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Neutron performance analysis for ESS target proposal

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A B S T R A C T

In the course of discussing different target types for their suitability in the European Spallation Source (ESS) one main focus was on neutronics' performance. Diverse concepts have been assessed baselining some preliminary engineering and geometrical details and including some optimization. With the restrictions and resulting uncertainty imposed by the lack of detailed designs optimizations at the time of compiling this paper, the conclusion drawn is basically that there is a little difference in the neutronic yield of the investigated targets. Other criteria like safety, environmental compatibility, reliability and cost will thus dominate the choice of an ESS target.

1. Introduction

Wide spread investigations have taken place starting with the ESS Preparatory Phase Study aimed at selecting the best suitable target concept for the European Spallation Source (ESS). One focus of this process, evidently, lies on the expected neutronic yield under the specific ESS conditions. Diverse numerical models have been compiled for a wide range of different possible target concepts. Facing the lack of engineering details, material choices and geometries have been based on principal requirements, e.g., concerning the suitability of particular materials, and on rough estimates for dimensions stemming from cooling requirements. Although at the current state these boundary conditions are not known at much detail, first simulations can give a clear indication of significant differences between the performances of the diverse approaches and, in case, can rule out certain options. In order to enhance the validity of the reported comparisons, some optimization has been performed individually for each concept, i.e., premoderator thickness, moderator dimensions, relative position between moderator and target and reflector dimensions have been varied to obtain near optimal performances. The obtained results allow for some meaningful benchmarking and at the same time give an indication of the margins for optimization of the different target types.

The following target variants have been investigated:

- Liquid metal (mercury, lead eutectics).
- Solid rotating target with cold plates (water cooled).
- Solid rotating target cooled by helium.
- Cannelloni target.

All calculations have been performed assuming the ESS beam parameters as available in 2010: Gaussian profile with $2\cdot\sigma_x = 10, 2\cdot\sigma_y = 3$ (in cm), 2.5 GeV per proton, and 5 MW beam power. The accelerator fires at a rate of 20 Hz, making the total energy per pulse 250 kJ. In addition to the expected long pulses (1 ms duration) the response for short pulses has been simulated too, thus obtaining more information on the fine-scale timing.

2. Methodology

In order to analyze the neutronics of the target–moderator–reflector assembly, several MCNPX models [1] have been developed based on SNS-STS proposal [2]. This configuration presents a Coupled Wing moderator with the following main parameters: three lines with 120 cm^2 of moderator surface view, a cylinder of pure parahydrogen at 22 K as moderator, light water as premoderator, beryllium cooled by heavy water (5% in volume) as reflector and several Al_3Mg claddings. Moderator height has been set to the view height, as increasing it reduces neutron performance.

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This geometry will be similar to the ESS final geometry, since parahydrogen moderators maximize the neutron flux in the range of interest [3] and their performance increases when a water premoderator is included [4]. Concerning the configuration of the moderator, Wing configuration reduces high energy neutrons background.

Fig. 1 shows the geometry used for the moderator–reflector assembly simulations.

The latest edition of the Los Alamos National Laboratory scattering kernel is applied [5] together with the ENDEF-VII cross-sections libraries [6]. There are several isotopes in which proton cross-sections are not included in this data library, in these cases TENDEL-2010 [7] has been used. For high energy reactions (above 20 MeV), the intranuclear cascade model CEM [8] is applied.

The reference figure of merit studied for the optimization is the "Time integrated neutron flux below 5 meV" on the moderator's surface. This figure has been used in other optimization studies [2,9,10] and has been found to be a representative figure of the assembly performance. An optimization loop has been carried out for each target design considering the main geometrical parameters, i.e., relative position of target and moderator, moderator radius, premoderator thickness and reflector dimensions. Therefore, figures of neutron performance have been calculated close to the optimal configuration. Since dozens of simulations need to be done for each target type, we need a figure of merit that is computationally cheap to find the optimal configuration, and, then, we can do a fine energy binning in order to have a more detailed characterization of the brightness. Concerning premoderator, only the target-side thickness has been optimized because far-target-side (5 mm) and lateral-side (10 mm) effects will be much lower than the first one [11].

