Simulation of a CZT - detector for application in SPECT imaging using GATE – a Geant4 plug-in

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Introduction

GATE (Geant4 Application for Tomographic Emission) is an advanced open source software that plays a major role in the design of new medical imaging devices, in the optimization of acquisition protocols and in the development and assessment of image reconstruction algorithms and correction techniques. It can also be used for dose calculation in radiotherapy experiments [1]. GATE supports simulations of Emission Tomography (Positron Emission Tomography - PET and Single Photon Emission Computed Tomography - SPECT), Computed Tomography (CT) and Radiotherapy experiments. It makes use of an easy-to-learn macro mechanism to configure simple or highly sophisticated experimental settings. Our research group at SSSIHL aims to design a CZT based detector for use in a small field of view imaging gamma camera. For this purpose, a CZT detector with a specific collimator design was simulated and its performance parameters like energy resolution, spatial resolution and detector efficiency were analyzed.

Detector Geometry

The dimension of the CZT [2] detector built was 96.8 mm × 96.8 mm × 0.5 mm (thickness) in 2×2 modules of 22×22 pixelated detectors yielding a total of 44×44 detector pixels. Each pixel was of 2×2×5 mm dimension with pixel pitch (made of plastic) of 2.2 mm.

Collimator Model:

The pixel-geometry-matching square-holed collimator was constructed with lead as collimator material. The collimator's hole size was matched to one detector pixel so that the center of each pixel was in a one-to-one correspondence to the detector.

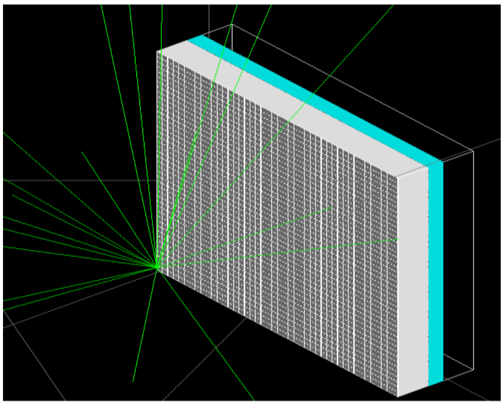

Fig. 1: Visualisation of the simultated gammas from a Co-57 source, interacting a collimator-detector geometry.

Results

1. Energy Resolution

The simulated energy deposition curve for CZT and NaI based detectors is shown in Fig. 2. The CZT based detector with its 5% resolution could resolve the two peaks for the Co-57 source at 122 KeV and 136 KeV while the NaI based detector with 10% resolution could not resolve the same.

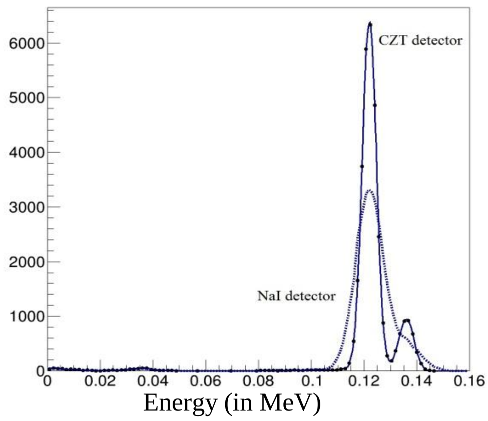

Fig. 2: GATE simulation of a Co-57 γ-spectrum taken using a CZT and a NaI detector.

2. Spatial resolution:

Spatial resolution is dependent on various factors. A simplified model was used taking into account only the (R_{int}) intrinsic spatial resolution (which was taken as the pixel size i.e 2mm) and the (R_{col}) collimator resolution contributions.

For analytical estimation [2]:

$R_{spa} = \sqrt{R_{int}^2 + R_{col}^2}$; $R_{col} = \frac{D}{L}$ x $(S_0 + L)$

where D-hole diameter, S_0-source distance, L-length of the collimator. L_{eff} used in [2] was approximated to L, neglecting the penetration effect.

For the pixelated detector, the R_{spa} was found by measuring the FWHM of the curve obtained by integrating the counts along the Y-axis and was compared with the analytically expected values (Table 1).

Table 1: Spatial Resolution for different collimator lengths and for different Source-Collimator distances. [Sim– simulated values; An- Analytical data calculated using above eq.s].

S-C Dist. (cm)	Spatial Resolution for collimator lengths-					
	1 cm		2 cm		3 cm	
	Sim	An	Sim	An	Sim	An
0	1.8	2.8	0	2.8	0	2.8
5	9.3	12	4.9	7.3	5.2	5.7
10	24	22	6.8	12	7.4	8.9
15	33	32	11	17	4.2	12
20	33	42	14	22	11	16
25	47	52	18	27	13	19
30	47	24	32	15	22	24

Table 2: Detector efficiency for different collimator lengths and for different Source-Collimator distances.

S – C Dist. (cm)	Detector Efficiency (%) for collimator lengths-		
	1cm	2cm	3cm
0	1.07	0.11	0.02
5	0.33	0.06	0.03
10	0.30	0.06	0.03
15	0.27	0.06	0.03
20	0.26	0.06	0.03
25	0.24	0.06	0.03
30	0.22	0.06	0.03

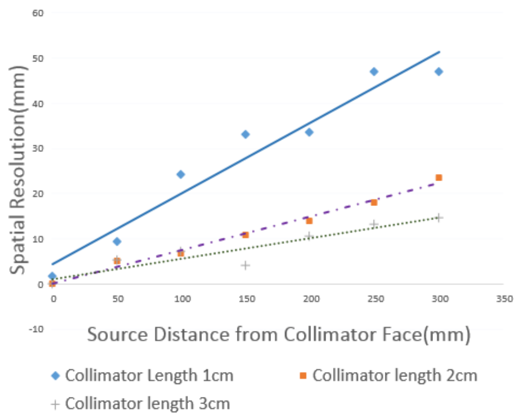

Fig. 3: Comparison of Spatial Resolution for different collimator lengths and different Source-Collimator distances.

For a given collimator length the resolution deteriorated with increasing source- collimator distance and for a given distance thicker collimator produced better resolution as illustrated in Fig 3.

3. Detector efficiency

The detector efficiency (reported in Table 2) was calculated from the simulation by taking the ratio of the number of detected particles to that of number of emitted particles.

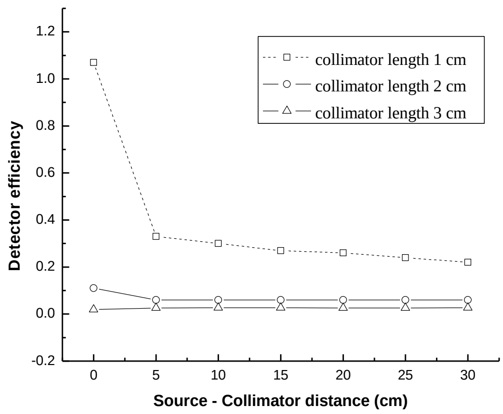

Fig. 4: Detector efficiency Vs. Collimator-source distance for different collimator length.

References

[1] http://www.opengatecollaboration.org/
[2] http://www.evproducts.com/spect_imager
[3] IEEE Nucl Sci Symp Conf Rec (1997).2013; 2013: 1–4