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# Liquid hydrogen for cold neutron production at European Spallation Source ERIC

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**Abstract.** The European Spallation Source (ESS) will be a 5 MW, long-pulsed spallation neutron research facility. One of the key feature is that ESS will use liquid hydrogen as a moderating media for the cold neutrons. The hydrogen operates at cryogenic temperatures at approximately 17K. The challenge for the cryogenic system is to meet the high neutronic heat load and maintain a narrow operational span. To handle the large variations in heat load a special developed pressure control device is designed. To maintain the hydrogen operating temperature, a Helium refrigerator with unique capabilities to control temperature in the hydrogen system is developed. It also has the capacity to react and compensate for a lower heat load than anticipated in the moderator system on short notice. Another key feature is the Ortho-Para catalyst and the in line OP measurement that verifies the high para content at all time, to optimize neutronic performance. This paper describes the process development, planned commissioning and operation of the cryogenic hydrogen and ancillary systems.

## 1. Development of the Cryogenic Moderator System (CMS)

### 1.1. The first conceptual design. [1]

The CMS at ESS was more or less a scaled up version of the SNS and J-Parc hydrogen systems [2], [3]. To cope with the larger power of ESS proton beam everything was 5 times bigger than J-Parc (1MW vs 5MW). At this stage none of the components in the system was detailed for the new requirements.

The specification was to keep the liquid para hydrogen at a supercritical pressure (>1.3MPa), and the temperature around 20K for optimal neutronic performance. Design pressure was 20 bara and expected heat load was 20 kW in the volume moderators. Moderator was similar to SNS/J-Parc.

To maintain the pressure in the loop, a pressure control buffer was included, consisting of two parts. The first was an accumulator with steel bellows, back pressured with helium to accommodate volume changes in the system. The second was a heater that compensated for the loss of beam power and maintained the heat load that the Target Moderator Cryoplant (TMCP) would expect. The main idea was to always feed the TMCP with a 20kW heat load regardless of whether or not the beam was on. A simplified schematic of the proposed system is shown in Figure 1.



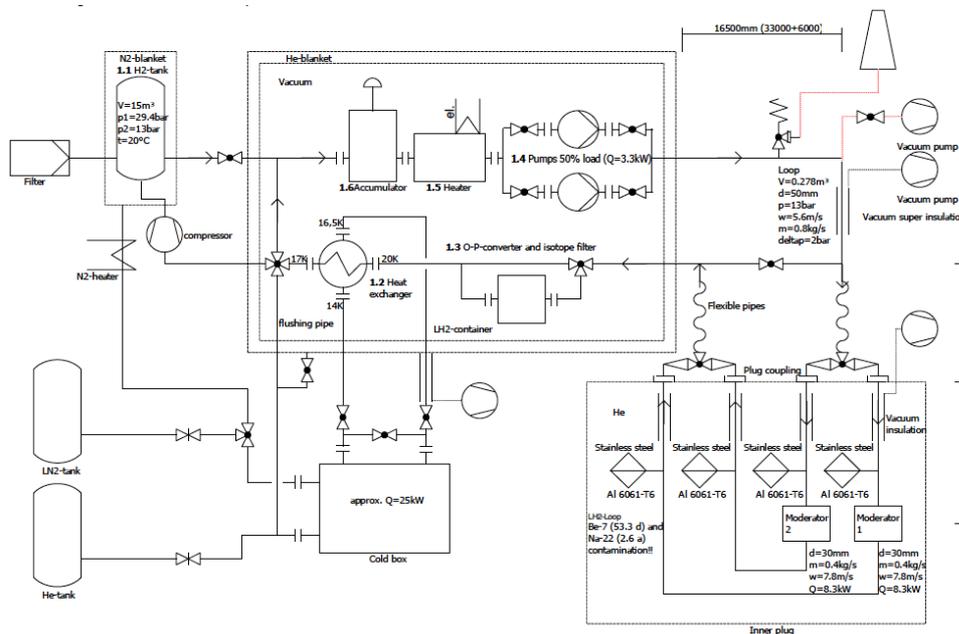


Figure 1, Concept P&ID courtesy of Y. Beßler

The system was set up with two pumps that operated in parallel to ensure availability. Both pumps should provide the full pressure head in the system (roughly 1.2 bar), but only half of the flow (400g/s), each. If one pump failed the other one would speed up to compensate for the flow loss. One drawback with this set up was the complicated design

of an impeller to coop with two different flows still meeting a high pressure head.

An Ortho-Para catalyst was foreseen in the system but the measurement method to verify the para content was not specified.

The hydrogen system was intended to be located close to the monolith in the A2T area and the helium cooler located just above inside the high bay as shown in Figure 3.

