **0.1 bar** to open both check valve
- Maximum pressure drop of **0.3 bar** (supercritical helium at 7 K and 7 bar) with a mass flow of **1.56 kg/s** (CFD calculation)
- 0.11 W heat load on the lower bath

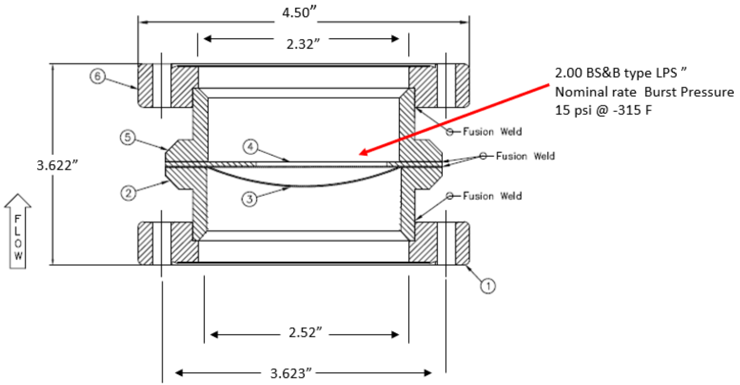




HFVMTF – Lambda plate Design and Safety

- **Two rupture disks** installed on the lambda plate:
  - One **50 mm diameter disk** to protect the lower bath in case of vacuum break
  - One **25 mm diameter disk** to protect the upper bath if the reverse check valve fails to open
- **1 bar burst pressure** at 4.5 K (certified in nitrogen)
- Resist full vacuum (type LPS)
- Both located on the upper bath for better accessibility
- **Burst sensors** to monitor the status
- Heat load on the lower bath:
  - 2.5 W for the 50 mm disk
  - 1 W for the 25 mm disk





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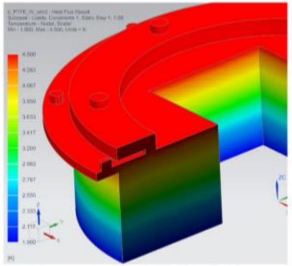
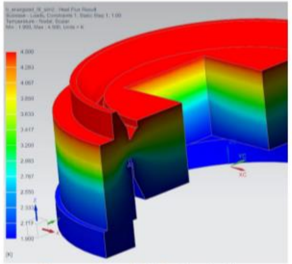
HFVMTF – Anticryostat

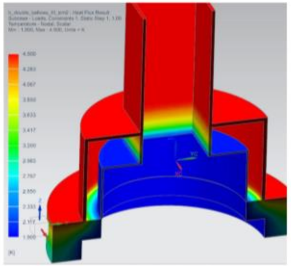
- Multiple sealing solution analyzed:
  - **PTFE Plug** (VMTF design at Fermilab)
  - **Spring Energized seal** (BNL design)
  - **CF Flange seal**
- Lowest heat leaks with the PTFE plug solution
- Stainless steel collar that can be replace if we use another design of anticryostat



Temperature distribution in the PTFE Plug

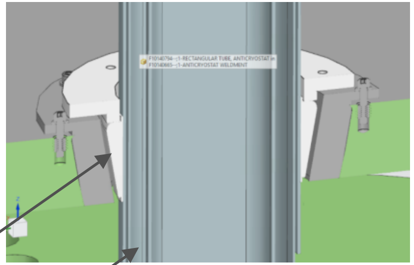


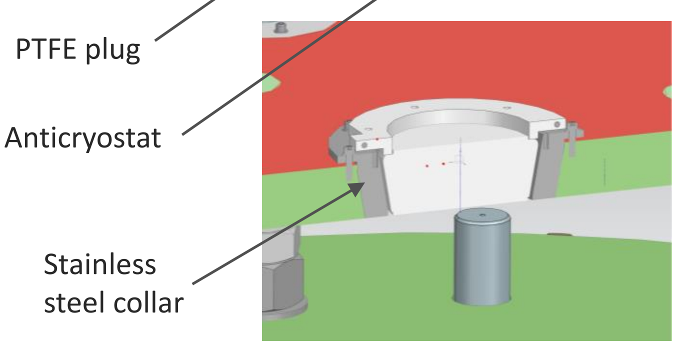
Temperature distribution in the Spring Energized Seal



Temperature distribution in the CF Flange Seal

Seal Type	FEA Heat Flow (W)
PTFE Plug	0.195
Spring Energized Seal	0.331
CF Flange Seal	0.663





HFVMTF – Lambda plate heat load

- Insulating materials (25 mm thick plate on top of the 304L lambda plate):
  - **G10/G11**, about 7 W heat load on the lower bath
  - **Ultem 2300/6200**, about 3.5 W (thermal conduction below 4.2 K unknown)
- General heat loads through the lambda plate:

