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Research Article

In-Pile ^{4}He Source for UCN Production at the ESS

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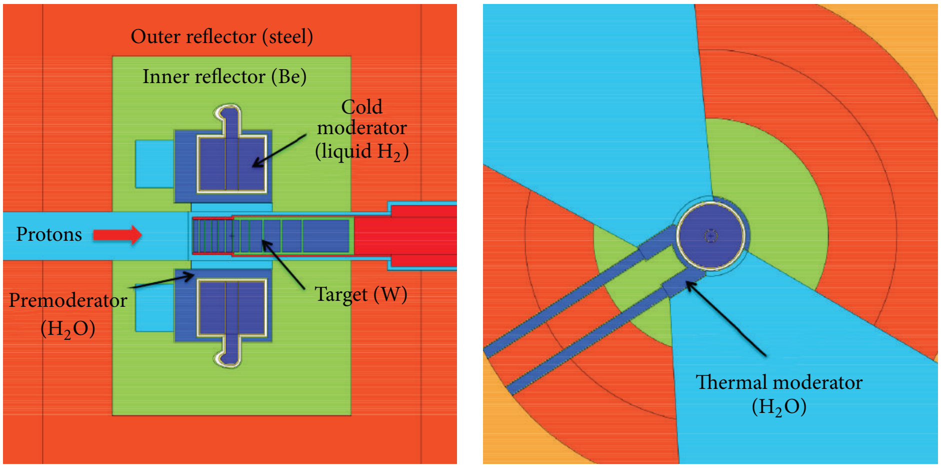
ESS will be a premier neutron source facility. Unprecedented neutron beam intensities are ensured by spallation reactions of a 5 MW, 2.0 GeV proton beam impinging on a tungsten target equipped with advanced moderators. The work presented here aims at investigating possibilities for installing an ultra cold neutron (UCN) source at the ESS. One consequence of using the recently proposed flat moderators is that they take up less space than the moderators originally foreseen and thus leave more freedom to design a UCN source, close to the spallation hotspot. One of the options studied is to place a large ^{4}He UCN source in a through-going tube which penetrates the shielding below the target. First calculations of neutron flux available for UCN production are given, along with heat-load estimates. It is estimated that the flux can give rise to a UCN production at a rate of up to $1.5 \cdot 10^8$ UCN/s. A production in this range potentially allows for a number of UCN experiments to be carried out at unprecedented precision, including, for example, quantum gravitational spectroscopy with UCNs which rely on high phase-space density.

1. Introduction

The fundamental physics community has expressed strong interest to investigate the possibility of installing source of ultra cold neutrons (UCNs) at the ESS. There are a number of different ways in which this could be realized. This paper focuses on the in-pile option, in particular the possibility that a UCN source could be hosted in a *through-going tube* that penetrates the monolith shielding as well as the outer and inner reflectors. This would allow the UCN converter to come as close as possible to the spallation region, thereby subject to the highest possible input neutron flux. In order not to conflict with the cold/thermal moderators at the ESS, the tube must pass under the lower moderator. The study presented here details the impact on the cold/thermal moderator performance inflicted by the introduction of a through-going tube and relates this to the location of the through-going tube. In addition first estimates of the possible UCN production rate are given.

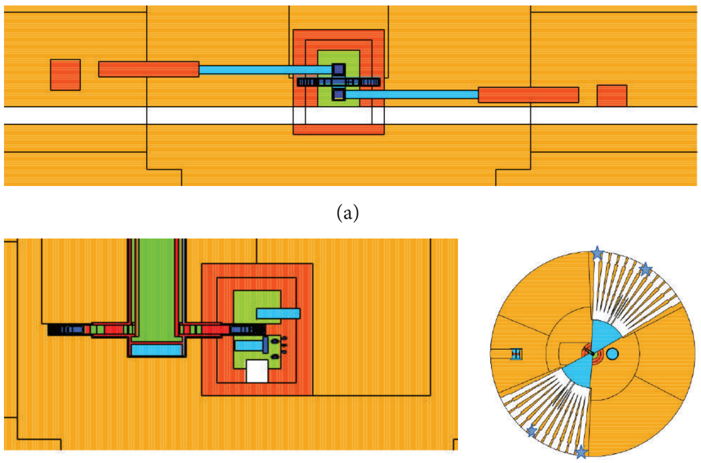
2. Through-Going Tube in Baseline Design

