Open Access Library Journal
2020, Volume 7, e6655
ISSN Online: 2333-9721
ISSN Print: 2333-9705

MC Simulates the Detection Efficiency of Different Sizes of BaClBr(Eu)

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How to cite this paper: Zhang, J.X., Jin, Y.F., Zhao, X., Liu, Q.S., Xu, R.Y. and Liu, Y. (2020) MC Simulates the Detection Efficiency of Different Sizes of BaClBr(Eu). *Open Access Library Journal*, **7**: e6655.
https://doi.org/10.4236/oalib.1106655

Received: July 24, 2020
Accepted: August 17, 2020
Published: August 20, 2020

Abstract

The performance of a new BaClBr(Eu) scintillator discovered in recent years was studied. The photon yield and detection efficiency of different sizes of the theoretical model of the BaClBr(Eu) detector were calculated by the MCNP program, and compared with the traditional NaCl(Tl) detector. Studies have found that the detection efficiency of the scintillator detector increases as the size of the scintillator increases. When the γ-ray energy is 662 KeV, the photon yield of the BaClBr(Eu) detector is lower than that of the NaCl(Tl) detector, and the light yield difference is 6.21% - 3.15%. The detection efficiency of BaClBr(Eu) scintillator is higher than that of NaCl(Tl) scintillator, and the relative efficiency is 11.7% - 22.52%. Simulating the effect of different ray energy on the photon yield and detection efficiency of the scintillator under the same crystal size, it is found that the photon yield of the BaClBr(Eu) scintillator is between the NaCl(Tl) and CsI(Tl) scintillator detectors. The detection efficiency of low-energy rays is close to that of NaCl(Tl), and the detection efficiency of high-energy rays is much higher than that of NaCl(Tl). The detection efficiency of the high and low ray energy range is close to that of the CsI(Tl) detector.

Subject Areas

Nuclear Physics

Keywords

Mento Carlo Method, Detection Efficiency, BaClBr(Eu) Crystal, γ-Ray

1. Introduction

With the advancement of photomultiplier tubes and other microscopic detection devices and technologies, scintillator detectors have been rapidly developed and widely used. They are usually used in nuclear physics and high energy physics, medicine, diffraction, nondestructive testing, national security and geological exploration and other fields [1] [2]. Since the discovery of scintillation crystal NaI(Tl) in 1948, scientists have been looking for scintillation crystal materials with high atomic number, high density, high transmittance, physical and chemical properties and excellent scintillation properties. In recent years, a new type of alkaline earth metal halide BaClBr(Eu) crystal has been discovered internationally [3] [4] [5]. It has the characteristics of high density, high atomic number, high light output and high energy resolution, and has good application prospects.

In this paper, the Monte Carlo method is used to simulate and calculate the effects of different sizes and different ray energies on the luminescence yield and source peak efficiency of BaClBr(Eu) crystals, and compare the performance with the scintillation crystal NaCl(Tl). On this basis, the influence of the size of the scintillator on the performance of the scintillator is discussed. The simulation results can provide reference for the selection of scintillator size and the manufacture of scintillator detector.

2. Mcnp Modeling

Monte Carlo method is a calculation method based on the simulation of photon and electron coupling transport problem [6]. MCNP (Monte Carlo Neutron and Photo Transport Code) program is based on the Monte Carlo method to deal with particle transport, which can effectively solve the photon and electron coupling transport process. It simulates the interaction of photons and electrons.

The geometric model of the BaClBr(Eu) detector is shown in **Figure 1**. Including two parts: ray source and detector. The ray source is a point source, which emits γ-rays with adjustable energy, 20 cm away from the detector. The detector includes a scintillator, a reflective layer, a protective layer and a light guide. The geometry of the scintillator is a cylinder with adjustable size. The reflective layer material MgO: 0.05 cm. The protective layer material Al: 0.2 cm. The light guide material SiO_2: 0.2 cm. The number of gamma photons: 10^7. F1 counter card records the output light integral flow through the contact surface of the scintillator and the light guide. The F8 counter card records the pulse height

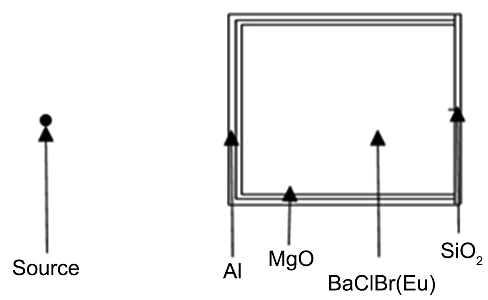

Figure 1. BaClBr(Eu) detector geometry model.

energy spectrum distribution of the γ-ray in the scintillator. The E8 card calculates the detection efficiency of the scintillator [7].

