BDF target cooling concepts

BDF Targetry Systems Advisory Committee - TSAC

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04/03/2025

Agenda

- BDF Target/Proximity Shielding Cooling requirements
- Water vs Helium – cooling
- Operational considerations
- BDF Prototype Helium Skid
- Conclusions

BDF Target/Proximity Shielding - Requirements

3 equipment requiring cooling:

1. Target
2. Proximity shielding
3. Hadron stopper (5 kW – outside shielding)

Target user requirements

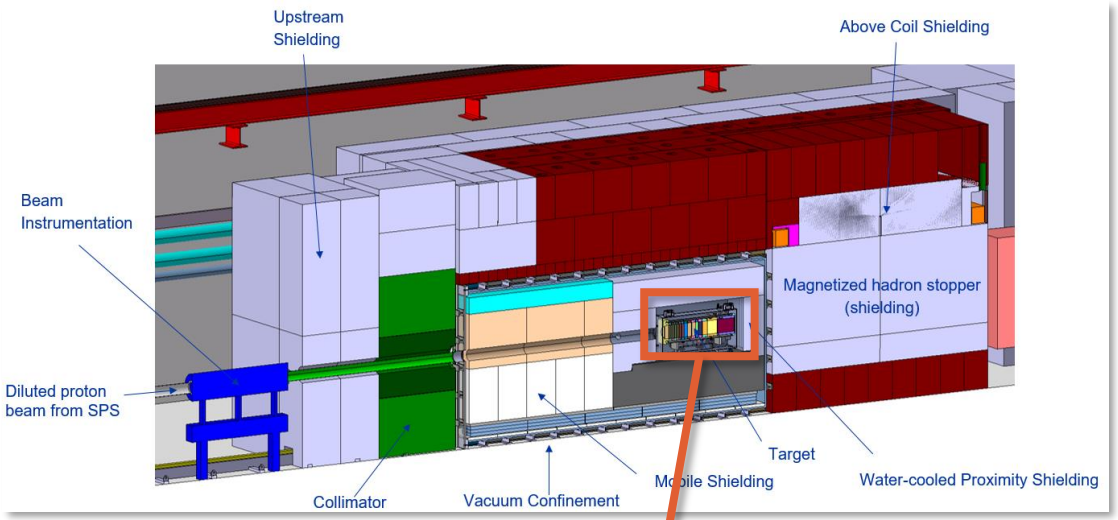
- Target deposited power: 305 kW
- Cooling medium inlet temperature: 30 °C + 3 K
- Pressure rating: 10^{-4} mbar(a) to PN25

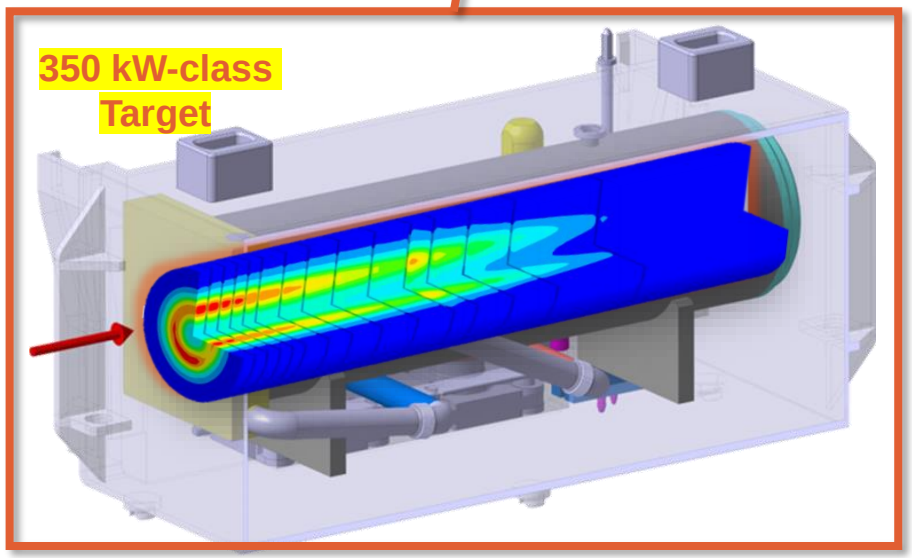
Proximity shielding user requirements

- Deposited power: 20 kW
- Cooling medium inlet temperature: 30 °C + 3 K
- Pressure rating: 10^{-4} mbar(a) to PN25

Functional requirements

- Compressor redundancy (pending)
- Operation 24/7 for 365 days – reduced mode during YETS





Cooling possibilities: Water vs Helium

Demineralised Water Cooling

- **Main parameters**
  - Water supply temperature: 30 °C ± 3 K
  - Water flow rate: 45 m^3/h (target) + 6 m^3/h (proximity)
  - Pressure rating: PN25
- **Characteristics**
  - Supply pressure: 22 bar(g) (target) / 5 bar(g) (proximity)
  - Differential temperature (after/before user): < 10K
  - 1 heat exchanger
  - Water activation + tritium production + potential water contamination if cladding is damaged + water radiolysis
  - 9 ion exchanger cartridges (6+1 for target and 1+1 for proximity shielding)

Helium Gas Cooling

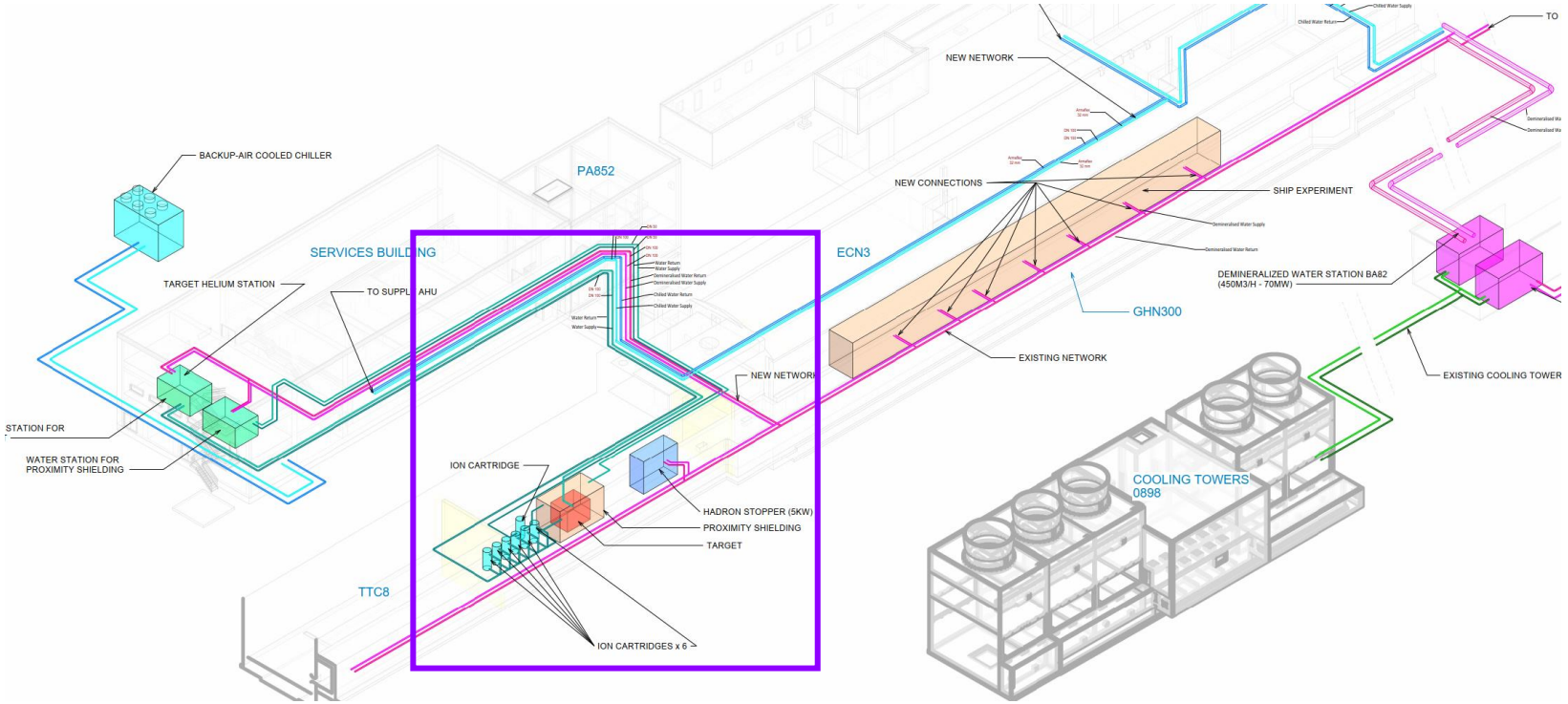
- **Main parameters**
  - He(g) supply temperature: 30 °C ± 3 K
  - He(g) flow rate: 400 g/s (target + proximity)
  - Pressure rating: PN25
  - Helium purity: > 99.9999% (Helium 60)
- **Characteristics**
  - Supply pressure: 16 bar(a)
  - Differential temperature (after/before user): 170 K
  - 3 heat exchangers
  - Tritium produced + possible outgassing (H_2O, CO, CO_2, O_2 , H_2)

