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Modeling and Simulation of a new collimator used in the nuclear techniques

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Abstract : The collimator is the most important part in the installation of the Prompt Gamma Activation Analysis technique (PGAA). This technique will be installed in the Moroccan TRIGA MARK II research reactor. The main purpose of this work is using the Monte Carlo simulation via the MCNP5 code to design the new collimator of the prompt gammas installation, to determine the optimal thickness of the bismuth (Bi) filter for gamma radiation. The obtained results of the collimator design and its filter are analyzed and discussed.
Keywords: Collimator; PGAA technique; NAA technique; TRIGA Research Reactor; MCNP code.

1. Introduction

PGAA is a non-destructive modern technique for a qualitative quantitative multi-elementary analysis of the major, minor elements and the trace- elements in a sample. The principle of the PGAA technique is based on the irradiation of the sample by a neutrons beam, the constitutive elements of sample absorb a part of these neutrons and emit prompt gamma-rays, in a very short time-interval [1E-10,1E-13 s], being measured with the gamma-ray spectrometer. The energies of these gamma-rays identify the elements originating from the

(n, γ) reactions, while the most intense prompt-gamma peaks give their concentrations [1,2]. PGAA technique requires mainly an installation which consists of a collimator for shaping and directing a neutron beam coming from the reactor core towards the sample, a target assembly to position the sample reproducibly in the neutron beam, a beam stop to absorb the neutrons that are not absorbed by the sample, a gamma-ray detector and shielding to protect against the neutron and gamma radiation [3]. The PGAA method has been applied in various domains as material science, chemistry, geology, mining, archaeology, environment, food analysis, medicine….. These advantages justify the choice of installing this technique at the TRIGA MARK II research reactor of Morocco.

Several studies on the prompt gammas Installation and its collimator have been performed. A PGAA facility at the Oregon State University TRIGA reactor was designed for the versatile multi-elemental analyses. The leakage neutrons, utilized by this facility, originating from beam port are collimated through a series of lead and Boral collimators and filtered through both bismuth filter and single-crystal sapphire[4]**.** The PGAA facility which consists of a radial beam port, external sample position with shielding, and a multi-mode counting system has been developed at the University of Missouri Research Reactor. For reducing the fast neutrons, a single-crystal silicon neutron filter installed inside the beam port was used [5]**.** A neutron radiography and computed tomography facility is based on a neutron collimator at the ENEA Casaccia TRIGA reactor, the preliminary choice of the materials to be employed in the collimator design and the MCNP calculated of thermal flux in channel were done[6]**.** The MCNP model has been extended to complete biological shielding of the reactor including the thermal column, radiographic collimator and four beam tubes of the TRIGA Mark II research reactor [7]**.** In this work, we utilized MCNP simulations for obtaining the optimal design of the collimator which will be installed in the interior of tangential channel (NB1) of the Moroccan TRIGA reactor (see **Fig.1**). For power of 250 kW, the corresponding thermal neutron flux measured in this channel is about 3E+11 n/cm^2.s [8]**.**

2. The Moroccan TRIGA reactor

The Moroccan Nuclear research reactor is a TRIGA Mark II. It is only the nuclear research reactor in Morocco that achieved initial criticality on May 2, 2007 of 2MWe nominal power, this reactor equipped with a graphite reflector, four beam ports and a thermal column. The beam ports (NB1, NB2, NB3 and NB4) are laterals channels provided around the circumference of the reactor. the beam port NB1 is located tangential to the reactor core edge [9], while the remaining beam ports NB2, NB3 and NB4 are positioned radial to the core centerline. These laterals channels allow access to beams of neutrons and gamma radiations having crossed the concrete shielding and the water of the tank. The internal section of every experimental channel consists of an aluminum tube of diameter 15.2 cm, the external section is a steel tube of diameter 20.3cm [8].

