# STUDY ON THE OPTIMAL OF CYLINDER SAMPLE GEOMETRIES USING MONTE CARLO SIMULATION FOR LOW BACKGROUND GAMMA SPECTRUM ANALYSIS METHOD

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**Abstract:** The efficiency of a low background gamma HPGe spectrometer is a significant factor in the determination of the specific radioactivity of environmental samples. Since the diversity of geometry and density of environmental samples, the gamma standard sources insufficient for the efficiency calibration. Hence, the Monte Carlo simulation method is a suitable choice for this purpose. In this study, GEANT4 and MCNP software are used to simulate and optimization cylindrical container geometries of environmental samples for measurement on low background gamma spectrometry system.

***Keywords***: *Gamma spectrometry, efficiency calibration, environmental samples, Geant4, Monte Carlo simulation.*

## I. INTRODUCTION

The measurement of environmental radioactivity is one of the research areas that are very interested in research and application of nuclear technology today. With the outstanding advantages of analytical methods using gamma spectrometry compared to other traditional methods simple sample processing, simultaneous analysis of multiple elements, as well as the development of technology for manufacturing transducers good quality semi-conductors, have made the gamma analysis method widely available in the world. In measurement and analysis of environmental samples, the recording efficiency of gamma spectrometer is a significant parameter and needs to be considered to calculate the radioactivity in the sample. The efficiency of the detector depends on many factors such as the volume of the sensitive area of the detector, the energy of the gamma rays to be measured, the distance from the sample to the detector, the sample geometry, the sample density, etc. In fact, environmental samples are quite diverse in the type of samples. Therefore, the sample geometry will also vary with each type of sample to suit the measurement, resulting in a significant change in the detector efficiency for each type of geometry. Could not to get a standard model for each type of geometry. On the other hand, even if the same geometry (Marinelli beaker or cylindrical container, etc.) but the sample density, radius and thickness are different, the detector's efficiency will also be different. Therefore, it is necessary to standardize for cylindrical container geometries environmental samples to achieve optimal efficiency by the Monte Carlo simulation method. There have been many works in the world applying simulation methods to calculate Detector. Guembou Shouop Joel and Cebastien [1] used the Monte Carlo method and the Geant4 toolkit to determine Detector's performance of BE6530 for environmental samples. O. Sima and C. Dovlete [2] use simulation methods to evaluate energy depletion as well as peak efficiency depending on the composition and density of environmental samples. In this paper, the authors based on the principle of Monte Carlo simulation in combination with Geant4 software [3, 4] to determine the detector's efficiency for disc geometry sample by changing the radius, thickness of geometry and density of the samples. [5].

## II. CONTENT

### A. Objects and methods

- Gamma Spectrometry system and standard sources. In this research, we used a gamma spectrometer system and a set of standard source available at the low radioactivity laboratory of the Environment Center, Da Lat Nuclear Research Institute. The detector is simulated in this study is GMX 30P4 with a nominal efficiency of 30% and an energy resolution of 1.9 keV at 1332 keV peak of Co-60. The main part of the detector GC3019 is a super pure Germanium crystal with an outer diameter of 55.8 mm and a height of 75.1mm, the window is Beryllium with a thickness of 0.5mm. Ge crystals are encased by a 2.7mm thick sealed aluminum box to ensure the absorption of low-energy photons. The distance between the upper surface of the Ge crystal and the lower surface of the Beryllium window is 3 mm. The detector is placed in a lead chamber about 10cm thick. The detector efficiency is calculated by the following formula:

$$\varepsilon_e = \frac{N_{pe}}{t_m \gamma A k e^{-\frac{t_w ln2}{T_{1/2}}}} \quad (1)$$

Where: $\varepsilon_e$ is the efficiency of the detector, $N_{pe}$ is net counts in photopeak after appropriate background subtraction, $t_m$ is the measurement time, $\gamma$ is the gamma ray intensity, A is the source activity at the time certification, k is the conversion factor from the other unit of activity measurement to unit Bq, $t_w$ is the time of decay from certification to the time of measurement and $T_{1/2}$ is the half-life. Relative error efficiency of detector $U_e$ is calculated as follows:

$$U_e = \sqrt{U_p^2 + U_\gamma^2 + U_a^2} \quad (2)$$

Where: $U_p$, $U_\gamma$, $U_a$ is the relative error of the contribution counts in the photopeak of the gamma spectrum ($N_{pe}$), the emission intensity of gamma rays ($\gamma$) and the measured source activity (A) similar application.