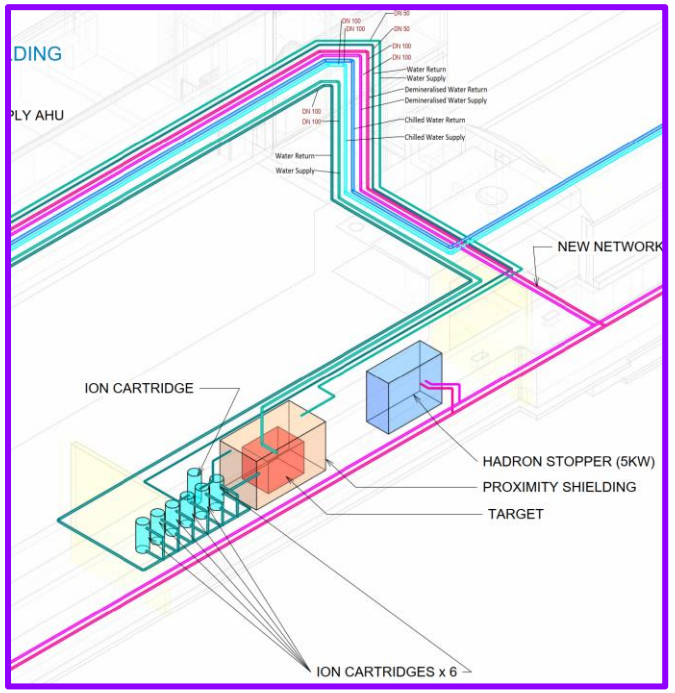
Cooling possibilities: 3 configurations

Configuration #1
Target: water cooled
Proximity: water cooled

Configuration #2
Target: helium cooled
Proximity: water cooled

Configuration #3
Target: helium cooled
Proximity: helium cooled





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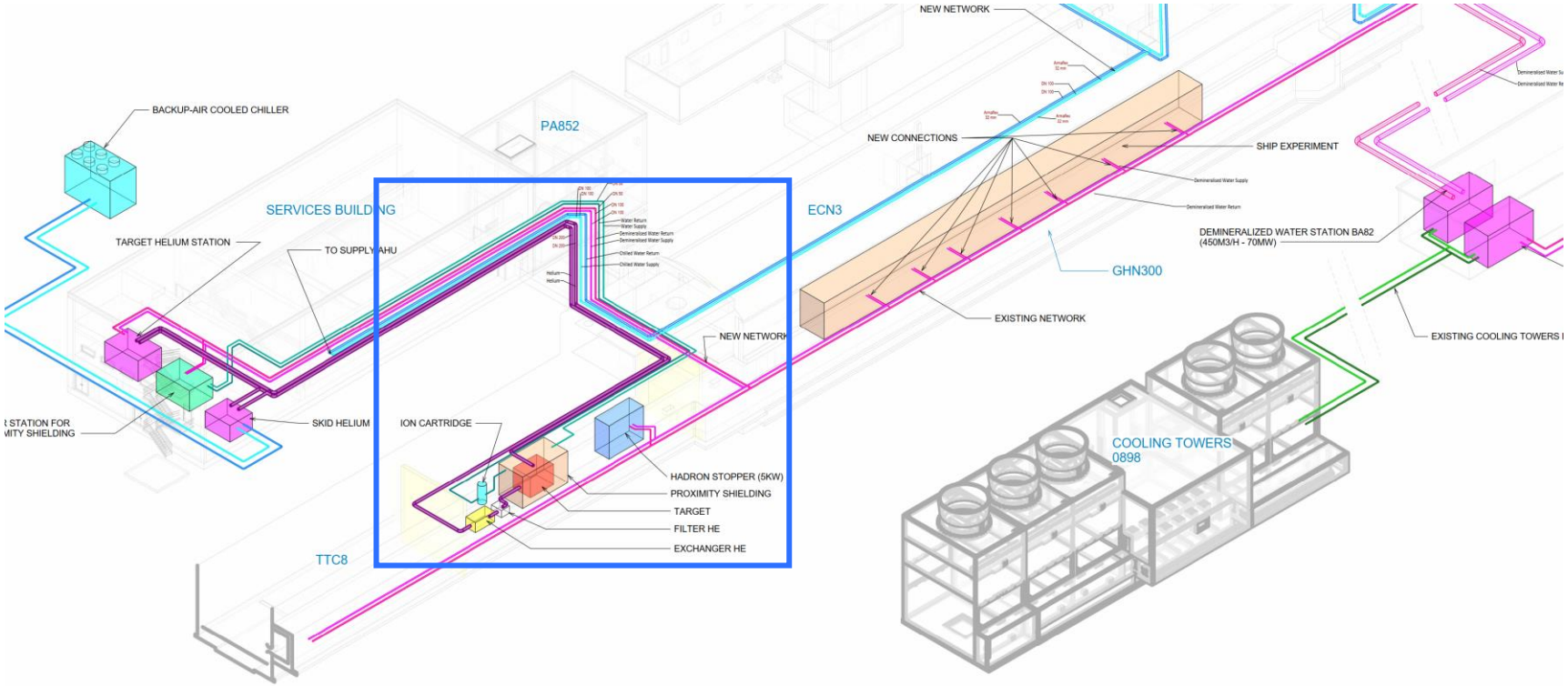