	G10	Ultem
Overall Plate (304L + insulation)	**7 W**	**3.5 W**
1” Rupture Disk	**1 W**	
2” Rupture Disk	**2.5 W**	
Check Valve	**0.11 W**	
Anticryostat (PTFE Plug)	**0.2 W**	
4 Feedthroughs (G10)	**0.04 W**	
4 current leads (copper RRR=50)	**5.2 W**	
Total	**16 W**	**12.5 W**

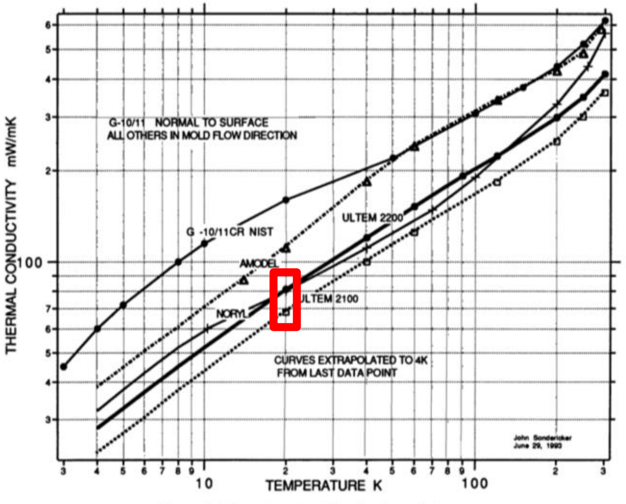
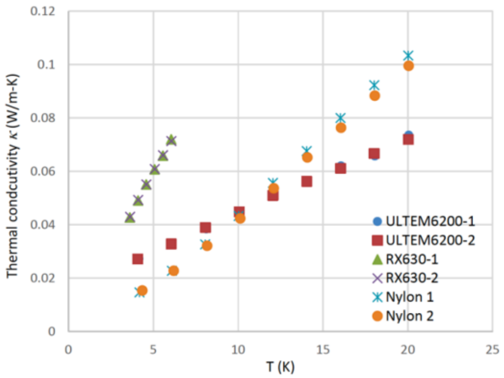


Figure 4. Thermal conductivity of various plastics.

Advances in Cryogenic Engineering Materials: Volume 40, Part A p1104



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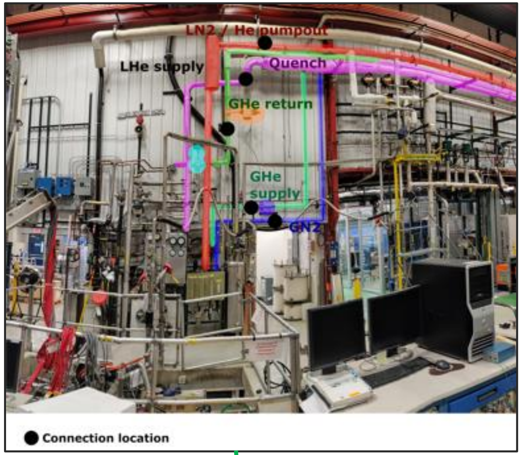
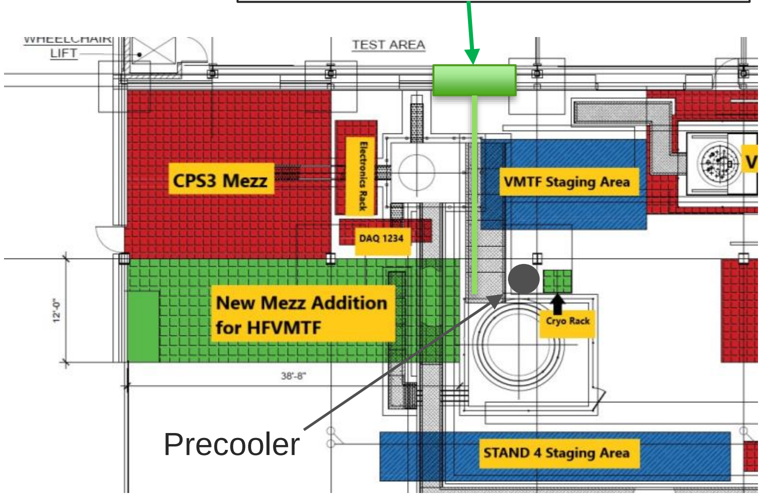
HFVMTF – Cryogenic distribution system

- Share piping connection with the actual **VMTF test stand** in IB1
- **LN2:**
  - Cryostat thermal shield
  - Pre-cooler nitrogen bath
  - Current leads (if needed)
- **GHe:**
  - Cool-down and warm up of the magnet
  - Anticryostat or current leads possible cooling
- **LHe:**
  - Cryostat (bottom part during cool-down and upper vessel in operation
  - Anticryostat if needed
- **Pumping and Quench** lines