In analyzing of environmental radioisotopes, Gamma energy levels are interested from 46 keV of 210 - Pb to 2614 keV of 208 - Tl. Due to the sample geometry, the gamma absorption effect of the sample is significant for low energies, especially at the 46 keV, 63 keV, and 186 keV. Therefore, it is necessary to select an appropriate sample geometry to ensure that, with such thickness and diameter, the effect self-absorption of gamma for low energy levels are not too large (still meeting the rate-rate condition in proportion to the sample mass) while the analytical sensitivity still responds to the required sample. In order to select the optimal sample thickness over the gamma self-absorption effect in the sample, a cylindrical geometry sample is calculated and surveyed. In this case, detector efficiencies are in proportion to these integral with the parameter mentioned in Fig. 1

$$I(\mu) = \int_0^R \int_0^t \frac{e^{-\mu z}}{r^2 + (x+d)^2} r dx dr \quad (3)$$

$$z = \frac{x\sqrt{r^2 + (x+d)^2}}{(x+d)} \quad (4)$$

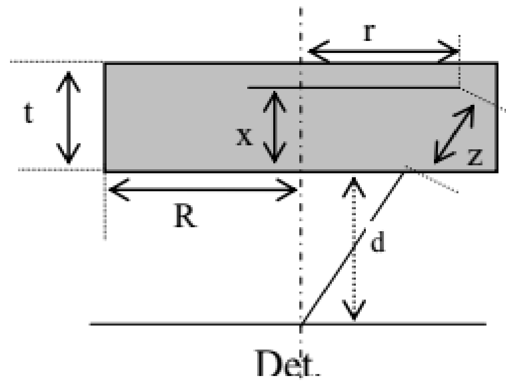


**Fig.1.**

The formula (3) is used to calculate the thickness of the sample geometries for gamma energies from 46 keV to 1462 keV.

- GEANT4 toolkit for Monte Carlo simulation

GEANT4 is a program developed at CERN in the late 1990s. Based on the C ++ object-oriented programming language, GEANT4 is rewritten from GEANT3 to help users simulate the movement and interaction of particles in a material environment. Through simulated geometry, GEANT4 calculates the average free distance of physical processes, selecting a process based on the relative intensity of each interaction channel and generating random numbers, then will determine the simulated physical processes. The transport of gamma radiation is monitored in different areas of geometry. If the energy of photons is lower than its threshold value or the photon leaves the detector's active volume, monitoring tops, and a new photon is generated from the source. Recording the number of photons interact with the detector and completely loss its energy or leave some of the energy in the detector's active volume is done through an algorithm used the C ++ program language. Efficiency in the GEANT4 simulation program is calculated by the following formula:

$$\varepsilon_{abs} = \varepsilon_{int}\left(\frac{\Omega}{4\pi}\right) \quad (5)$$

Where

$$\varepsilon_{int} = \frac{N}{N_0} \quad (6)$$

Where: $\varepsilon_{abs}$ is the absolute efficiency,

$\varepsilon_{int}$ is the intrinsic efficiency,

$\Omega$ is the solid angle, $\Omega = 2\pi(1-\cos\theta)$

$\theta$ is distribution angle (degree),

*N is the number of pulses recorded in photopeak*,

$N_0$ is the number of radiation quanta emitted by a source.

The uncertainty $\delta\varepsilon/\varepsilon$ (%) is calculated by the following formula:

$$\frac{\delta\varepsilon}{\varepsilon} = \frac{\sqrt{N}}{N} \quad (7)$$

**B. Results**

In order to validate the accuracy of the input file, the comparison between the simulated and experimental efficiencies has been performed by using standard point and disk shape sources. The obtained values were given in Table I and Table II.