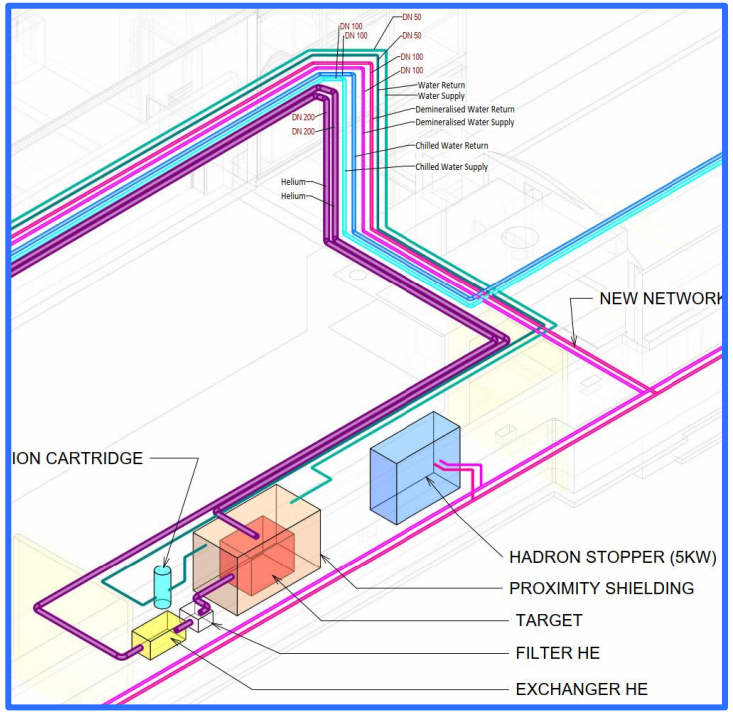

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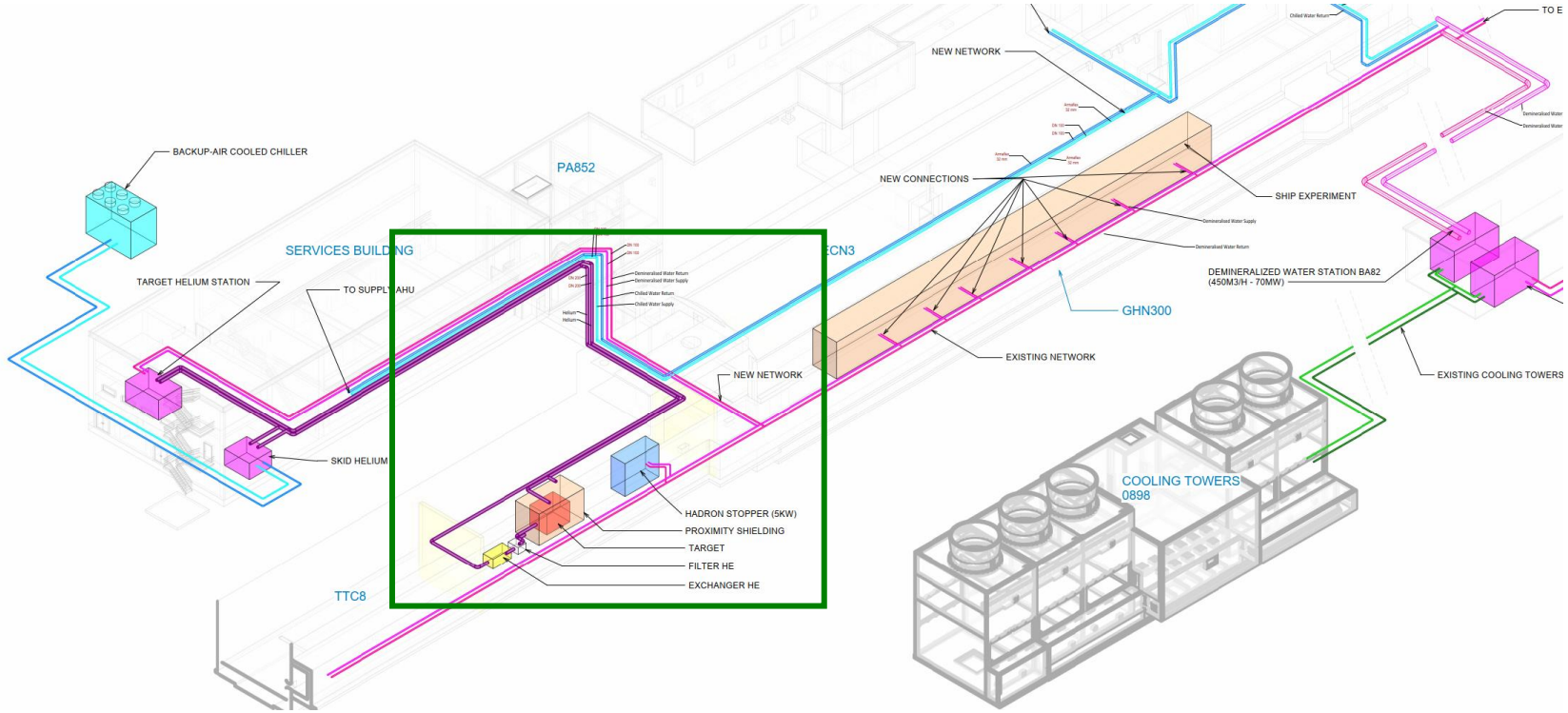
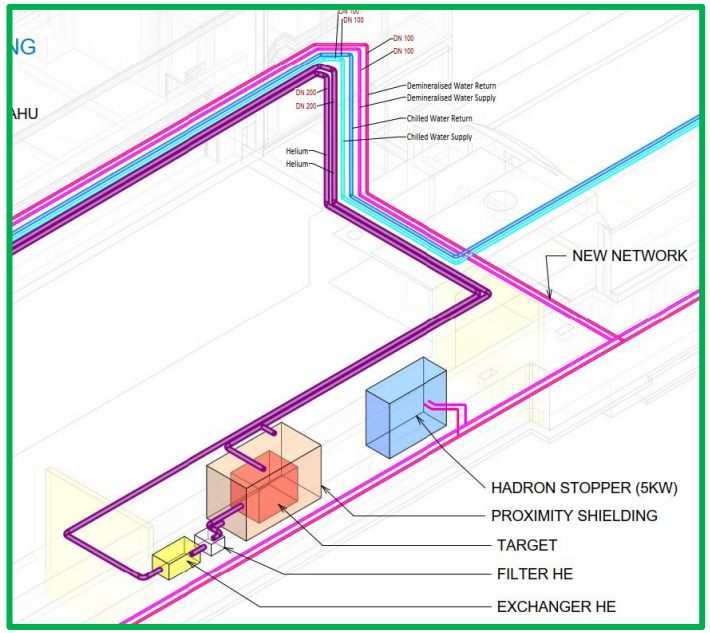
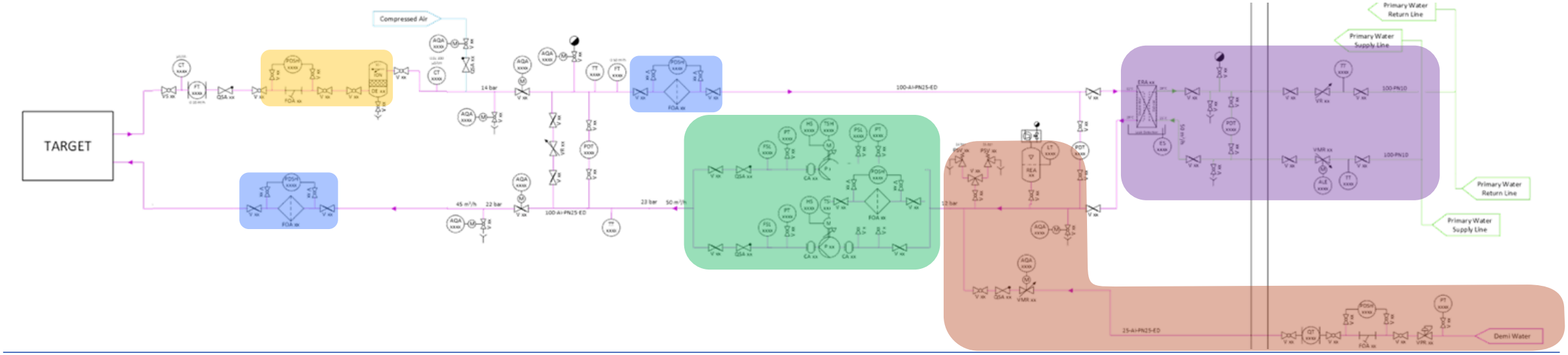




