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Nuclear PET Sensitivity Study using a 68-Ge Line Source

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Abstract

An experimental study of sensitivity was carried out with a newly designed prototype nuclear PET camera having a transaxial field-of-view of 20cm. The goal is to see the scanner detection performance of coincidence events produced in positron-electron annihilation. Coincidence data were acquired in 2D mode using a 68-Ge line source with an activity of 0.4 MBq. The direct plane sensitivity measured as approximately 9% lower than the cross plane except a few end planes. The sensitivity observed in the end planes is anomalously low probably the line source did not extend fully into these planes. By summing counts from all planes, the overall absolute sensitivity was also measured as 8.2 ±0.4 cps/kBq at the centre, 8.7±0.4 cps/kBq at the 5cm off-axis and 9.5±0.4 cps/kBq at the 10cm off-axis. The sensitivity increases slightly as the source is moved off-axis.

Key words: *PET, Sensitivity, 68-Ge line source & Cyclotron.*

1. INTRODUCTION

Positron emission tomography (PET) is a powerful medical imaging technique which produces a three-dimensional picture of functional processes in the body [1-4]. The most sophisticated part of a PET-CT installation is the cyclotron. Cyclotron is a particle accelerator produce proton rich isotopes such as 18-F, 15-O, 11-C etc through nuclear reaction. However, in the PET technique the pairs of back-to-back 511keV γ-rays produced in positron-electron annihilation are used in constructing sinograms followed by PET images. After design, set-up and calibration of a PET camera, it is very important work to measure its characteristics such as spatial resolution, NECR, sensitivity, etc. Sensitivity is one of the more important characteristics of a PET camera. Sensitivity of a PET scanner represents its ability to detect coincidence events for true counts. It is defined as the rate of true events per unit radioactivity. The unit of sensitivity is usually expressed in cps/kBq or sometimes in cps/kBq/ml.

Sensitivity of a PET camera can be measured in various ways. Usually, the sensitivity is measured with a low activity source in the absence of attenuating media where the randoms and dead time contribution are nearly zero. The sensitivity of a positron camera has traditionally been measured using a distributed source of a relatively long-lived tracer (such as cyclotron product 18-F) in water [5-6]. The measurement was then done without doing any scattered and attenuation correction. Later on, many PET scientists found the contribution of Compton scattered gamma rays in the scanner field of view (FOV), which is 2 to 5 times greater when the scanner operated as septaless condition. As the huge amount of scattered events (20-50% or more) contributes in 3D PET, so in case of cylindrical source, a scatter correction must be considered in the calculation of sensitivity. The present work aims to study the PET scanner performance in the detection of coincidence events for true counts using a 68-Ge positron-emitting line source in 2D mode (ring difference ≤ 3) but without septa.

2. MATERIALS AND METHOD

A nuclear PET camera with 16-rings crystal elements and a transaxial field-of-view of 0.2m has been designed as prototype using 64 BGO blocks and electronics. In preparing the newly designed camera for use, three major stages such as 1) testing the detector modules, 2) setup

and 3) normalisation were performed under the calibration process using a uniform positron emitting source. After assembling the camera, we established that the serial line communication worked between the camera and the ECAT Host CPU, and then checked that each detector module responded. The four image plane coincidence processors (IPCPs) and clock were also checked. After setup and proper calibration of the camera, its characteristic of sensitivity was measured. The sensitivity of the system was then measured using a uniform source phantom. The phantom was a relatively long lived 68-Ge line source (CTI services, Inc) 14.1 cm long and 3 mm diameter with an activity of 0.4 MBq [Fig. 1].

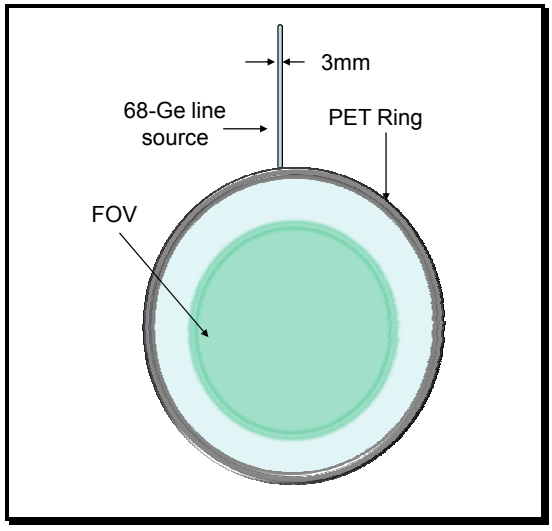

Fig. 1: Block diagram for the measurement of PET sensitivity; the 68-Ge line source was placed at the axial position of the camera field-of-view.