**Table I***:* The detector efficiency for the point source by experimental and simulation methods

*(The distance from the source to the detector is 10cm)*

| Isotope | Energy (keV) | Experimental efficiency | Simulated efficiency by G4 | Simulated efficiency by MCNP | Deviation Exp/G4 (%) | Deviation Exp/MCNP (%) | Deviation G4/MCNP (%) |
|---|---|---|---|---|---|---|---|
| Ba-133 | 81.00 | 0.01108 | 0.01177 | 0.01079 | 6.2 | 2.6 | 9.1 |
| Cd-109 | 88.00 | 0.01236 | 0.01217 | 0.01148 | 1.5 | 7.1 | 6.0 |
| Co-57 | 122.06 | 0.01346 | 0.01231 | 0.01234 | 8.5 | 8.3 | 0.2 |
| Co-57 | 136.47 | 0.01284 | 0.01199 | 0.01204 | 6.6 | 6.2 | 0.4 |
| Ba-133 | 276.40 | 0.00651 | 0.00714 | 0.00705 | 9.7 | 8.4 | 1.2 |
| Ba-133 | 302.85 | 0.00599 | 0.00649 | 0.00642 | 8.4 | 7.1 | 1.2 |
| Ba-133 | 356.01 | 0.00526 | 0.00553 | 0.00544 | 5.2 | 3.4 | 1.7 |
| Ba-133 | 383.85 | 0.00485 | 0.00509 | 0.00505 | 4.9 | 4.0 | 0.8 |
| Cs-137 | 661.66 | 0.00290 | 0.00303 | 0.00295 | 4.5 | 1.7 | 2.7 |
| Co-60 | 1173.20 | 0.00187 | 0.00182 | 0.00179 | 2.5 | 4.6 | 2.2 |
| Co-60 | 1332.50 | 0.00169 | 0.00161 | 0.00161 | 4.3 | 4.7 | 0.4 |

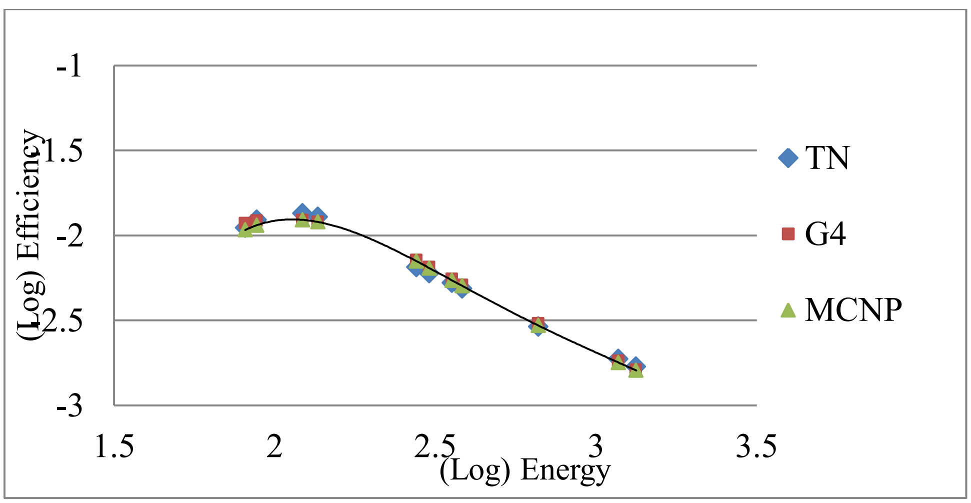


**Fig.1** Simulated and experimental efficiencies at the 10cm point source-detector *distance*

**Table II.** The detector efficiency for disk source by experiment and simulation methods *(source close to the detector, radius of 3.65cm, the thickness of 1.2cm and sample density of 1.95g / cm$^3$)*

