IOSR Journal Of Applied Physics (IOSR-JAP)
e-ISSN: 2278-4861.Volume 12, Issue 5 Ser. II (Sep. – Oct 2020), PP 28-33
www.Iosrjournals.Org

Simulation study for NaI and $CeBr_3$ Scintillators for Gamma-RaySpectroscopyusing Monte Carlo Code

R.A.El-Tayebany, H.Elbegawy
Department of Nuclear Safeguards and Physical Protection, Egyptian & radiological regulatory Authority (ENNRA)
3 Ahmad El-Zomor Str., El-Zohoor Dist., Nasr City, P.O. Code 11762, Cairo, Egypt

Abstract
The scintillation process remains one of the mostuseful methods available for the detection and spectroscopy of a wide assortment of radiations. The world seeks to development and implementation of equipment and services related to radiation detection.A new scintillator, cerium bromide ($CeBr_3$), for gamma-ray spectroscopy was proposed. The 3" x 3" cylindrical Cerium Bromide ($CeBr_3$) and (Sodium Iodide) NaIscintillation detectors were simulatedby MCNP-5 code and compared.The Gaussian Energy Broadening (GEB) card was used in simulation codeto study the full energy peak efficiency (FEPE) ofsuch detectors. Gamma lineslying in the energy range from 100keV to 2 MeV are used as indicators to compare these two types of detectors.The scintillation response was measured using standard gamma ray sources (^{57}Co, ^{235}U,^{137}Cs and^{60}Co). The response of the two detectors to gamma rays was compared and discussed.

Keywords:*MCNP Code, Cerium Bromide ($CeBr_3$), Sodium Iodide (NaI), Non-Destructive Assay (NDA).*

Date of Submission: 19-09-2020 Date of Acceptance: 25-09-2020

I. Introduction

Cerium Bromide ($CeBr_3$) has good energy resolution in gamma-ray measurements. It's resolution of less than 4% (FWHM) by measuring 662 keV photons (^{137}Cs source) at room temperature [1].Scintillation spectrometers are common detectors that used in detectionand spectroscopy of energetic photons (X-rays andγ-rays) at room temperature. These detectors are commonlyused in nuclear and particle physics research, medical imaging,diffraction, non-destructive testing, nuclear treaty verificationand safeguards, nuclear non-proliferation monitoring, andgeological [2].The γ-ray stopping efficiency of $CeBr_3$ issignificantly higher than that of NaI(Tl), the most commonscintillation detector.High lightoutput, good proportionality, fast response and excellentenergy and timing resolution have been measured for small$CeBr_3$ crystals. Based on the results, $CeBr_3$ is very promisingfor γ-ray spectroscopy. Its properties are very similar to thoseof another recently discovered scintillator, cerium dopedlanthanum bromide ($LaBr_3$:Ce).The photon detection assembly can comprise a photomultiplier tube, a photo diode, or a PIN detector.The crystal can be coated with, a reflective layer, a moistureresistant layer, or a vapor barrier, and the like. The reflectivelayer is typically to cover the surfaces of the scintillator crystal not exposed to the photon detector assembly [9].

II. Detector simulation

Cerium Bromide scintillators feature very high light yields, fast response, and high density properties. The key advantage to the material, when compared to other high resolution scintillators, is its very low intrinsic background noise.$CeBr_3$ is also fast without any slow components.The scintillators are hygroscopic and are available from BNC encapsulated with an entrance window, integrally coupled to a light sensor such as a PMT or

SiPM, or fully integrated in detector assemblies with light sensor and front-end electronics. Sizes ranging from pixels for arrays to volumes as large as 102 x 127 mm are currently available.