Water Cooling – Technical Solution – P&ID

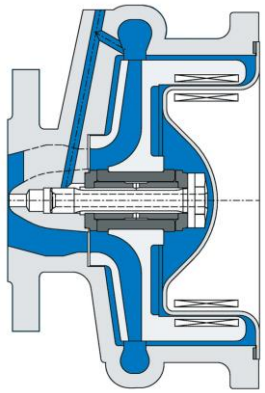
1 cooling circuit for target and 1 circuit for proximity shielding

- Pumping group – 1+1 redundancy
- 1 Heat exchangers (Water/Water)
  - Gasketed Plate Heat– safety type
  - Demineralised water on primary side
- Filtration
  - Cartridge filters 20/50 µm
- Ion Exchange Cartridge – 200 L
  - 6+1 cartridges (target)
  - 1+ 1 cartridges (proximity shielding)
  - Nuclear grade resin
- Filling and pressure maintenance system
  - Helium bottle racks with precision pressure reducers



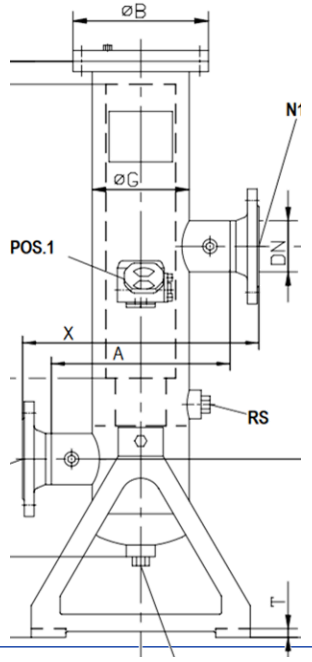
Water Cooling – Pump, heat exchanger, filters

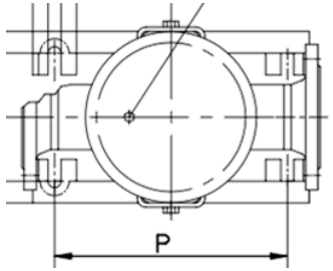
- **Pumps**
  - Magnetic Drive Centrifugal Pumps
  - Stainless steel
  - Hydro-lubricated bearings
  - Manufacturer: CP Pump®



- **Heat exchanger**
  - Gasketed plate heat exchanger
  - Double wall construction possible
  - Flanged connections
  - Manufacturer: Alfa Laval®

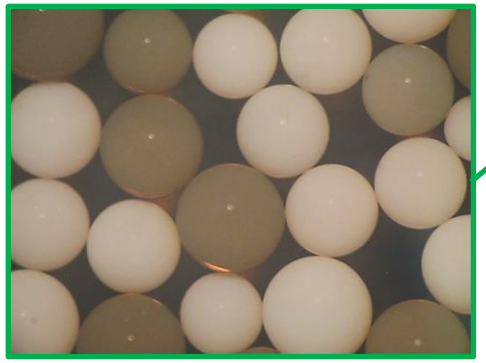
- **Filter**
  - Multi cartridge type
  - Filtration grade: 20/50 µm
  - Manufacturers: Bollfilter®

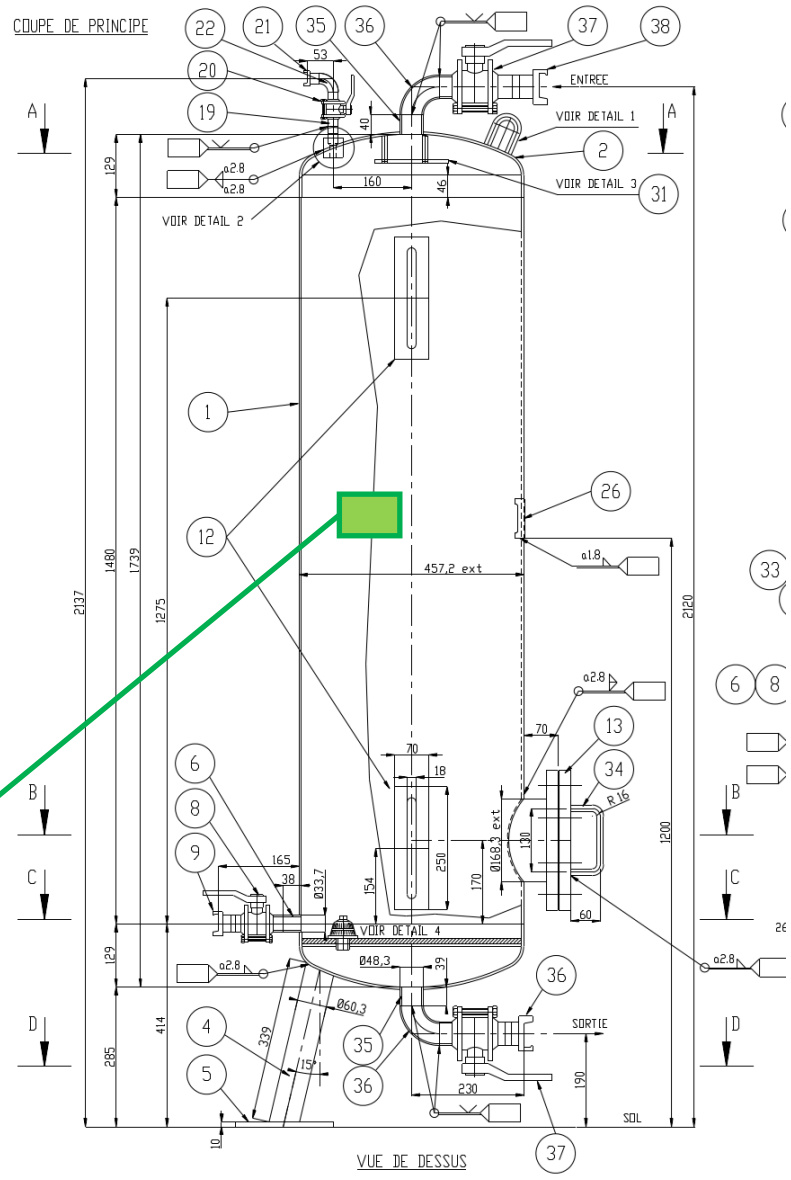




Water Cooling – Water purification

- Ion Exchange Cartridges
- Max cartridge flow rate: 8 m^3/h
- Number of cartridges: 6+1 (target) / 1+1 (proximity)
- Nuclear grade resin: AmberLite® IRN9882
- High activation expected
- Technology
  - Mixed bed: 40% cation resin
  - 60% AmberLite ® IRN9766 OH resin
- Manufacturer: Dupont®