| Isotope | Energy (keV) | Experimental efficiency | Simulated efficiency by G4 | Simulated efficiency by MCNP | Deviation TN/G4 (%) | Deviation TN/MCNP (%) | Deviation G4/MCNP (%) |
|---|---|---|---|---|---|---|---|
| $^{210}$Pb | 46 | 0.08745 | 0.08004 | 0.07792 | 9.3 | 12.2 | 2.7 |
| $^{238}$U | 63 | 0.08810 | 0.08140 | 0.08022 | 8.2 | 9.8 | 1.5 |
| $^{226}$Ra | 186 | 0.09346 | 0.09126 | 0.09449 | 2.4 | 1.1 | 3.4 |
| $^{212}$Pb | 238 | 0.07217 | 0.07876 | 0.07578 | 8.4 | 4.8 | 3.9 |
| $^{214}$Pb | 295 | 0.05980 | 0.06293 | 0.06073 | 5.0 | 1.5 | 3.6 |
| $^{214}$Pb | 352 | 0.05053 | 0.05214 | 0.05031 | 3.1 | 0.4 | 3.6 |
| $^{214}$Bi | 609 | 0.02857 | 0.03001 | 0.02885 | 4.8 | 1.0 | 4.0 |
| $^{137}$Cs | 662 | 0.02707 | 0.02807 | 0.02669 | 3.6 | 1.4 | 5.2 |
| $^{228}$Ac | 911 | 0.02129 | 0.02097 | 0.02002 | 1.5 | 6.4 | 4.8 |
| $^{40}$K | 1461 | 0.01223 | 0.01345 | 0.01281 | 9.0 | 4.5 | 5.0 |

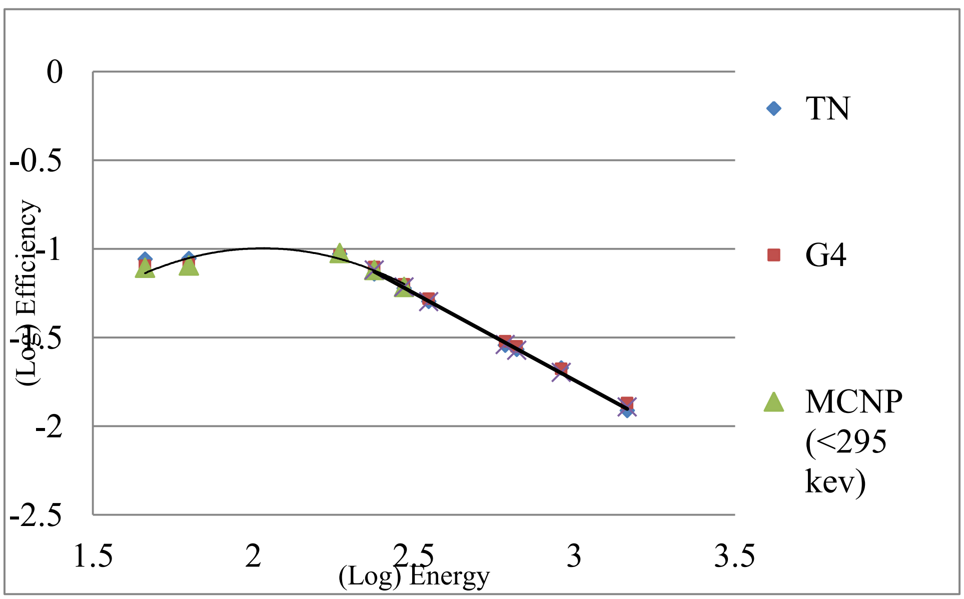


**Fig.2**, Efficiency linear for disk source by experiment and simulation

*(Source close to the probe face radius of 3.65cm,the thickness of 1.2cm and sample density of 1.95 g/cm$^3$)*

After testing the accuracy of the Input file, the dependence of detector efficiency on changing of column geometry: radius from 0.5cm to 5cm; thickness from 1cm to 10cm and density from 0.6g/ cm$^3$ to 2.4 g/cm$^3$. From the results, the detector efficiencies decrease by the increasing of radius, thickness or density of samples. This decreasing is apparent at low energy peak (lower 295 keV).

