^{176}Lu effect on the minimum detectable activity limits for a dual head, LSO:Ce based, PET system.

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***Abstract*—Novel molecular imaging applications increasingly involve studies were very low amount of radiotracer is injected into the subject. This is a challenging problem in terms of image quality, especially when intrinsic radioactivity from the detector is considered. LSO crystals contain ^{176}Lu, which spontaneously emits b^{-} particles and γ photons which increase the statistical noise of the recorded events. Using a dual head PET prototype camera, a series of acquisitions was performed in order to investigate the effect of the energy window to the counting rate performance and the image quality and the minimum detectable activity. In addition, the experiments were simulated with GATE, and the results were validated over the experimental. The used activities ranged below 104kBq. The coincidence images were calculated using the focal plane tomography method. Very good agreement between experimental and simulated results was demonstrated and a well validated model of ^{176}Lu simulation is available. In addition the minimum detectable activity of the system was found to be approximately 13kBq, when a linear capillary source and a 450–650keV energy window were used. Using a wider energy window, 380–650keV, and a cylindrical water phantom with diameter (4cm) we observed a positive impact one image quality at low activities, in terms of SNR. Even thought the rise on the scattered photons was not negligible the positive impact on the simulated true events was considered as a the driving factor.**

***Index Terms*—LSO, SNR, minimum detectable activity, dual head PET, GATE**

I. Introduction

NOVEL molecular imaging applications demand the use of low injected activities to the small animals. These imaging tasks introduce a strong challenge on the system performance. The concept of the minimum detectable activity (MDA) has been extensively investigated for cylindrical geometries [1], [2]. Dual head PET cameras are proven valuable tools for preclinical, imaging mainly due to their low cost, the ability to adjust their field of view (FOV), according to the specific needs and fast creation of planar images which are suitable for radiopharmaceuticals with fast kinetics [3], [4]. The importance of the minimul detactable activity (MDA) rises when referring to ^{176}Lu based scanners which have a non-negligible background count rate, due to ^{176}Lu intrinsic radioactivity.

In this study the authors aim to evaluate the counting performance of a small animal dual head, LSO–based PET prototype at low activities using a high contrast linear source (<105kBq), placed at the center of the FOV. In addition, using the GATE simulation toolkit (v.6.2) [5] a model which simulates the system's geometry, incorporating the ^{176}Lu intrinsic radioactivity, was designed and validated. Furthermore we investigated the effect of different energy windows under these low activity conditions in order to propose the optimal acquisition settings.

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II. Materials and Methods

A. System Architecture & GATE geometry.

The small animal PET prototype camera, which was used as reference, has been extensively presented previously[3], [6], [7]. In brief, it consists of two LSO:Ce based heads, the crystal arrays have 20×20 pixels and H8500 Hamamatsu PSPMTs. The distance between the two heads was adjusted to 70mm, which is suitable for small animal imaging. The coincidence window of the system was 6ns and the hardware threshold was set at 160keV. All coincidence images were reconstructed using the focal plane tomography method (FPT)[3], [8].

The LSO intrinsic radioactivity was simulated using an ion source of ^{176}Lu, which was placed at the same global coordinates as the crystals, but not confined to them[2], [3]. The activity of the ^{176}Lu source was set to $277\frac{Bq}{cm^3}$ as described in literature[9].

B. Sources & Phantoms.

A glass capillary source, 5cm long and with 1.1mm inner diameter, filled with a ^{68}Ga water solution, was placed at the center of the field of view. The ^{68}Ga solution had clearance 99.9%. Successive scans were performed approximately every 20min, as the source decayed naturally from the initial 700kBq activity. The acquisition's as well as the simulation's duration was 300sec, to allow for adequate statistics and unbiased noise properties.

In the simulations, the ^{68}Ga source, was considered to be 100% clear; an ion source was used in order to simulate the complete ^{68}Ga emission spectrum and the natural decay.

III. Results

A. GATE model validation & count rate performance

In the count rate performance experiments an energy window 450 – 650keV, was applied; both in the experimental and the simulated studies. The energy window in the simulations was applied post simulation, during the data processing. The FPT acceptance angle was set at 10°. As illustrated in Figure 1, GATE model predicts accurately the system's count rate performance under the complete range of activities. On Table I the GATE model parameters, are summarized.

