MCNP SIMULATION OF THE BACKGROUND NEUTRON RADIATION IN THE 11B EXPERIMENTAL ROOM OF THE IBR-2 REACTOR

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INTRODUCTION

An experimental setup has been developed to determine the fundamental composition of materials including ultra-low hydrogen concentrations by Prompt Gamma-ray thermal Neutron Activation Analysis (PGNAA) on the 11b channel of the IBR-2 reactor at the Frank Laboratory of Neutron Physics [1]. PGNAA is a measurement technique for non-destructive fundamental analysis in which samples are irradiated by thermal neutrons with the mean energy of ~ 0.025 eV. Considered PGNAA technique is significantly sensitive to the background radiation in the experimental room. In this work, we take into account only the neutron part of the background which is a source of secondary gamma radiation as well. It is mostly determined by thermal neutrons transported from a moderator through a curved mirror neutron guide and scattered by the sample. However, there is also a direct beam of fast neutrons from the reactor with energies up to several MeV. Such neutrons pass through a mirror wall of the neutron guide but are still transported inside its vacuum-housing to the experimental room.

In this work, we present the results of the simulation of the fast neutron propagation through the polyethylene/boron carbide (BPE) composite proposed for the background minimization and the protection from fast neutrons.

Fig. 1. The neutron protection is installed near the local beam shutter inside the experimental room of the 11b channel.

METHODS AND MATERIALS

Monte Carlo N-Particle Transport Code eXtended, version 27e (MCNP) was used to calculate neutron angular and energy distributions as well as neutron fluxes through all the faces of the BPE cube with a side length of 60 cm [2]. We divided the faces of the cube into the 10×10 matrix of segments to see a mesh distribution of the neutron flux. Here, the BPE cube represents the real neutron protection shown in figure 1. Fast neutrons with the discrete kinetic energies of 1, 2, and 3 MeV fall normally on the front surface of the cube at a distance of 4.5 cm to the right from the surface's center. This distance reflects a real spatial separation of fast and thermal neutron beams on the 11b channel.

Table 1. The compositions and density of the BPE material.

Material	Element	Fraction, wt. %	Density, g/cm^3
Polyethylene $(CH_2)_n$ (97% of total mass)	C	83.0592	0.90 g/cm^3
	H	13.9408	
Boron carbide B_4C (3% of total mass)	B	2.3478	2.52 g/cm^3
	C	0.6522	

MCNP is a highly stable code tracking neutrons, photons, and electrons, and using evaluated nuclear data libraries for interaction probabilities. MCNP provides seven standard neutron tallies. We obtained angular distribution, flux, and energy spectrum of neutrons on the surfaces of the cube by using F1 with C1 (cosine card), F2 with FS2 (segment card) tallies, and E0 energy card, respectively. In our simulation, detectors have been located on the surfaces of the cube.