The detector efficiency for the radius of the disk source by simulation methods *(sample thickness: 2cm and density: 1.95g/cm$^3$).*

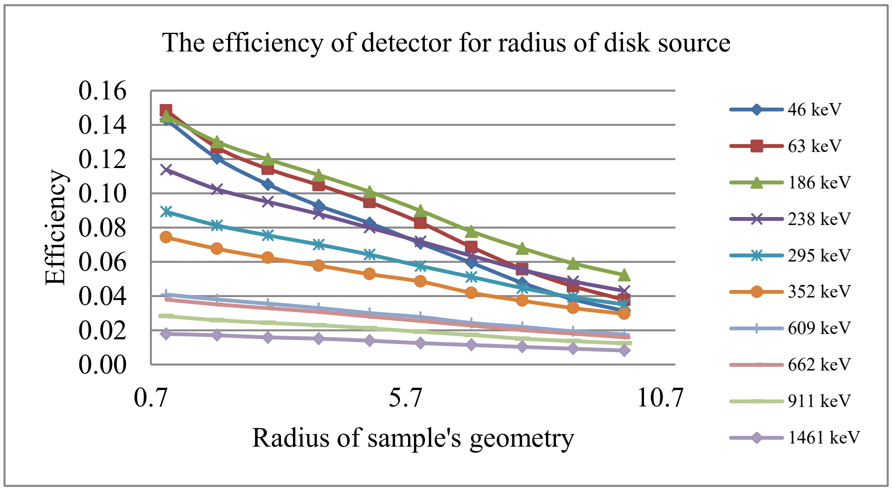


**Fig.3**. The variation of detector efficiencies by changing of the radius of sample's geometry *(sample thickness: 2cm and density: 1.95g/cm$^3$).*

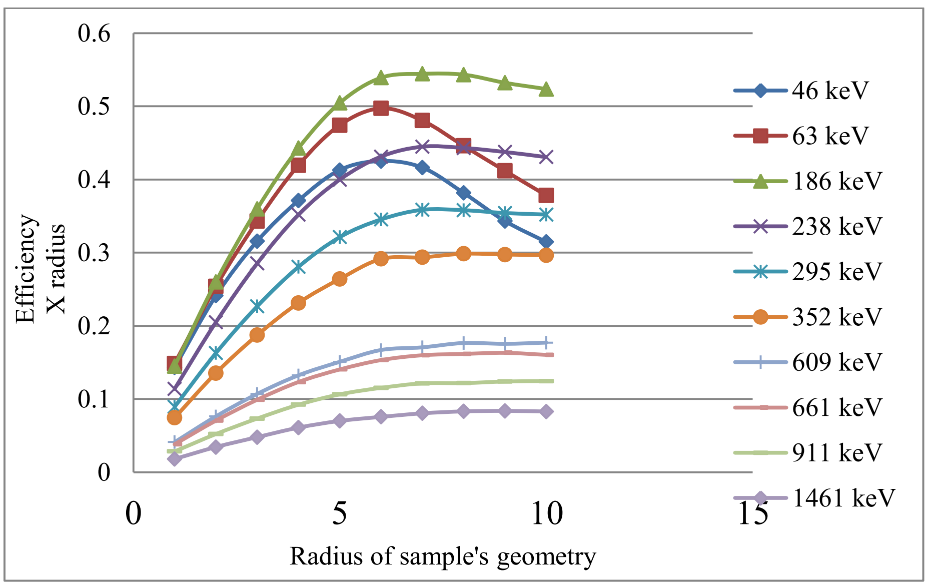


**Fig.4**. The saturation of detector efficiencies by changing the radius of the sample's geometry *(Sample thickness: 2cm and density: 1.95g/cm$^3$).*

The detector efficiency for the thickness of the disk source by simulation methods *(sample radius: 3.65cm and density: 1.95g/cm³)*