3. Photon Yield and Detection Efficiency

Photon yield and detection efficiency are two important indicators to measure the performance of scintillator detectors [8]. Photon yield represents the ability of a scintillator to convert absorbed ray energy into light pulses [2]. The higher the photon yield of the scintillator, the more photons converge to the optoelectronic device, and the higher the energy resolution, and the better the performance. The photon yield is defined as the ratio of the number of photons generated during the scintillation process to the energy lost by the particles in the scintillator, and the expression is:

$$Y_{ph} = n_{ph} / \Delta E \quad (1)$$

In the formula: Y_{ph} is the photon yield, in MeV^{-1}. n_{ph} is the number of photons produced in the scintillator. ΔE is the energy lost by the particle in the scintillator, in MeV.

There are many ways to record the detection efficiency, which can generally be divided into source detection efficiency and source peak detection efficiency. In order to eliminate the influence of counting and noise interference caused by the scattering of surrounding objects and other factors [9], source peak detection efficiency can be selected to describe the performance of the detection crystal itself. The detection efficiency of the source peak detection efficiency is defined as the ratio of the count of all-energy peaks in the γ energy spectrum to the number of γ photons emitted by the radioactive source. The expression is:

$$\varepsilon_{sp} = N_i / N \quad (2)$$

In the formula: ε_{sp} is the source peak detection efficiency. N_i is the count within the all-energy peak of the γ energy spectrum. N is the number of γ photons emitted.

4. MC Simulation Calculation

4.1. The Influence of Different Sizes on Photon Yield and Detection Efficiency

The experiment simulated the effects of different sizes of BaClBr(Eu) scintillators and NaCl(Tl) scintillators on photon yield and source peak efficiency. Set the energy of the radioactive source to 662 keV, and the diameter and radius of the scintillation crystal to vary from 30 mm to 90 mm. **Table 1** shows the changes in relative photon yield and detection efficiency when the size of BaClBr(Eu) scintillators and NaCl(Tl) scintillators change. It can be seen that the detection efficiency of the scintillator detector increases as the size of the scintillator increases. Under the same size, the photon yield output of the BaClBr (Eu) scintillator is less than that of the NaCl(Tl) scintillator, and the maximum light yield difference is 6.21% and the minimum is 3.15%. Under the same size, the

Table 1. The effect of scintillator size on photon yield and relative efficiency.

