Modeling of Gamma Response of BGO using GEANT4

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Introduction

Development of an experimental system based on Tagged Neutron Method [1] for illicit material detection using in-house developed DT neutron generator at BARC is under progress. The system has a position sensitive (64 multi pixel of YAP:Ce) alpha charged particle detector coupled with DT neutron generator, gamma detectors (BGO) and VME based front end electronics. The underlying principle is to use 14 MeV neutrons tagged by associated alpha charged particles. Gamma rays are produced when neutron undergoes inelastic scattering or other reactions induced by fast neutrons, in the materials of interest. They are detected by fast gamma-ray scintillation detectors. Detecting them in coincidence with the alpha particle allows the construction of a neutron time-of-flight (TOF). The use of tagged neutrons improves the signal to noise ratio in gamma detection. Gamma-ray spectroscopy provides information about the elemental composition of the interrogated materials, because the energies of the gamma rays are specific to the present isotopes. These energy spectra are unfolded by using a database of pure element spectra. The relative fractions of carbon, oxygen and nitrogen are then calculated to discriminate explosives (small C/O and C/N ratios), drugs (high C/O and C/N) and benign substances (intermediate ratios).

The gamma detector is a major component of such systems and their response for gamma (~1-10 MeV) play significant role in spectrum analysis, unfolding with data base of pure elements as well as in quantitative analysis of complex spectra. Building a data library of the major elemental gamma-ray signatures (C,O,N, Al, Fe, Si, Na, Cl, K and Pb etc) to unfold their contributions in the spectrum of inspected item with tagged neutron system is a challenging task. Due to the long and difficult process of building reference database experimentally with API system, at first hand it is always preferred to have simulation approach. In order to understand the realistic spectral features of various elements and to generate database of elemental signatures with API system vi simulation, response of the gamma detector must be incorporate in simulation.

In this context, a simulation study to model the BGO's gamma response at different gamma energies (0.511-4.44 MeV) was performed and compared with experimentally measured one. For the measurements the gamma sources ^{22}Na, ^{137}Cs and ^{60}Co were used with the BGO and high energy response at 4.438 MeV was measured using an Am–Be source (30 mCi). This source emits neutrons with typical neutron spectrum [2], together with photons of energy 4.438 MeV.

$$^{241}\mathrm{Am} \rightarrow {}^{237}\mathrm{Np}+\alpha$$
$$^{9}\mathrm{Be}+\alpha \rightarrow {}^{12}\mathrm{C}+n+\gamma\ (4.438\ \mathrm{MeV})$$

In this paper we report the simulation study performed for gamma response of the BGO for energy range 0.511-4.44 MeV.

Methodology

The simulations were performed using Geant4 [3] with the standard electromagnetic interaction package. GEANT4 offers a Monte Carlo programming environment for simulating problems of production and transport of radiation through different materials. Simulations were carried out with histories of 10^5. In simulation, a simplified model of detector cell of 76 mm diameter having cylindrical shape filled with $Bi_4Ge_3O_{12}$ material of density 7.13 gm-cm^{-3} was considered. The detector was surrounded by an aluminum casing of 1 mm thickness. For the purpose of the gamma response simulation, a point source of gamma-rays was positioned along the cylindrical symmetry axis of the detector cell at a distance of 10 cm from its face. The source emission was forced into the solid angle subtended by the detector. The response was simulated for monoenergetic gamma energies of 0.511 MeV, 0.662 MeV, and 4.438 MeV. In order to mimic the ^{60}Co source, two energies (1.173 and 1.330 MeV) were emitted with a particular ratio. The amplitude of the detector signal was provided by a sensitive-detector class which recorded the total energy deposited in the detector volume. To obtain the response function and match with experimental spectrum it is essential to apply some corrections. The major correction is for the effect of energy resolution observed in the experimental spectrum which depends on the energy of the photon. The required energy broadening factor was generated using the energy resolution (FWHM) of experimental spectrum at gamma energy 662 KeV and introduced it in the simulation.

Results and discussion

Simulated and measured energy spectra of different gamma energies 0.511 MeV, 0.662 MeV, 1.173 MeV&1.330 MeV and 4.438 MeV are presented in Fig1. It shows that the simulated spectra are in close match with experimental result except at 4.438 MeV energy. The energy resolution at 4.438 MeV obtained from experimental spectrum of Am-Be was 5.8 % slightly higher than that of 4.6 % obtained through simulated spectrum. This is due to the presence of neutron spectrum and neutron induced gamma background from Am-Be isotropic source in the experimental data which was not taken into account in simulation.

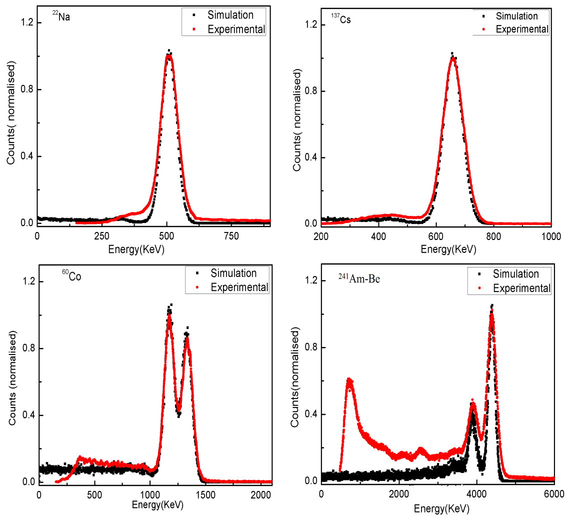

Fig. 1 Simulated and measured (normalized) gamma energy spectra of BGO.

Conclusion

A BGO detector of 3”x 3” was successfully modeled in GEANT4 for gamma response in the energy range of 0.511-4.44 MeV. The simulated spectra were in close match with experimentally measured ones.

References

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