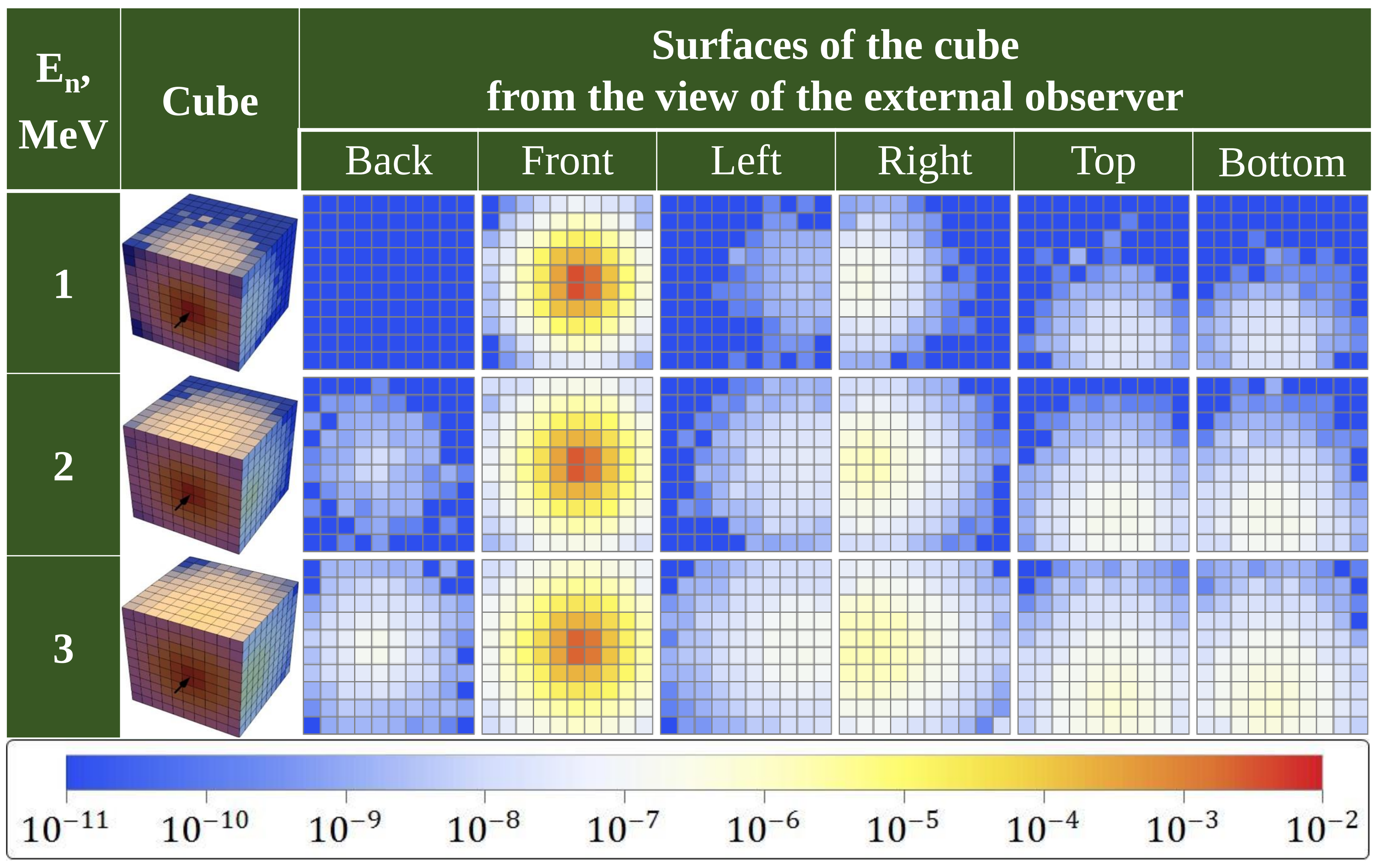
SIMULATION RESULTS

The properties of neutron propagation in the BPE material were investigated within the Monte Carlo simulation. We considered the processes of neutron scattering and absorption in the BPE.

Table 2. The probabilities of the reflection from the front surface of the BPE cube P_{ref}, transmission through the back surface P_{trs}, scattering and exit through the side surfaces P_{sides}, and absorption P_{abs} for neutrons with energy E_n.

E_n, MeV	P_{ref}	P_{trs}	P_{sides}	P_{abs}
1	$3.7097_{\pm0.0003}$E-1	0	$8.1363_{\pm0.0227}$E-5	$6.2895_{\pm0.0003}$E-1
2	$3.0026_{\pm0.0003}$E-1	$2.7179_{\pm0.1025}$E-6	$5.1912_{\pm0.0112}$E-4	$6.9922_{\pm0.0003}$E-1
3	$2.5541_{\pm0.0005}$E-1	$4.7704_{\pm0.0426}$E-5	$1.5528_{\pm0.0071}$E-3	$7.4299_{\pm0.0005}$E-1

Table 3. The mesh distribution of neutron fluence, cm^{-2}.



The thermalization of fast neutrons increases the probability of scattering and absorption during the propagation in the BPE media. As the result, the simulation confirms close to the isotropic angular distribution of the partly thermalized neutron fluxes through all of the cube faces.

