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Simulation study of BGO array for characteristic gamma rays from neutron-stimulated elements

TANG Shibiao[1,*] MA Qingli[2] YIN Zejie[1] HUANG Huan[1]

([1] Department of Modern Physics, University of Science and Technology of China, Hefei 230026, China;
[2] Electronic Department, Electronic Engineering Institute, Hefei 230037, China)

Abstract Characteristic gamma rays of 100 keV to about 6 MeV from different elements stimulated by neutrons have been applied to diagnostic biological imaging. In this paper, BGO detectors are used for the spectrum simulation. Signals from a single crystal and after correction are both simulated, and the energy spectrum summing adjacent signals seems possible to achieve excellent energy resolution for each high-energy photon. Some ideal suppositions are involved and more other information, such as spatial resolution and difficult electronics, should be considered after this correction.

Key words Gamma, BGO, Correction, Energy spectrum
CLC numbers TL816$^+$.2, R817.4

1 Introduction

Nowadays, characteristic gamma rays of different elements stimulated by neutrons have been applied to many new diagnosis approaches, such as neutron stimulated emission computed tomography (NSECT)[1-3], an imaging technique to provide in vivo tomographic spectroscopic image of elemental distribution in a body. Similar in concept to conventional gamma emission computed tomography (ECT), NSECT can be pictured as a modification of ECT where the gamma emissions are not from radioisotopes, but instead are from stable isotopes that are stimulated to emit characteristic gamma photons through inelastic scattering of an external neutron beam[1-3]. These stable isotopes can be either a natural part of the body composition or an introduced label that is tagged to a molecule of interest. While similar in concept, NSECT places significantly different requirements on imaging technology from ECT. The gamma energies from the stimulated emissions range from below 100 keV to about 6 MeV[1-3]. Therefore, in previous reports[4-6], the projection path is defined by the neutron beam position and the detector with sufficient detection efficiency does not require reporting any spatial information.

In this paper, computer simulations focused mainly on characteristic gamma rays from neutron stimulated elements and the BGO array for high-energy photons are reported. The possibility of correcting the gamma spectrum by summing adjacent BGO signals is discussed.

2 Methods

To achieve high resolution for high-energy gamma ray spectra of scintillation detectors, a fast, dense and bright scintillator is required. Due to its high density of about 7.1g/cm^3 and short luminescence decay time (~300ns), bismuth germanate (BGO) is widely used in positron emission tomography (PET)[7-8]. In this study, BGO was used to compose a scintillator array. To achieve considerable spatial resolution, the pixel of BGO is 5 mm×5 mm. For better

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* Corresponding author. E-mail: [illegible]
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detection efficiency and low cross talk, the BGO detectors are 4 cm in length. A polished reflection mode with air layer was added in the simulation[9].

The simulation was carried out using GEANT4.8.1 Monte Carlo toolkit, which was initially developed for simulating performance of detectors used in nuclear and high energy physics experiments[10,11], and has been used in other applications, such as space radiation physics[12] and medical physics[13]. It can trace the particle trajectories and their interactions with materials as they pass through a medium.

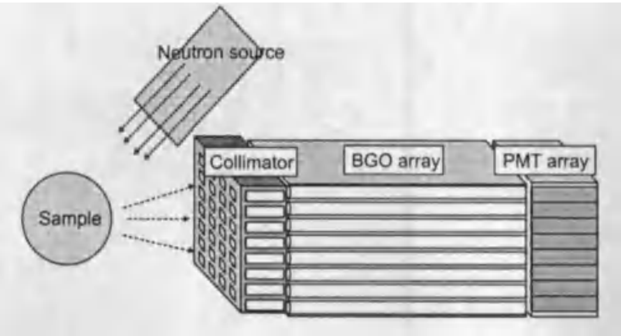

Fig.1 The experimental apparatus for simulation.

As shown in Fig.1, neutrons from a source interact with elements of the sample and characteristic gamma photons are emitted through inelastic scattering. Since we focus on gamma spectrum of the BGO array in this study, we introduced an ideal collimator that stop particles of various energies once they hit the collimator walls, though it is very difficult to construct such a perfect collimator for high energy photons. After passing the collimator, the gamma photons are detected by a 20×20 BGO array through Compton effect, pair-production, and other interactions[14]. A set of models describe these processes and its corresponding interaction thresholds with certain those processes are implemented in the Geant4 toolkit. The low-energy electromagnetic physical model was chosen in the Geant4 simulations[15]. Photons entering the BGO array and the secondary particles created in it were tracked. Particle energies below a secondary production threshold would be deposited inside the detectors. The secondary production threshold was established by defining a range cut, which is the traveling distance of the particles[10,16]. In our simulation the range cut was 0.1 mm for all the particles. Such a range corresponded to a production threshold of 1 keV for photons in plastic scintillation fibers (PSF). We found that as long as the BGO diameter is much larger than the range cut, the simulated energy deposition is not sensitive to the range cut chosen. The minimum diameter of the BGO simulated in this work was above 1 mm. Thus the results obtained using the 0.1 mm range cut should be reliable.