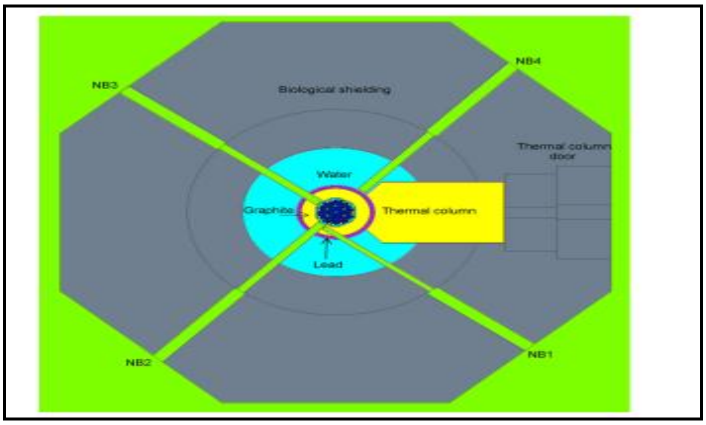

Figure1.The radial view of the model of TRIGA reactor via MCNP Code

3. Simulations using the MCNP code for the new collimator of PGAA installation

3-1. Collimator

The simpler collimator receives in the entry a beam with a uniform isotropic spatial distribution, at the exit gives a fine parallel beam. The collimator consists of a hollow cylinder internment aligned sheets used for absorbing the thermal neutrons and for reducing the diffused neutrons on the internal surface. The expected collimator of the PGAA installation consists of two coaxial cylinders of 1m length as shown in **Fig. 2**. The first cylinder being an aluminum tube internally aligned by 6Li Polymer sheets (6Li-poly) is aimed at conveys the neutrons coming from the reactor towards the sample in the irradiation chamber. The second cylinder is considered as shielding. It was selected to eliminate the neutrons and the gammas. In this work, it is going to undergo several calculations via MCNP code, in order to have the optimal configuration of the collimator. According to the literature, the polyethylene of boron (5% boron) and the lead are the shielding material having been placed in second cylinder, to thermalize and absorb the neutrons and to eliminate the gammas radiation due to boron neutron capture, respectively [13]**.** These circular materials are placed in parallel one after the other alternatively in the channel at a distance of 1m from reflector [12]**.**The crystal sapphire (Al203) and the bismuth (Bi) are considered as filters of the epithermal and fast neutrons and the gammas respectively. These filters are placed in the entry of the collimator of the PGAA installation respectively [10,11]**.**

3-2 Simulation results and discussions

3-2.1 Study of variation of the neutrons and gammas intensities in the shielding material of collimator (polyethylene of boron and lead) for various configurations

In this work, we have performed calculations of simulation using MCNP code for two configurations of collimator appropriate to PGAA technique as shown in Fig.2 and Fig. 4, in order to obtain the optimal geometry. The effect of collimator on a spectrum of neutron energy coming from the reactor and the effect of bismuth (Bi) filter on the gammas intensities were examined. Finally, each configuration and its results will be presented below.

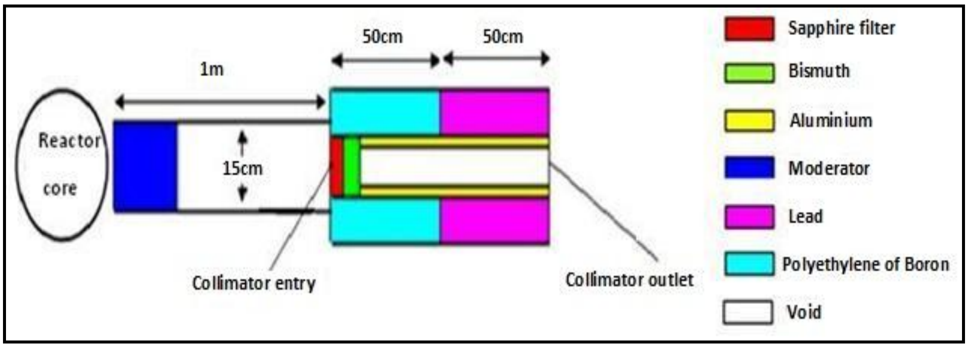

Figure2. Collimator and filters configuration of PGAA installation with combination of blocks of polyethylene of boron - lead [50 cm] using MCNP code.

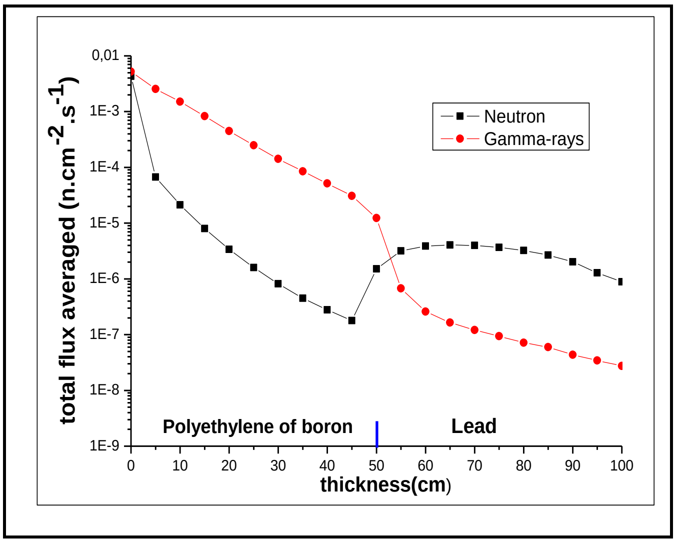

Figure3. The variation of the averaged flux of the neutrons and the gammas in blocks of polyethylene of boron (50cm) and lead blocks (50cm) respectively.

