AN INVESTIGATION OF THE NEUTRONIC PERFORMANCE OF THE ULTRACOLD NEUTRON SOURCE UCN USING MCNPX

M. Wohlmuther

Several design options of the UCN D_2O moderator tank have been studied using the Monte-Carlo particle transport code MCNPX. In particular the influence of different tank materials on the thermal neutron fluxes in the solid D_2 converter was investigated. The neutron fluxes vary on a 10 % level.

INTRODUCTION

An ultra-cold neutron source – UCN source [1] – is going to start operation at PSI in 2007. The essential elements of the UCN source are the spallation target assembly, a large heavy-water moderator of about 4 m^3 at room temperature, a converter system of 30 liters of solid deuterium (SD_2) at a low temperature for the production of ultra-cold neutrons and a storage volume for the ultra-cold neutrons. Spallation neutrons will be thermalized in the D_2O moderator and further cooled in the SD_2 volume which is located inside the moderator tank. Some of these cold neutrons will be downscattered in the SD_2 so that they enter the storage volume in the ultra-cold energy regime. One of the essential design parameters for the UCN source is the thermal neutron flux in the SD_2 converter as it determines the number of ultra-cold neutrons produced. Therefore, the influence of several layout options of the heavy-water moderator tank on the thermal neutron flux in the SD_2 converter was studied. The calculations were performed with the Monte-Carlo particle transport code MCNPX [2].

THE MODEL

A cross section of the geometrical model of the UCN source used for the study is depicted in Figure 1. The target, which was simulated to consist of lead only, the SD_2 converter, and the inner radius of the D_2O moderator tank, remained unchanged in all cases that were considered. Four different design possibilities for the D_2O moderator tank have been investigated, where the construction materials of the D_2O tank were altered and a possible reflector was introduced. Table 1 gives an overview of the various design options.

Case	Moderator	Inner tank	Reflector	Outer tank
	R=80 cm	T=1 cm	T=7 cm	T=0.8 cm
1	D_2O	$AlMg_3$	-	-
2	D_2O	Steel	-	-
3	D_2O	$AlMg_3$	H_2O	Steel
4	D_2O	D_2O	D_2O	Steel

Table 1: Materials used in the MCNPX simulations for the D_2O moderator tank. T is the thickness of a layer and R is the radius of the moderator tank.

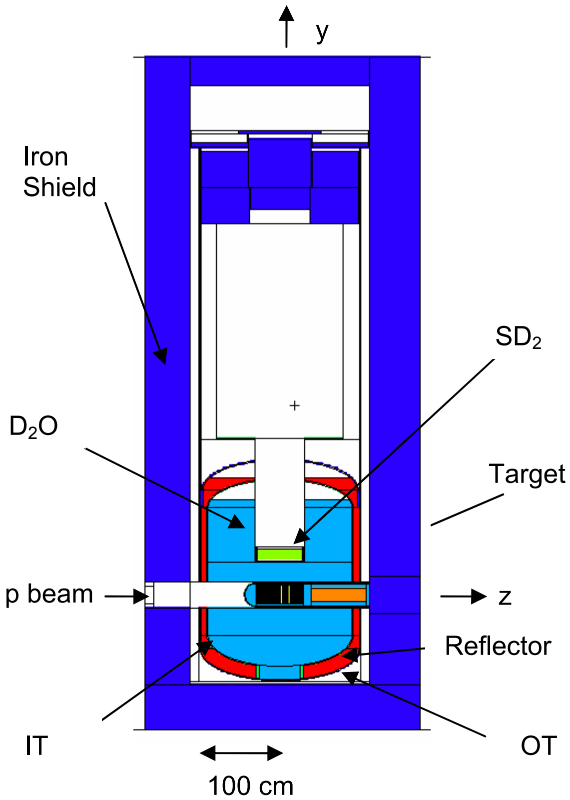

Fig. 1: Cross section of the geometrical model of the UCN source used in the MCNPX simulations. The SD_2 converter (SD_2), the D_2O moderator (D_2O) and the target remained unchanged, while the materials of the inner tank wall (IT), the reflector, and the outer tank wall (OT) were changed – see Table 1. The drawing corresponds to case 3.

The base case consists of an aluminum moderator tank with a radius of 80 cm without any reflector. In a second step the aluminum was replaced by steel of the same thickness – 1cm – and still no reflector was introduced. In the third case under consideration, a 7 cm thick light-water reflector was introduced around the D_2O moderator. The inner tank material was chosen to be aluminum with a thickness of 1 cm, and steel of a thickness of 0.8 cm was introduced as the outer tank material. The fourth option that was simulated was the extension of the D_2O moderator to a radius of 88 cm, leaving the outer tank material as steel with a thickness of 0.8 cm.

