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Simulation of Low Energy Neutron Shielding by GEANT4 and MCNP4C Code

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Authors' contributions

This work was carried out in collaboration between both authors. Both authors read and approved the final manuscript.

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ABSTRACT

In this work neutrons shielding of ^{252}Cf source simulated with GEANT4 program and MCNP4C code. The relative neutron flux rates are calculated for different materials. Among various physics models of GEANT4 for the hadronic interaction of neutron, we have used the High Precision (HP) model, which is based on the ENDF-V1 data and is able to treat elastic scattering, inelastic scattering, fission, fusion and capture. The simulation results of GEANT4 are compared with the results of MCNP4C.

Keywords: Neutron shielding; simulation; Geant4; MCNP4C.

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1. INTRODUCTION

Today with the advancement of technology, the use of nuclear technology in various fields of industry, medicine and research...is increasing [1,2]. Gamma rays and neutrons are emitted in various nuclear reactions. Gamma rays have great penetrating power and can pass through

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the human body. Radiation protection is a term applied to concepts, requirements, technologies and operations related to protection of people against the harmful effects of ionizing radiation. In early days, only the most obvious forms of hazards resulting from high doses of radiation, such as radiation burns, were observed and protection efforts focused on their prevention, mainly for practitioners rather than patients. Although the issue was narrow, this was the origin of radiation protection as a discipline. Over the middle decades of this century, it was gradually recognized that there were other, less obvious, harmful radiation effects such as radiation-induced cancer, for which there is a certain risk even at low doses of radiation. This risk cannot be completely prevented. It can only be minimized. Mass in the form of concrete, lead or water is used to shield us from them. Neutrons have mass but no charge. Neutrons can penetrate deep into the body, and while doing so, can produce gamma rays through their interaction with tissue atoms. Thus, all neutron exposures involve some gamma rays.

These rays have great penetrating power ability and can pass through human body and without appropriate shielding can lead to serious and irreversible harm to humans [3]. In particular, construction and design neutron shielding is of vital importance related to health and safety issues. For that reason, the validation of neutron interaction models in simulation plays a very important role.

2. GEANT4

GEANT4 is a general purpose toolkit for Monte Carlo simulation of particle transport in matter [4]. GEANT4 is an open-source physics simulation toolkit originally created at CERN. It was developed especially for high energy physics but, but nowadays is widely used for various fields. Abundant hadronic processes are available in Geant4 from thermal energy neutron interactions to energetic particle interactions available only at large accelerators or in cosmic rays. In some cases, there are multiple models for a given interaction so that users can select among them according to their requirements, in terms of application, precision and computing time. Physicists use simulation to optimize detectors and software algorithms with the goal to measure, with utmost efficiency, marks that previously unobserved particles predicted by new theories would leave in their experimental devices, but nowadays it is widely used for various applications [5]. Its areas of application include high energy, nuclear and accelerator physics, as well as studies in medical and space science [6].

2.1 Geometry for Neutron Source and Shield

Californium (Cf) is a metallic chemical element with an atomic number of 98. Many isotopes of this element exist, however, the most relevant of them to this project is the Cf-252 isotope. The reason behind this isotope's selection is because it is a very good source of neutrons, with a single microgram capable of emitting millions of neutrons per minute. It is because of this fact that only small volumes of the Cf-252 isotope are required, which are thus encapsulated and used as a neutron source. The average energy of neutrons from ^{252}Cf is 2.35 MeV. The geometry of the neutron source shielding is shown in Fig. 1.

The distance between neutron source and detector is 40 cm and the distance between neutron source and shield is 15 cm. The thickness of the shield is chosen to be 5, 10 and 20 cm.

