U.P.B. Sci. Bull., Series A, Vol. 81, Iss. 2, 2019 ISSN 1223-7027

TESTING OF FLUKA MONTE CARLO TRANSPORT CODE FOR DIFFERENT SHIELDING CONFIGURATIONS

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Even with the most state-of-the-art algorithms and even when using tremendous computing power, the results obtained through any numerical simulation can only be considered reliable if they can be validated by experimental measurements. The aim of this study is to compare the results of a simulation done using the FLUKA Monte Carlo simulation package with the actual results of experimental measurements. We used an ^{241}Am(α,n)Be neutron source, shielded with different types of material, and compared the measured and simulated ambient dose behind the shielding. After analyzing the results, we can say that the measured and simulated ambient dose are in good agreement.

Keywords: FLUKA, dose equivalent, shielding materials, neutron source.

1. Introduction

Radiological safety aspects of particle accelerators confronts distinctive challenges to radiation protection and dosimetry. The operation of high energy particle accelerators is typically accompanied by neutron fields which are broadly distributed in energy. The characteristics of these neutron fields vary on a mixture of operating parameters like the energy of the primary beam, the type of the primary beam, the target used and others. The assessment of radiation that may appear in such a facility, both primary and residual, is a challenging task. The growth of sophisticated computational techniques has nowadays made it possible to allow faithful estimations of the radiation dose levels.

The purpose of this work is to obtain accurate experimental values for the neutron dose given by a simple field (provided by an 241Am) source and compare the results with the simulated values obtained with the FLUKA Monte Carlo package.

As we are now merely trying to answer a question about the reliability of a numerical simulation, we will focus on a simple irradiation case with an ^{241}Am(α,n)Be neutron source shielded with materials used in the shielding of accelerators.

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The experimental measurements and numerical simulation were performed at GSI (Helmholtzzentrum für Schwerionenforschung, Darmstadt) in the Safety and Radiation Protection Department.

This paper is divided as follows: in the first section we present the materials and methods employed in the measurements, in the second section we describe the FLUKA Monte Carlo inputs implemented. The last section presents the results obtained with the FLUKA Monte Carlo simulation code and the comparison with the measured results.

2. Materials and method

For the purpose of this experiment we used thermoluminescence dosimetry cards (TLDs) based on lithium fluoride which are often used for neutron detection.

Typically, TLDs consist of an aluminum foil with four crystals: two with ^{6}Li (TLD^{C1}_{600}, TLD^{C2}_{600}) used to detect neutrons and gammas (total thermal neutron cross sections 950 barn) and two with ^{7}Li (TLD^{C1}_{700}, TLD^{C2}_{700}) used to detect only gammas (total thermal neutron cross section 0.0454 barn) [1]. We used a polyethylene (PE) sphere of 15.25 cm radius to perform neutron fluence to ambient dose conversions [2].

We performed five types of measurements in which we used an ^{241}Am(α,n)Be neutron source with nominal intensity 2.2×10^{6} neutrons/s. The neutron spectrum of ^{241}Am(α,n)Be source is given in Figure 1, as determined by Kluge and Weise [3].

We used different configurations (M1 - M5) of shielding materials and measured the neutron ambient dose equivalent behind the shielding for each one.

M1: The PE sphere was positioned at a 2 meters distance from the ^{241}Am(α,n)Be neutron source without any shielding in between. The TLD cards were inserted in the center of the sphere and irradiated for 20 hours.

M2: The PE sphere was positioned at a 180 cm distance from the ^{241}Am(α,n)Be neutron source and in between was introduced a 10 cm layer of Paraffin. The TLD cards were inserted in the center of the sphere and irradiated for 22 hours.

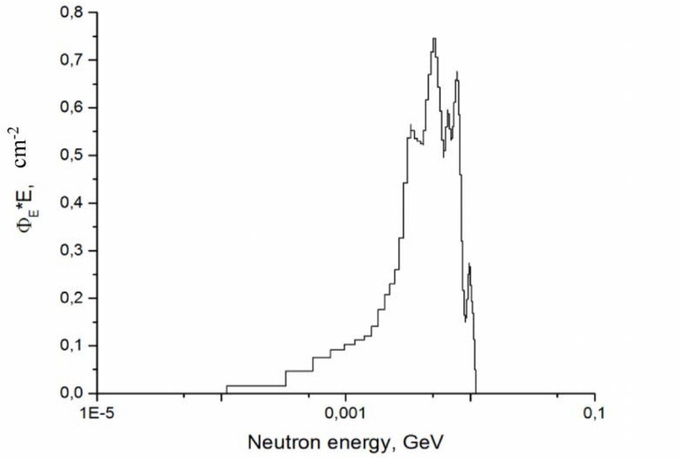

Fig. 1. The neutron spectrum from a ^{241}Am(α,n)Be source [3]

M3: The PE sphere was positioned at a 174.5 cm distance from the ^{241}Am(α,n)Be neutron source. 5 cm of Lead and again 10 cm of Paraffin were introduced between the source and the PE sphere. The TLD cards were inserted in the center of the sphere and irradiated for 22 hours.

M4: The PE sphere was positioned at a 182 cm distance from the ^{241}Am(α,n)Be neutron source and we removed the Paraffin layer thus remaining only with the 5 cm Lead layer. The TLD cards were inserted in the center of the sphere and irradiated for 22 hours.