The 68-Ge line source was axially positioned inside the camera FOV. The coincidence data were acquired for the line source at three different positions in the camera field of view. Firstly, the source was positioned at the centre of the camera, and then 5cm and 10cm off-axis. The data were acquired for 5 minutes in each case. The activity of the source was very low so the randoms contribution was extremely low. The data acquired from the line source were used to evaluate the plane sensitivity, axial sensitivity profile and absolute sensitivity of the scanner.

The sensitivity profiles for each axial positions of the camera field-of-view were analyzed by considering the scan files. The counts from all planes were recorded in the calculation. Among these, counts for plane 10 and plane 13 were analysed. Axial sensitivity was represented graphically. The absolute sensitivity was also calculated from the scan files, but in this case all the 31 plane counts were summed as

Total counts = $\sum_{i=1}^{31} P_i$, where P is the plane counts, and 'i' is the number of planes, i.e., i = 1, 2, 3, 4, … … …, 31.

3. DATA ANALYSIS

3.1 Cross Plane Sensitivity (Plane 10)

For 5 minutes scan with the source positioned in the camera field-of-view (FOV) the number of coincidence events in the plane10 was recorded as 29865±173. Therefore, the count rate was

$$\textit{Count rate} \text{ in the plane } 10 = \frac{\text{Number of counts in the plane } 10}{\text{Total acquisition time}}$$

$$= \frac{29865 \text{ counts}}{300 \text{ sec}} = 99.5 \pm 0.6 \text{ cps}$$

The length of the 68-Ge line source was 141±1 mm and its activity was 0.4±0.04 MBq.

The width of each plane is defined as 3.375 mm.

The branching ratio of positron decay in 68-Ge is 0.9, so the positron activity in this plane was

$$0.9 \times 0.4 \times \frac{3.375}{141} = 8.6 \text{ kBq}$$

The sensitivity in the plane can be calculated as

$$\text{Sensitivity in the plane} = \frac{\text{Count rate in the plane}}{\text{Positron activity in the plane}}$$

Therefore the approximate sensitivity in the plane 4 was

$$\text{Sensitivity} = \frac{99.5}{8.6 \times 10^3} = (11.6 \pm 1.3) \times 10^{-3} \text{ cps/Bq}$$

3.2 Direct Plane Sensitivity (Plane 13)

For 5 minutes scan with the source positioned in the camera field-of-view (FOV) the number of coincidence events in the plane13 was recorded as 24686±157. Therefore, the count rate was

$$Count\ rate = \frac{23186}{300} = 77.3 \pm 0.5 \text{ cps}$$

Therefore the approximate sensitivity in the direct plane 4 was

$$= \frac{\text{Count rate in the plane } 13}{Positron\ activity \text{ in the plane } 13}$$

$$= \frac{77.3}{7.97 \times 10^3} = (9.7 \pm 1.1) \times 10^{-3} \text{ cps/Bq}$$

The sensitivities measured for the camera are slightly lower than the theoretical values [7-9] partly because the effective radius of the small ring PET system is greater than 25 cm. The sensitivities values are, therefore, reasonably consistent with those expected theoretically assuming an intrinsic detector efficiency of 0.50 [9]. The direct plane sensitivity is approximately 9% lower than the cross plane sensitivity regardless the end planes.

3.3 Absolute Sensitivity

The absolute sensitivity was calculated from the 31 plane counts obtained from the line source at different axial positions inside the camera field-of-view. The results were calculated by summing counts from all the planes.

- At the centre (0, 0): Coincidence data were acquired for 300 sec from the 68-Ge line source at the centre of the scanner. The line source had activity 0.4 MBq, of which 0.29 MBq was in the camera field-of-view.

  The sum of all plane counts, $\sum_{i=1}^{31} P_i$ = 712956.

  Therefore, allowing for the 0.9 positron branching ratio of 68-Ge, the absolute sensitivity at the centre = 8.2 ±0.4 cps/kBq.

- At the 5cm and 10cm off-axis: Calculations were done using data from the same source and same acquisition time but the positions of the source were different. However, considering the above formula the absolute sensitivity measured as 8.7±0.4 cps/kBq at 5cm off-axis and at 9.5±0.4 cps/kBq 10cm off-axis.

4. RESULTS AND DISCUSSION

Generally, PET scanners are designed with crystal ring based. The manufacturers are currently designed the scanners with small size crystal elements (approximately 4×5×20mm) having 20-35 detector rings. Sinograms are produced using a lot of lines-of-response (LORs). LOR is a line joining the two opposite detectors position. The PET scanner under the study was operated in 2D mode (ring difference ≤ 3) but without septa. Also, we acquired the data for a very low activity source in order to avoid an appreciable amount of randoms (Coincidence events from two unrelated decay). Randoms produced artefacts in the reconstructed image. For producing artefact-free images it needs to avoid any significant randoms and scattered events so that the camera was set as the ring difference ≤ 3. The camera under such condition, the sensitivity was measured in different axial positions inside the camera field-of-view.