### 1.2. Preliminary design to final design

Along the road to a viable preliminary design, some drawbacks appeared while attempting to scale up the design. First of all the intended location of the TMCP was moved to the cryogenic building and co-located with the Accelerator helium cryo plants. This was done to gather all helium cryoplants in the same area. This resulted in a 335m long cryogenic transfer lines to connect to the CMS heat exchanger. The hydrogen room was also moved because of safety regulations. Originally located in the A2T area it was now located on the top floor of the target building as shown in Figure 3.

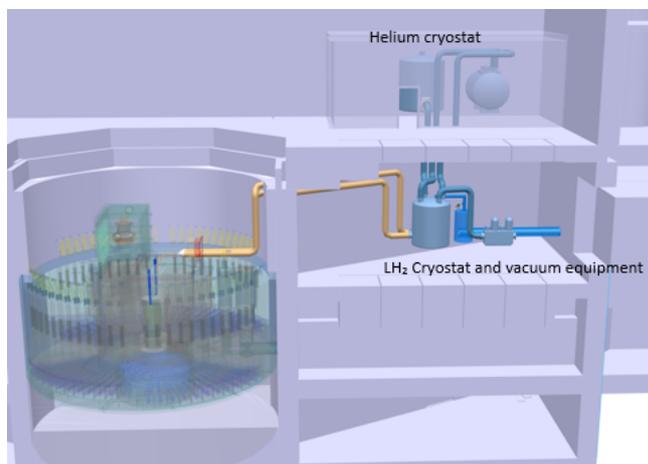


Figure 2, Original layout A2T room with TMCP above.

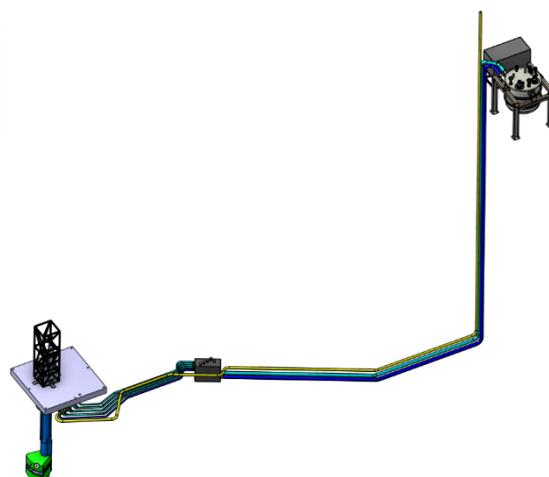


Figure 3, New routing through the building. CMS connected to the moderator plug. TMCP moved 300m outside.

In the spring of 2014, the neutronic team made some quantum leaps in moderator design and in enhanced brightness. First out was the pancake design which later was replaced with the current butterfly 2 design, see Figure 4.

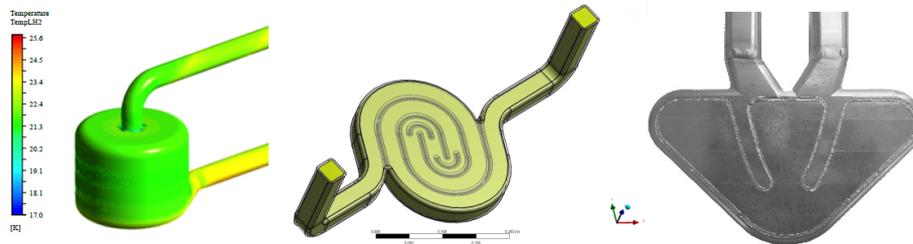


Figure 4, Moderator development: Volume, Pancake and butterfly 2(implemented).

The new refined design resulted in a new neutronic heat load of 19kW (which includes some contingency). For the hydrogen system this meant that when adding static heat loads, pump efficiency etc. the expected heat load/cooling capacity will be increased to roughly 28kW. Calculations showed that the accumulator would be large. The heater that was intended to compensate for beam power, would contain a large amount of liquid hydrogen and have too slow response time. As the overall requirement is to minimize the total H<sub>2</sub> inventory which was increasing due to the move of the equipment, the accumulator/heater was shown to be an unacceptable solution. The possibility to use a buffer vessel was investigated and an actively controlled buffer was implemented as the solution. The heater was removed and the decision to let the TMCP handle the temperature swings in the hydrogen was taken.

Two pumps in parallel was discarded for two pumps in a serial set-up. A benefit is that each pump provides half the pressure head but the full flow. If one pump fails the system has the possibility to speed up the remaining one to maintain the full flow and the full pressure head.

For the Ortho-Para measurement a Raman spectroscopy with an in-line measurement is decided. For the catalyst Oxisorb is the first choice but the design will coop with Ionex as well. Ongoing research on the materials kinetic data is ongoing and a part of ESS scope. Sapphire glass viewports are to be installed in the hydrogen pipeline which enables sensors to look into the hydrogen flow.