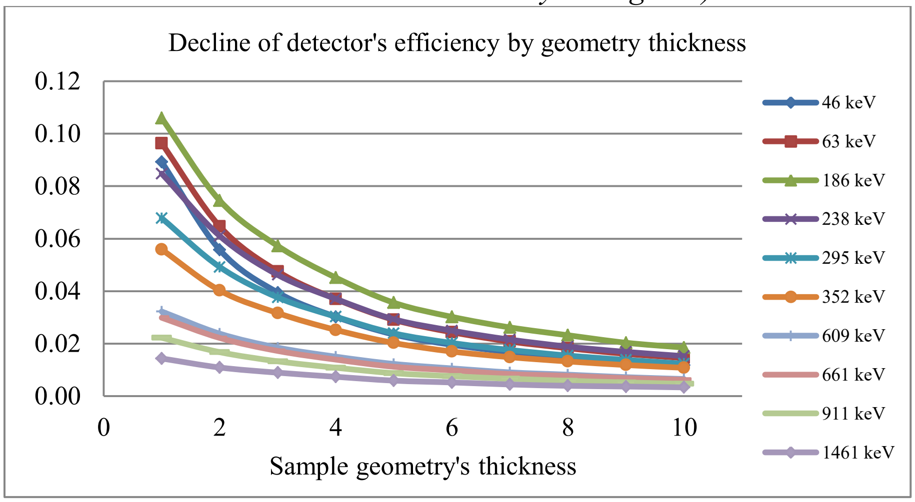


**Fig.5**. The decline of the detector efficiency by sample thickness *(Sample radius: 3.65cm and density: 1.95g/cm³)*

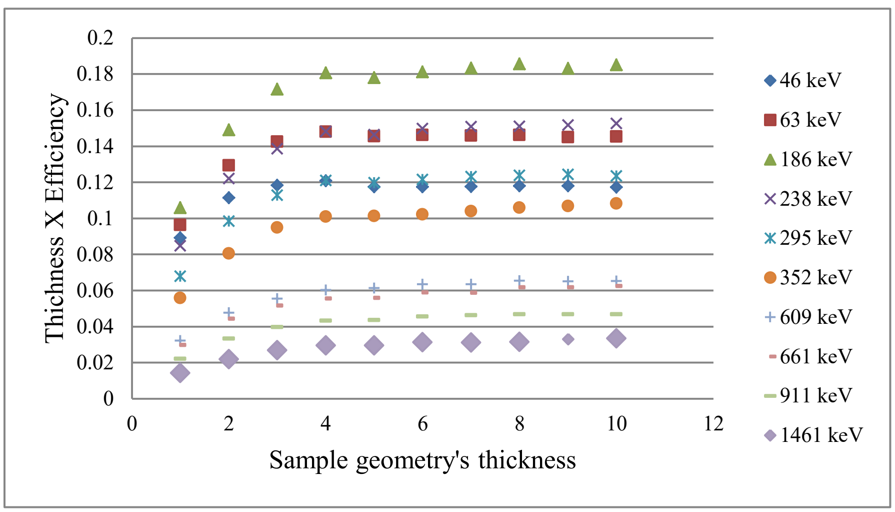


**Fig.6**. The saturation of detector efficiencies by changing the thickness of the sample's geometry *(Sample radius: 3.65cm and density: 1.95g/cm³)*

The detector efficiency for the density of the disk source by simulation methods *(Sample radius: 3.65cm and thickness: 2cm)*

