Performance comparison between GEANT4 and MCNP6 for moderation of fast neutrons

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Introduction

Neutron shielding material is essential in nuclear research for personnel safety. Shielding materials should have high tolerance in extreme environments such as high temperatures, mixed radiation fields, etc. The most widely used materials for neutron moderation are polyethylene, concrete, heavy water, and polycarbonate, due to high hydrogenous content. These materials are used for shielding along with rubber sheets containing Boron as Boron has high thermal neutron capture cross-section.

Many complicated experiments require Monte Carlo simulations to predict the results in advance. Simulation packages like FLUKA, GEANT4, and MCNP6 can simulate neutron transport in the material. Recently Kim et al. [1] carried out the experiment using a ^{252}Cf source and CLYC (Cs_2LiYCl_6) detector for the detection of the thermal neutrons by varying polyethylene thickness. They also made realistic simulations using MCNP6 code and compared the results with those obtained from the experiment. However, MCNP6 is not an open-source code.

In the present work, we have carried out realistic simulations using GEANT4 which is an open-source toolkit to understand the performance comparison between MCNP6 and GEANT4.

Simulation Details

GEANT4 is a simulation toolkit for understanding the transport of particles through matter. It is implemented in the C++ programming language [2]. We have used GEANT4-10.3.0 in the present work. The physics list used in the code was QGSP_BIC_HP_physics which takes into account neutron interaction processes in the form of G4NeutronHPInelastic, G4NeutronHPElastic and G4NeutronHPCapture. A ^{252}Cf neutron source of spherical shape, having a radius of 0.785 mm, was used in the simulations. It emits neutrons up to 8 MeV [3]. The source was placed 25 cm from the detector's front surface.

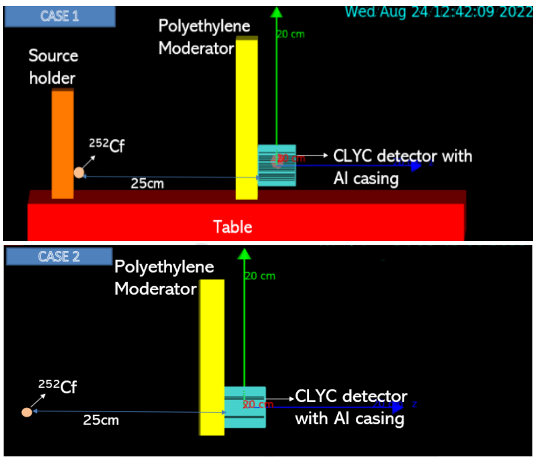

FIG. 1: Geant4 visual description.

These simulations were performed for two cases. In case 1, the detector, source, source holder, and moderator were placed on a wooden table. This case resembled the experimental environment described in Ref. [1]. In case 2, the detector, source, and moderator were simulated without the wooden table and the source holder. Fig. 1 shows the snapshots obtained from the simulations. In both cases, 10^7 neutrons from the source are allowed to

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fall on the detector's front face. In case 1, the source was put in a source holder made of polycarbonate with dimensions 15 cm × 15 cm × 3 cm. A polyethylene (PE) moderator sheet was placed between the detector and the source. The sheet was cuboidal in shape, having a length of 20 cm, breadth of 20 cm, and density of 0.93 g cm^{-3}. The thickness of the sheet varied from 1 cm to 9 cm. The thermalized neutrons were detected using a $2'' \times 2''$ cylindrical CLYC (Cs_2LiYCl_6) crystal encased in aluminium. The wooden table had a length of 60 cm, a width of 60 cm, a thickness of 5 cm, and a density of 0.64 g cm^{-3}.

Results and Discussion

The simulations were performed to detect thermal neutron counts after fast neutrons got moderated by the PE sheet. The interaction of thermal neutron with ^{6}Li (present in CLYC), results in the emission of alpha with energy 2.06 MeV and triton of energy 2.72 MeV via ^{6}Li(n, t)α reaction. Moderator thickness was varied from 1 to 9 cm. The thermal neutron counts in each setup were normalized to the maximum value of counts. We compared our results with those reported using MCNP6 [1] and presented them in Fig. 2. Thermal neutron counts were found to increase with an increase in PE thickness until they reached a maximum of 6 cm in case 1; and of 7.5 cm in case 2. Beyond these thicknesses, the counts were found to decrease with the increase in thickness of PE due to the backscattering and capture of thermal neutrons by the moderator. Though a maximum of 15% discrepancy was observed for values below the optimal thickness, there is no discrepancy in the optimum thickness obtained using both toolkits.

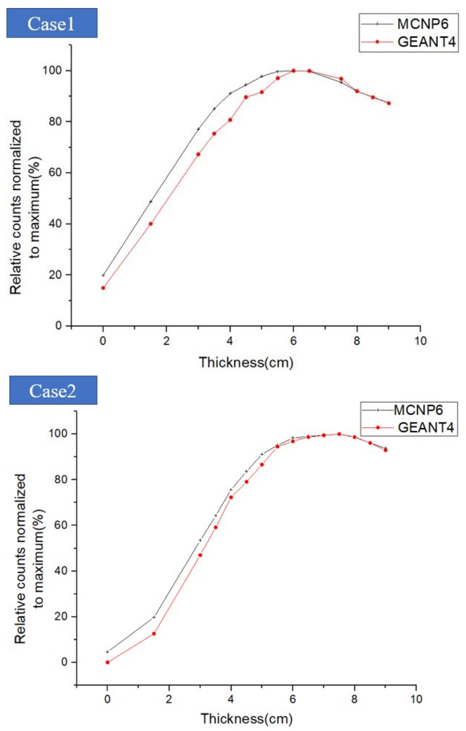

FIG. 2: Comparison of GEANT4 results with those of MCNP6 [1] for two different cases.

Summary

In the present study, the moderation ability of PE was studied using the GEANT4 toolkit, and obtained results were compared with MCNP6 results reported in the literature. The observed results showed excellent agreement near the optimum thickness of the moderator. Thus, GEANT4 which is an open-source toolkit can be a better alternative over the MCNP6 which is not an open-source toolkit for studying the moderation of fast neutrons.

References

[1] H.S. Kim, et al., J. Radiat. Prot. Res. **42**, 48 (2017).
[2] https://geant4.web.cern.ch/
[3] F.D. Becchetti, et al., Am. J. Phys. **81**, 112 (2013).