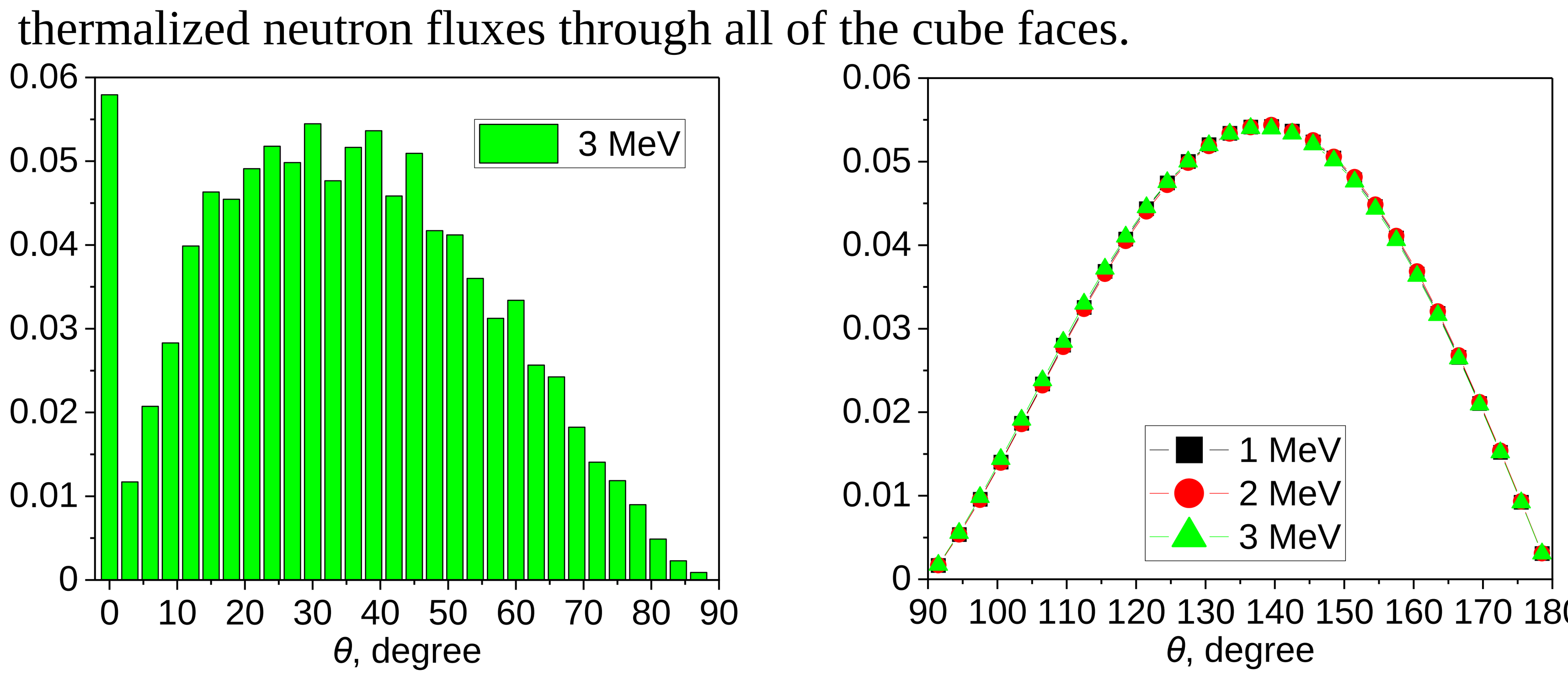
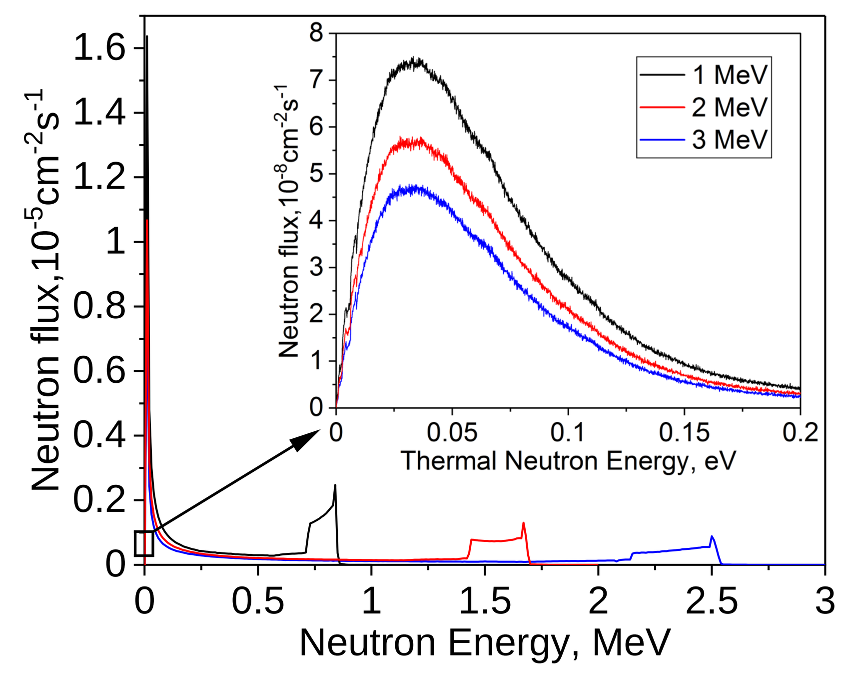


Fig. 2-3. The discrete probability densities of transmitted (on the left) and reflected (on the right) neutrons as functions of polar angle θ, which is an angle between the incident and the scattered directions of a neutron.

Fig. 4. The neutron spectrum and the Maxwellian distribution of neutrons on the front face of the cube.



CONCLUSIONS

1. Simulation of the interaction of fast neutrons with a protection material made from the BPE allowed us to estimate the neutron fluxes on its surface.
2. Taking it into account, as well as the probability of a neutron scattering to the narrow solid angle of the HPGe-detector, and it's capturing in the HPGe or capturing in the surrounding materials with further gamma emission and it's propagating through the lead protection and hitting the detector, we conclude that fast neutrons have a weak effect on the PGNAA results.
3. Based on the previous conclusions we suppose an insignificant contribution of fast neutrons to the total neutron background, which is mainly formed by thermal neutrons scattered on the sample inside the PGNAA-installation.
4. The existing BPE cube in the 11b experimental room doesn't need to be upgraded for the fast neutron protection in the case of its perfect assembly.

LITERATURE

1. Hramco, C., et al. (2019). Thermal neutron prompt gamma activation facility at IBR-2 reactor. Poster presented at the 27th International Seminar on Interaction of Neutrons with Nuclei, JINR.
2. D.B. Pelowitz, Ed., "MCNPX Users Manual Version 2.7.0“ LA-CP-11-00438 (2011) (https://mcnp.lanl.gov/).

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