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Engineering developments of the ESS Moderator and Reflector systems

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Abstract. The on-going project for construction of the European Spallation Source (ESS), the 5 MW long-pulsed neutron research facility in Lund, Sweden, has entered the phase in which design work and development are focused on realising solutions that shall satisfy well-defined requirements. The Target Station, which converts the pulsed proton beam delivered by the linear accelerator to cold and thermal neutron beams tailored for neutron science applications, consists of several systems. Each of these elements offers unique design challenges for the engineering teams both in terms of providing the necessary primary function and in satisfying complex requirements for physical and functional interfaces between systems.
The Moderator and Reflector systems are a central part of the ESS and directly impact the overall performance of the facility. These are defined as the plug holding the neutron moderators and reflectors as well as the associated cryogenic fluid and refrigeration systems.
The recent development of the neutronic design of flat moderators and their application and use by the neutron scattering systems has called for a re-engineering of the moderator and reflector systems for the ESS. In addition, this novel moderator concept has a major impact on the layout of the monolith and the remote handling procedures.
This paper presents the ESS Moderator and Reflector systems from the engineering perspective. Different aspects of the moderator concept chosen for ESS are addressed, focusing on the latest progress of the development work.

1. General description Target Station

The function of the target station is to convert the intense proton beam from the accelerator into a number of intense neutron beams. This conversion is achieved by the interplay of a number of basic functions. In the heavy metal target the impinging proton beam radiation from the accelerator is converted via the spallation process into fast neutrons as the useful product, while generating a large amount of heat, radioactive isotopes and prompt radiation as unavoidable by-products. The moderator-reflector assembly surrounding the target transforms the fast neutrons emitted by the target into slow neutrons, which are the final form of useful radiation provided by the neutron source, while further radioactive waste is produced by the absorption of neutrons by various target structures. (Here, “fast” means neutrons with velocities in the range of 10% of the velocity of light and “slow” means velocities comparable to the speed of sound.) These two neutronically active systems are surrounded by a radiation shielding system of approximately 7000 tons of steel, in order to contain the extreme level of highly penetrating gamma and fast neutron radiation created in the target and its vicinity. The beam extraction system provides intense slow neutron beams through beam guides, which traverse the target shielding. These neutron beam guides are accessible at the surface of the shielding, for delivery to and use at the neutron-scattering instruments facing the beam ports at variable distances. The proton beam window separates the high vacuum in the accelerator from the atmospheric-pressure inert helium gas inside a large container vessel, in which all of these systems are housed. They form, together with the tight container, the target monolith, which takes the shape of an 11 m diameter and 8 m high cylinder.

At ESS, the proton beam will deliver 5 MW power in the form of kinetic energy. About 10% of this energy is converted to mass through the nuclear reactions in the spallation process that produces neutrons, other nuclear fragments, isotopes and gamma radiation. The energy of these particles makes up the remaining 90% of the proton beam energy, and it is almost all deposited within a distance of 1 m from the site of proton beam impact in the target. Different cooling circuits in the target monolith remove this large amount of heat from the target itself (3 MW), from the moderator-reflector assembly (1.2 MW) and from the monolith shielding (0.3 MW). The proton beam window is directly heated by the traversing beam and requires cooling of about 6 kW, though this value is strongly dependent on window design details.

Radiation damage and fatigue limit the lifetime of the three most strongly affected systems: the target, the reflector-moderator assembly and the proton beam window. All of these systems will need to be changed multiple times during the lifetime of the facility, with frequencies ranging between 6 months and 5 years, as conservatively estimated on the basis of available experience at spallation sources. The removed used components represent a considerable amount of radioactive waste. The other part of the radioactive waste consists of gases, volatiles and airborne particles, which will be continuously captured by a variety of efficient filters and traps.