$CeBr_3$ is characterized by its relatively high density, high Z, and its proportional response to gamma rays. The typical energy resolution provided by the material is 4% FWHM for 662 keV. It has fast light pulse rise time, $CeBr_3$ detectors can provide sub-nanosecond time resolutions only slightly inferior to BaF_2 detectors. In addition, the material exhibits fast decay times of 20 ns with negligible afterglow. With a background count as low as <0.001 c/cc/s in the Ac-227 complex, $CeBr_3$ presents a distinct advantage over other high-resolution scintillators which suffer from this intrinsic activity. There are currently two versions of $CeBr_3$ that are commercially available, standard background and low background (LB) $CeBr_3$. The low background variety results in less activity in the Ac-227 peaks when compared to standard CeBr3. Standard: 0.025 c/s/cc and Low Background: 0.00125 c/s/cc in the Ac-227 complex.

NaI(Tl) scintillation crystals are widely used in most standard gamma spectroscopy applications due to their unmatched high light output and excellent match of their emission spectrum to the sensitivity of photomultiplier tubes. The aim of the paper is simulation study the full energy peak efficiency (FEPE) for two types of scintillation detectors NaI(Tl) and CeBr3 detectors with dimensions 3”×3” for each one using various point sources (^{57}Co, ^{235}U, ^{137}Cs and ^{60}Co).

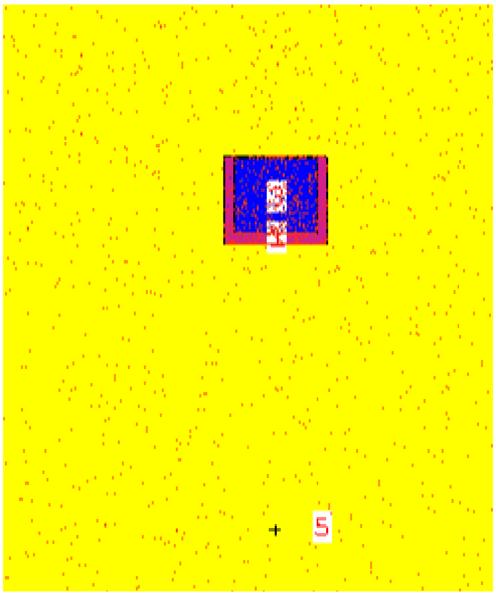

Fig.(1) Detector configuration by visual editor

III. Monte Carlo simulation

The Monte Carlo (MC) method was developed in the 1940sof last century. This method is widely used in many fieldscomprising mathematics, economy, astronomy, and physics.In the physics phenomena, where the analytical approachesfail to give the correct results, the numerical approaches,including the MC method, proved that they were the effectiveapproaches. In nuclear physics, the Monte Carlo methodwas used to simulate the interaction of a particle with matter.Nowadays, with the development of the high-performancecomputer, the MC method provides powerful tools to solvethe problems related to nuclear physics.MCNP (Monte Carlo N-Particle) code, which isbased on the MC method, is a powerful and reliable toolto simulate the response function of detectors in radiationmeasurements [8].

Pulse-Height Tally

The pulse-height (F8) tally generates the energy distribution of pulses created in a detector. This type of tally is akin to a physical detector and can be used in conjunction with the Gaussian Energy Broadening special tally treatment card to simulate real-life detector responses. In an F8 tally, the result is a histogram, in which each energy bin corresponds to the total energy deposited in a detector by each physical particle. Most other tallies record the energy of the particle being scored. The F8 tally is incredibly useful when modeling a real-world experiment. In this research, the F8 tally was used to model the detector responses from the simulated detectors.Special Tally Treatment Cards MCNP simulates detector responses by applying special treatments to specific tally cards. The most common special tally treatment is the Gaussian Energy Broadening (GEB) card, which applies a statistical Gaussian broadening to events recorded in the tally to better match experimental results [5].

Gaussian Energy Broadening For a radiation particle of a particular energy, a real-life radiation detector records its energy as a Poisson distribution, commonly simplified as a Gaussian function. This spread is due to noise in the detector, the detector's inherent imperfect collection efficiency, and variation in the amount of charge carriers for any one event. Therefore, to simulate the pulse height spectrum from a detector, an F8 tally must be modified by a virtual Gaussian spreading function. When an event is recorded in a tally, the energy of the particle is broadened by sampling from a Gaussian function as in eq.(1) ; where E is is the broadened energy, E_0 is the unbroadened energy of the tally, C is a normalization constant, and A is the Gaussian width. We can obtain the Gaussian width, A, using the full width half maximum (FWHM) of a peak using equation