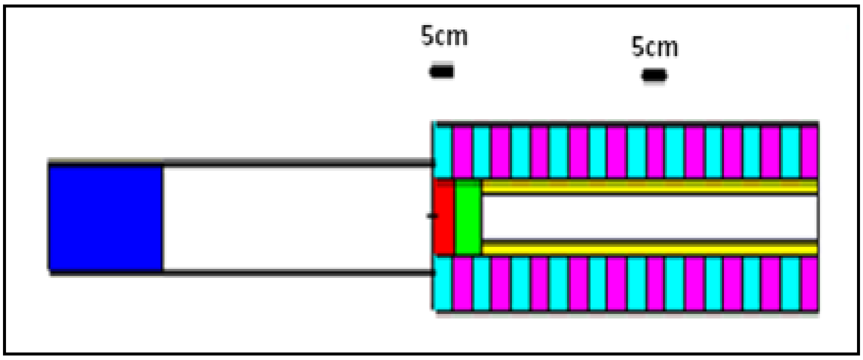

Figure4. Collimator configuration with combination of blocks of the polyethylene of boron - lead [5 cm] using MCNP code

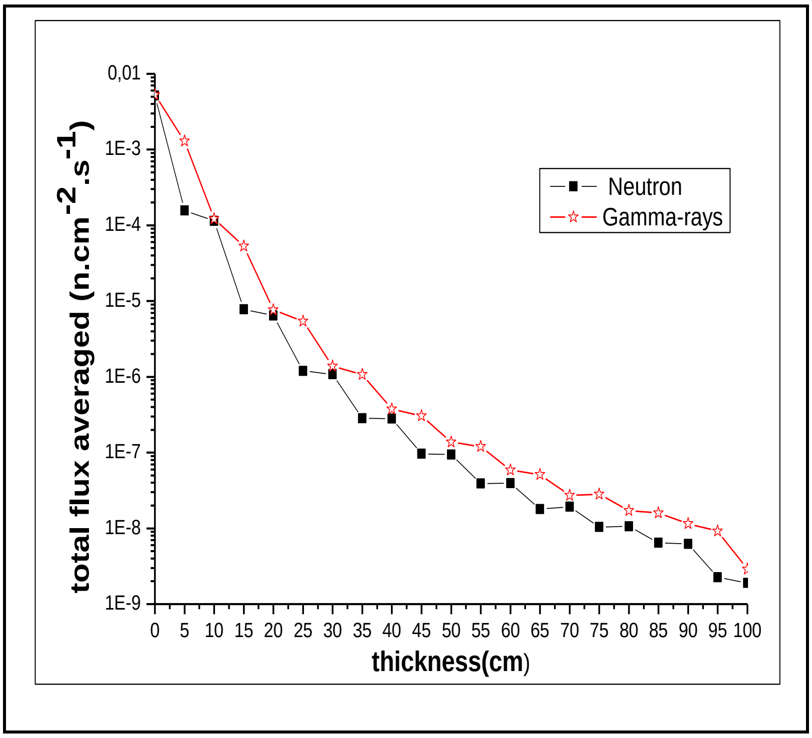

Figure5. Effect of the alternately combination of blocks of the polyethylene of boron and lead of a5cm step on the neutrons and gamma-rays flux