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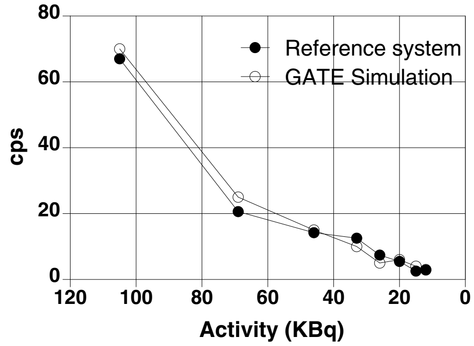


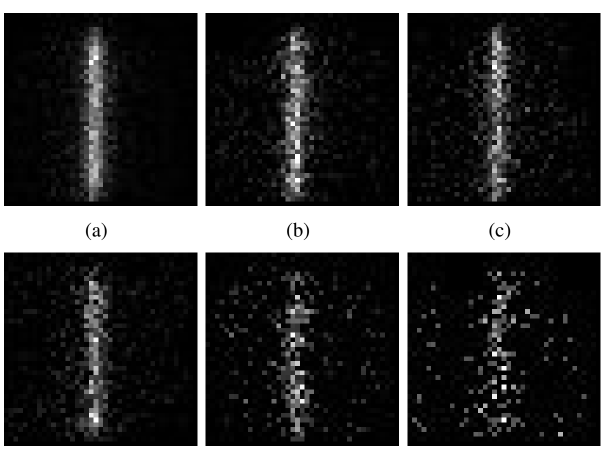
Fig. 1: Validation of the simulation model in terms of cps.

TABLE I: GATE model parameters.

Parameter	Value
Threshold (Singles)	160keV
Dead time (Singles)	2050ns (non paralysable)
Coincidence window	6ns
Dead time (Coincidences)	4000ns (paralysable)

B. Minimum detectable activity

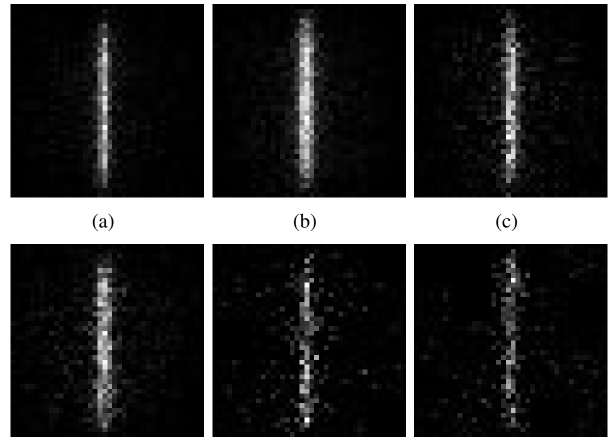
In Figure 2 coincidence images from the reference camera acquired for 300sec with energy window 450–650keV, are illustrated. For the given imaging conditions the MDA was found to be 12.4kBq. The MDA strongly depends on the contrast of the source and the specific imaging conditions.
In Figure 3 simulated coincidence images, with the same acquisition settings as the experimental, are presented. The noise properties of the simulated images appear to be better than the experimental, due to the lack of the simulation of some noise sources e.g. the electronic noise, the statistical nature of the detector's response etc and quality degrading factors like crystal inefficiencies and non homogeneity etc.



(a) (b) (c)

(d) (e) (f)

Fig. 2: Coincidence images from the reference system using a ^{68}Ga source with activity 104KBq(a), 69KBq(b), 46KBq(c), 33KBq(d) 20KBq(e) and 12.4KBq(f).



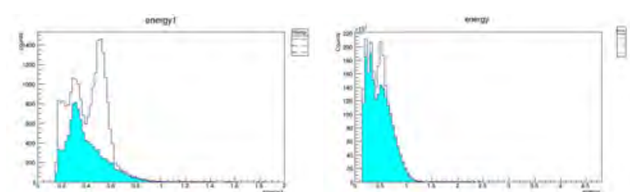
(a) (b) (c)

(d) (e) (f)

Fig. 3: Simulated coincidence images from the reference system model using a ^{68}Ga source with activity 104KBq(a), 69KBq(b), 46KBq(c), 33KBq(d) 20KBq(e) and 12.4KBq(f).