Time integrated neutron flux and neutron time distributions have both been evaluated by means of a point detector placed 10 m away from the moderator surface. The point detector was enclosed in a collimator, using cells with zero importance, to avoid indirect contributions. The collimator is sized so that all neutrons at the point detector need to come from the moderator surface. The time binning was influenced by a user supplied TALLYX subroutine such that the moderator emission time (time at which the neutrons exit the moderator) was scored rather than the arrival time at the detector point. This detector modification is known in literature under the name time-of-flight-corrected point detector [12,13]. Neutron time distribution is calculated for energies within 4.5 and 5.5 meV.

Optimization has been performed for each variable, as cross-effects have been shown to be small, so we can consider the brightness as a product of independent variables, with sufficient accuracy for our purposes. The entire array of results, resulting from the optimization of each parameter for each target, is too large for this paper to show, but Figs. 2 and 3 show the trend of most variables. The slopes around the maximum are not steep, meaning that, from an engineering point of view, it is possible to change the parameters around the optimum without a great sacrifice of neutron performance.

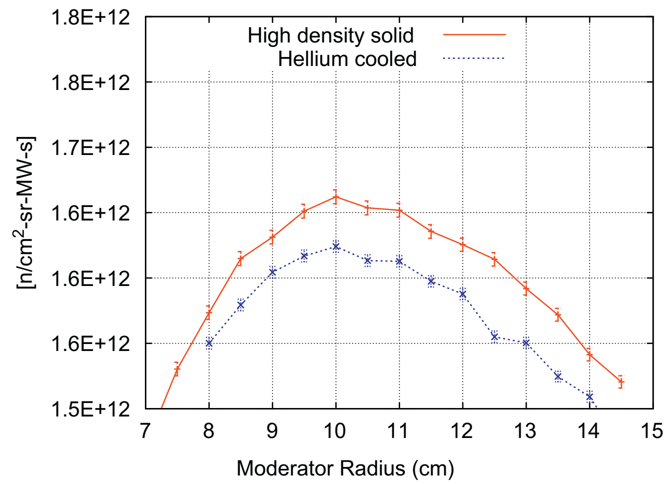

Fig. 2. Sensitivity of target performance to moderator radius.

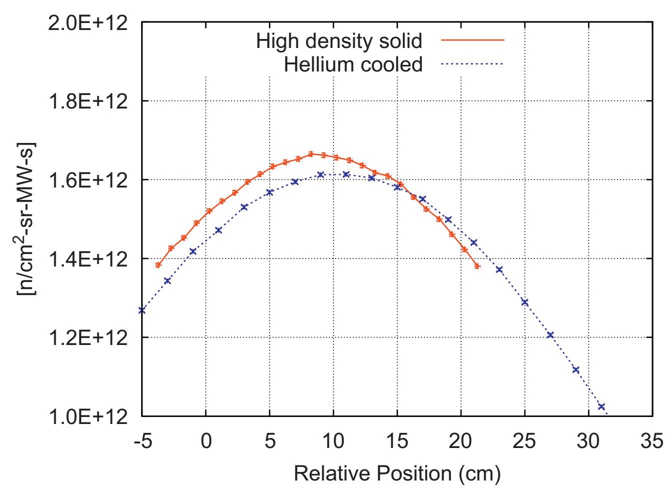

Fig. 3. Sensitivity of target performance to moderator position.

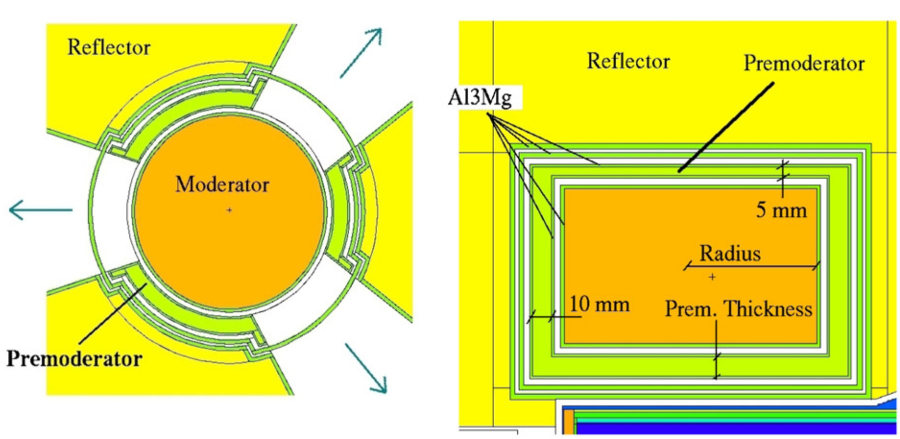

Fig. 1. Wing parahydrogen moderator geometry.