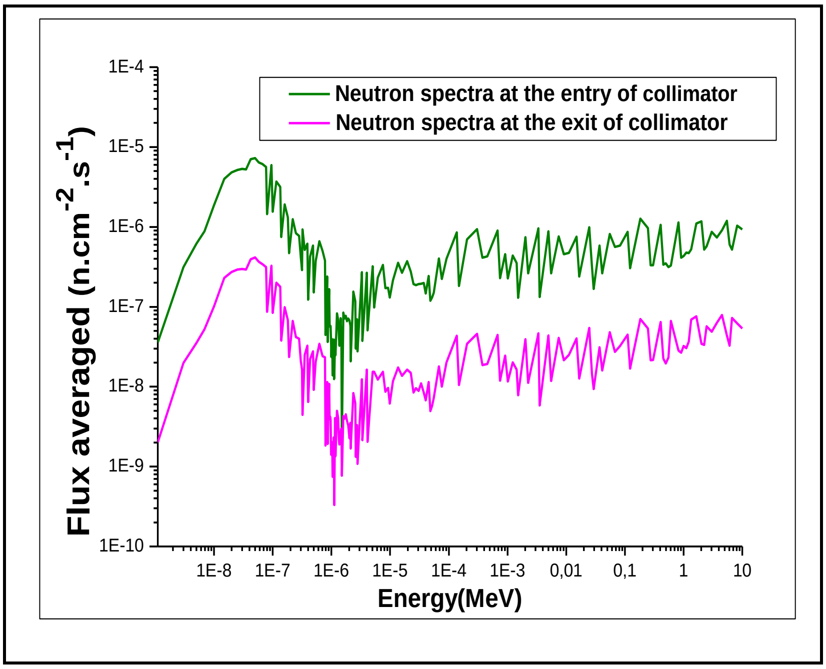

Figure6. The effect of collimator on neutron spectra without filters along a trajectory of a 1 meter from the entry of collimator to its outlet

3-2.2. Fast and epithermal neutrons filter (Sapphire)

As already mentioned, the fast and epithermal neutrons generated from the source are moderated by graphite. Even after moderating the beam, the remaining fast neutron flux should be filtered. In this work, a sapphire cylinder of 5,3cm thick will be installed in the entry of collimator of expected installation PGAA. An experimental study about this filter dimension has been performed to evaluate the proportion of fast, epithermal neutrons filtered[15]. This sapphire reduces the fast and epithermal flux components of a factor about 5 and the thermal component is only reduced of 13% [16]. The gammas have be also reduced from 1, 2 mSv/h to 0, 5 mSv/h. Al2O3 is also considered as a filter of thermal neutron with wavelengths less than 0.1 nm [14]. The following figure shows that the sapphire crystal has an effect of the attenuation on the normalized count of gamma-rays.

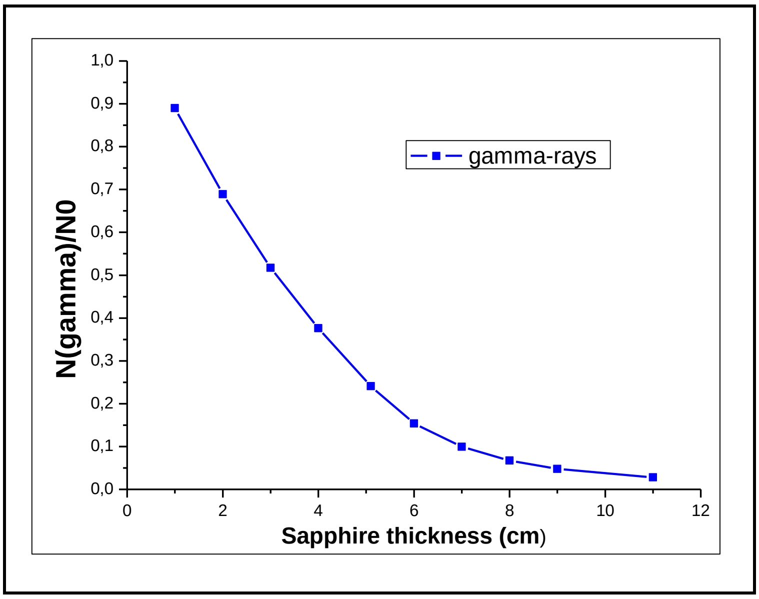

Figure7. The attenuation Curve of the normalized count of gamma radiation, varying with sapphire thickness (from 1 to 11 cm), fitted with the exponential law

3-2.3. Gamma-rays filter (Bismuth)

The gamma-rays present always in the neutron flux, require a filter suitable to reduce them. Thanks to its big effective section of absorption of the gammas, the Bismuth was chosen to limit the gammas resulting from the reactor and which were not stopped by the sapphire. The geometry adopted of bismuth is a cylinder will be placed immediately after the sapphire filter of 5,3cm thick. The calculations of simulation are carried out to define of normalized count [$\mathbf{N_{Bi}}$ **(gamma)/$\mathbf{N_0}$]**, such as No and N_{Bi} (gamma) are the total gammas flux in the entry of bismuth and at its exit respectively. The effect of the variation of bismuth thickness on the gammas flux is shown in **Fig.8**.