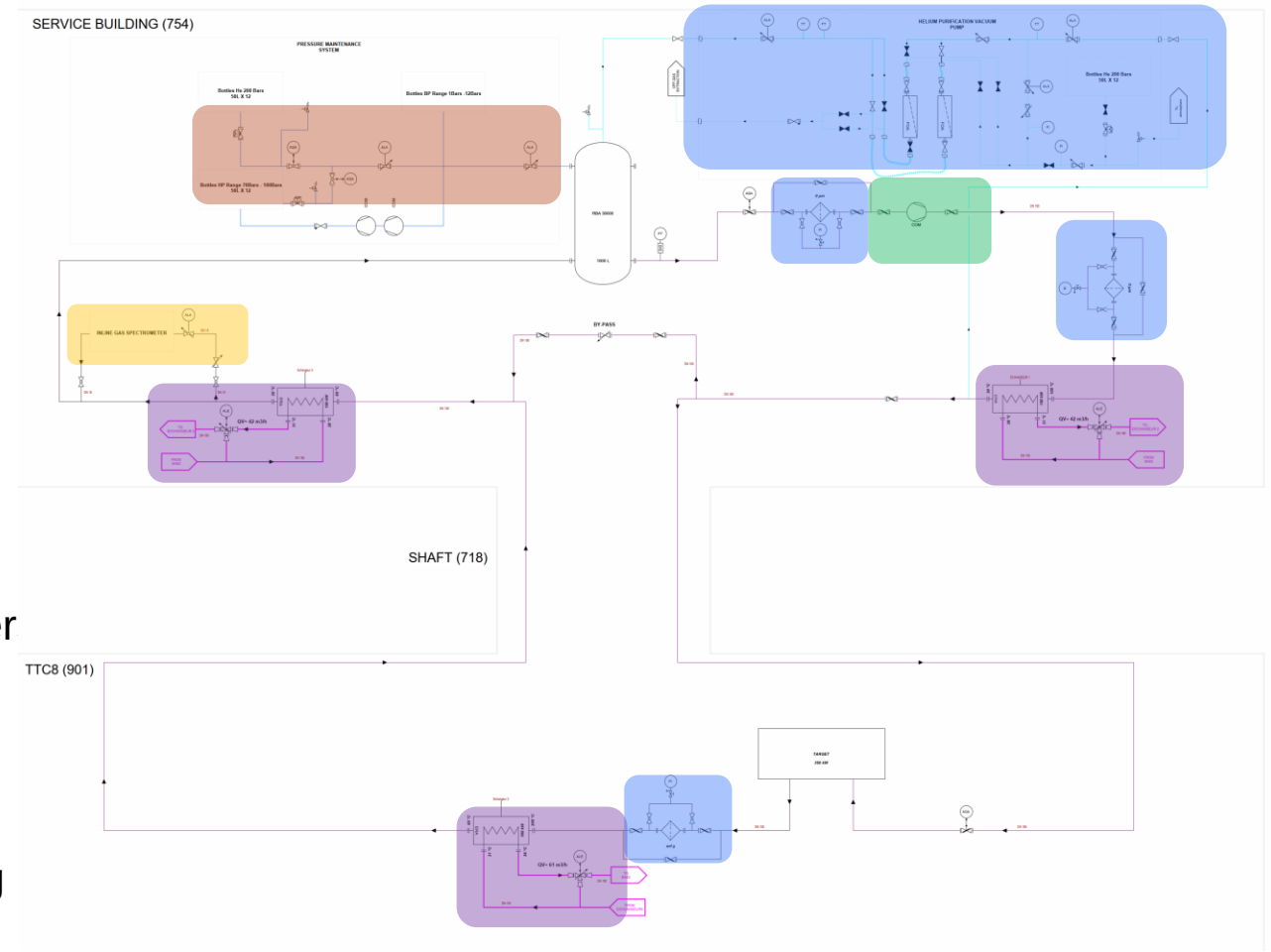




Helium Cooling – Technical Solution – P&ID

1 cooling circuit for target and proximity shielding

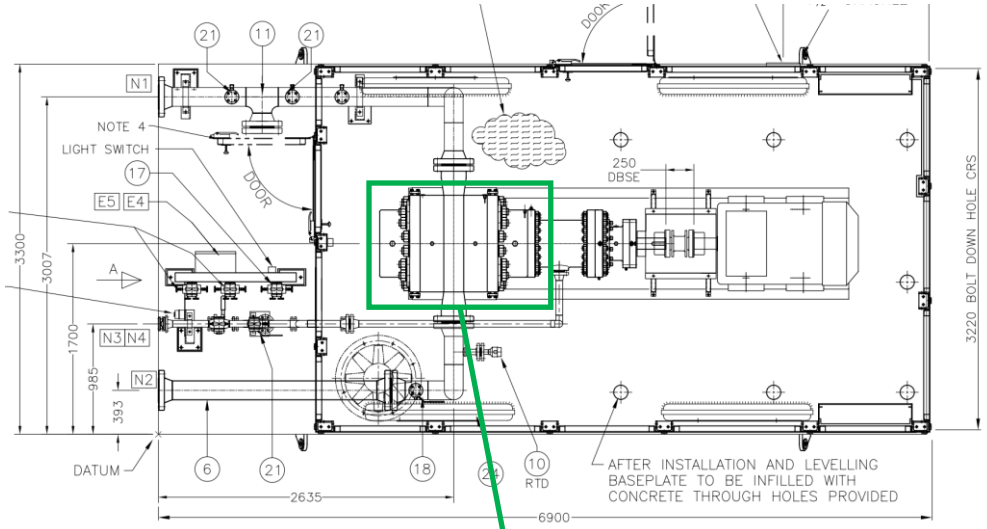
- Compressor skids - 12/15 bar(g)
- 3 heat exchangers (Water/$He_{(g)}$)
  - Shell and tube construction – safety type
  - Demineralised water on primary side
- Filtration
  - HEPA gas filters
  - Chemical getters for impurities absorption
- Filling and pressure maintenance system
  - Helium bottle racks with precision pressure reducer
- Inline gas spectrometer
  - Continuous sampling machine
- Vacuum pumps
  - To remove air from the circuit for subsequent filling



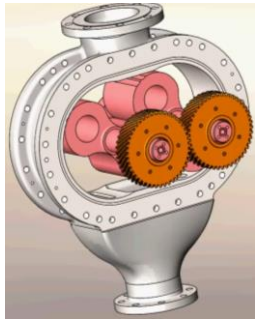
Helium Cooling – Compressor

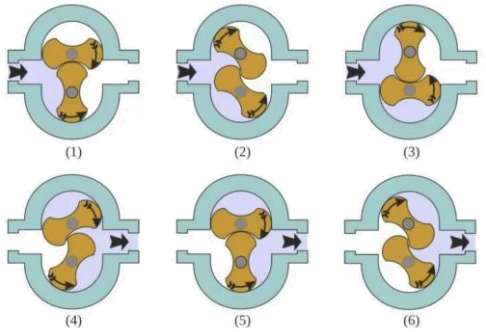
- Rotary lobe compressor
- Pressure regime : <u>13.0/16.0 bar(a)</u>
- Working pressure range: -1/80 bar(g)
- Helium leak tightness: <10^{-6} mbar/(l × s)
- Shaft seal options
  - Magnetic coupling
  - Hermetic solution
- Oil lubrication: Oil free
- Pulsation dampened via silencer on outlet
- Manufacturers: Roots (UK)
- Other contacted manufacturer:
  - Aerzen (DE) – dry screw compressor – used at ESS – big footprint – the roots machine is more compact
  - Ateko (CZ) - two-stage turbo-circulator equipped with radial and axial air bearings – used at ESS – however our maintenance team prefers to remain in low range of rotation speed
  - Kaeser (DE) – screw compressor derived from production line

