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Mathematical modeling utilizing the MCNP code and determination of response curves of a NaI(Tl) detector

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1. Introduction

This report presents a mathematical modeling for a NaI(Tl) radiation detector using the MCNP code and the determination of its response curves. A detector the measures a type of radiation with high efficiency can be unsuitable for other types, so the choice of the detector depends on the type of radiation it is operating with, among other parameters [1]. To be able to determine the operating voltage, efficiency and energy resolution several measurements were made utilizing the NaI(Tl) detector and various radiation sources. The operating voltage can be obtained by running several experiments with different voltages and observing the voltage range in which the measurement counts are stabilized. The efficiency can be calculated utilizing those measurements and known values such as the source activity, while the energy resolution of the detector can be obtained from the photopeak full width at one-half of the maximum height (FWHM) [2]. The mathematical model developed was based on a cylinder-shaped detector with a 2 cm radius and 5.3 cm length and was utilized to simulate the measurements of a ^{137}Cs source so that the results could be compared to the experimental ones.

2. Methodology

Initially, measurements were performed utilizing a NaI(Tl) detector and a ^{137}Cs source. The detector operating voltage was obtained by varying the voltage from 600 to 800 V, in steps of 20 V. After this procedure, several measurements were performed with different radiation sources (^{241}Am, ^{133}Ba, ^{137}Cs, ^{60}Co), in order to obtain the absolute efficiency and energy resolution curves of the detector [3]. The efficiency can be calculated utilizing counts per second, probability of emission, source activity and decay correction, as shown in Eq.1. Meanwhile, the energy resolution can be calculated using the measure of the full width at the half height of the photopeak for the energy relative to each source, as shown in Eq. 2. Along with the experimental measurements, a mathematical model was also developed in the MCNPX with approximately the same dimensions as the experimental model. In other to evaluate the simulated detector, its response for the ^{137}Cs source was compared with the result obtained in the experimental measurements.

$$\varepsilon(E) = \frac{S}{t.P.A.k_c} \tag{1}$$

$$R(\%) = 100\frac{FWHM(keV)}{E_{\gamma}(keV)} \tag{2}$$

After those measures, variations were made in the original dimensions of the mathematical model of the detector in order to analyze how those affected the results. The length of the photomultiplier was increased from 5 to 10 cm and the radius was increased from 2 to 5 cm. The material that composed the photomultiplier region was also changed from aluminum to copper, silver and iron in order to analyze how that specific material influenced the results.

3. Results and Discussion

The results of measurements at different voltages with the NaI(Tl) detector and the ^{137}Cs source presented the number of counts increases with the voltage until a small stabilization is reached around 720 and 750 V. The absolute efficiency curve of the detector was calculated, as shown in Fig. 1 considering the ideal operating voltage of the detector. The efficiency peak, as shows, was found to be around 100 keV.

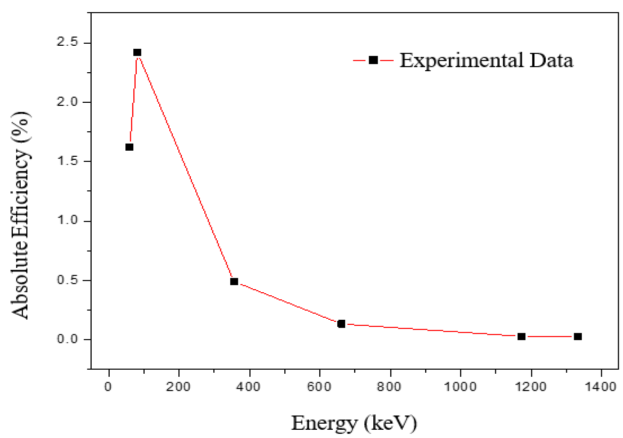

Figure 1: Efficiency curve for the NaI(Tl) detector.

The energy resolution was calculated from the same energy spectrum and is shown in Fig. 2. The calculated energy resolution for each energy. By the results obtained it is possible to observe that the resolution decreases as the energy increases.

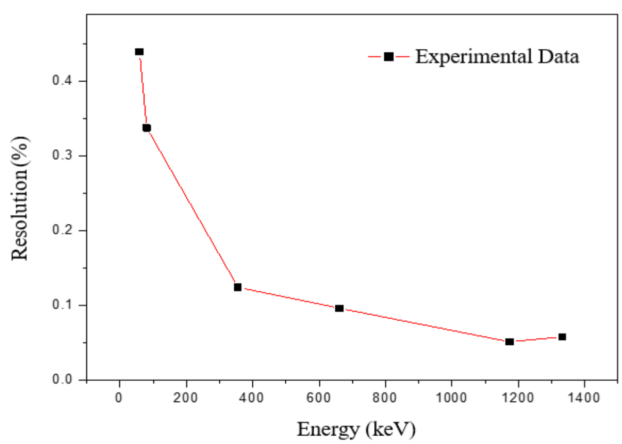

Figure 2: Energy resolution curve for the NaI(Tl) detector.