M5: The PE sphere was positioned at a 147 cm distance from the ^{241}Am(α,n)Be neutron source. 17 cm of Polyethylene and 10 cm of Paraffin were introduced between the source and the PE sphere. The TLD cards were inserted in the center of the sphere and irradiated for 20 hours.

After each irradiation, the TLD cards are read out with a Harshaw 6600 TLD reader.

We used for the computing of the absorbed neutron dose the following relation:

$$D_{n_{measured}} = \frac{TLD_{600}^{C1} + TLD_{600}^{C2} - TLD_{700}^{C1} - TLD_{700}^{C2}}{2} \ [mGy] \qquad (1)$$

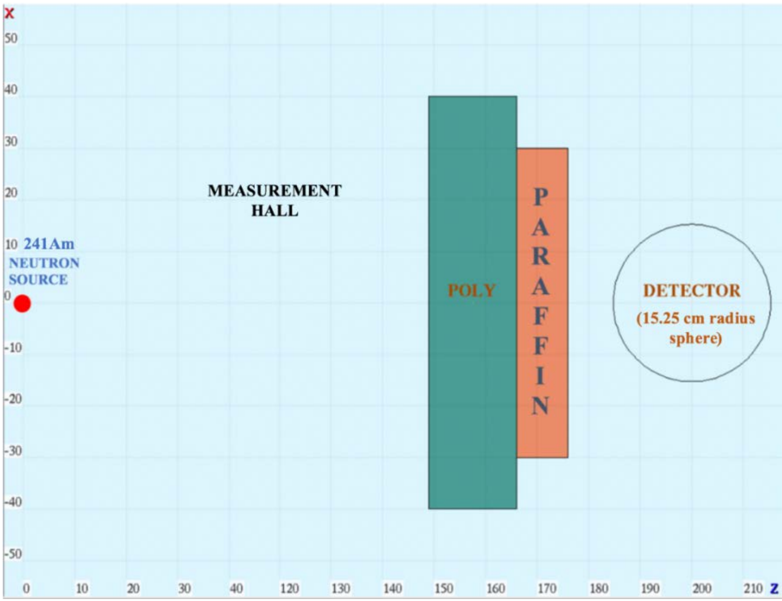

Fig. 2. Layout for the 5th measurement (see text for details)

In order to obtain the neutron ambient dose equivalent we had to multiply the absorbed neutron dose with a conversion factor (*CF*) [4].

$$H_{n_{measured}} = D_{n_{measured}} \times CF\ [mSv] \tag{2}$$

3. Monte Carlo simulations with FLUKA

FLUKA represents a Monte Carlo code, used for calculation of particle transport and interaction with matter, with a broad spectrum of applications such as shielding, activation, dosimetry, radiotherapy, etc. [5,6]. We used the FLuka Advanced InteRface (FLAIR) that represents a handy graphical user interface to run FLUKA [7]. For each of the above described measurements we created a simulation input in accordance with the real experimental configuration.

The code's input consists of different cards, each card belonging to particular categories. For simpler cases, the primary particle properties can be easily defined with only two default input cards: BEAM and BEAMPOS used for specifying the type of particle, its energy, starting position and direction. In our case, that is not enough because our particle source has a more complex distribution, thus we used the SOURCE card and user routine, that overrides the parameters that were defined with the BEAM and BEAMPOS cards, containing the energy spectrum of the ^{241}Am(α,n)Be neutron source. For the SCORING of the neutron ambient dose we used the USRBIN card [5,6]. The output of the USRBIN card is expressed in units of pSv/primary assuming 1 cm^3 detection volume. Given the fact that the output is not normalized to the region volume, we performed some normalizations in order to finally obtain the neutron ambient dose equivalent with respect to the volume of the detector (the 15.25 cm radius PE sphere) and to the intensity of the ^{241}Am(α,n)Be neutron source.

$$H_{n_{simulated}} = \frac{H_{n_{FLUKA}}}{Volume\ of\ detector} \times Intensity\ of\ source \tag{3}$$

4. Results and discussion

Table 1

Measured neutron ambient dose equivalent compared with simulated neutron ambient dose equivalent

Measurement	$H_{n\text{-measured}}$ [μSv/h]	$H_{n\text{-simulated}}$ [μSv/h]
M1	11.51(6)	11.39(2)
M2	5.08(3)	5.81(1)
M3	5.66(3)	5.09(1)
M4	9.70(5)	9.13(2)
M5	3.47(2)	3.46(1)

After comparing the simulated neutron ambient dose equivalent with the measured neutron ambient dose equivalent, we can observe that they are in good agreement. The differences can arrive from a series of factors such as the different composition and density of the walls' concrete as described in the FLUKA simulation. The experimental errors come from: the errors provided by the TLD manufacturer [1] and the characteristic errors in measuring time and distances. Also, it can be observed that the 5th type of shielding, with Polyethylene and Paraffin is the most efficient as opposed to the 4th type of shielding, with Lead.

5. Conclusions

We investigated a simple irradiation case using an ^{241}Am(α,n)Be neutron source in different environmental surroundings to approve the reliability of the neutron transport in FLUKA and its ability to calculate the ambient neutron dose behind different types of shielding. After analyzing and comparing the results from the simulations with the actual dose measurements, we can safely say that the results are in good agreement. Furthermore, simulations with more complex geometries and configurations in FLUKA can provide reliable calculations regarding radiological studies.

R E F E R E N C E S

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