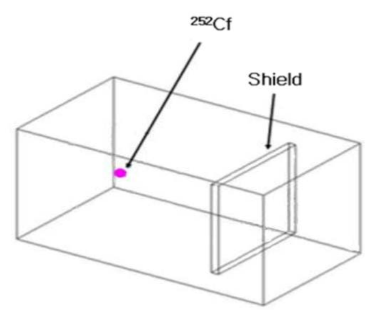

Fig. 1. Geometry for neutron source and shield

2.2 Hadronic Models

There are seven major process categories in GEANT4 that are meant to encompass the various types of interactions that particles could experience: electromagnetic, hadronic, transportation, decay, optical, photolepton hadron, and parameterization [6]. GEANT4 toolkit supports various hadronic models. We use G4HP (High Precision) model which includes four physical processes for neutron elastic scattering, inelastic scattering, fission and capture. G4HP model is a data driven model. The energy coverage of the HP model is from thermal energies to 20 MeV. The HP model is based on the data formats of ENDF-v1. This model includes cross section and final state information for elastic and inelastic scattering, capture, fission and isotope production [7].

3. SHIELDING MATERIALS

Three different shielding materials are used in this work. Concrete is widely used as one of the most common and the most cost-effective elements for the construction of a shield [3,8]. In order to have a safe biological nuclear power plants, medical, industrial and nuclear research centers, heavy weight concrete (magnetite concrete) that uses heavy natural aggregates such as barites or magnetite or manufactured aggregates such as iron or lead shot is extremely used [9,10]. The main land-based application is for radiation shielding (medical or nuclear). Heavyweight concrete is used for ballasting pipelines and similar structures [11]. The components of these shielding material and mass fraction are listed in Table 1.

4. MCNP4C

The MCNP Code developed and maintained by Los Alamos National Laboratory is the internationally recognized code for analyzing the transport of neutrons and gamma rays (hence NP for neutral particles) by the Monte Carlo method. The MCNP code can also treat the transport of electrons, both primary source electrons and secondary electrons created in gamma-ray interactions [12]. It can be used in several transport modes:

> neutron only, photon only, electron only, combined neutron/photon transport where the photons are produced by neutron interactions, neutron/photon/electron, photon/electron, or electron/photon. The neutron energy regime is from 10-11 MeV to 20 MeV, and the photon and electron energy regimes are from 1 keV to 1GeV.

5. RESULTS

5.1 Neutron Flux

We have calculated the neutron flux for different shielding materials and thicknesses. The result of MCNP4C simulation is shown in Figs. 2, 3 and 4. These figures show the neutron flux verses energy for different thickness.

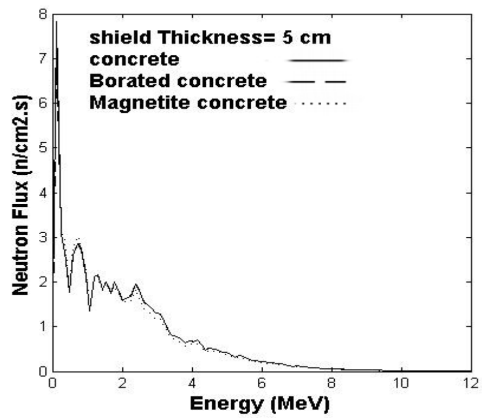

Fig. 2. Neutron flux for different materials

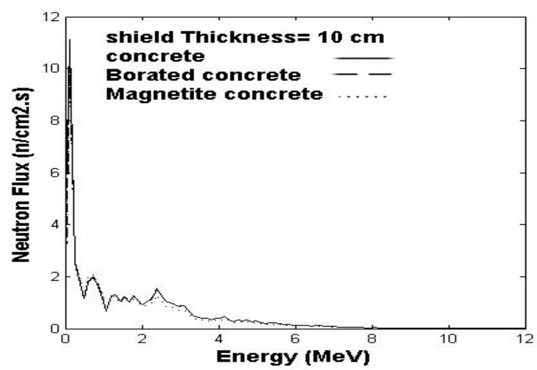

Fig. 3. Neutron flux for different materials

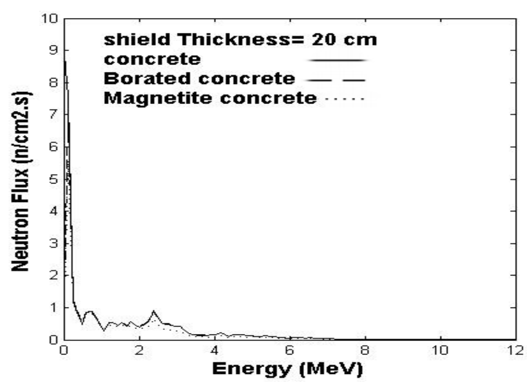

Fig. 4. Neutron flux for different materials

The addition of boron increases the efficiency of conventional concrete, because boron element contains a high absorption cross section for neutrons of low energy. Heavy concrete is more efficient than concrete and borated concrete because of its higher density.