The possibilities for installing a UCN moderator at the ESS strongly depend on the layout of the target-moderator-reflector. In Figure 1, the central parts of the target-moderator-reflector are shown according to the baseline design of the Technical Design Report [1]. In this scenario, voluminous parahydrogen moderators (two cylinders of 16 cm diameter, 13 cm high) are situated on each side of the target and thus close to the spallation neutron density hotspot. The introduction of a UCN moderator would have to stay clear of the two existing moderators, for example, by placing it in a through-going tube underneath the lower parahydrogen moderator. As the main focus of the ESS facility is providing cold and thermal neutrons, it is essential when altering the baseline design to monitor the performance impact on the cold/thermal neutrons available in the instruments beamlines. Therefore, a study was carried out monitoring the flux available for UCN moderation versus



(a) (b)

FIGURE 1: Vertical (a) and horizontal (b) cross-section of the target-moderator-reflector geometry in the Technical Design Report [1].



(a)

(b) (c)

FIGURE 2: Geometry of the target, moderator, and reflector showing the UCN through-going tube (white areas in upper and lower left-hand inserts) placed at $y = -47.5$ cm (central), corresponding to the topmost of the studied geometries. The blue stars in the lower right-hand insert show the position of the lower point detectors. Note that the xz-plane (lower right-hand insert) is cut at $y = -18$ cm; wherefore the UCN tube is not visible.

the impact on neutron flux in the cold/thermal beamlines—for different vertical positions of the through-going tube.

3. Simulation Setup

Based on the baseline MCNPX [2, 3] model used for the neutronics calculations of the ESS Technical Design Report (TDR) [1], a 25 cm × 25 cm tube is defined. To avoid the forward directed high energy shower particles from the proton beam impacting the target wheel, while obtaining maximal thermal flux, the tube is centered around and parallel to the x-axis (i.e., perpendicular to the proton beam). The tube is centered at $z = 0$ while the y coordinate (the "depth" under the proton beam) is left free and various possibilities are studied: $y \in [-47.5; -62.5]$ cm (central in tube) (the coordinate system used at the ESS is right-handed, with the protons travelling along the z-axis, impacting the target in the origin; the y-axis is positive upwards (i.e., opposite gravity)). Figure 2 shows an example in which the void volume (the UCN through-going tube) replaces parts of the beryllium inner reflector (red) but more severely impacts the outer reflector (orange).

To measure the possible impact on cold/thermal beamlines, eight representative point detectors are placed in the beam-ports at the boundary of the target-moderator-reflector (TMR) plug, corresponding to the blue stars on the lower right insert of Figure 2.

4. Results

Comparing flux ratios between modified (i.e., including UCN tube) and baseline design in the three energy bins (cold,

TABLE 1: Heat-load on cryogenic ^4He and integrated cold/intermediate/thermal flux for the ESS implementation of Golub's UCN design discussed in the text and shown in Figure 4. The relative statistical uncertainties are ~0.1%.

Heat-load [mW/cm^3]	Flux [0–5] meV [n/cm^2/s]	Flux [5–20] meV [n/cm^2/s]	Flux [20–100] meV [n/cm^2/s]
2.5	$3.8 \cdot 10^{12}$	$9.0 \cdot 10^{12}$	$1.8 \cdot 10^{12}$