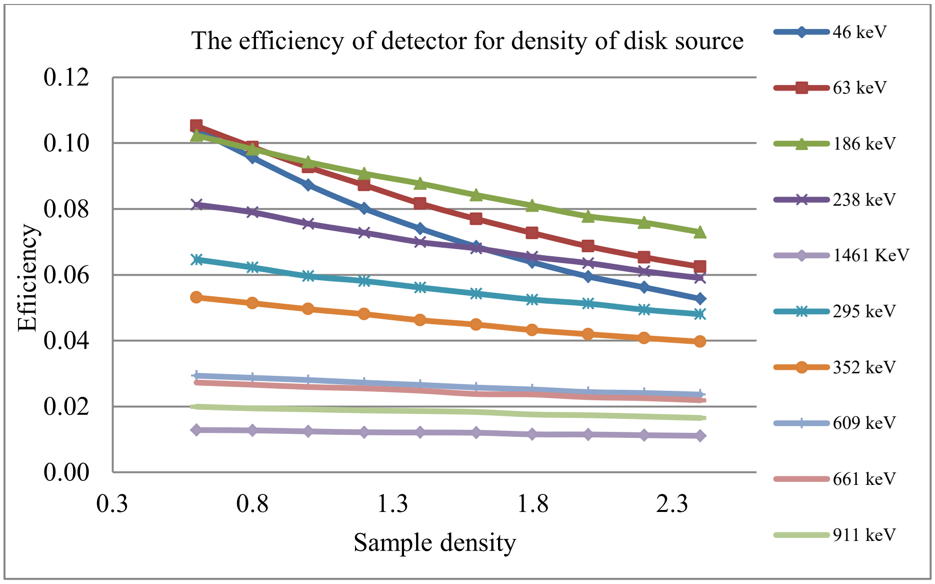


**Fig.7.** Detector efficiency by sample density
*(sample radius: 3.65cm and thickness: 2cm)*

**C. Discussion**

In this article, the author used an experimental method to check the accuracy of the GEANT4 emulation input file. The results obtained from experimental and simulation methods are preeminent, the relative error between the two methods is below 10%.

After executing the process of simulating efficiency's detector for disc-shaped volume measurements, some of the following comments can be drawn:

Simulation results show that the efficiency of the detector depends on many factors. The efficiency decreases with increasing radius, density, and thickness, especially in low energy areas. The self-absorption effect increases when the sample thickness increases. For the low energy from 46 keV to 295 keV, the thickness of the sample greatly affects the efficiency, the energy of 295 keV or more, the thickness of the sample is less affected. From Fig 4 and Fig 6, we determined optimal thickness and radius respectively 4,0cm, 3,5cm. In fact, when measuring environmental samples, the density of the sample is needed to be adjusted accordingly. The thickness and sample radius can control according to the measurement of the user. The sample density depends on each sample object to be analyzed. For energy areas of 295 keV or more, it is less affected by density. The energy area of less than 295 keV has a clear influence on the efficiency of the detector when changing the sample density.

**III. CONCLUSION**

In the study of environmental radioactivity samples, the activity of the sample can be calculated through a standard sample with gamma-ray emission with them, or it can be determined from the standard performance curve. Calibration curves can be constructed from standard samples with the same geometry, composition, and density as the sample. In fact, it is not easy to do this, so other methods such as simulation or semi-experimental methods are used to be able to examine the efficiency of the detector with variable measurement configurations, especially with the support of today's powerful computer system. Recognizing the importance of the applicability of Monte Carlo simulation in calculating volumetric sample performance, the authors exploited the applicability of this method to the maximum in structures, different picture. Specifically, survey the detector efficiency by the radius, thickness and sample density to give a set of efficiency data for each configuration. In fact, Monte Carlo simulations cannot be completely replaced. However, the simulation method is capable of providing complex measurement configurations that the experiment is difficult to do, as well as reducing the time-consuming and cost-effective experiments.

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# NGHIÊN CỨU TỐI ƯU HÓA MẪU HÌNH TRỤ SỬ DỤNG MÔ PHỎNG MONTE CARLO ĐỐI VỚI PHƯƠNG PHÁP PHÂN TÍCH PHỔ GAMMA PHÔNG THẤP


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**Tóm tắt:** Hiệu suất ghi của hệ phổ gamma phông thấp là một yếu tố quan trọng trong việc xác định hoạt độ phóng xạ của các mẫu môi trường. Do tính đa dạng về loại mẫu, hình học và mật độ của các mẫu môi trường là rất khác nhau. Do đó các nguồn chuẩn gamma không đủ để đáp ứng các yếu tố này trong việc xây dựng các đường chuẩn hiệu suất. Chính vì vậy, phương pháp mô phỏng Monte Carlo là một lựa chọn phù hợp cho mục đích này. Trong nghiên cứu này, phần mềm GEANT4 và MCNP được sử dụng để mô phỏng và tối ưu hóa mẫu đo hình trụ của các mẫu môi trường thường dùng để đo trên hệ phổ kế gamma phông thấp.



***Từ khóa:*** *Phổ Gamma, hiệu suất ghi, mẫu môi trường, mô phỏng Geant4, Monte Carlo.*