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Monte Carlo Simulation for Compton Reduction Factors

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1. Introduction

It has been widely investigated through many γ-ray spectroscopy researches on the suppression of Compton continuum caused by Compton scattering events [1-4]. In this study, Monte Carlo simulations were performed in order to figure out the most appropriate arrangement of Compton suppression system that can maximize Compton suppression effect in a practical laboratory environment using HPGe detector and NaI(Tl) detector.

2. Simulation Features

2.1 General Features

In this simulation, EGS5 Code [5] has been used to evaluate the performance of Compton suppression system(CSS). The system consists of a closed-ended coaxial type HPGe detector located in the center of the system and several NaI(Tl) detectors functioning as an anti-Compton shield around the HPGe detector. Setting the origin of a Cartesian coordinate on the center of the cover, HPGe detector was arranged along to the z-axis. The anti-coincidence method for Compton suppression was realized by ignoring the energy of the γ-ray deposited in the HPGe detector whenever there is any simultaneous energy deposition in the NaI(Tl) for each event. The degree of suppression was represented in terms of average reduction factor(ARF) defined as following; [4]

$$ARF = \frac{\sum\{(Count)_{\text{unsuppressed}} / (Count)_{\text{suppressed}}\}}{Total\ number\ of\ channels}$$

with excluding the full-energy peak channels.

2.2 Propensity study

In optimization study of CSS, it is crucial to obtain information regarding propensity of scattered γ-rays. Thus, a pipe-shaped 75 cm-long NaI(Tl) crystal geometry was devised for z component distribution calculation with 4 cm inner radius and 6 cm thickness. Surrounding HPGe detector with NaI(Tl) crystal by locating it along to the z-axis from -25 cm to 50 cm, z-component of scattered γ-ray was recorded at the moment of its detection on NaI(Tl) crystal.

Additional simulations were performed for a pipe-shaped 10 cm-long NaI(Tl) detector with 10 cm inner radius and 10 cm thickness. The energy of γ-rays taken into consideration in this simulation was 661.67 keV, 1173.238 keV and 1408.022 keV. Arranging the NaI(Tl) detector to be aligned with (the front side of) HPGe detector, average reduction factor was calculated about various locations, lengths, thicknesses and inner radii of the NaI(Tl) detector.

2.3 Optimized arrangement of NaI(Tl) detector

In order to figure out an appropriate arrangement of NaI(Tl) detector for the most effective CSS in a practical laboratory environment, simulation was performed for different CSS arrangements composed of 3×3 in. NaI(Tl) detectors regarding 351.9 keV, 661.67 keV, 1173.238 keV and 1408.022 keV γ-rays. Simulation for the first setup was done surrounding central HPGe detector with 6 NaI(Tl) detectors located parallel. ARFs were obtained for each case by varying the locations of NaI(Tl) detectors along to z-axis. Next simulation was performed in the same manner for the arrangement positioning 6 NaI(Tl) detectors facing toward the HPGe detector.

3. Simulation results

The simulation result for z-component distribution is shown in figure 1. Scattered γ-rays appeared to be detected mainly at the region from 0 cm to 20 cm, and peaks of the biggest count appeared between 5 cm and 10 cm according to the energy of incident primary γ-ray.

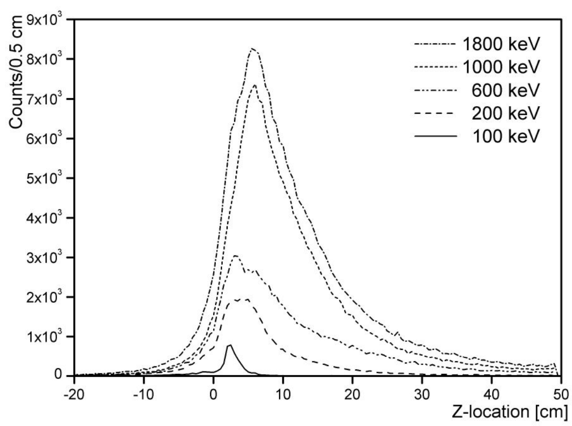

Figure 1. Z-component distribution of scattered γ-rays.

