Comparative Study of Sensitivity, CTR, and Energy Resolution in Different Crystal Shapes for Optimization of Total-Body PET

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Introduction

The total-body positron emission tomography (PET) scanner marks a significant advancement in nuclear medical imaging technology [1]. This study aims to calculate and compare sensitivity, intrinsic coincident time resolution (CTR) and energy resolution at different source positions for three different detector crystals: Standard cuboid-shaped LYSO (Lutetium-Yttrium Oxyorthosilicate), pyramid shaped LYSO [3] and pyramid shaped $CeBr_3$ (Cerium Bromide). We also cross-validate the sensitivity of the uEXPLORER scanner using the GEANT4 simulation toolkit [2], to use its geometry in the comparative study of sensitivity. This evaluation provides insights into the merits of different scintillator materials and geometries for total-body PET applications. These findings help optimize future scanner designs, benefiting nuclear medicine.

GEANT4 Simulations

The uEXPLORER total-body PET scanner with LYSO crystals was simulated using GEANT4 with actual scanner parameters [4]. Sensitivity was measured according to NEMA-2018 standards [5] using a line source phantom (700/1700 mm length, 2/3.2 mm inner/outer diameter) containing F-18 (3.84 MBq). Sensitivity calculations involved progressive 2.5 mm aluminum layers, and results were extrapolated to ideal sensitivity (Count Rate/Initial Activity) without attenuation, validated against experimental data. Using the same geometry, we measured sensitivity for pyramid-shaped LYSO and $CeBr_3$ detectors.

For CTR measurement, two single detector crystals (2.76×2.76×18.1 mm) were placed 25 cm apart with a ^{22}Na source in between. The crystals were modified to pyramid shaped LYSO and $CeBr_3$ to study CTR improvements. Optical photons were simulated with an optical physics list and reflector-surface properties. One face of the detector was made sensitive to optical photons generated from 511 keV gamma photons. CTR was defined by the FWHM of the time difference between first-hit coincident photons. The same setup was used to investigate energy resolution dependence on source angular position for LYSO cuboid, LYSO- Pyramid, and $CeBr_3$-Pyramid detectors.

Results

1. Sensitivity

The simulation results for LYSO sensitivity at a 0 cm transverse offset showed 176 kcps/MBq for the 70 cm phantom and 153 kcps/MBq for the 170 cm phantom, closely matching experimental values of 174 kcps/MBq and 146 kcps/MBq,

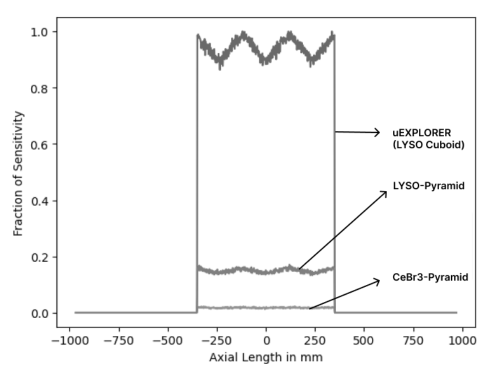

Fig 1: Axial sensitivity profile of scanner with different crystal geometries

respectively [4]. Using the same scanner geometry, we calculated the axial sensitivity

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(Fig. 1) for pyramid-shaped LYSO and $CeBr_3$ crystals, which are 20% and 1% of the LYSO cuboidal sensitivity. The profile's plateau regions show multiple peaks and valleys due to a maximum 4-unit (84 rings ea.) difference between coincident crystals.

2. CTR

The pyramid-shaped crystal demonstrated superior intrinsic CTR compared to the standard cuboidal LYSO crystal (Fig.2). achieving an impressive CTR of 42.6 ps and 27.2 ps, respectively, for LYSO and $CeBr_3$. This represents a massive improvement over the 107 ps observed with the standard LYSO crystal.

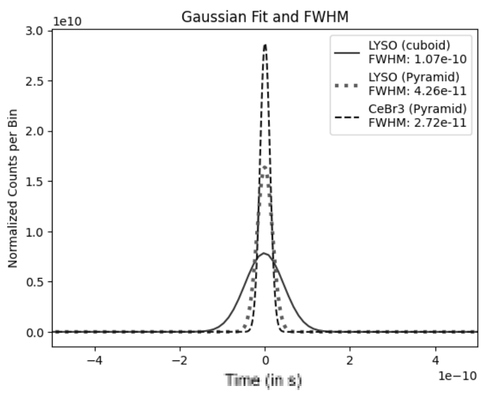

Fig 2: CTR values for different geometries of LYSO and $CeBr_3$ crystal.

3. Energy Resolution

Energy resolution remained largely constant across different incident angles for all tested different detector materials (Fig.3), indicating that energy resolution is independent of angular positions along the axial line. Pyramid shaped LYSO and $CeBr_3$ showed improvements of 1.15% and 3.37%, respectively, in energy resolution compared to their cuboidal counterparts.

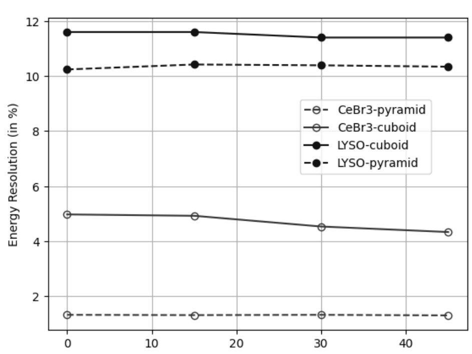

Fig 3: Energy resolution v/s angular position plot for different detectors

Conclusion

Our study reveals that pyramid-shaped crystals significantly outperform traditional cuboidal crystals in time and energy resolution, offering potential advancements in PET scanner design. While pyramid-shaped crystals show decreased sensitivity, this can be mitigated through depth of interaction (DOI) techniques. The axial positioning of the phantom does not substantially impact energy resolution, indicating consistent performance across the scanner's field of view. These findings pave the way for optimized PET scanner crystal geometries, potentially enhancing image quality and quantitative accuracy in clinical and research applications.

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