



Design challenges of a 33kW, liquid hydrogen cooling system for The European Spallation Source cold moderators

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Introduction



The European Spallation Source is a neutron science facility funded by a collaboration of 17 European countries currently under design and construction in Lund, Sweden.

The ESS accelerator will deliver protons with 5 MW of power to a rotating metal target at 2.0 GeV with a nominal current of 62.5 mA.

A key feature of ESS is a tungsten target wheel, which will create fast neutrons via the spallation process from an impinging high-energy proton beam. A moderator-reflector system then transforms these fast neutrons into slow neutrons, which are the final form of useful radiation provided by the neutron source.

Another key feature of the target system will be the hydrogen moderators, which use liquid hydrogen at supercritical pressure at 17 K and 1.5 MPa to reduce the energy of the neutrons before they reach the instrument lines. The neutrons will deposit significant amounts of energy into the hydrogen that must be removed to maintain the hydrogen at its nominal operating temperature of 17 K.

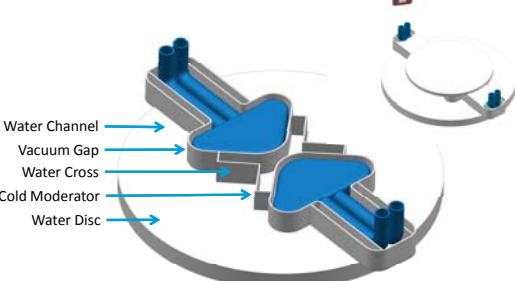
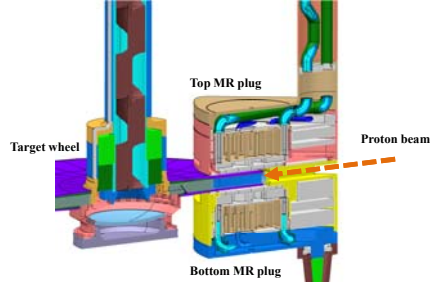
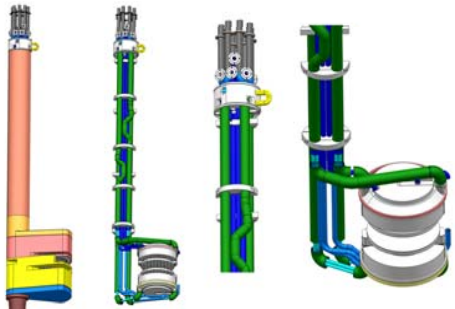
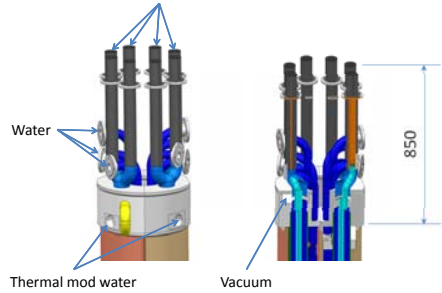
The target moderator cryoplant (TMCP), will provide the cooling for this hydrogen cryogenic moderator system (CMS). The heat deposited into the hydrogen will be removed via a heat exchanger in a hydrogen circulation cold box that will transfer the heat from the hydrogen circuit to a gaseous He circuit operating at nominally 17.5 K which is connected to the target cryoplant cold box.



The cooling objects

One vital component in the ESS target station is the moderators which purpose is to slow down the neutrons to energy levels appropriate for the instruments. There are two types of moderators. One is the cold moderator which consists of liquid hydrogen at 17-20K and the other is the thermal moderator which consists of water at 20-30°C. Around the moderators there are reflectors which purpose is like the name implies to reflect neutrons that “miss” the neutron guides in order to increase the number of useful neutrons. The inner reflector is made of beryllium and the outer of stainless steel. These components are called the upper and lower MR-Plug and these plugs are mounted on a shaft in order to facilitate easy change of the components since its lifetime will only be 1-2 years.

Pipe Connector on Top of Monolith
Bayonet connectors



Moderator evaluation

“Three new moderator assemblies are evaluated and compared to the baseline configuration. Two make use of the new “butterfly” concept, resulting in a **significantly higher thermal brightness** compared to the water wings of the pancake moderator. The third is a variant of the Optimised Thermal configuration, changing one of the viewed sectors from East to South.
The **preferred solution** is to replace the top pancake moderator with a **butterfly assembly of the same height**. This will have a negligible impact on the cold-neutron instruments, while **substantially improving the performance of the bi-spectral instruments**. Replacing the bottom “optimised thermal” moderator with a butterfly assembly of the same height, viewable in all instrument sectors, will have little effect on the performance of the individual instruments, but will **dramatically increase the flexibility of the instrument layout**, allowing all instruments to freely choose the optimum moderator for their needs.”