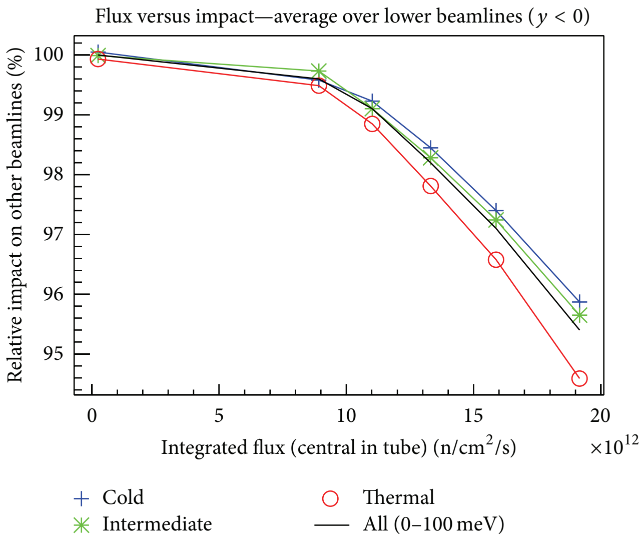


FIGURE 3: Relation between cold, intermediate, and thermal flux in the lower cold/thermal beamlines versus the flux available for UCN, central in the through-going tube. The black curve shows the (unweighted) average between the cold, intermediate, and thermal curves. Each point corresponds to a specific vertical position of the through-going tube.

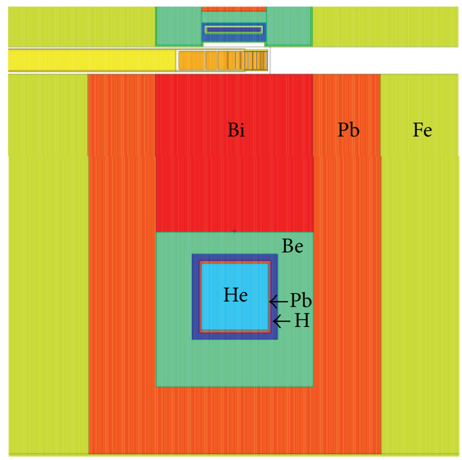


FIGURE 4: Assuming that all cold/thermal neutron scattering instruments can be served by a single flat moderator on top of the target wheel, a large ^4He source is installed below the target.

intermediate, and thermal) shows that regardless of the position of through-going tube, the upper beamlines are unaffected.

Furthermore, the impact is approximately energy independent and does not fluctuate significantly between the four lower tally positions; therefore, the response of all lower tallies is collapsed to one average for each position of the through-going tube.

Finally, the relation between the impact in terms of relative decrease in available cold/thermal flux at the cold/thermal instruments versus the (central) flux available for UCN production is shown in Figure 3.

5. Discussion

There are several conclusions to be drawn for Figure 3. First, one can conclude that with proper design and carefully chosen distance from other moderators, a UCN moderator could be installed at the ESS without seriously impacting the performance of the scattering experiments. Unfortunately, one can also see from the figure that regardless of position under the lower parahydrogen moderator, the flux available for UCN production is very limited.

Despite these somewhat discouraging conclusions, there is some reason for hope. Simultaneously to the work presented here on through-going tube options, work is being carried out on the design of the cold moderators at the ESS. From the neutronics group of the ESS it is suggested to use flat moderator(s) for increased brightness [4, 5]. One feature of a flat moderator is that it is only viewed at a small area. Thus the amount of reflector "removed" per beamline is rather small, and the number of beamlines viewing a single moderator can be increased with respect to setup outlined in the TDR. In fact all the 22 foreseen instruments at the ESS can view one single flat moderator, with insignificant performance loss. Even in the case where two flat moderators of different heights will be installed, the reduced height of the moderator could allow for the installation of a second moderator below the target at a position favourble in terms of neutron flux (see Figure 3). In principle this reopens opportunity for installing a moderator below the target of a completely different type than the upper flat parahydrogen moderator.

One possibility would be to install a large ^4He moderator close to the spallation target, as initially suggested by Golub and colleagues more than 30 years ago [6]. Figure 4 shows an implementation of a UCN source inspired from this early work.

From this design, the heat-loads and fluxes shown in Table 1 are obtained from a MCNPX simulation of the geometry shown in Figure 4.

In [7] Golub and coauthors provide a scheme for calculating maximum UCN production, given an incoming cold/thermal spectrum and integrated flux. Inserting the values of Table 1 and the observed spectrum, one arrives at a total maximal UCN production rate in 30 cm × 30 cm × 30 cm ^{4}He to be $1.5 \cdot 10^8$ UCN/s. It should be stressed that this is the maximum production rate, and it does not take into account any of the challenges confronted when attempting to store, extract or handle the UCN's.

Conflict of Interests

The authors declare that there is no conflict of interests regarding the publication of this paper.

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