In all cases the UCN tank was surrounded by iron shielding blocks (Fig. 1).

The calculations were performed with MCNPX version 2.5.d. No variance reduction technique was applied. The number of primary protons per run was 10^6.

RESULTS

The quantity of interest is the thermal neutron flux in the SD_2 converter. This was estimated by calculating the track-length flux of thermal neutrons within the volume of the SD_2 converter. On average 12.7 neutrons are produced per incident proton in the overall system. This number is a result of the pure lead target used for the simulation and will decrease – due to neutron absorption in structural materials - on a 10 % level if a more realistic target is used. The neutron fluxes (Φ_n) for neutrons with energies below 1.4 eV, as well as the flux gain factors for the different cases, are presented in Table 2. The statistical errors of all flux values are below 1 %.

Case	Φ_n	Flux Gain
1	$3.43\ 10^{-3}$	1.00
2	$3.49\ 10^{-3}$	1.01
3	$3.80\ 10^{-3}$	1.10
4	$3.93\ 10^{-3}$	1.13

Table 2: Neutron fluxes (Φ_n) [n cm^{-2} p^{-1}] in the SD_2 converter and flux gain for the different design options.

The flux gain in the SD_2 converter is due to an increase of the reflected neutron current at the periphery of the D_2O moderator tank.

For case 1, the aluminum tank without any reflector, 2.1 % of the neutron flux in the SD_2 converter stems from neutrons backscattered from the periphery of the assembly. As aluminum is rather transparent for thermal neutrons (reflectivity ~ 5 %), most of the backscattered neutrons originate in the iron shielding blocks. A neutron flux contour plot for this layout option is given in Figure 2.

If the aluminum is replaced by steel (case 2), neutrons reaching the periphery of the tank are more likely to be scattered back towards the SD_2 converter because of the higher reflectivity (33 %) of steel. As a consequence the flux contribution of neutrons from the periphery of the system slightly increases, leading to a small flux gain of 1 %.

The introduction of an additional light-water layer outside the D_2O moderator tank (case 3) leads to an increase of the neutron flux in the SD_2 converter of about 10 % with respect to the base case of a bare aluminum tank. The gain in flux is due to the high reflectivity of H_2O for thermal neutrons (approximately 81 %). This increase in flux is in good agreement with values calculated for the H_2O layer at SINQ [3]. In addition to the flux gain, a reduction of heat load at the inner part of the iron shielding is found.

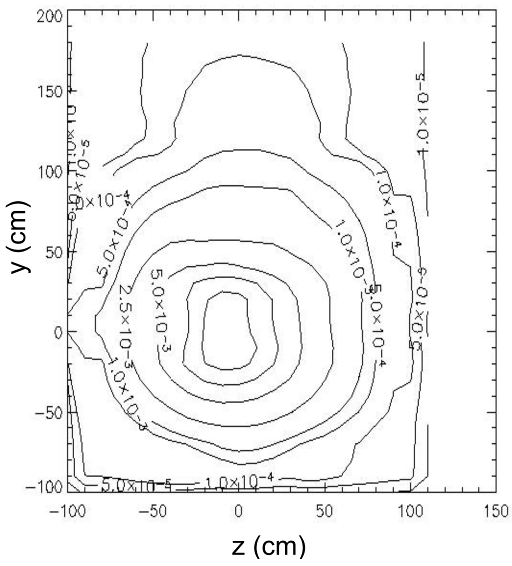

Fig. 2: Contour plot of the neutron flux (E < 1.4 eV) [n cm^{-2} p^{-1}] in the x = 0 plane of the UCN source. The center of the target is located at the position (z = 0 cm, y = 0 cm).

The high flux gain of the extended D_2O tank with a radius of 88 cm (case 4) is somewhat surprising since the reflectivity of D_2O is smaller than that of H_2O. However, an explanation for the higher flux is that additional heavy-water was introduced in the upper part of the tank. In total, this option would require approximately 1.5 m^3 more D_2O than the other cases.

REFERENCES

[1] A. Fomin et al., *An ultra cold neutron facility at PSI*, TM-14-01-01, 2001.

[2] L.S. Waters et al., *MCNPX User's Manual Version 2.4.0,* Los Alamos National Laboratory report LA-CP-02-408, Los Alamos, New Mexico, 2002.

[3] F. Atchison, *The effect of a H_2O layer around the moderator tank*, SINQ Report, SINQ/816/AFN-802, 1988.