K. Andersson, Pancake and Butterfly Moderators, 4-3-2015.

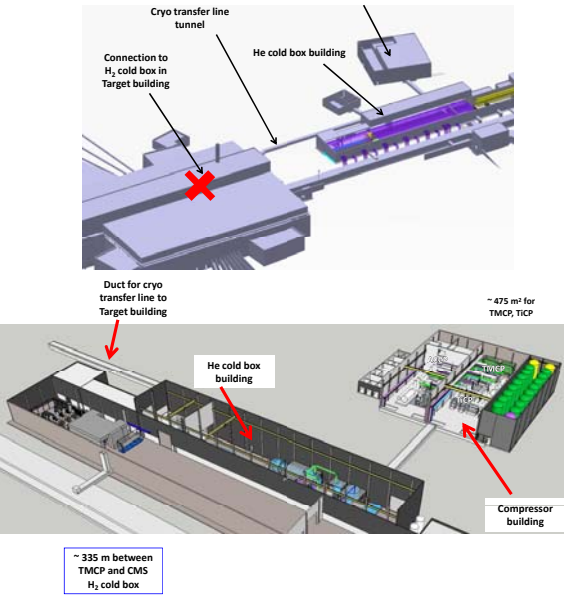
Heat load according to CFD and numeric analysis
3cm BF2 9.4kW
6cm BF2 11.9kW

	Top moderator	Bottom BT	Bottom BT	Bottom BT	Bottom BT
Opening	2x 120°	2x 120°	2x 120°	2x 120°	2x 120°
Heat brightness, B ₀	2.33e1	3.07e13	1.04e13	1.04e13	2.44e13
Gold length, L ₀ , m	6.25e1	7.05e13	6.11e13	4.52e13	3.44e13
Heat out to PC, Q _{PC}	1.00	1.33	1.50	1.00	0.05
Cool out to PC, Q _{PC}	1.00	1.33	1.50	1.00	0.05
Thermal mod. width	1.57 cm	7.0 cm	6.0 cm	6.0 cm	6.0 cm
Gold mod. width	14.4 cm	6.7 cm	6.2 cm	6.2 cm	6.2 cm



Target Moderator Cryoplant Location

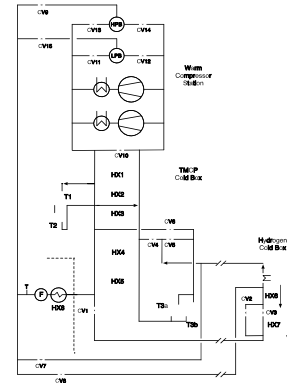
Cryogenic systems location overview



Target Moderator Cryoplant Unique attributes of the TMCP

- TMCP cooling requirement is 35 kW
- CMS allowable temperature range is 17-20 K
- TMCP helium minimum allowable temperature set by H₂ freezing point of 13.8 K. With some margin, minimum TMCP supply temperature is set at 15 K. Maximum temperature set by maximum CMS temperature of 20.5 K
- Low temperature rise results in low enthalpy change in helium, and therefore **high helium mass flow rate**. That is:
 $Q = m \Delta H$
 $\text{kJ/sec} = \text{kJ/kg} * \text{kg/sec}$
High heat load = (low change in enthalpy) * (high mass flow)

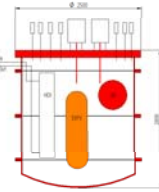
- High helium inventory
- Early in the project, a decision was made to co-locate all helium cryoplants, resulting in a long helium transfer line between TMCP and CMS. Advantages to co-locating cryoplants was:
 - Consolidate physical location
 - Common buildings and utilities
 - Ease of maintenance
- Initial heat load estimate (prior to butterfly moderator design) was 20 kW. This required lower helium flow rate than current 35 kW requirement, and therefore smaller CTL piping.
- Relocation of CMS to 150 level of D02 and larger diameter CTL size results in **~1/3 increase in helium inventory** above original estimate



Cryogenic Moderator System

The H₂ cryostat

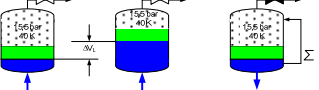
It consist of a vacuum vessel which contains the system components.
The cryostat shall be designed in such a way that maintenance etc. can be done in a safe way.
The vacuum insulated cold box has a diameter of 2,5 m and a height of 2,8 m.
The top plate is home of the two hydrogen circulation pumps, two helium transfer line connections, 2 hydrogen transfer line connections and 7 cryogenic valves. The top plates will have ribs that act as both structural support and as bracket for heat exchanger, expansion vessel and the O-P convertor.



Accumulator

The accumulator is the main pressure compensator in the system. When the heat load in the system is absorbed by the cold H₂, it will expand. If the system is numb, the pressure will raise due to the extra volume that the H₂ will claim. To ensure a constant pressure at all time, a volume expansion vessel will be installed.

Actively controlled buffer



Heat input	Heat load (Neutronics)	max	26.5	Requirements
	Heat load (static)	max	4.0	
	Total Heat load	max	32.58	
Pumps	Head	Design	1.5bar	
	Mass flow	Design	1000	
	Power	Design	3x400V	
Ortho-Para hydrogen Converter	Material type	max	T80	
	Size	max	50L	
	Ratio Para H ₂	min	>95.5%	
	Detection type	max	In line	
	Time to full conversion	max	240s	
Heat exchanger	Media	max	He - H ₂	
	Pressure class	max	PN25/PN25	
	Flow rate He	max	1000g/s	
	Flow rate H ₂	max	1000g/s	
	Cooling Capacity	min	33kW	
Operational parameters	Design P	max	1.7bar	
	Operation P	min	1.5bar	
	Operation T	min	15.0K	
	Allowed ΔT	max	21.0K	
	Total mass flow	nominal	1000g/s	
		Top moderator	2x220g/s	
		Bottom Moderator	2x220g/s	
Accumulator/expansion vessel	Pressure control	Range	0.5 bar	
	Expansion volume	Range	1.5x10.5% of system volume	