$$f(E) = Ce^{-\left(\frac{E-E_0}{A}\right)^2} \qquad (1)$$

$$A = \frac{FWHM}{2\sqrt{ln2}} \qquad (2)$$

$$FWHM = a + b\sqrt{E + cE^2} \qquad (3)$$

The detector-dependent parameters for a GEB function, a; b; and c, can be obtained by fitting equation (3) to experimental spectra from a specificdetector. Anexample of this procedure for a stilbene scintillation detector is given by Kim in 2015.For a 3 in. by 3 in. cylindrical NaI(Tl) crystal (the type of detector used for this research)the GEB parameters are: a = - 0.00789, b = 0.06769 , and c = 0.21159. AlthoughGEB is a great approximation for most detectors, it is not a perfect solution for non-linearcrystals [6].

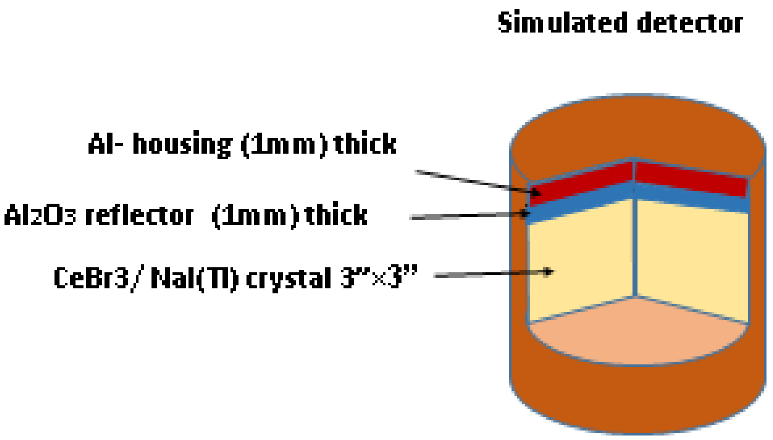

Fig.(2) : detector simulation by MCNP-5

IV. Results

Cerium bromide ($CeBr_3$), for gamma-ray spectroscopy. Crystals of this scintillator have been grown using Bridgman process. In CeBr3, Ce3+ is an intrinsic constituent as well as a luminescence center for the scintillation process, has high light output (~68,000 photons/MeV) and fast decay constant (~17 ns). Furthermore, it shows excellent energy resolution for gamma-ray detection [10].CeBr3 scintillation crystals offer an alternative to NaI(Tl) crystals for high resolution gamma spectrometry. Above an energy of 200 keV, the resolution is superior to NaI(Tl). Fig.(1) depends on data in ref.(3).