3 Simulation results

3.1 Simulated photon spectrum of Fe

The simulated photon spectrum of Fe under a 6 MeV neutron source is given in Fig.2. As can be seen, a specialized peak is at about 0.846 MeV, another peak over 6 MeV is the background. By detecting the characteristic photons, Fe distribution in a black body can be presented.

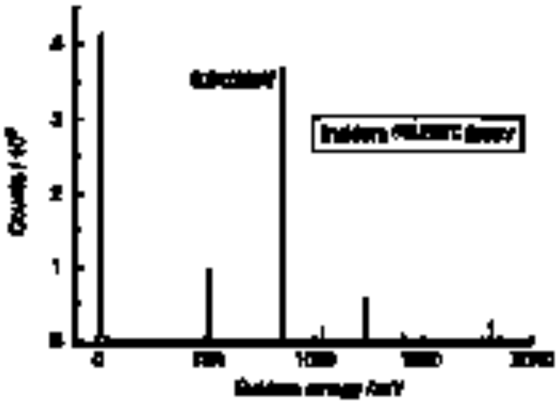

Fig.2 Simulated Iron spectrum to incident neutron energy of 6 MeV.

3.2 Energy spectrum of BGO

When we characterized the BGO array, a gamma source, instead of a neutron source, was used directly to save computer time. Because the photon energy ranges from about 100 keV to 6 MeV, incident gamma rays of 2, 4 and 6 MeV were chosen. They should be appropriate in describing general characteristics of the detector array, and could be applied in lower energy ranges, where Compton scattering and pair-production effects are the dominating interaction[14].

In simulating the gamma spectrum of a single BGO, due to severe energy leakage, three unwanted effects were found, i.e. Compton continuum spectrum (CC), single-escape peak (SE), and double-escape peak (DE), as shown in Fig.3, in which the full-energy peak for 6 MeV is not likely to distinguish.

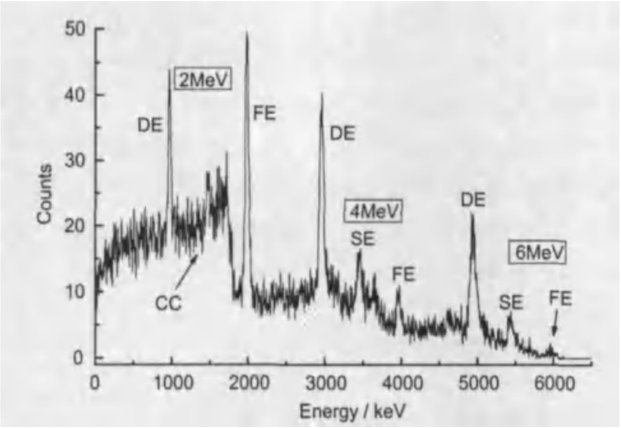

Fig.3 Simulated spectrum for single crystal output in BGO array (CC: Compton-Continuum Spectrum, SE: Single-Escape Peak, DE: Double-Escape Peak, and FE: Full-Energy Peak).

3.3 Spectrum correction

Obviously, such a blurry full-energy peak should be improved to achieve appropriate energy resolution. In this work, we did a correction with the incident gamma rays by summing signals from adjacent crystals to the crystal of interaction to improve the detector performance. To achieve a good approximation in terms of spatial resolution, the correction was done only when the crystal had the maximum signal among its adjacent summing crystals.

This method is a compromise by increasing the complexity of electronics to improve the energy resolution. Summing different adjacent crystals (4 or 8) was studied in this work. Three ways of summing the crystals, i.e. no summing, summing four adjacent crystals, and summing eight adjacent crystals, are illustrated in Fig.4. By comparing the results of summing different kinds of crystals, we were able to choose the most proper one for high energy photons.