Radius/mm	Diameter/mm	BaClBr(Eu) photon yield	NAI(Tl) photon yield	Difference in photon yield/%	BaClBr(Eu) source peak efficiency	NACI(Tl) source peak efficiency	Relative efficiency/%
30	30	4.73×10^{-1}	5.35×10^{-1}	−6.21%	1.3×10^{-10}	1.1×10^{-10}	22.52%
	40	3.40×10^{-1}	4.01×10^{-1}	−6.18%	1.6×10^{-10}	1.3×10^{-10}	20.05%
	50	2.40×10^{-1}	3.00×10^{-1}	−6.05%	1.8×10^{-10}	1.5×10^{-10}	18.17%
	60	1.72×10^{-1}	2.24×10^{-1}	−5.14%	2×10^{-10}	1.7×10^{-10}	16.23%
	70	1.22×10^{-1}	1.69×10^{-1}	−4.65%	2.1×10^{-10}	1.8×10^{-10}	15.44%
	80	8.71×10^{-2}	1.26×10^{-1}	−3.89%	2.1×10^{-10}	1.9×10^{-10}	14.33%
	90	6.26×10^{-2}	9.41×10^{-2}	−3.15%	2.2×10^{-10}	1.9×10^{-10}	13.35%
40	30	4.67×10^{-1}	5.27×10^{-1}	−5.92%	2.4×10^{-10}	2×10^{-10}	21.81%
	40	3.38×10^{-1}	3.98×10^{-1}	−6.06%	3×10^{-10}	2.5×10^{-10}	19.45%
	50	2.42×10^{-1}	3.01×10^{-1}	−5.96%	3.4×10^{-10}	2.9×10^{-10}	18.19%
	60	1.74×10^{-1}	2.26×10^{-1}	−5.18%	3.7×10^{-10}	3.2×10^{-10}	16.07%
	70	1.24×10^{-1}	1.71×10^{-1}	−4.69%	4×10^{-10}	3.5×10^{-10}	15.07%
	80	8.90×10^{-2}	1.29×10^{-1}	−3.97%	4.1×10^{-10}	3.6×10^{-10}	13.95%
	90	6.39×10^{-2}	9.67×10^{-2}	−3.27%	4.3×10^{-10}	3.8×10^{-10}	12.63%
50	30	4.64×10^{-1}	5.22×10^{-1}	−5.79%	3.9×10^{-10}	3.2×10^{-10}	21.29%
	40	3.38×10^{-1}	3.97×10^{-1}	−5.89%	4.8×10^{-10}	4.1×10^{-10}	19.25%
	50	2.44×10^{-1}	3.03×10^{-1}	−5.94%	5.6×10^{-10}	4.7×10^{-10}	17.95%
	60	1.76×10^{-1}	2.30×10^{-1}	−5.33%	6.1×10^{-10}	5.2×10^{-10}	15.90%
	70	1.26×10^{-1}	1.74×10^{-1}	−4.79%	6.5×10^{-10}	5.6×10^{-10}	14.84%
	80	9.14×10^{-2}	1.32×10^{-1}	−4.03%	6.8×10^{-10}	5.9×10^{-10}	13.62%
	90	6.58×10^{-2}	9.98×10^{-2}	−3.41%	7×10^{-10}	6.2×10^{-10}	12.55%
60	30	4.60×10^{-1}	5.18×10^{-1}	−5.84%	5.7×10^{-10}	4.6×10^{-10}	21.86%
	40	3.37×10^{-1}	3.96×10^{-1}	−5.94%	7.1×10^{-10}	5.9×10^{-10}	19.40%
	50	2.44×10^{-1}	3.04×10^{-1}	−5.93%	8.1×10^{-10}	6.9×10^{-10}	18.03%
	60	1.77×10^{-1}	2.31×10^{-1}	−5.32%	8.9×10^{-10}	7.7×10^{-10}	16.04%
	70	1.28×10^{-1}	1.76×10^{-1}	−4.76%	9.5×10^{-10}	8.3×10^{-10}	14.87%
	80	9.26×10^{-2}	1.34×10^{-1}	−4.10%	1×10^{-9}	8.8×10^{-10}	13.57%
	90	6.66×10^{-2}	1.02×10^{-1}	−3.50%	1×10^{-9}	9.1×10^{-10}	12.63%