C. Energy spectra

In Figure 4 simulated energy spectra of the coincidences (a) and the singles (b), are illustrated. The activity of the source was 12.4KBq and the simulation time was 300sec. The shadowed portion denotes the ^{176}Lu spectrum. It can be clearly seen, for the specific imaging conditions, the effect of ^{176}Lu on coincidences is rather significant.
A great advantage on our reference system is the 6ns coincidence window which, on higher activities strongly rejects the random events from the ^{176}Lu.



(a) (b)

Fig. 4: Simulated energy spectra from coincidences (a) and singles (b) for 12.4KBq activity. The colored part denotes the recorded events originating from the ^{176}Lu intrinsic radioactivity.

D. Energy window effect and SNR

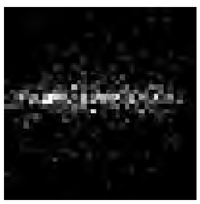
In order to explore the effect of the energy window on the MDA, under more realistic imaging conditions, an additional water phantom was simulated to approximate the scatter fraction on an average mouse body. The water phantom was a cylinder with diameter 4cm and height 5cm centered at the FOV.
Table II shows simulated coincidence images with activity 12.4KBq applying two energy windows. A narrow 450–650keV and a wide 380–650keV. Using a wider window the number of the scattered events is increased. This is an image

quality degrading factor, but on the other hand there is a rise in the true , which enhances the clarity of the source's shape. In addition, using Eq. 1 the SNR of the images was calculated. ROI_1 is selected inside the imaging object while ROI_2 is selected at the background of the image. In order to properly sample the background counts, ROI_2 was the average value of two background ROIs [10]. The size of the ROIs was 149 pixels.

In Figure 5, the SNR values of the corresponding coincidence images are plotted. As it can been seen the SNR peaks on the 350keV energy window lower limit threshold, which is approximately 20% better than with the standard 450keV limit.

$$SNR = \frac{\int ROI_1 - \int ROI_2}{\sqrt{\int ROI_1}} \tag{1}$$

TABLE II: Effect of the energy window on simulated images using activity 12.5KBq.

Parameter	380–650keV	450–650keV
Image	(a) 	(b) 
Total coincidences	1950	1357
Trues	1303	1087
Randoms	7	3
Scattered	630	217
SNR	16.56	14.49

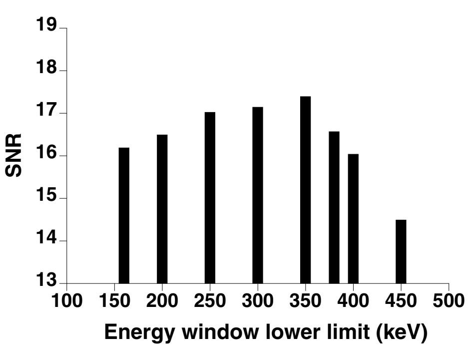


Fig. 5: SNR in respect to the lower limit of the energy window.

IV. Conclusion and Future work

In this study we have shown that very week, low contrast, sources with activity concentration above 12.5kBq can be successfully detected by a dual head PET when a 450–650keV energy window is applied in combination with a 160keV LLD threshold. In addition it has been shown that using a high LLD threshold before the coincidence modules increases the number of true events and reduces the random, due to the early rejection of many ^{176}Lu photos and low energy scattered photons.

In addition, it has been shown that in small animal imaging it is possible to reduce the lower limit of the energy window to near 350keV, improving the statistics of the image, due to the fact that the phantom scattering is usually low, when using a high LLD threshold. The improvement of the image statistics has a positive impact on the SNR and the visual clarity of the source.

On the other hand, the use of the wide energy window, leads to a rise of the scattered events, compared to narrow energy windows. However, the rise on the true counts could be proven beneficial in the case of the low activity sources.

Finally, it has been shown that the simulation study with GATE reproduces the results of the experimental data analysis. In this way a validated model has been developed to further investigate the MDA limitations under different imaging conditions, including the potential use on animal computational models.

Acknowledgment

This research has been co-financed by the European Union (European Social Fund–ESF) and Greek national funds through the Operational Program "Education and Lifelong Learning" of the National Strategic Reference Framework (NSRF)–Research Funding Program: Heracleitus II. Investing in knowledge society through the European Social Fund.

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