The axial sensitivity pattern of the scanner measured using a line source is shown in Fig. 2. According to the figure, all the planes sensitivity in each source position show bio-modal pattern except a few end planes. On the whole, the relative sensitivities correspond closely to the numbers of detector ring combinations contributing to each plane. In the camera under study, direct planes contain 3 combinations while cross planes contain 4 combinations. The end planes (1, 2 and 30, 31) contain only a single combination. It is possible that the line source used in the experiment did not extend fully into these planes. However, the sensitivity observed in the end planes produced by the camera is anomalously very low.

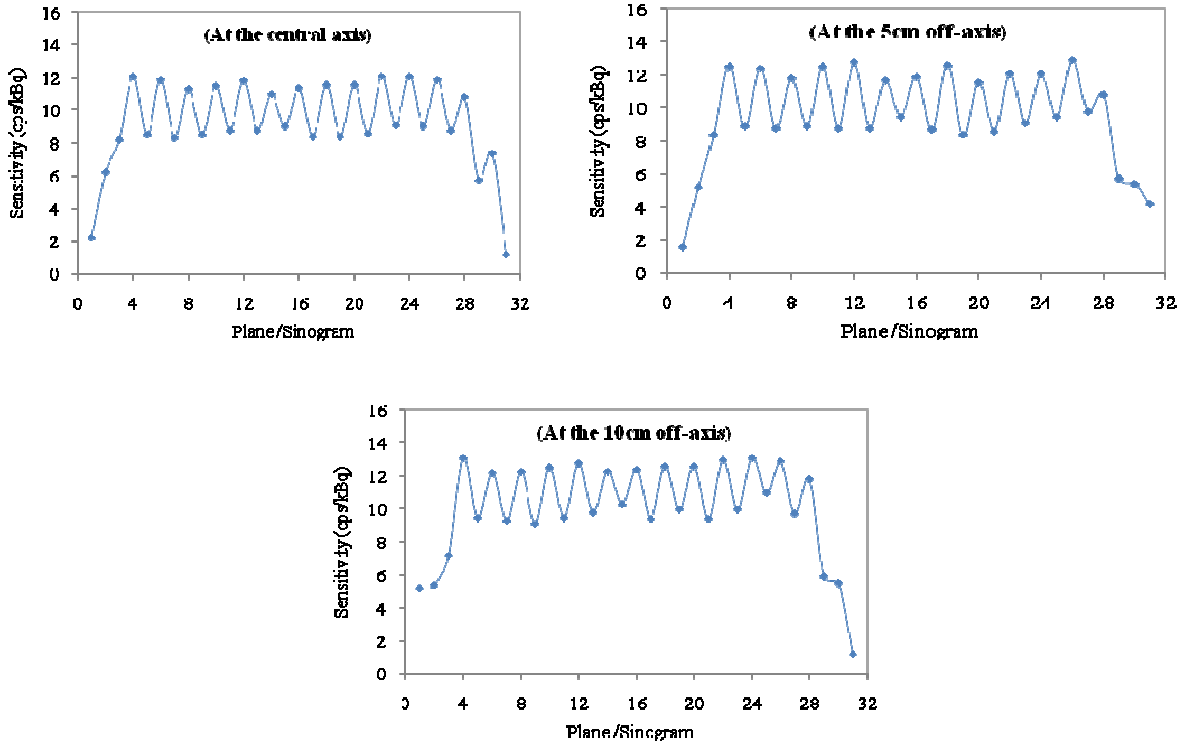

Fig. 2: Sensitivity patterns for a positron emitting 68-Ge line source with an activity of 0.4 MBq was plotted as a function of the axial plane position of the PET camera FOV: i) at the centre (top), ii) 5cm off-axis (middle) and iii) 10cm off-axis (bottom).

The absolute sensitivity values of 11.6 cps/kBq (cross plane) and 9.7 cps/kBq (direct plane) are slightly lower (by approximately 13% in each case) than the values calculated using the simple geometrical model and assuming a detector efficiency of 0.5 [10]. The sensitivity increases slightly as the source is moved off-axis. By summing counts from all planes, the overall absolute sensitivity was also measured as 8.2 ±0.4 cps/kBq at the centre, 8.7±0.4 cps/kBq at the 5cm off-axis and 9.5±0.4 cps/kBq at the 10cm off-axis. The direct plane sensitivity measured as approximately 9% lower than the cross plane except a few end planes.

5. ACKNOWLEDGEMENT

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