Continued

70	30	4.59×10^{-1}	5.17×10^{-1}	−5.80%	7.7×10^{-10}	6.4×10^{-10}	21.62%
	40	3.36×10^{-1}	3.97×10^{-1}	−6.05%	9.7×10^{-10}	8.1×10^{-10}	19.44%
	50	2.45×10^{-1}	3.04×10^{-1}	−5.91%	1.1×10^{-9}	9.5×10^{-10}	17.83%
	60	1.78×10^{-1}	2.32×10^{-1}	−5.37%	1.2×10^{-9}	1.1×10^{-9}	15.92%
	70	1.29×10^{-1}	1.77×10^{-1}	−4.85%	1.3×10^{-9}	1.1×10^{-9}	14.67%
	80	9.30×10^{-2}	1.35×10^{-1}	−4.19%	1.4×10^{-9}	1.2×10^{-9}	13.39%
	90	6.76×10^{-2}	1.03×10^{-1}	−3.57%	1.4×10^{-9}	1.3×10^{-9}	12.38%
80	30	4.57×10^{-1}	5.15×10^{-1}	−5.79%	1×10^{-9}	8.3×10^{-10}	21.50%
	40	3.36×10^{-1}	3.97×10^{-1}	−6.05%	1.3×10^{-9}	1.1×10^{-9}	19.43%
	50	2.46×10^{-1}	3.05×10^{-1}	−5.93%	1.5×10^{-9}	1.2×10^{-9}	17.68%
	60	1.79×10^{-1}	2.33×10^{-1}	−5.39%	1.6×10^{-9}	1.4×10^{-9}	15.75%
	70	1.30×10^{-1}	1.79×10^{-1}	−4.89%	1.7×10^{-9}	1.5×10^{-9}	14.48%
	80	9.40×10^{-2}	1.37×10^{-1}	−4.25%	1.8×10^{-9}	1.6×10^{-9}	13.21%
	90	6.78×10^{-2}	1.04×10^{-1}	−3.65%	1.9×10^{-9}	1.7×10^{-9}	12.15%
90	30	4.57×10^{-1}	5.15×10^{-1}	−5.77%	1.3×10^{-9}	1×10^{-9}	21.18%
	40	3.36×10^{-1}	3.97×10^{-1}	−6.09%	1.6×10^{-9}	1.3×10^{-9}	19.06%
	50	2.46×10^{-1}	3.06×10^{-1}	−5.99%	1.8×10^{-9}	1.6×10^{-9}	17.26%
	60	1.80×10^{-1}	2.34×10^{-1}	−5.44%	2×10^{-9}	1.7×10^{-9}	15.35%
	70	1.30×10^{-1}	1.80×10^{-1}	−4.93%	2.2×10^{-9}	1.9×10^{-9}	14.10%
	80	9.46×10^{-2}	1.38×10^{-1}	−4.30%	2.3×10^{-9}	2×10^{-9}	12.78%
	90	6.87×10^{-2}	1.05×10^{-1}	−3.67%	2.3×10^{-9}	2.1×10^{-9}	11.70%

source peak efficiency of the BaClBr(Eu) scintillator detector is higher than that of the NaCl(Tl) scintillator detector, with the maximum relative efficiency being 22.52% and the minimum being 11.7%. The BaClBr(Eu) scintillator detector has the best performance when the size is Φ90 mm × 90 mm, the light yield difference is small, and the source peak efficiency is the highest.

4.2. Exploring the Impact of Different Energy Levels on the Photon Yield and Detection Efficiency of the Scintillator

The experiment simulates the influence of different ray energy on the photon yield and source peak efficiency of the BaClBr(Eu) scintillator detector, NaCl(Tl) scintillator detector and CsI(Tl) scintillator detector in size Φ90 mm × 90 mm. **Table 2** shows the changes in photon yield and detection efficiency of BaClBr(Eu) scintillators, NaCl(Tl) scintillators and CsI(Tl) scintillators with a size of Φ90 mm × 90 mm under different ray energy. **Figure 2** and **Figure 3**

Table 2. Scintillator photon yield and detection efficiency under different γ-ray energy.

γ-ray energy/KeV	Nuclides	BaClBr(Eu)		NaCl(Tl)		CsI(Tl)	
		Photon yield	Detection efficiency	Photon yield	Detection efficiency	Photon yield	Photon yield
160	^{47}Sc	2.55×10^{-1}	8.37×10^{-1}	2.55×10^{-3}	8.33×10^{-1}	2.52×10^{-3}	8.49×10^{-1}
320	^{51}Cr	6.60×10^{-3}	7.32×10^{-1}	1.21×10^{-2}	7.14×10^{-1}	3.76×10^{-3}	7.68×10^{-1}
412	^{198}Au	2.02×10^{-2}	6.70×10^{-1}	3.51×10^{-2}	6.37×10^{-1}	1.32×10^{-2}	7.12×10^{-1}
478	^{7}Be	3.23×10^{-2}	6.32×10^{-1}	5.50×10^{-2}	5.89×10^{-1}	2.38×10^{-2}	6.74×10^{-1}
662	^{137}Cs	6.87×10^{-2}	5.45×10^{-1}	1.05×10^{-1}	4.88×10^{-1}	5.97×10^{-2}	5.84×10^{-1}
835	^{54}Mn	9.98×10^{-2}	4.87×10^{-1}	1.43×10^{-1}	4.23×10^{-1}	9.18×10^{-2}	5.21×10^{-1}
1332	^{60}Co	1.66×10^{-1}	3.82×10^{-1}	2.17×10^{-1}	1.30×10^{-4}	1.61×10^{1}	4.06×10^{-1}