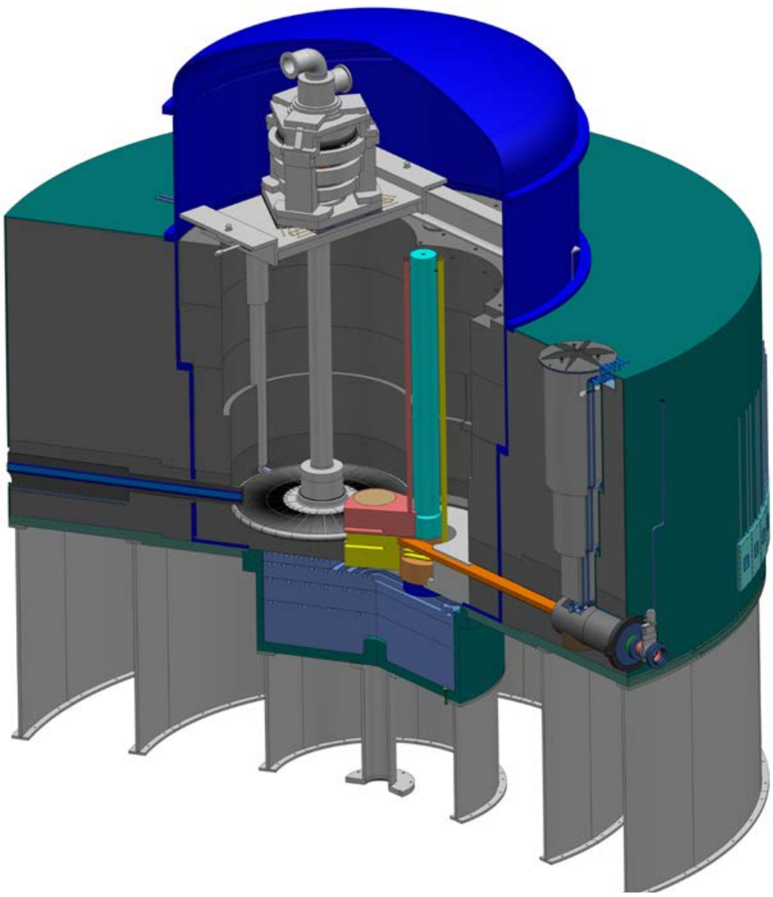

Figure 1 Monolith with Moderator & Reflector Assembly Inside

2. IMPROVEMENTS ON MODERATOR & REFLECTOR ASSEMBLIES

2.1. Flat Moderator Design

The ESS Target station has, as a result of the promising development and implementation of the Flat Moderator design, developed an engineering solution to handle the novel design significantly.

The size of the liquid hydrogen moderator is according to the current conceptual optimization at a height of 3 cm and diameter of approximately 24 cm. The cold moderator is enclosed within a vacuum chamber for insulation and placed above a flat 3 cm thick water disc acting as thermal moderator. The disc is connected to the water wings pointing out angular against the beam lines horizontally adjacent to the cold moderator allowing the instruments to align their view both the cold liquid hydrogen moderator as the well as the thermal water wings. Outside of the liquid hydrogen moderator sits a second thermal moderator flushed with water, see figure 2.

Both the outer thermal moderator and the liquid hydrogen cold moderator are designed with a serial flow pattern to allow even gradual temperature deposition through the tanks.

The reflector surrounding the moderator assembly is filled with beryllium blocks enclosed in the aluminium tank continuously flushed with cooling water.

In the concept design it is anticipated that all shells, tanks and components will be manufactured out of Al 6061-T6.

