Design and optimization of a collimator for a New PET system using GATE simulation

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Introduction

Single Photon Emission Computed Tomography (SPECT) and Positron Emission Tomography (PET) are increasingly used as diagnostic tools for cancer treatments. These techniques do not yield the locations of decay vertex of individual emissions which necessitate the statistical methods. The image reconstructions rely on the directionality of photons emitted from the sources embedded in patients' bodies, and resort to back projection techniques to locate the tumors. In case of PET, an additional disadvantage is the random motion of positron before its annihilation, which blurs the image.

It is well known feature of gamma cascade decays of radioactive isotopes that the angular correlations, while being specific to each pair, are non-collinear. Thus a coincidence detection of the pair, with same electronic arrangement as in PET, will yield the decay vertex of each nucleus and constitutes an image point. This is achieved by attaching a multi-hole collimator, just as in SPECT. While there is a loss of geometric efficiency due to collimation, it would be more than overcompensated by the image reconstruction efficiency.

We identified the 372 and 617 keV γ- ray pair in the decay of ^{43}K (β^-)^{43}Ca as a good test case. Rangacharyulu et al. [1] produced this isotope by ^{44}Ca(p,2p)^{43}K reaction at the AVF cyclotron of RCNP, Osaka university and ascertained the nearly uniform angular correlations of this pair.

As we embark on the next phase of establishing this new modality of medical imaging with cascade γ- correlations, we are engaged in imaging with a prototype micro PET system of RIKEN/ KOBE laboratory with a collimator attachment. To design and optimize the collimator, we use the GATE simulation toolkit [2].

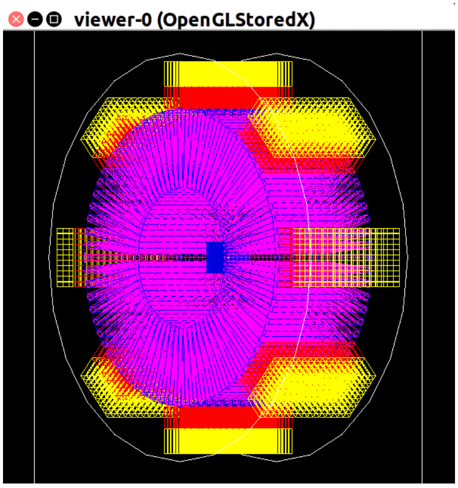

Fig. 1 The micro PET system attached with the cylindrical (ring-like) collimator

An overview of the simulation

In the macro file, we begin by designing the geometry of the cylindrical PET system. This is done by specifying the dimensions of a ring like structure having an inner radius of 47.5 mm and an outer radius of 65.0 mm. Enclosed in the ring is a cuboid, called as a module, of dimensions 15 x 18.7 x 37.5 mm, which contains a dual layer matrix of 165 GSO detectors [3], of dimensions 15 x 1.6 x 2.4 mm, that fills the cuboid. The module is then repeated 8 times around the ring. To choose a suitable collimator shape, we use a pencil beam source. This pencil beam is directed along the *x*-axis, having a beam radius of 1mm, the number of primaries (γ-rays) being 10^4 and each primary having an energy of 617 keV. Our aim is to choose between a cylindrical (ring-like) collimator [Fig.1] and a cuboidal one, [Fig.2], both having the same depth (2.5 cm) and containing the same material (lead). In the cylindrical collimator, the holes are arranged such that they point radially outward and, in the cuboidal one, the holes are arranged in the conventional uniform matrix format. These holes are hexagonal in shape, of length 2.5 cm and contain air. The length of the septa, in the cylindrical collimator, for a fixed angle is 1 mm. The length of the septa is also 1 mm for the cuboidal collimator.

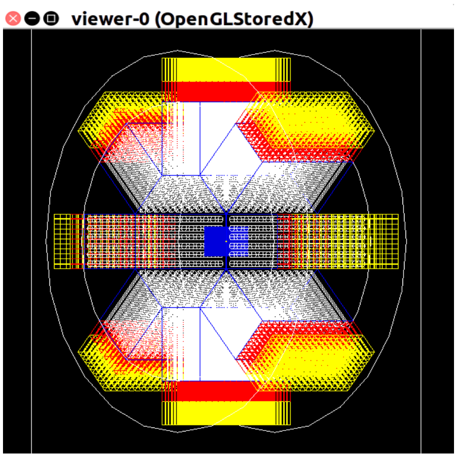

Fig. 2 The micro PET system attached with the cuboidal collimators

Results and discussion

The output was generated as a *root* file. By changing the placement of pencil beam along the *y*-axis, the number of events (a measure of the sensitivity of the system) recorded by the detectors was displayed in the form of a histogram [Fig. 3(a) and 3(b)]. This procedure was repeated for both the cylindrical and the cuboidal collimator and, the values obtained were tabulated [Table1]. From this table, we inferred that if the source is off-center, then the sensitivity of the detector falls sharply for the system attached with the cylindrical collimator as compared to the cuboidal one. So, the collimator best suited for the new PET is cuboidal. To optimize the cuboidal collimator, we let the pencil beam pass completely into a hole and note the number of events registered. We then orient the pencil beam completely on the septa. We again check for the number of events recorded by the detectors. Then, we change the length of the septa and the orientation of the beam simultaneously till we obtain the least number of events. This happens only for the proper septal length. The collimator material can be chosen by repeating the above process.

Table1: Number of events for diff. placings

Sl. No.	Placement (x,y,z) mm	Total events	
		Cyl. Coll.	Cub. Coll.
1	(0,0,0)	1382	3881
2	(0,5,0)	304	2020
3	(0,7,0)	361	2054

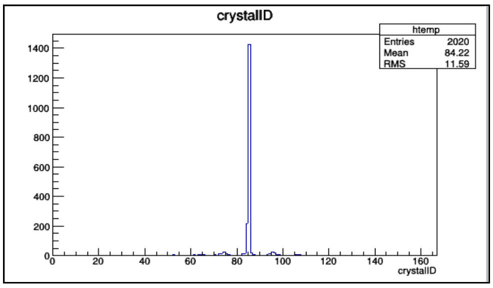

Figure 3(a): For the cuboidal collimator

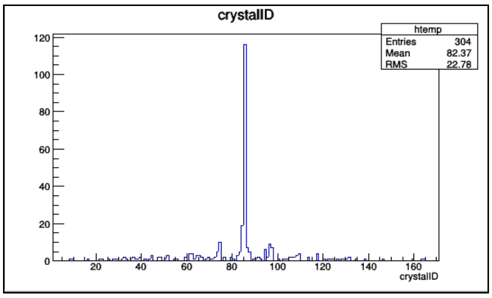

Fig.3(b) For the cylindrical collimator

Figs.3: The histograms showing the number of events recorded by all the 165 detectors in all modules for (a) the cuboidal collimator and (b) the cylindrical collimator.

References

[1] C. Rangacharyulu, T. Fukuchi et al, "Angular correlations of γ- cascade of ^{43}K β- minus as novel medical imaging modality" Private communication

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