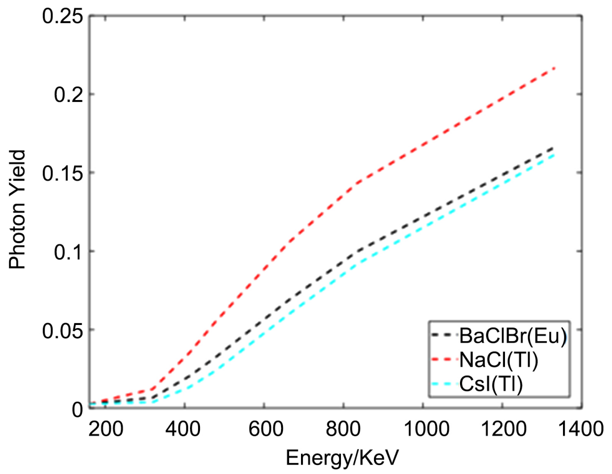

Figure 2. Photon yield of three scintillators under different γ-ray energy.

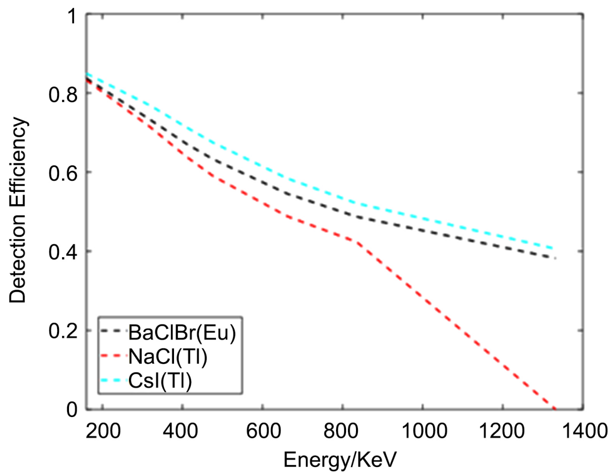

Figure 3. Detection efficiency of three kinds of scintillators under different γ-ray energy.

show the changes in photon yield and detection efficiency of BaClBr(Eu) scintillators, NaCl(Tl) scintillators, and CsI(Tl) scintillators. It can be seen from **Figure 2** that the photon yield of BaClBr(Eu) scintillator is lower than that of NaCl(Tl) scintillator, and the photon yield is higher than that of commonly used CsI(Tl) scintillator, indicating that BaClBr(Eu) scintillator has a relatively excellent photon yield. It can be seen from **Figure 3** that the detection efficiency of BaClBr(Eu) scintillators and NaCl(Tl) scintillators in the low-energy range are relatively close, and the detection efficiency in the high-energy range far exceeds the latter. The detection efficiency of BaClBr(Eu) scintillator and CsI(Tl) scintillator is relatively close.

5. Conclusion

According to the simulation results of the MCNP5 program, the photon yield and detection efficiency of the scintillator detector are affected by the size of the scintillator. They also are affected by the magnitude of the ray energy. The detection efficiency of the scintillator detector increases as the size of the scintillator increases. The photon yield of the new BaClBr(Eu) scintillator detector is not as good as that of the traditional NaCl(Tl) scintillator, but the detection efficiency is higher than that of the NaCl(Tl) scintillator, which indicates that the new BaClBr(Eu) scintillator detector has excellent detection effectiveness. Under different γ-ray energies, the photon yields detected by the BaClBr(Eu) scintillator detector and the CsI(Tl) scintillator are relatively close, and both are lower than the NaCl(Tl) scintillator detector, indicating that its scintillation performance is good. The detection efficiency of BaClBr(Eu) scintillator detector is equivalent to CsI(Tl) scintillator detector under high and low energy rays. The detection efficiency of BaClBr(Eu) scintillator detector is compared with NaCl(Tl) scintillator detector under low energy rays. It is far surpassing NaCl(Tl) scintillator detector under high-energy rays. The simulation results of this research show that the new BaClBr(Eu) scintillator detector has good scintillation performance (energy resolution) and detection efficiency, which can be a reference for the manufacturing and selection of scintillator detection.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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