13.0/16.0 bar(a) – 160 kW – 6.9m x 3.2m



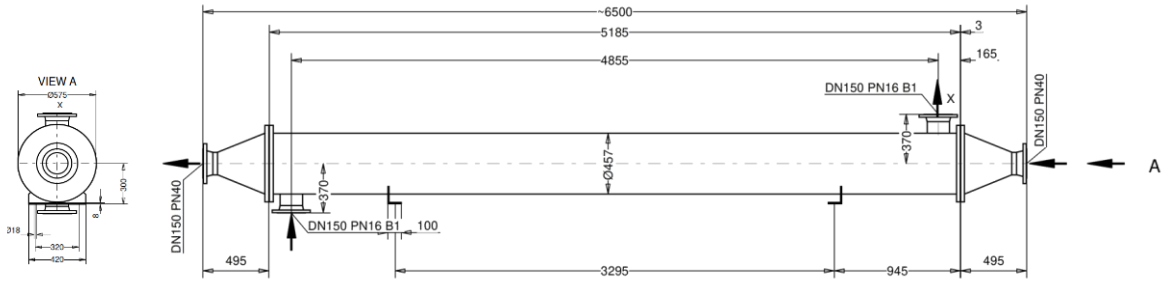
Lobe compressor



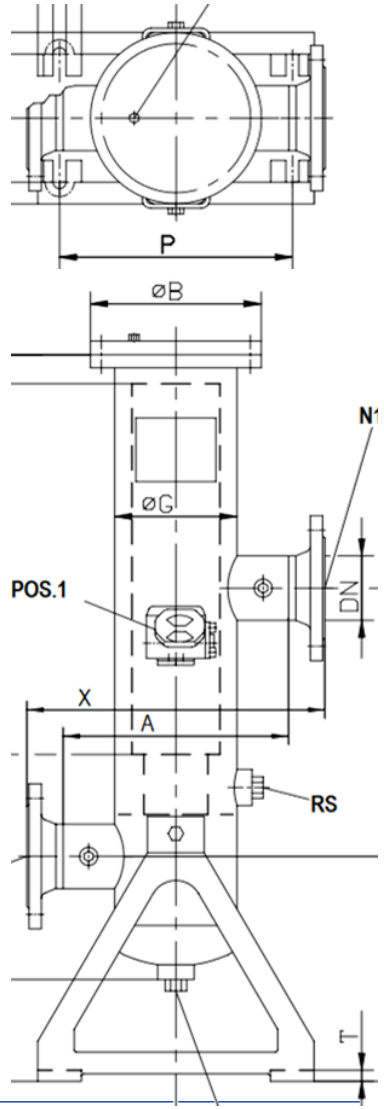


Helium Cooling – Heat exchangers and Filters

- Shell/Tube type – common design for all
- Temperature rating: up to 250 C
- Pressure rating: PN25
- Single pass
- Double wall - Safety configuration
  - Helium as interstitial gas
- Pressure drop (gas side): 0.05 bar
- Manufacturers: Funke (DE), ETS(CH), MTA(IT)

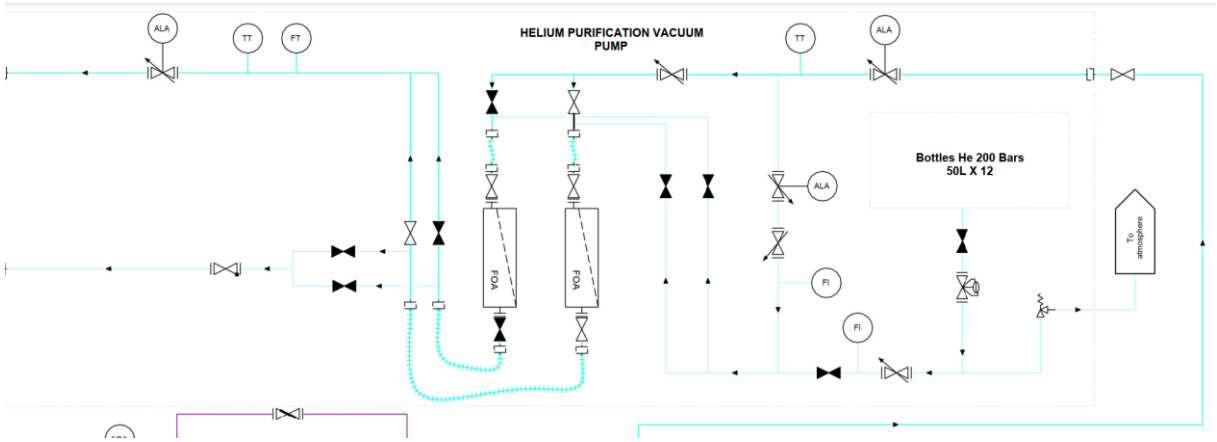


- Cartridge filter type
- Welded construction
- Filtration: 0.1 µm
- Pressure rating: PN25
- Pressure drop: 0.05 bar
- Flange connections
- Manufacturer: Bollfilter (DE)



Helium Cooling – Helium purification

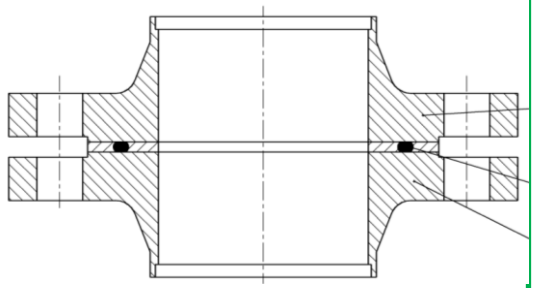
- Gas purifier IX Media – same solution used at ESS
- Technology
  - Absorption by chemical media
  - Impurities permanently trapped
  - Achieved purity: H_2O, O_2, CO, CO_2, H_2 (<100 pptV each), Sulfur Compounds (<1 ppbV)
- 2% overall flow rate circulated through them
- Manufacturer: Entegris®



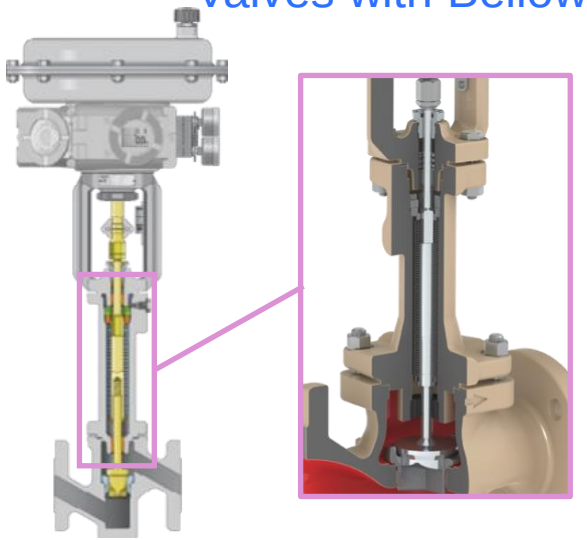
Helium Cooling – Pipework, flanges and fittings

- **Pipework**
  - TIG butt-welded stainless steel pipework (AISI 304L)
  - Warm target outlet: vacuum insulated pipe
  - Degreased and cleaned for rough vacuum
- **Flanges**
  - EN 1092-1 B2 flanges. Two choices of gaskets:
    - Spiral wound gasket (Flexitallic®)
    - Captive gaskets
  - ISO 10423 (API 6A) Flanges with metal gasket (Helikoflex®)
- **Valves**
  - Globe valves with bellow inserts
  - Good variety of pressure and temperature ratings
  - Flanged or welded
  - Manufacturers: Samson®/Flowserve®