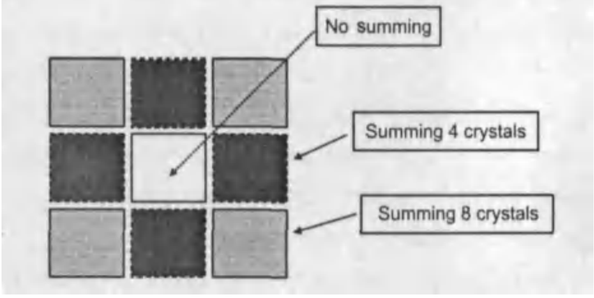

Fig.4 Three kinds of crystal in the summation: crystal of interaction, crystal for summing 4 adjacent crystals, and crystal for summing more 4 adjacent crystals.

The comparison between spectra with and without the correction is illustrated in Fig.5. The spectrum was improved indeed after the correction. The full-energy peak of 6 MeV gamma rays became much more distinct. However, summing eight crystals did not produce an obvious improvement to the result of summing four crystals, and we should be cautious of summing more crystals. On the other hand, using more crystals means more cables and sophisticated electronics. Therefore, we will use only four adjacent crystals.

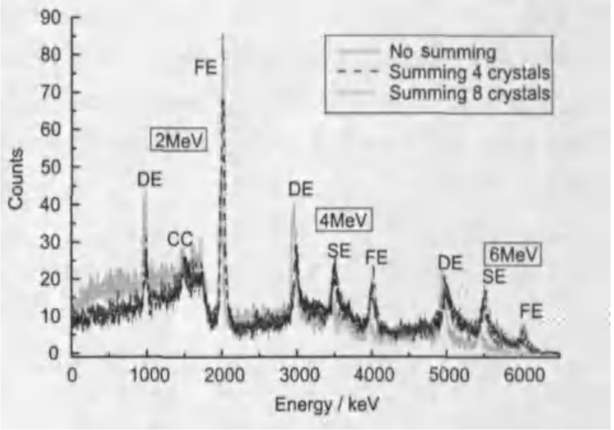

Fig.5 Spectrums with and without the correction.

3.4 Energy resolution

The energy spectrum of summing four adjacent crystals in Fig.5 shows a considerable background. For the reason of simplicity, full width at half maximum (FWHM) of the three peaks (CC, SE, and DE) were used to quantitatively assess the sharpness of the peaks. The average FWHM of 60, 110 and 130 keV were found for 2, 4 and 6 MeV gamma rays, respectively. In practice, the non-monochromatic incident gamma rays and the practical collimator will certainly further degrade the energy resolution.

4 Discussion

In summary, it means that using signals from single BGO crystal is impossible to achieve excellent energy resolution for gamma rays from 100 keV to about 6 MeV. When summing additional signals from adjacent crystal, the energy spectrum becomes much better for gamma rays in this energy range. In this study, some ideal suppositions were introduced and the actual performance will certainly be poorer, especially when the background is introduced. Furthermore, how to have a compromise between the energy resolution and other information, such as spatial resolution and difficult electronics, through summing adjacent signals should be considered in future.

References

1 Floyd C E, Howell C, Harrawood B, *et al.* Medical Imaging 2004: Physics of Medical Imaging, Proceedings of SPIE, 2004, **5368**: 248-254.

2 Floyd C E, Bender J E, Sharma A C, *et al.* Physics in Medicine and Biology, 2006, **51**(14): 3375-3390.

3 Tang S, Yin Z, Zhu D, *et al.* Nuclear Techniques, 2007, **30**(3): 189-191.

4 Floyd C E, Sharma A C, Bender J E, *et al.* Nuclear Instruments and Methods, 2007, **B254**: 329-336.

5 Liu H C. SPIE Conference on Input/Output and Imaging Technologies, 1998, **3422**: 293-297.

6 Simone W, Daniela C, Marcel K, *et al.* IEEE Trans Nucl Sci, 2003, **50**(5): 1370-1372.

7 Zavattini G, Domenico D G, Gambaccini M, *et al.* IEEE Trans Nucl Sci, 2003, **52**(1): 222-230.

8 Carrier C, Lecomte R. Nuclear Instrum Methods, 1990, **A292**: 685-692.

9 Agostinelli S, Allison J, Amako K, *et al.* Nucl Instr Meth, 2003, **A506**: 250-303.

10 Allison J, Amako K, Apostolakis J, *et al.* IEEE Trans Nucl Sci, 2006, **53**(1): 270-278.

11 Gurtner M, Desorgher L, Fluckiger E O, *et al.* Advances in Space Research, 2006, **37**(9): 1759-1763.

12 Tang S B, Yin Z J, Huang H, *et al.* Nuclear Science and Techniques, 2006, **17**(5): 276-279.

13 Knoll G F. Radiation detection and measurement, Hoboken: John Wiley & Sons, 2000.