

Neutron Shielding Calculation for Barite-Boron-Water

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Unstable nuclei may emit radiation in order to make transition to stable form. This radiation may also be neutron besides other particles or electromagnetic radiation. Besides using radiation in a variety of different fields, its effect on cells makes it dangerous for human health. Neutron is more interesting than others as it is more dangerous due to its neutral and heavy character. Therefore shielding from it is also more difficult than other radiation types. The aim of this work is to investigate shielding material properties against neutron particles emitted by spontaneous fission source ²⁵²Cf, using FLUKA Monte Carlo simulation code for some materials of barite-water-boron.

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1. Introduction

From the beginning of universe which is defined by Big-Bang theory, radiation has existed due to the long life radionuclides created as first materials. However, its discovery became possible in around nineteenth century and since then it has been used in a variety of different fields. In order to use radiation, especially neutron safely, it is important to know its interaction with matter and this may be done experimentally but it is usually done by calculation as it is easy and also possible to do it taking more conditions into account. FLUKA Monte Carlo simulation code is the most popular code and may be used for general purpose application from accelerator shielding to target design, calorimetry, activation, dosimetry, detector design, accelerator driven systems, cosmic and neutrino physics, radiotherapy, and so on [1]. The FLUKA code is one of the most practical simulation tools for many applications in high-energy physics and engineering fields. FLUKA can simulate the interaction and propagation in more than 60 different particles, such as heavy ions, electrons, neutrons, photons, neutrinos, and muons, and in many types of research fields, such as shielding design, detector response studies, cosmic ray studies, medical physics, and dosimetry calculations. In recent years FLUKA has been extensively developed and improved. The newest version introduces many fundamental changes to the implementation of modern physics algorithms, as well as programming upgrades [2, 3].

The neutron is a neutral particle with a mass approximately equal to proton mass. The neutrons are produced as:

- decay from unstable nucleus,
- one of the atomic fission particles,

- a result of nuclear fusion,
- from the cosmic rays components,
- artificially.

Besides being a hazardous particle, the neutron is also a high penetration particle because it is electrically neutral, and can cause the emission of beta and gamma radiation when it interacts with matter. Therefore, we need heavy shielding to reduce neutron radiation exposure [4–6].

In order to investigate shielding properties of any materials from neutrons, microscopic cross-section (σ), which is related to probability of interaction of neutrons with the target material, should be obtained. The sum of the microscopic cross-sections of the individual nuclei in the target material per unit volume is called the macroscopic cross-section (Σ):

$$\Sigma = N\sigma,$$

where N is the atomic density of the target, $\Sigma = \frac{1}{x} \ln(T) \text{ cm}^{-1}$, where x is sample thickness [7, 8].

Using macroscopic cross-section, one can express the mean free path (λ) as:

$$\lambda = \frac{1}{\Sigma}.$$

which is the mean distance a neutron travels between interactions. The mean free path could be assumed to be the average thickness of a medium in which an interaction is likely to occur and is similar to mean life of a radioactive atom [9, 10].

In this work shielding of neutrons from ²⁵²Cf source has been investigated for various materials using FLUKA code.

2. Material and method

The simulations were performed with the version 2011.2c of the FLUKA Monte Carlo code [1]. For FLUKA there are many options for input files as

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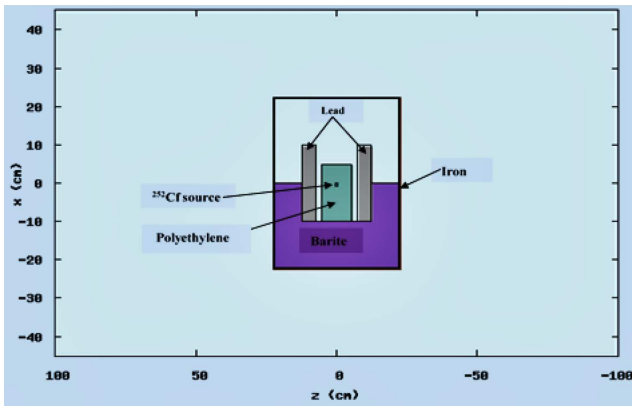


Fig. 1. FLUKA simulation geometry used in the study [5].

beam properties, irradiation geometry, material definition, physical settings, score options, and primary radiation weight [2]. Each option is represented by an input card and the sequential order of these cards is important. Simulations were done for 10^6 primary particles and the code was run for 5 cycles. The results were read by output files of USRBIN and USRBDX. The ^{252}Cf fission neutron source was used as neutron source (2.14 MeV). The geometry used in simulation is displayed in Fig. 1.