Flange gaskets



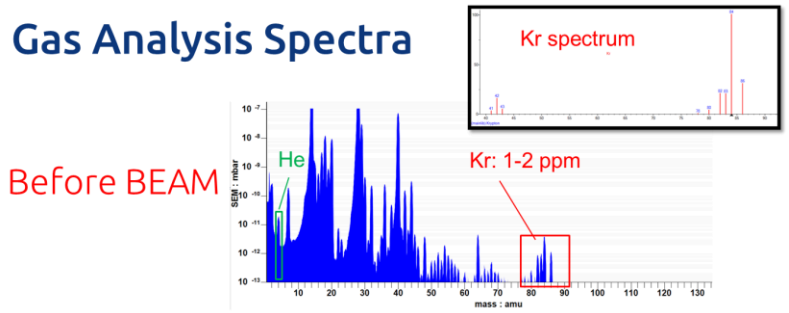
Valves with Bellow seals



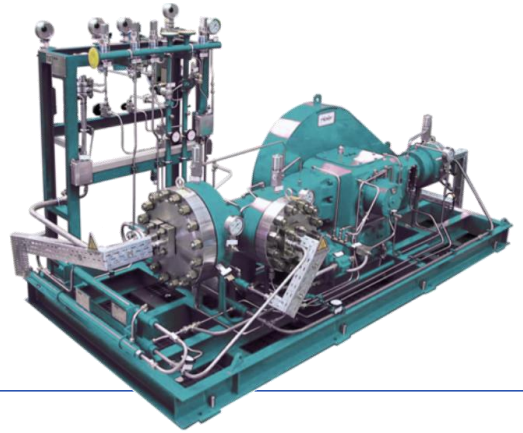
Helium Cooling – Additional considerations

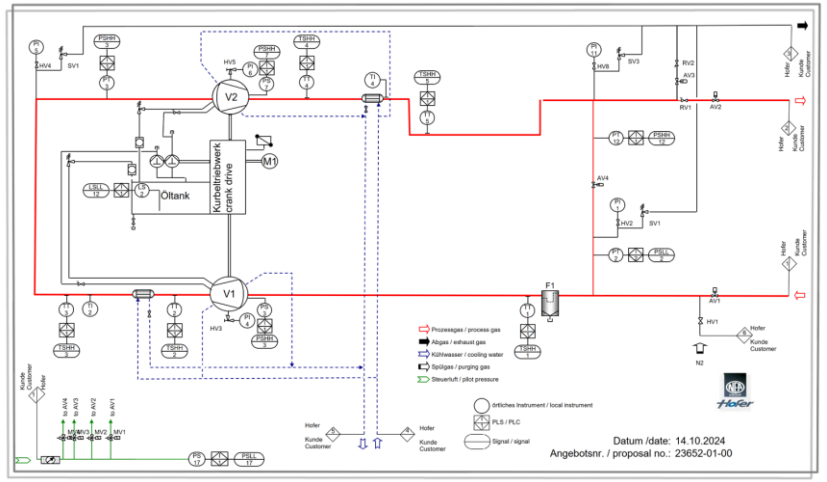
- **Circuit Filling**
  - Create vacuum in circuit (10^{-3} mbar)
  - Series of rough vacuum and turbomolecular pumps
  - Helium filling from bottles

- **Inline gas spectrometer**
  - HIDEN HPR-20 Gas analyser
  - Inlet pressure range -0.9/2bar(g)
  - PPB precision
  - Already installed at CERN

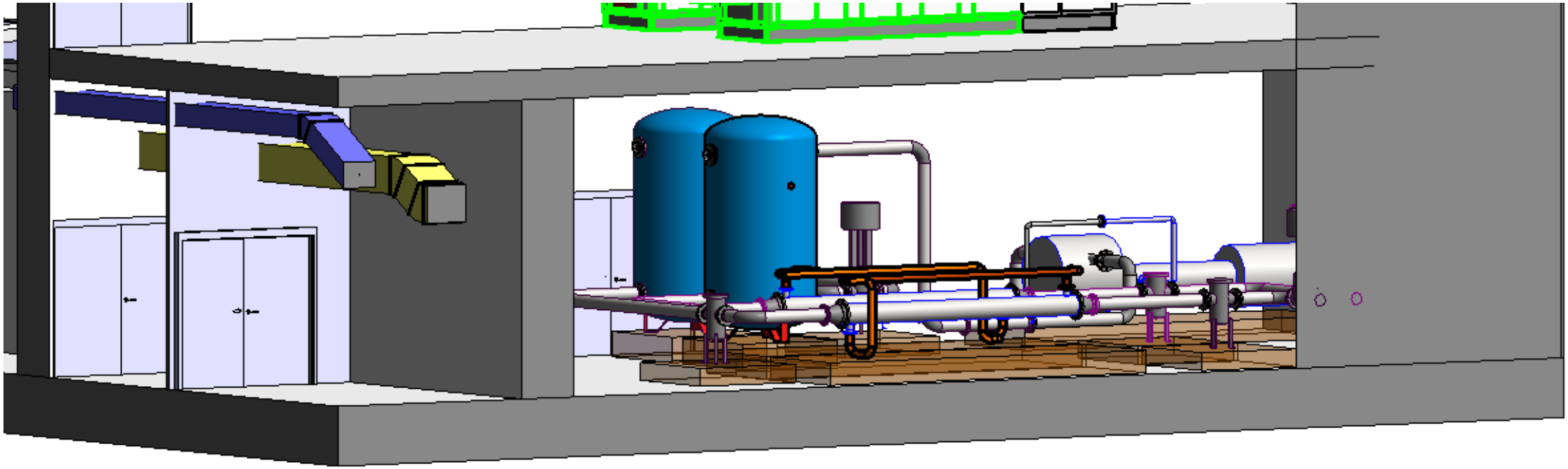


- **He recovery skid**
  - Oil-free diaphragm pumps
  - Helium from circuit sent to secondary storage
  - Used both in operations and when stopped
  - Manufacturers: Sera®, Hofer®





Helium Cooling – Initial Integration



Operation consideration: Water vs Helium

Demineralised Water Cooling

- **Advantages**
  - Known architecture: years of operational experience
  - Lower differential temperature – no need of vacuum insulated pipework
  - Easier leak tightness

- **Disadvantages**
  - Higher supply pressure: 22 bar(g)
  - Water activation/tritium production
  - Higher level of radioactive waste (ion exchange cartridges, resins)
  - Need space in TTC8 outside target shielding to store filters and all cartridges (in-line configuration)
  - Leaks will require decontamination
  - Requires H_2 recombination system

Helium Gas Cooling

- **Advantages**
  - Easy removal of H_2, CO, CO_2, O_2
  - Lower supply pressure: 16 bar(a)
  - Helium leaks in dynamic confinement and can be monitored
- **Disadvantages**
  - No operational experience (Helium skid will help)
  - Tritium production/outgassing
  - Need specialist maintenance on lobe compressor
  - Need of vacuum insulated pipework between target outlet and heat exchanger installed in TCC8
  - Need space in TCC8 outside target shielding to store filter and heat exchanger
  - More challenging leak tightness

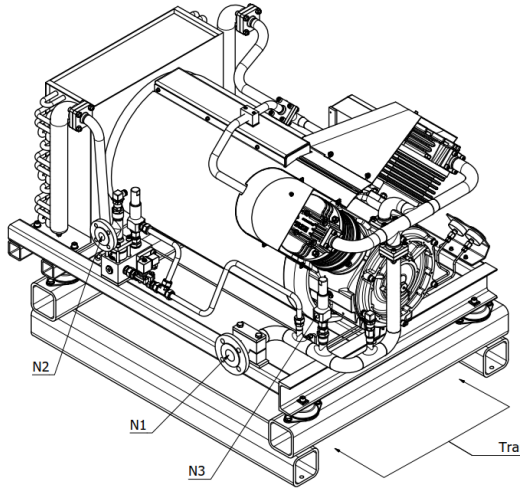
Operation considerations: Helium gas leaktigthness

