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Prediction of Gamma Ray Spectra for Some Nuclear Material by MCNP Simulation

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Abstract— **In the present work, the possibility of creation gamma-ray spectrum, for natural and depleted uranium, by using Monte Carlo simulations has been investigated. Detector efficiency has been calculated for HPGe detector. The broadened signal in the detector caused by electronics of the detector has been simulated by using GEB (Gaussian energy broadening) function. Three standard radioactive sources (Ba-133, Cs-137 and Co-60) have been used to calculate full width at half maximum (FWHM) function parameters. Two Standard Nuclear Material (SNM) samples with different enrichment (Depleted and Natural) in cylindrical aluminum containers have been used to obtain the experimental data. The comparison between the shape of the simulated gamma-ray spectrum and that obtained from experiment indicates a good agreement with a little dispersion for X-rays on spectrum shape formation.**

***Index Terms*— Gamma-ray spectrum, Monte Carlo simulations, Gaussian energy broadening, full width at half maximum.**

I. Introduction

Obtain accurate result, in verification of nuclear material field, required a gamma-ray detector with good energy resolution. HPGe detector has high resolution feature so it can consider the best choice [1]. The response function of the detector can be determined, in a precise way, by simulation of the detector using computational technique [2]. Calculation of the HPGe response function is difficult since it has high resolution which requires narrower bins around the peak and the cryostat geometry is complicated.

Gamma-ray interacts with the detector and produce voltage pulses. These pulses analyzed by a multichannel analyzer (MCA) and reshapes as peaks (lines) in the spectrum. The shape of the peak is usually a Gaussian distribution. Resolution of the detector determines the width of the peaks. Full Width at Half Maximum (FWHM) is used to express the resolution of the detector. In order to simulate the broadened of the signal, which produces by electronics of the detector, by Monte Carlo MCNP code the Gaussian Energy Broadening (GEB) card is used, which is a special treatment for tallies. The GEB feature provides a spectrum that can be compared with the experimental spectrum of gamma-ray [3].

This paper aims to investigate the possibility to generate gamma-ray spectra for some nuclear material using MCNP Simulation. Two Standard Nuclear Material (SNM) samples with different enrichment (Depleted and Natural) in cylindrical aluminum containers have been used to obtain the experimental data.

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II. Materials and Method

A. *Gamma-ray sources*

Three reference point sources (Cs-137, Co-60 and Ba-133) with different activities have been used. The parameters of each source are listed in Table 1.

Table 1: Specification of the reference point sources [4]

Source	E (keV)	Iγ %	Activity (kBq)	Production date
Ba-133	80.9971	34.06	37.8 ± 5%	1/12/1995
	276.398	7.164		
	302.853	18.33		
	356.017	62.05		
	383.851	8.94		
Co-60	1173.23	99.97	40.2 ± 4%	
	1332.5	99.98		
Cs-137	661.7	85.1	38.6 ± 4%	

Two Standard Reference Material (NBS, SNM-969) consists of U_3O_8 powder, with nominal ^{235}U abundances of 0.31 & 0.71 mass percent, encased in aluminum cans were used for non-destructive assay, to generate gamma ray spectrum experimentally. Each sample contains 200.1 ± 0.2 g of U_3O_8 powder [5]. These materials are subject to the international nuclear safeguards. Fig. 1 shows the shape and example for dimensions of the assayed NM samples. The specifications and characteristics of the NM samples are given in Table (2).

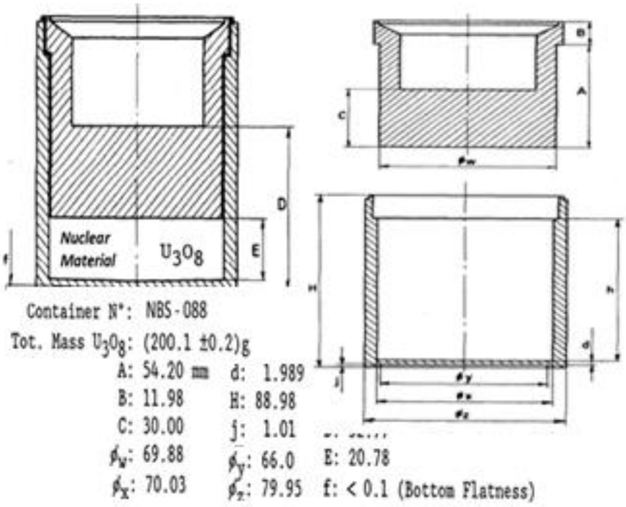

Fig. 1: Example of dimensional control can and the shape of the measured SRM 969 samples [5]

Table 2: Specifications of the certified NM standards [5]

Sample	Enr.%	U-235 mass (g)	U-238 mass (g)
DU	0.31	0.537	169.144
NU	0.71	1.208	168.473

B. HPGe detector

A commercial Cryo-Pulse® 5 HPGe detector (Model GC6020), which was purchased from Canberra [6], and it is shown in Fig. 2. Germanium crystal has a diameter of 67.70 mm and a length of 71.1 mm. The crystal is placed 5.32 mm from the front window. The front window is made of 0.6 mm-thick carbon composite. The recommended bias voltage is (+) 3800 V. The data acquisition system in this work involves a pre-amplifier (Model 2002CSL) and the Genie-2000 software (manufacturer information).