3. Results and discussion

Neutron shielding properties of barite, water, and boron were calculated using Monte Carlo code of FLUKA. In Fig. 2, the dose rate from ^{252}Cf source is displayed for shielding materials of barite (BaSO_4), water, and boron. It can be seen from the figure that the ^{252}Cf source dose rate is increasingly higher for barite, water, and boron, respectively. This means that the shielding properties are increasingly higher for boron, water, and barite respectively. It is also clearly seen in this figure that the radiation dose due to the neutrons from ^{252}Cf source which passed through material is under dose limit defined by IAEA [11] for all materials.

The total neutron cross-section Σ_t (cm^{-1}) which is defined as the probability of interaction of neutrons with the atoms were calculated by FLUKA code and the results are displayed in Fig. 3. It can be clearly seen that the total neutron cross-section is increasingly higher for boron, water, and barite, respectively. This is in good agreement with the dose rate results (Fig. 2).

As the mean free path for a material is important in terms of shielding properties, the mean free path for those materials have been calculated by FLUKA code and the results were shown in Fig. 4. As it can be seen from the Fig. 4, the neutron mean free path (cm) is increasingly lesser for boron and water materials than barite, respectively.

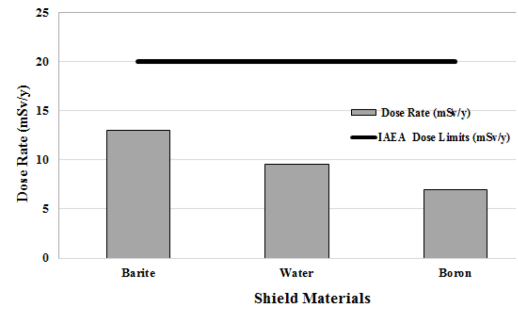


Fig. 2. FLUKA calculation results of dose rate for shielding materials and comparison with IAEA dose limits.

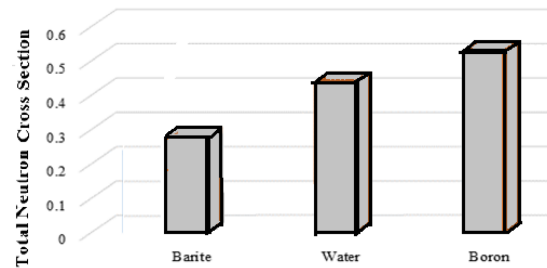


Fig. 3. The total neutron cross-section Σ_t for shielding materials.

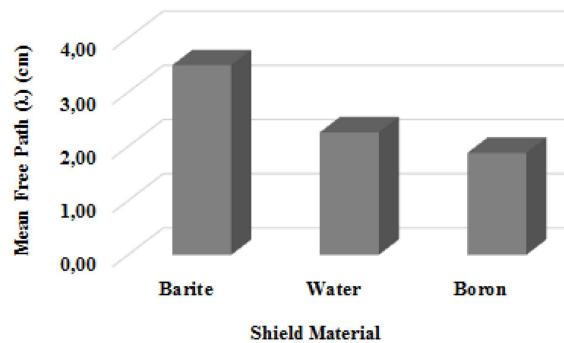


Fig. 4. Neutron mean free path (cm) calculated by FLUKA code for three types of shielding materials.

4. Conclusion

The neutron shielding from ^{252}Cf source has been investigated using FLUKA simulation code for three different materials of barite, water, and boron. The results are obtained for dose rate, mean free path, and total neutron cross-section. From all results it was clearly concluded that the boron is the best neutron shielding material in comparison with the others. It was also seen that using dose materials is good enough for shielding of ^{252}Cf source.

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