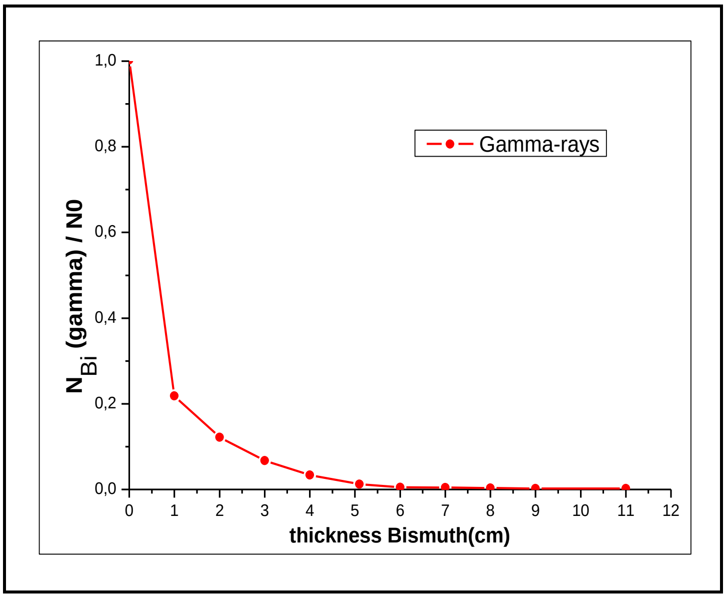

Figure8. Curve of the normalized count total of gamma radiation varying with bismuth thickness (from 0 to 11 cm)

3-2.4. Discussion

According to the results found above, from Fig.3 and Fig.5, we have concluded thatthe alternating configuration (5cm poly-boron and 5cm lead, Fig. 4) is more optimal compared with the configuration of 50 cm. In the alternating configuration of 5cm, the gammas produced by the neutron absorption in a boron block of 5cm, are immediately attenuated by a lead block of 5 cm and so forth, what gives the lower dose rate at the exit of collimator as shown in Fig.5. However, in the second configuration (50 cm Poly of boron and 50 cm lead, Fig.2) the neutrons are well absorbed in the first boron block, while the variation of gammas follows attenuation law. In the second lead block the neutrons are increased for the first 10 cm of lead before stabilizing, and then they will attenuate, whereas the attenuation of gammas becomes very important as illustrated in Fig.3. This increase is mainly due to the effect of neutron leakage coming from the channel. As a result, the alternating configuration of 5cm remains a good choice in this work because its dose rate at the exit of collimator is lower than one of configuration of 50cm. Figure 6 illustrates that the effect of the collimator on neutron spectra without filters along a distance of 1 meter from the entry of the collimator to itsoutlet is the decrease of the neutron amount by factor 10. This decrease of the beam intensity is mainly due to the elimination of neutrons having a direction unparallel to the cylinder axis by ^{6}Li Polymer sheets, in order to have an almost fine and parallel beam at the collimator outlet.

Figure7 shows that the sapphire plays another role of decreasing exponentially the quantity of gammas coming from reactor according to its thickness. The quantity of gamma-rays is almost constant after the sapphire of 5,3cm thick. The results of simulation do not be of a great interest for a filter having a thickness more than 5,3cm. Therefore, the thickness of 5,3cm was the best choice to be used in our collimator.

To reduce the gammas coming from the reactor and which do not have been stopped by sapphire, a bismuth cylinder is directly installed after the sapphire filter of 5,3cm as indicated above. Figure 8shows the influence of bismuth thickness over the normalized count of gamma (N_{Bi} (gammas) /N0). This ratio follows the exponential law and is equal to almost zero after bismuth of 6cm thick. The results of simulation regarding bismuth lead to choose a cylindrical block of 6 cm as optimal values for expected collimator of prompt gammas installation.

4. Conclusion

The performed study focused on the simulation of the important components of PGAA installation, in particular the collimator and the filter of gamma-rays (bismuth). In this work, it has been concluded that the collimator model consisting of blocks of polyethylene of boron and the lead blocks, which are placed alternately with a step of 5 cm is the best configuration. This configuration of the collimator gives excellent results against the other configurations that one has simulated. Another work focuses on the study of effect of bismuth on the intensity of gammas for the determination of an optimal thickness of this filter which will be used in the collimator. Theobtained results are very encouraging for implementing the PGAA technique at the TRIGA Mark II reactor will allow exploiting the advantages of this technique in the various domains.

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