Fig. 2: Cryo-Pulse® 5 HPGe detector.

C. Experimental

Reference point sources have been located at a distance equal to 10 cm from the cap of the HPGe detector and pulse-height spectrum of gamma-rays has been recorded for 600 s time interval. To calculate the parameters specify the FWHM in the GEB card the FWHM for eight gamma energy lines, obtained from the three reference sources, in the range from 81 keV to 1.332 MeV (Table1) has been determined. The relation between the FWHM and gamma-ray energy has been drawn by OriginPro 8 program and it is shown in Fig. 3.

Gamma-ray spectrums for the NM samples have been obtained by placing at a distance equal to 20 cm from the cap of the HPGe detector for 600 s time interval. Genie-2000 was used for the acquisition of the gamma-ray spectrum.

D. MCNP simulation

MCNP5 model has been developed for each experimental setup, detector and source. F8 tally and the GEB option has been used in order to obtain a spectrum that can be compared with the experimental spectrum. The GEB option can be used to simulate a physical radiation detector in which energy peaks exhibit Gaussian energy broadening [7]. The desired FWHM is specified by:

$$FWHM = a + b\sqrt{E + cE^2} \quad \text{------------ (1)}$$

Where E is the incident gamma-ray energy, a, b, and c are the parameters specify the FWHM in the GEB card. These parameters have been obtained from the fitting result produced from OriginPro 8 program (a = 0.000920585 MeV, b = 0.000109805 $MeV^{1/2}$, c = 34.81012 MeV^{-1}). Only Gamma-ray photo-peaks have been entered in the source definition card of MCNP5, F8 tally was used to determine the response function of the HPGe. A history of 10 7 photons was applied to get good statistics. Obtained a, b, and c parameters have been entered into FTn card.

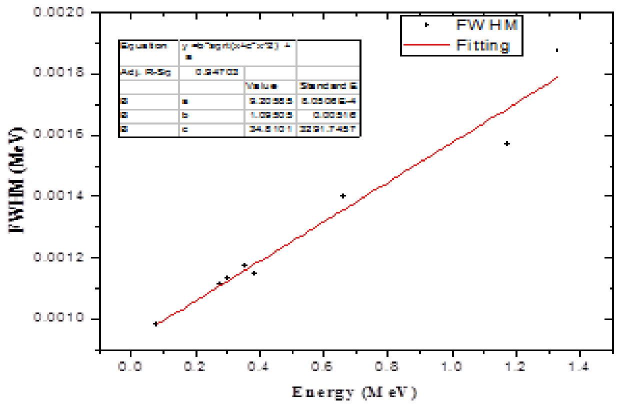

Fig. 3: FWHM versus measured gamma-ray energy spectrum used to extract a, b, and c parameters.

III. Results and Discussion

To examine the validation of the simulated results, the spectrum obtained from MCNP5 simulation and experimental spectrum for the Ba-133, Cs-137, and Co-60 point sources have been plotted. Each plot displaying MCNP5 simulation results vs. experimental results for a given source. Fig. 4 (a, b and c) show the plots for the spectrums. A good agreement between simulated and experimental spectrum has been obtained, the discrepancies between the simulated and experimental spectrum might be caused X-ray.