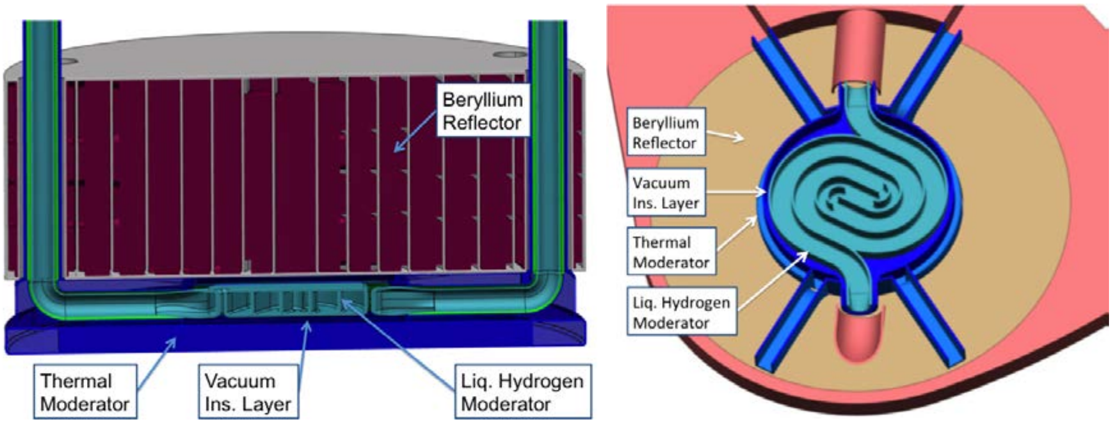

Figure 2 Flat moderator design concept

2.2. Moderator & Reflector Plug

Engineering development of the concept design has aimed towards a design of a plug that can assemble and hold a typical moderator and reflector assembly within the defined envelope, ensure a managed pipe-routing and the possibility to handle installation and removal of the plugs in/out of the monolith operational position in an effective and controlled way. Calculations have shown that a size of 70 cm for the assembly of the moderators and reflectors should be adequate still allowing changes in the detailed moderator design up to a level that could be reasonable to expect coming out of the development and experience that will be collected during commissioning and initial operations. Based on those calculations a plug was developed that could fit different combinations of moderators and reflectors of different designs and materials within this defined envelope. The plug concept thereby allows for changes in moderator type from a flat design to tube design or other moderator geometries.

The plug's design and support structure allows viewing of moderators up to 120 degrees in two directions, see figure 3, however certain moderator designs performs better with narrower viewing slots.

ESS has with the engineering design the possibility to further develop and update the moderator as neutron science progresses and new innovations are discovered without having to do major modifications of the target station. Thereby being prepared to without extensive modifications allow implementation of new ground-breaking developments to continue to improve performance of the neutron source.

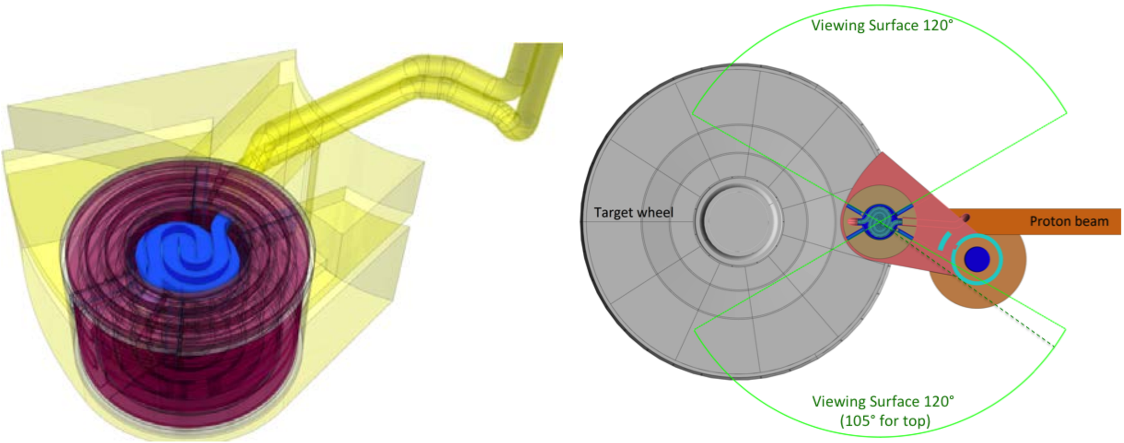

Figure 3 The lower MR assembly (left) and indicated possible viewing angles (right) for neutron science instruments

2.3. Moderator and Reflector Plug Configuration

An assembly concept design has been developed to include the new moderator and plug concept with the purpose of, being able to in a controlled and smart way of install and remove the moderator plugs, while allowing the surrounding structure and target wheel to remain in place to a large degree. The sequence of operation for replacing the moderator plugs permits exchanging them more often than the other adjacent components as the moderators will most likely be expected to have a shorter lifespan.

The two plugs can be introduced or removed independently from each other, see figure 4, by rotating the individual pipe and bracket holding each plug before attaching a custom lifting fixture that will take it of the support pipe and up into the transport cask for transfer to the hot cell. As the plugs are independently supported this allows for different exchange periods for each of the moderators enabling plugs with completely different designs i.e. lifetimes.