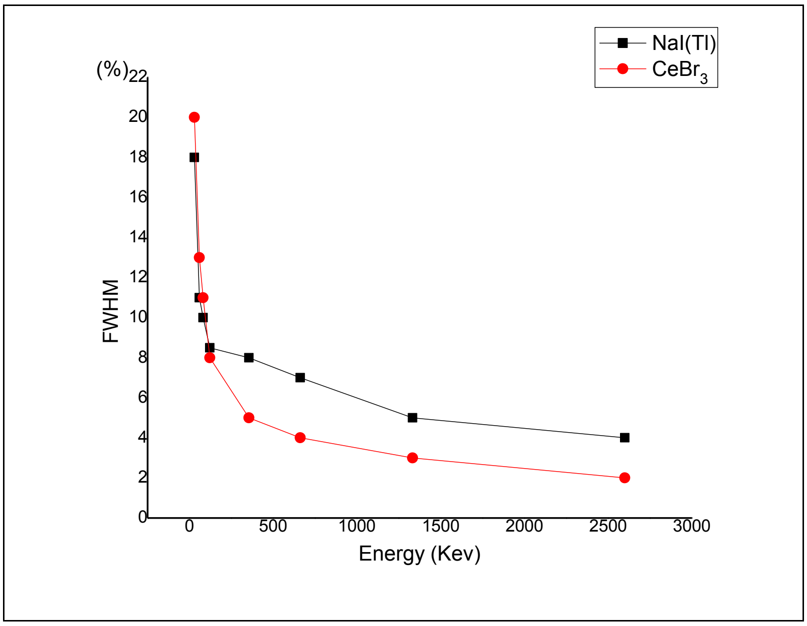

Fig.(3): Typical energy resolution (FWHM) in %

The NaI(Tl) and $CeBr_3$ detectors were modeled as rectangular cylinders measuring 7.6 cm in diameter and 7.6 cm in length. F8 (pulse height) tallies were assigned to the detector cells to simulate $CeBr_3$ and NaI(Tl) responses. The GEB special tally treatment card was used to broaden both F8 tallies. Fig.(3) showed that the resolution of both simulated detectors nearly the same at energy $\leq$ 200Kev; then the curves began to diverge from each other to prove that the resolution of CeBr3 detector is better than NaI(Tl) detector.Comparative study is presented between the calculated results for NaI(Tl) and CeBr3 detectors in the same dimensions and internal layers. The energy lines that used are 122.1,185.7,661.7 and 1173.2 Kev using standard gamma ray sources (^{57}Co, ^{235}U, ^{137}Cs and ^{60}Co) respectively.Fig.(4,5) shows that the full energy peak efficiency for ^{57}Co^{235}U at energy line 122.1,185.7 Kev for simulating both detectors. The figure shows that the results for both detectors are in coincidence with each other. This agree with the results in ref.(1) where the measured energy peak < 200Kev.