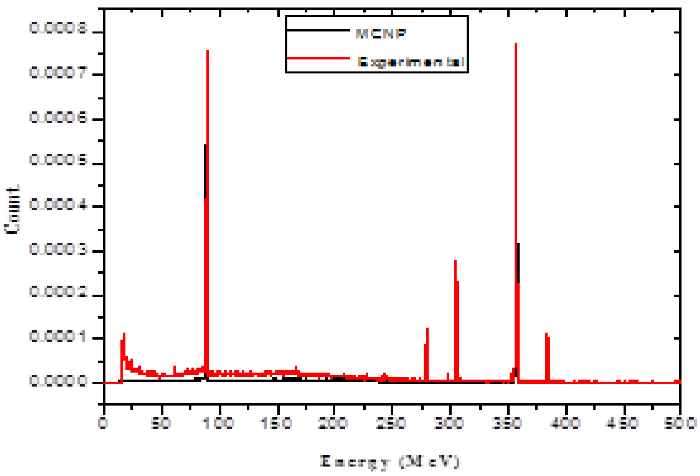

Fig. 4 (a): Ba-133 spectrum

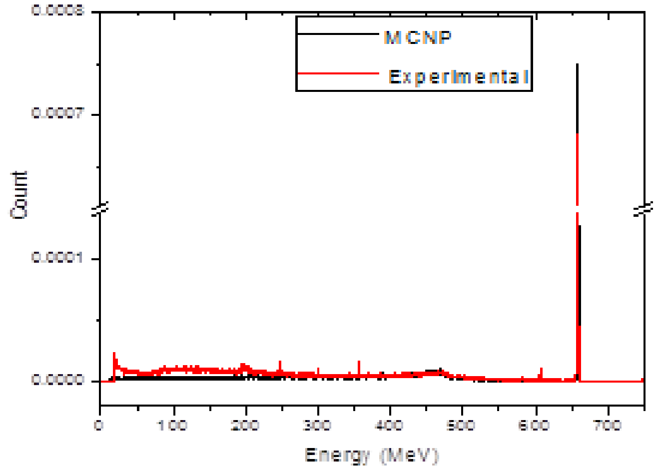

Fig. 4 (b): Cs-137 spectrum

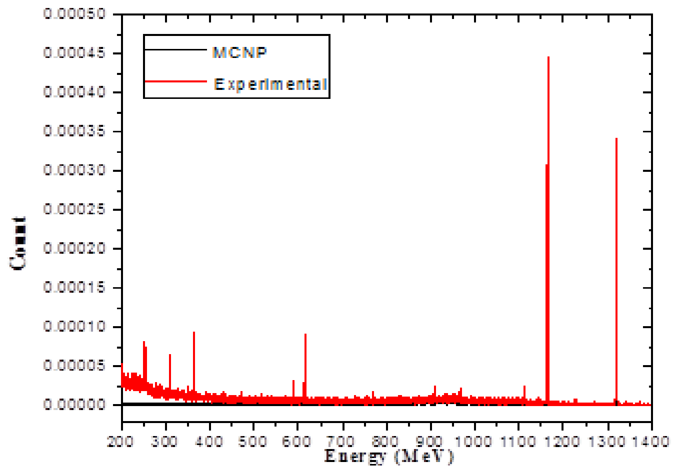

Fig. 4 (c): Co-60 spectrum

Fig. 4: MCNP vs. experimental results for the three reference point sources.

Also, the spectrum obtained from MCNP5 simulation and experimental spectrum for the Two Standard Nuclear Material (SNM) samples with different enrichment (Depleted and Natural) have been plotted, each plot displaying MCNP5 simulation results vs. experimental results for a given source. Fig. 5 (a and b) show the plots for the spectrums.

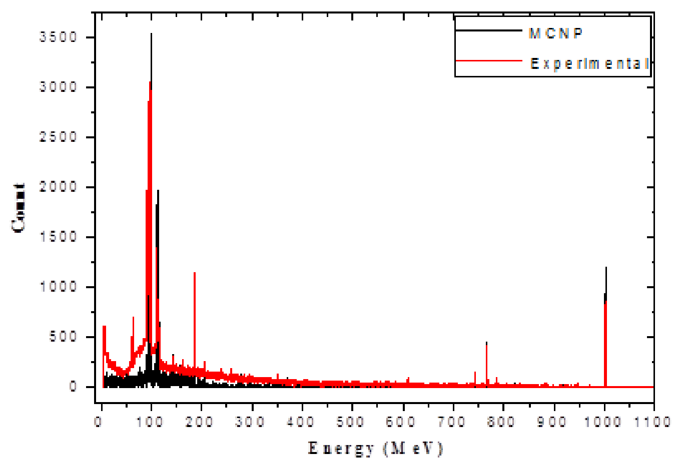

Fig. 5 (a): Spectrum for DU sample

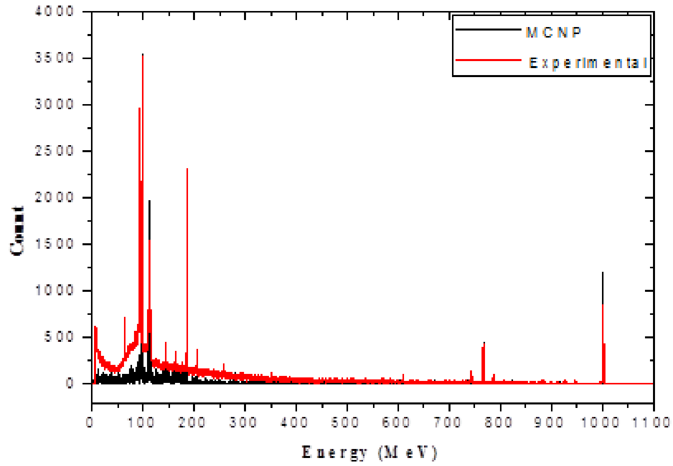

Fig. 5 (b): Spectrum for NU sample

Fig. 5: MCNP vs. experimental results for the two Standard Reference Materials

A good agreement between simulated and experimental spectrum has been obtained, the discrepancies between the simulated and experimental spectrum might be caused X-ray.

IV. Conclusions

In this work gamma-ray spectrums for the NM samples have been simulated by MCNP5 code. Gaussian energy broadening (GEB) option has been used within FTn card to construct the MCNP5 input file for generation the spectrum. Three reference point sources (eight energy lines) have been used to calculate the parameters specify the full width at half maximum in the GEB option. Spectrums obtained from MCNP5 simulation have been compared with those obtained experimentally; a good agreement has been obtained with some effect to X-rays.

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References

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