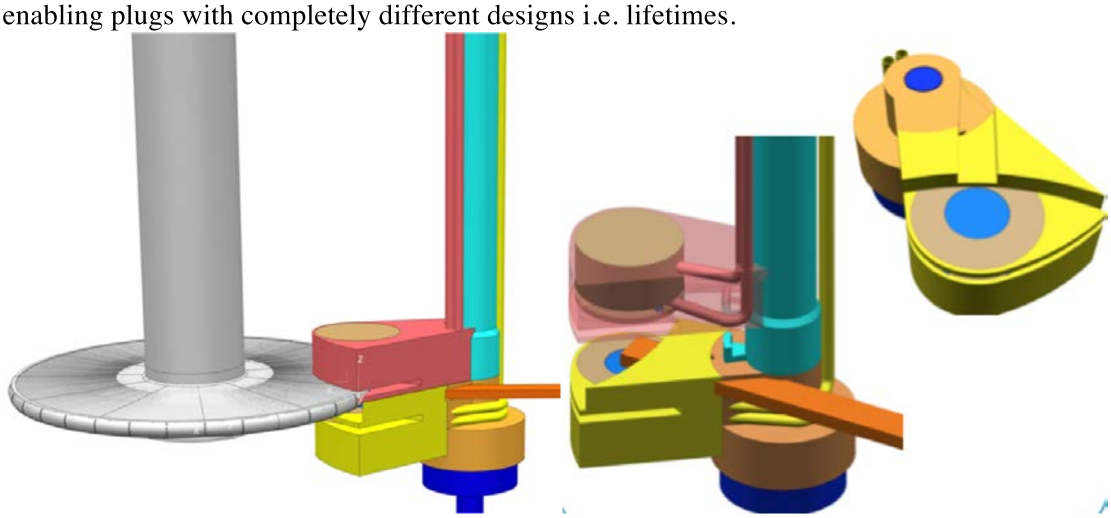

Figure 4 Configuration of the moderator and reflector plugs relative the target

2.4. MR Plug Handling System

The illustrations in figure 5 show the sequence of removing both moderators while keeping the target wheel and surround structure in place. Each of the MR Plugs is attached to a rotating support-pipe, the two support-pipes, one for each MR plug, are supported on each other and together on a stiff axis that has its foundation into the monolith foundation.

Shielding blocks will need to be removed to let each of the plugs to be rotated from operational position into service position, and then lifted up. Pipes are permanently connected to each of the plugs and belong to the plug assembly. As the plugs are introduced or removed the pipe-bundle must be practically handled simultaneously with the plugs and when being installed connected to the supporting structure to prevent vibrations.

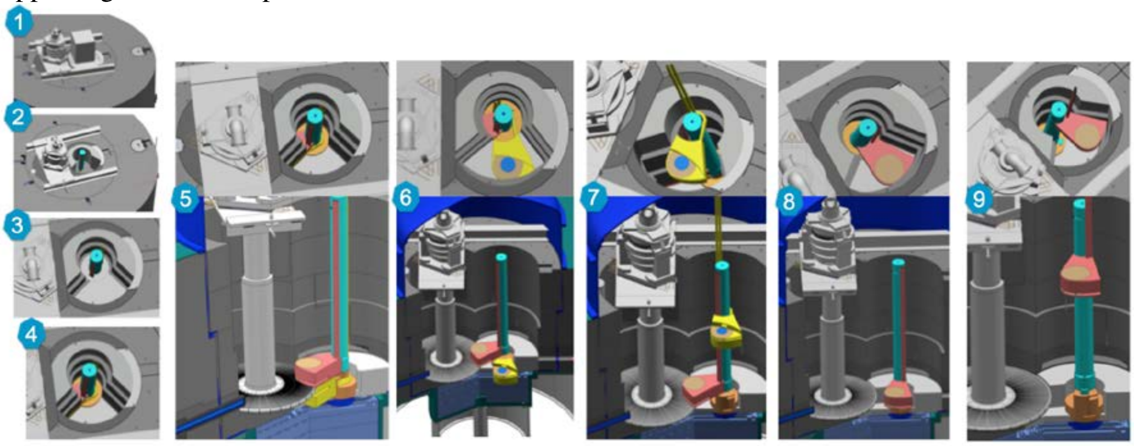

Figure 5 Handling sequence of removing both moderators

2.5. In-Kind Contribution

The construction of the ESS in Lund is strongly based on In-Kind contributions from member states. During 2014 several In-Kind collaboration meetings have been performed. Institutes within ESS member states were invited and the different work scopes presented. It is planned to reach an agreement with a European institute for taking the responsibility for the final design and delivery of several parts of the described system during first half of 2015.

References

[1] S. Peggs, "ESS Technical Design Report", ISBN 978-91-980173-2-8.