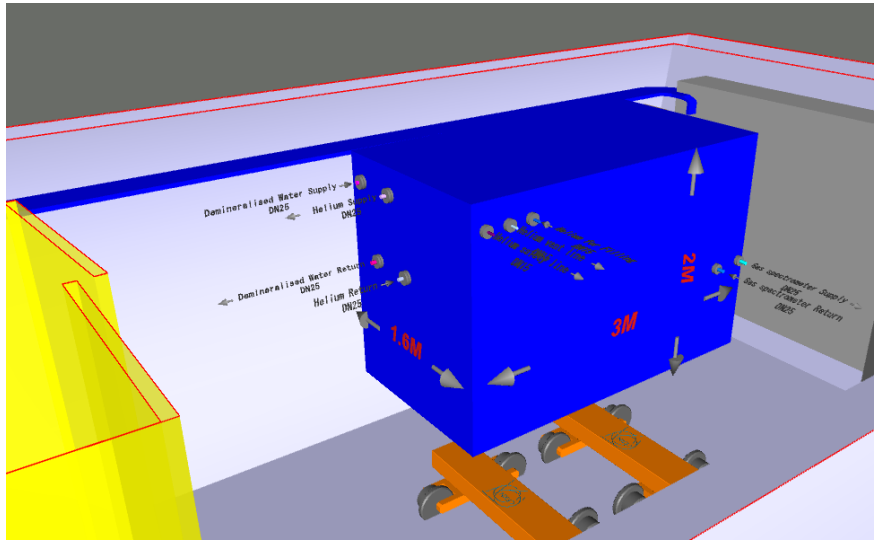
- **Design for minimal leak paths**
  - Maximise welded joints (100% X-rays in critical areas)
  - Globe valves with bellows, VCR® fittings
  - Metallic gaskets for flanged joints
- **Leak testing in vacuum and pressurised conditions**
  - Outside-in (vacuum inside, helium spray on outside joints) at 10^{-4} mbar(a)
  - Inside-out (pressure inside, filled with helium) at 15 bar(g)
- **Pressure testing at 1.43 x Nominal pressure**

Max leak rate joint< 10^{-6} mbar l/s → 3.6 x 10^{-6} L/h → 6.4 x 10^{-7} g/h joint
Assuming 50 flanged joints → 0.28 g/year

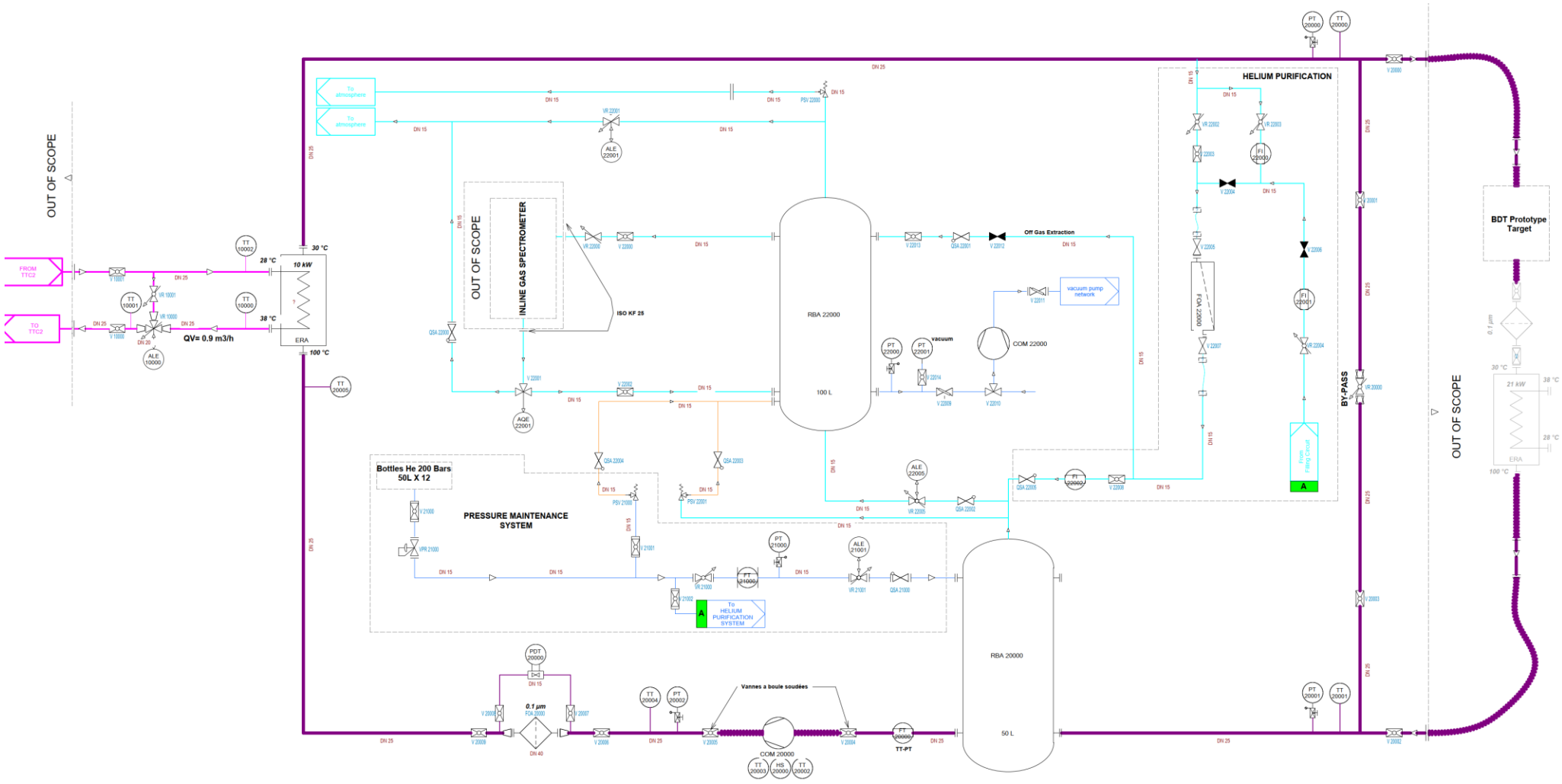
Helium skid – BDF Prototype in TCC2

- **Test skid – representative elements**
  - Compressor: piston compressor (different technology however same pressure range 13/16 bar(a))
  - Filters: same as target station
  - Heat exchangers: non safety but similar type shell/tube (cannot validate HX leak detection)
  - Chemical getters and gas purification: same as target station
  - Flanges: EN 1092-1 B2 with captive gaskets
  - Valves: welded valves + globe valves with bellows + VCR® fittings in helium purification circuit
  - Vacuum pumps: scroll pump (same vacuum range)
  - Instrumentation: same as target station
  - Cold source: same as target station (demineralised water)
  - Control system: same as target station
- **Test skid – non-representative elements**
  - No helium recuperation skid
  - No regulation on heat exchanger downstream the target
- **Skid Test**
  - 100% VT and X-rays
  - Leak rate tests: vacuum test and pressure test
  - Pressure test





Helium skid – BDF Prototype in TCC2 – P&ID



Conclusions and open questions

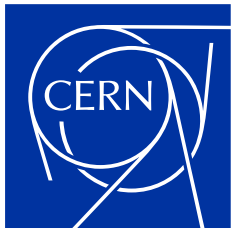
- **Target and proximity cooling station**
  - 3 technical solutions possible and quite well defined
  - Equipment selection
    - Demineralised water cooling: on CERN long operational experience
    - Helium gas cooling: based on similar facilities at ESS and KIT
- **Helium skid**
  - Technical solution defined currently in procurement
  - Representative of most technological solutions
  - Possibility to reuse as backup in final station

Conclusions and open questions

- **Safety valve release: need for additional extraction flow rate?**
  - Small confined volume kept in underpressure with high flow rate?

- **Flanged joints**
  - Any suggestion beyond what is proposed?

- **Contamination risks**
  - Permeability of Tritium through SS 304L at 30/200 °C and low partial pressure can be estimated
  - HT, T2 or HTO dominant?
  - Any recommendation on SS treatment post installation? Baking and purge after installation?



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