Table 1. Component and mass fraction of shielding materials used in this work

Element	Concrete	Borated concrete	Magnetite concrete
H	0.010	0.090	0.007
B		0.018	0.013
O	0.539	0,535	0,350
Na	0,020	0.016	0,014
Al	0,030	0.028	0,020
Si	0,034	0.326	0,020
K	0,010	0.009	
Ca	0.040	0.038	0,028
Fe	0,020	0,019	0.550

5.2 Relative Neutron Flux Rates

The relative neutron flux rate is defined as the neutron flux with the shield to the neutron flux without the shield. In the Figs. 5, 6 and 7 we compare the simulation results of GEANT4 with the results of MCNP4C and as can be seen there are a good agreement between the results.

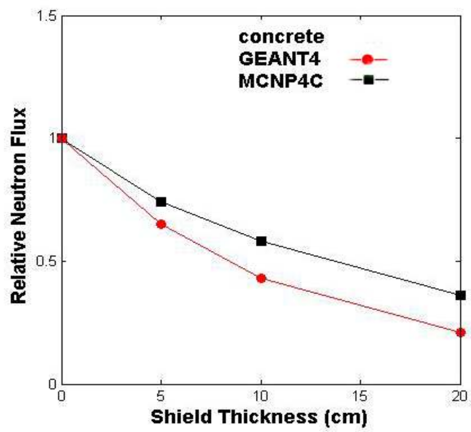

Fig. 5. Comparison between the results of Geant4 and MCNP for concrete

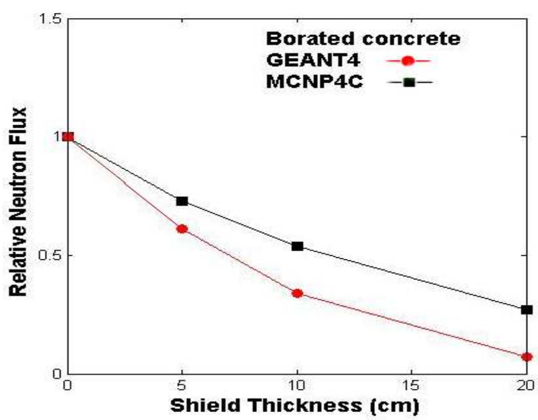

Fig. 6. Comparison between the results of Geant4 and MCNP4C for borated concrete

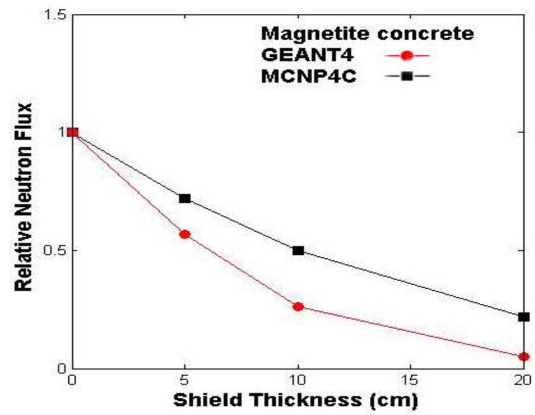

Fig. 7. Comparison between the results of Geant4 and MCNP4C for magnetite concrete

6. CONCLUSION

We have calculated the relative neutron flux rate using GEANT4 and MCNP4C. We see the difference between the results of GEANT4 and those of MCNP4C. Heavy concrete is more efficient than concrete and borated concrete because of its higher density.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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