High requirements on the moderator vessel in terms of reliability resulted in a change of design pressure to 17bar. We assumed that keeping the system pressure range between 13-17bar at all time was an impossible task. To make sure that the system doesn't blow of the hydrogen unintentional, an investigation started to clarify if it's possible to reduce the system pressure. The biggest risk we foreseen was boiling and two phase flow in the moderator vessel. With an acceptable margin in temperature, the decision was taken to increase operational range to 9-17bar during operation.

### 1.3. Target Moderator Cryoplant, (TMCP)

The initial design of the TMCP [1] followed the conceptual design of the SNS system, with a fairly simple cryoplant operating at constant heat load of 25 kW at 16 K. Due to the challenges of using a heater in the hydrogen circuit to compensate for beam power, ESS decided to allow the TMCP to perform this function. Additionally, as the required cooling capacity of the TMCP will vary significantly especially during the first years of operation as beam power ramps up, the TMCP design evolved to allow significant turndown in capacity. Compensating for beam power is accomplished by bypassing a small flow from the cold helium supply to the CMS, warming it with an ambient heater, and introducing the warm gas to the helium return line from the CMS. This allows the TMCP to operate at a constant heat load in the case of short-term beam trips. In the case of longer periods with low or no beam power, the cryoplant is designed with two parallel warm compressors and two parallel cold turbines. Turning off one of the compressor/turbines can easily cut the cooling capacity in half. Cooling capacity can be further reduced by discharging a portion of the helium from the cooling loop to warm helium buffer tanks, thereby reducing the system pressure and helium mass, while

maintaining a relatively constant pressure ratio between the low and high pressure sides of the refrigerator. The TMCP can operate between 2.3 and 30.3 kW capacity, providing helium at 15 K to the CMS for hydrogen cooling. A simplified schematic of the TMCP and is shown in Figure 5.

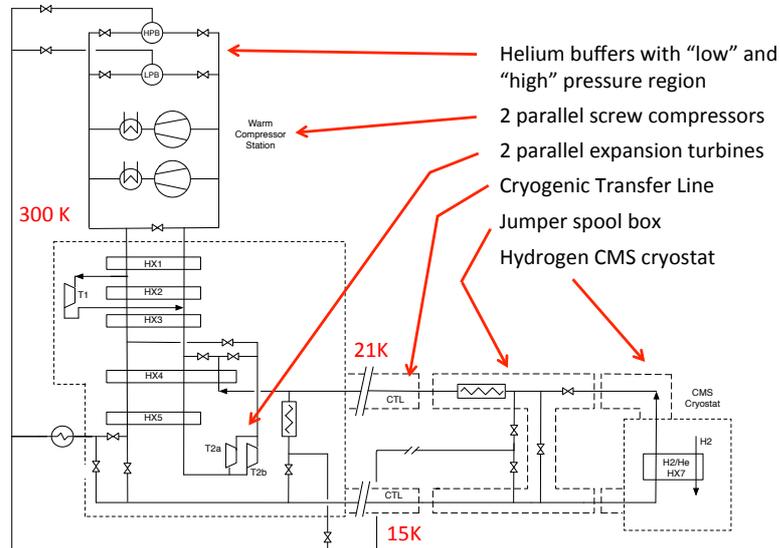


Figure 5, P&ID of the TMCP

## 2. Manufacturing, assembly and installation

A design review for early procurement was performed in spring 2016 for the pumps and they were purchased early autumn the same year. This was necessary due to the roughly one year long lead time. They are planned for installation into the cryostat August 2017.

The hydrogen transfer lines specification has been finalized and a call for tender was issued spring 2017. Installation and testing are expected early 2019.

A Critical Design Review for the CMS was successfully performed in February 2017 and components and instruments will now be purchased and manufactured.

The cryostat and all designed parts will be produced in-house by our In-kind partner Forschungszentrum Jülich (FZJ). They are also responsible for assembling, testing of components, installation, Factory Acceptance Test and Site Acceptance Test. The process development and cryogenic know-how are developed by Technische Universität Dresden (TUD).

Planned access to the Target building/hydrogen room is March 2019 and installation of the cryostat, hydrogen transfer lines and the helium transfer lines will take place at the same time. The TMCP is delivered by Linde and will be ready to perform Site Acceptance Test (SAT), in Q2 2019 and the CMS will be ready for SAT February 2020.

Scheduled beam on target is March 2020.

## 3. Commissioning and start of operation

Beam on target ends the construction phase and take the project into the commissioning phase. The beam power during commissioning will be low thus also the expected heat load on the hydrogen system. During this time we plan to fine tune the process controls, learn the system behavior and make the system as robust as possible. First users expect us to deliver cold neutrons for the instruments 2023.

## References

- [1] ESS Technical Design Report ESS-0016915
- [2] Technical Design Report of Spallation Neutron Source Facility in J-PARC, 2012 JAEA
- [3] Spallation Neutron Source Project Completion Report, SNS 100000000-BL0005-R00