The results obtained from the simulated measurement with the ^{137}Cs source were compared with the experimental ones in Fig. 3. The photopeak area showed good compatibility while the scattering region shows a considerable discrepancy that may be explained by background radiation.

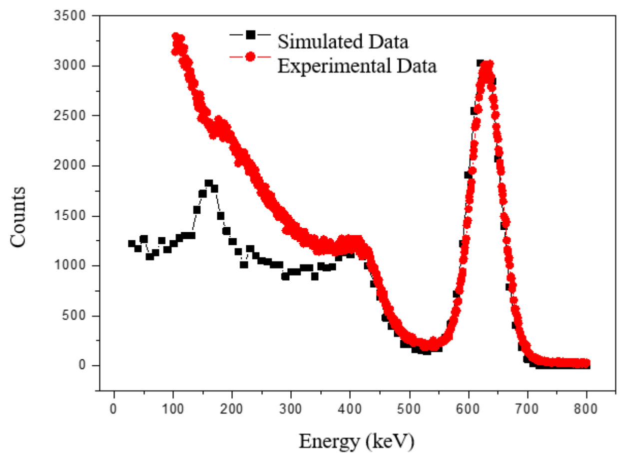

Figure 3: Experimental and simulated measurement comparison.

The results from simulation performed with the detector's dimensions being varied are shown in Fig. 4 and 5.

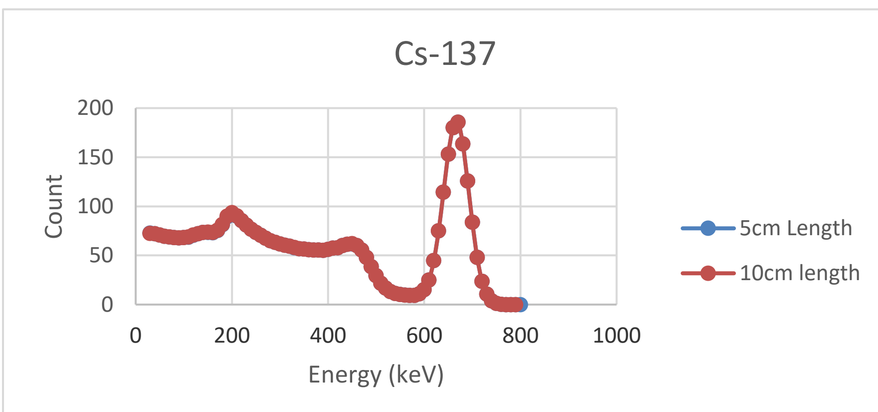

Figure 4: Comparison between results obtained for 5 and 10 cm lengths.

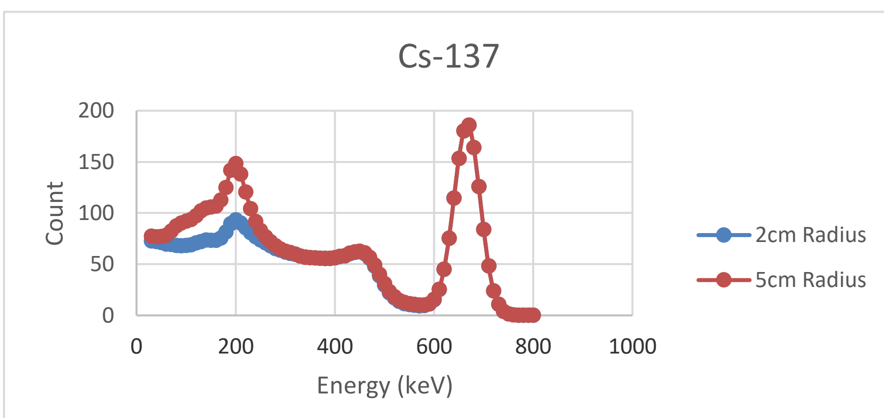

Figure 5: Comparison between results obtained for 2 and 5 cm radius.

As can be observed the only variation that influenced the results was the radius variation from 2 to 5cm. The change in result can be explained by the greater number of reflected beams.

4. Conclusions

In this work, the calibration and determination of the response curves of a NaI(Tl) detector were obtained. The simulated detector has been experimentally validated. In addition to the experiments carried out with the detector, knowledge about the MCNPX code was obtained so that it was possible to develop a mathematical model with its experimental validation.

The different simulations made with the different detector dimensions showed that the radius variation was the only one that affected the results. The greater amount of material present caused a greater number of scattered beams increasing the measured count in the Compton scattering region.

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