The spectrum of 1173.238 keV γ-ray detected in the HPGe detector surrounded by 10 cm-long NaI(Tl) detectors is shown in figure 2. Suppressed energy region of the spectrum shows a distinct difference according to the location of the NaI(Tl) detector. ARFs for each energy γ-ray are represented in figure 3. in terms of the

NaI(Tl) detector's location. This also corresponds with the result of z-component distribution of scattered γ-rays.

The average reduction factor appeared to be increasing over elongation of NaI(Tl) detector and increment of NaI(Tl) detector thickness. For the thickness over ~10 cm, the average reduction factor did not show any significant changes. Meanwhile, the average reduction factor has been shown to be decreasing in a shape similar to $1/r^2$ according to NaI(Tl) detector inner radius.

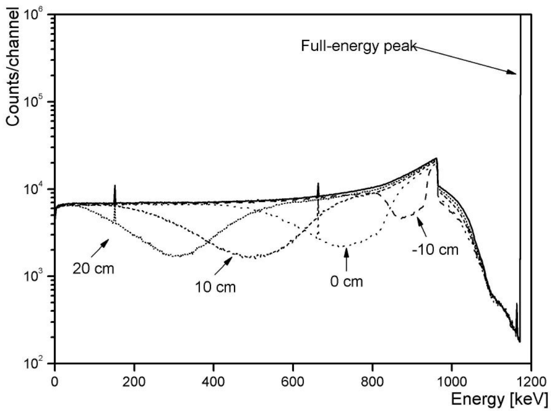

Figure 2. The spectra of 1173.238 keV γ-ray for different locations of NaI(Tl) detector.

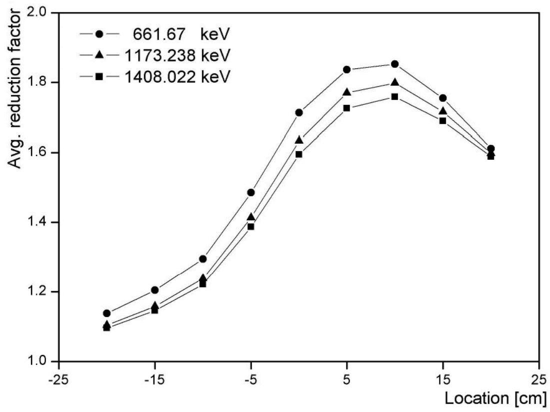

Figure 3. The average reduction factors according to the locations of the NaI(Tl) detector.

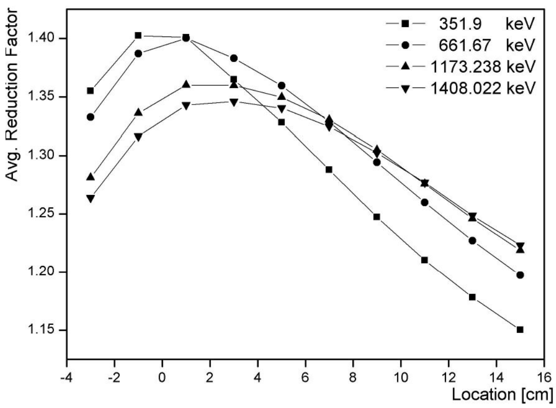

Figure 4. The average reduction factors for different locations of NaI(Tl) detector in the case of the first setup.

In the simulation with 3×3 in. NaI(Tl) detectors, the average reduction factors for the first setup are presented in figure 4. The maximum value of average reduction factor appeared to be 1.35~1.40 when 6 NaI(Tl) detectors are arranged parallel to HPGe detector, whereas 1.16~1.18 in the second setup.

4. Conclusion

In the simulation results, the Compton suppression system was turned out to be more effective as nearer are the NaI(Tl) detectors located to the HPGe detector and 3×3 in. was concluded to be reasonably thick enough to achieve a considerable suppression effect. The biggest average reduction factor has been obtained when NaI(Tl) detectors are arranged parallel to the HPGe detector at the 5 cm z-component location.

In the arrangements with 6 NaI(Tl) detectors, Compton continuum is suppressed for only limited region in the spectrum due to the limited length of NaI(Tl) crystal. For more distinct analysis on γ-ray spectrum, it is recommendable to make suppression happen on overall energy regions of spectrum. Thus, such arrangements are suggested as locating two or three suppression detectors in a row around the HPGe detector even though the ARF may decrease slightly due to smaller angle covered by suppression detectors.

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