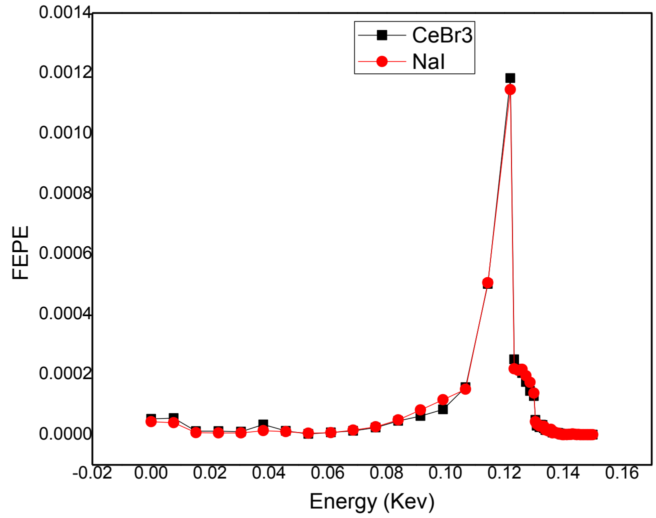

Fig.(4) FEPE versus energy scale (Kev) at 122 Kev for CO-57

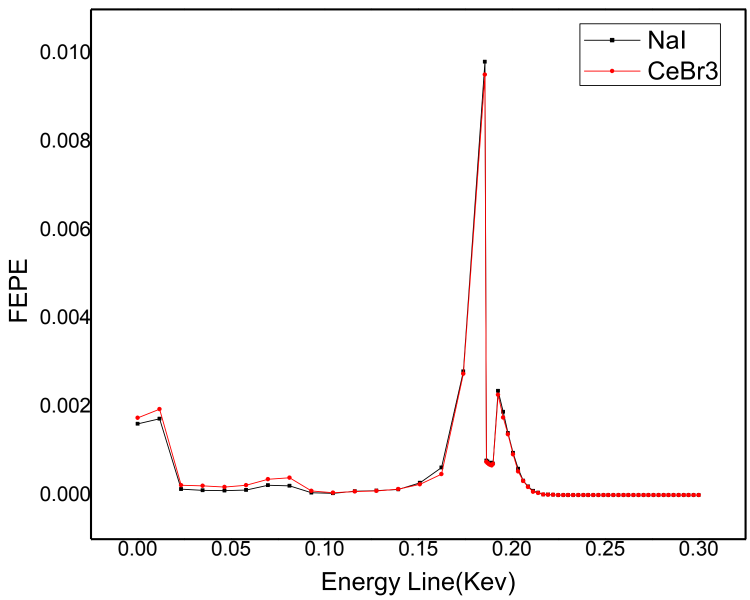

Fig.(5)FEPE versus energy scale (Kev) at 185.7 Kev for u-235

Figures (6,7) shows that the energy lines 661.7 and 1172.5 Kev for 137Cs and ^{60}Co. the calculated results presented the similarity for the calculated full energy peaks. This contrasted with the results for ref.(3). This justified as the internal layers for CeBr$_3$ detector are not the same as in NaI detector. It may be contains undeclared internal dimensions may be taken as a patent for the manufacturer.

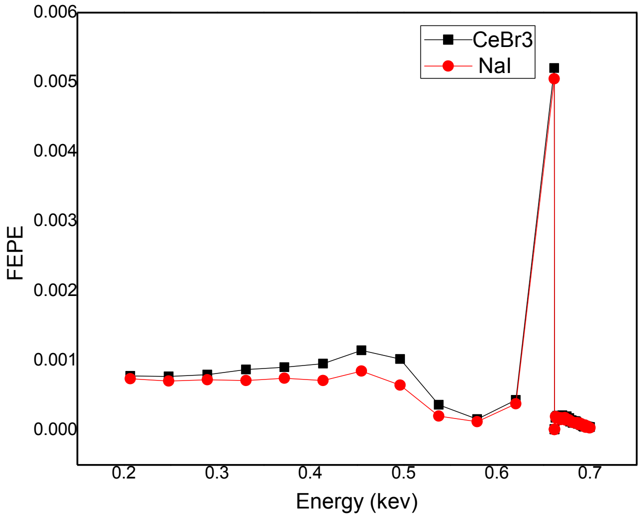

Fig.(6) FEPE versus energy scale (Kev) at 661.7 Kev for Cs-137

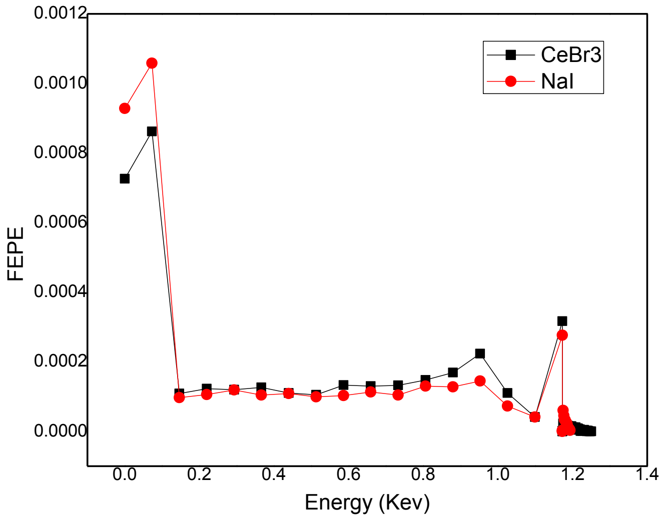

Fig.(7) FEPE versus energy scale (Kev) at 1172.5 Kev for CO-60

V. Conclusion

Comparative study for CeBr$_3$and NaI(Tl) scintillation detectorsfor high resolution gamma spectrometry. The calculated results that obtained from the NaI andCeBr$_3$ simulation by MCNP-5 code were explained. This results indicated to there were similarity of the photo energy peaks that produced from both detectors. The similarity was at all tested peaks above and below 200Kev. The justified reason for this that the internal layers for CeBr$_3$ detector may be not the same as in NaI detector. It may be contains undeclared internal dimensions and may be taken as a patent for the manufacturer. It recommended to use for applications such as non-destructive evaluation; nuclear security verification and non-proliferation monitoring.

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R.A.El-Tayebany, et. al. “Simulation study for NaI and CeBr3 Scintillators for Gamma-Ray Spectroscopy using Monte Carlo Code.” *IOSR Journal of Applied Physics (IOSR-JAP)*, 12(5), 2020, pp. 28-33.