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

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

**Key words**  Geant4, BGO, Correction, Energy spectrum

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## 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) [1,2], 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[1,2]. 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[1-4],

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 germinate (BGO) is widely used in positron emission tomography (PET)[5-7]. 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

detection efficiency and less cross talk, the BGO detectors are 4 cm in length. A polished reflection mode with air layer was added in the simulation[8].

The simulation was carried out using GE-ANT4.8.1 Monte Carlo toolkit, which was initially developed for simulating performance of detectors used in nuclear and high energy physics experiments[9,10], and has been used in other applications, such as space radiation physics[11] and medical physics[12]. It can trace the particle trajectories and their interactions with materials as they pass through a medium.
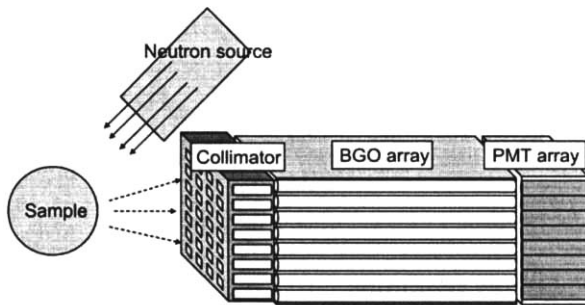


**Fig.1**    The experimental apparatus for simulation.

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[13]. A set of models describe these processes and in corresponding interaction thresholds with matters these processes are implemented in the Geant4 toolkit. The low-energy electromagnetic physical model was chosen in the Geant4 simulations[9]. Photons entering the BGO array and the secondary particles created in it were traced. 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[9,10]. 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 pho-

tons in plstic 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    Stimulated 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 speculated peak is at about 0.846 MeV, another peak near 0 MeV is the background. By detecting the characteristic photons, Fe distribution in a black body can be presented.
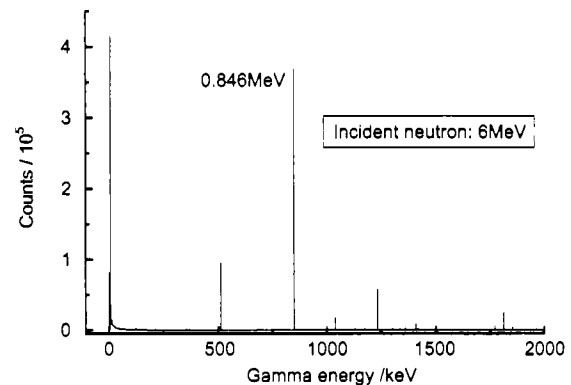


**Fig.2**    Simulated iron spectrum as incident neutron energy is 6 MeV.

### 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[13].

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 too blurry to distinguish.