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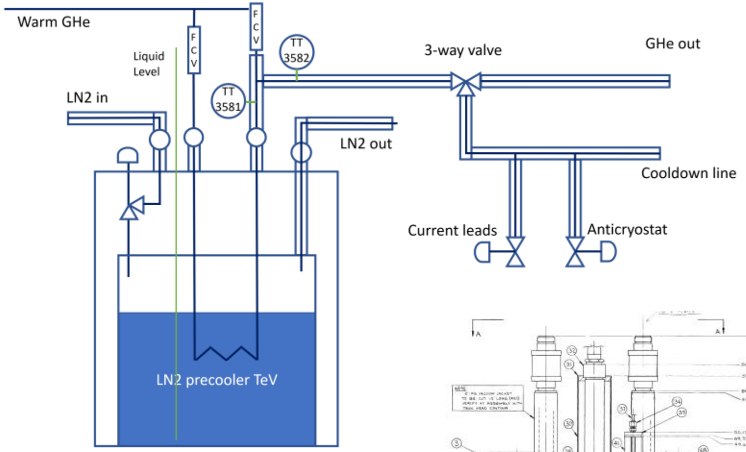
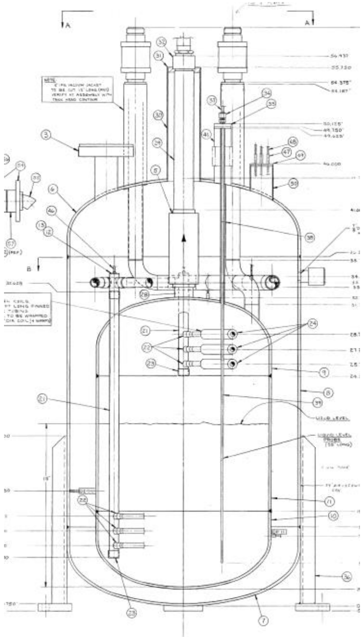
HFVMTF – LN2 precooler

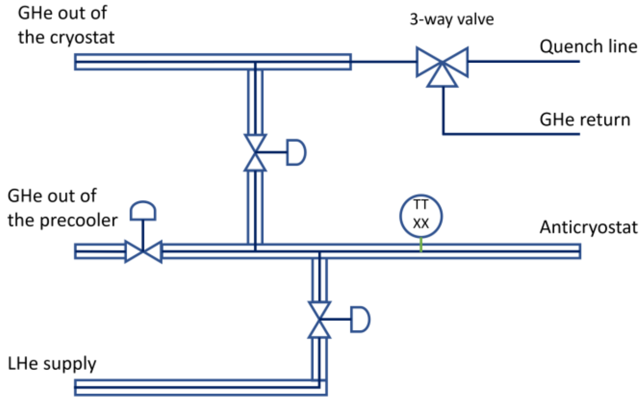
- Use an old **Tevatron Helium precooler** (Nitrogen bath instead of Helium)
- Maximum mass flow of **30 g/s at 4 bara** to reach 80 K at the oulet (10 g/s required for the cool down)
- 2 mass flow controllers to regulate the helium temperature
- 2 additional controlled valves to supply the current leads and/or the anticryostat with cold helium gas

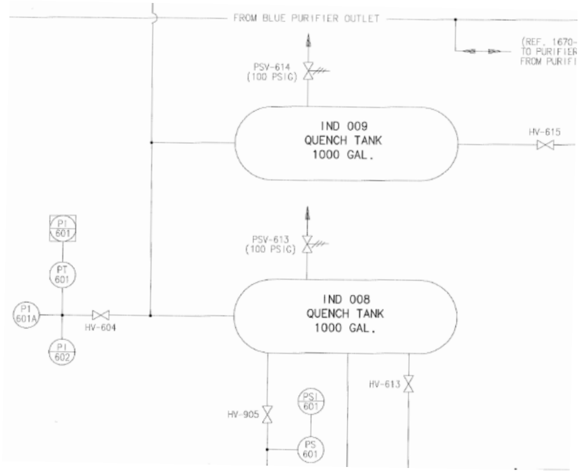




HFVMTF – Gas Helium outlet

- The **gas helium outlet** can be used to cool down the anticryostat
- The outlet gas can be mixed with LHe or GHe at 80K (precooler) to regulate the **temperature of the anticryostat**
- **3-way valve** connects the outlet of the cryostat to the GHe return or to the quench line
- **2 Quench tanks** (similar system to VMTF) 1000 gallons each ($4m^2$)
- **1 Buffer volume** can be used 123 m^2 to recover more helium during quench





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HFVMTF – Timeframe

- **Cryostat (Ability):**
  - **PDR** done (11/2/2022) and **FDR** in mid December 2022
  - **PRR** and **beginning of fabrication** in January 2023
  - **Delivery** end of July 2023
- **Lambda/top plate:**
  - Thermal conductivity of Ultem to measure
  - Final Internal Design review in December
  - Parts will be ordered separately in 2023
- **Piping integration:**
  - Tevatron Precooler leak tests now
  - Start working on the piping design and Fabrication (Fermilab)
- **Cryocontrols** (Siemens PLC similar to stand 4):
  - Cabinets delivered
  - Siemens PLC + modules in March 2023

Siemens PLC system

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