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Feasibility study of a highly sensitive $LaBr_3$ PET scanner based on the DOI-dependent extended-energy window

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Elsevier use only: Received date here; revised date here; accepted date here

Abstract

Conventionally, PET scanners are used for scintillators which have high effective atomic number. Recently, novel scintillators like $LaBr_3$ have been developed which have excellent timing and energy resolutions. $LaBr_3$ has high performance for PET scanner use, but its effective atomic number is lower than that of LSO. As another alternative, we developed a scatter reduction method using depth-of-interaction (DOI) information and energy information to obtain high sensitivity. Sensitivity of the PET scanner with $LaBr_3$ can be improved using the DOI-dependent extended-energy window (DEEW). In this work, our method is applied to the whole-body LSO/$LaBr_3$ PET scanner using GATE. Simulation results show the number of true coincidences can be increased while keeping low scatter and low random coincidences by using the DEEW method. NECR can be improved by 20-70 % for the whole-body DOI-PET scanner. Sensitivity of the PET scanner with a scintillator of low effective atomic number can be improved by the DEEW method.

Keyword: PET, Energy window, Depth-of-interaction

1. Introduction

Conventionally, positron emission tomograph (PET) scanners are used for scintillators which have high effective atomic number. Recently, novel scintillators like $LaBr_3$ have been developed which have excellent timing and energy resolutions. The PET scanner with $LaBr_3$ has higher imaging performance than other modern PET scanners using time-of-flight information [1]. But effective atomic number of $LaBr_3$ is lower than that of LSO.

Recently, depth-of-interaction (DOI) detectors were developed for several PET scanners [2]-[4] for small animal and brain imaging. Conventionally, the DOI-PET scanner has two kinds of scintillators. DOI information can minimize the effect of the crystal penetration of obliquely incident gamma rays. As another alternative, we developed a scatter reduction method [5] using DOI information and energy information for high sensitivity. The DOI detector can make an upper layer of scintillators act as an absorber of patient scatter events for a lower layer of them. Sensitivity of the PET scanner with $LaBr_3$ can be improved using this method. In this work, our method is applied to the whole-body LSO/$LaBr_3$ PET scanner using GATE [6].

2. Materials and Methods

In a conventional PET scanner, coincidence events are limited by the energy window for detection of photoelectric events. In contrast, Compton scatter events with energy lower than that of the photoelectric events are the result of an interaction within the patient or with a detector crystal. Patient scatter causes scatter coincidences with a misplaced line-of-response, but crystal scatter has useful information about the activity distribution. However, this scatter has a broad energy distribution and a conventional detector can not discriminate between patient scatter and crystal scatter events.

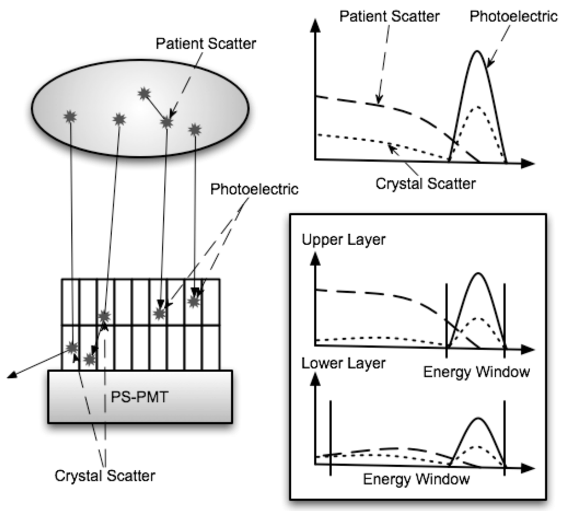

Fig. 1. Illustration of the DEEW method

The DOI-dependent extended-energy window (DEEW) method has different energy windows for each layer of the DOI detector considering the scatter fraction (SF) as shown in Fig. 1. The energy window of the upper layer is limited to the region of photopeak events in the same manner as for the conventional PET scanner. On the other hand, the energy window of the lower layer is extended to the region of crystal scatter and photopeak events. Using this method, we can improve sensitivity while we keep a low SF for higher image quality.

The DEEW method is applied for the whole-body DOI-PET scanner using the specifications in Table I. This DOI-PET scanner is based on the SET-3000 G/X [7]. The DOI detector can make a thin LSO layer act as an absorber of patient scatter events for the $LaBr_3$ layer. A paralysable dead time (250 ns) is applied to the single events for each detector block. Detector blocks are axially arranged into a bank with a non-paralysable dead time (256 ns) before judging coincidences. Only the coincidence with the highest deposited energy in one crystal is recorded from among all allowed multiple coincidences.

The NECR test utilizes a solid polyethylene cylinder phantom (70 cm long and 20 cm in diameter) with a 70-cm line source at 4 cm off-axis. The phantom is based on the NEMA NU-2 2001 standard [8]. This phantom is placed in the center of the field-of-view (FOV). To evaluate the effective count rate for practical use, the NECR is calculated as $NECR=T*T/(T+S+R)$, where T, S, and R are the true, scatter, and random count rates, respectively.

Table I Basic characteristics of the DO-PET scanner

Crystal layer (upper)	LSO (2.45x5.1x5 mm^3)
Crystal layer (lower)	$LaBr_3$ (2.45x5.1x25 mm^3)
Number of crystals	9x10x2 (per detector)
Number of rings	50
Number of detector blocks	440 (5ring of 88)
Ring diameter	66.4 cm
Maximum transaxial FOV	60 cm
Axial FOV	26 cm
Coincidence time window	4 ns
Energy resolution	15 % (LSO), 10 % ($LaBr_3$)
Default energy window	450 - 700 keV

3. Results

Fig. 2 shows energy spectra with and without patient scatter events obtained by the DOI-PET scanner. Patient scatter events interacting with the LSO layer are the dominant events at lower energy.

In the $LaBr_3$ layer, the amount of patient scatter is the same as the amount of detector scatter from 100-keV to 300-keV lower level discriminations (LLDs). The LLD of the LSO layer is 450 keV for the best NECR.

Fig. 3 shows true count rate with different LLDs of the DEEW and the conventional energy window methods. Fig. 4 shows SF with different LLDs of the DEEW and the conventional energy window methods. Activity of the 70-cm cylinder phantom is 150 MBq. In the DEEW method, LLD is controlled for only the lower layer. True count rate is a flat distribution at 350-450 keV. In the DEEW method, the SF is mainly increased between 350 and 500 keV.

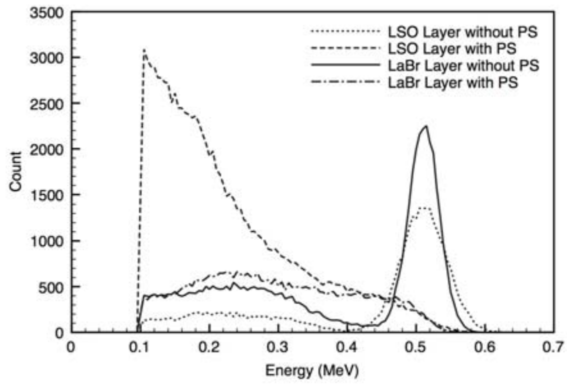

Fig. 2. Energy spectra with and without patient scatter (PS) events.

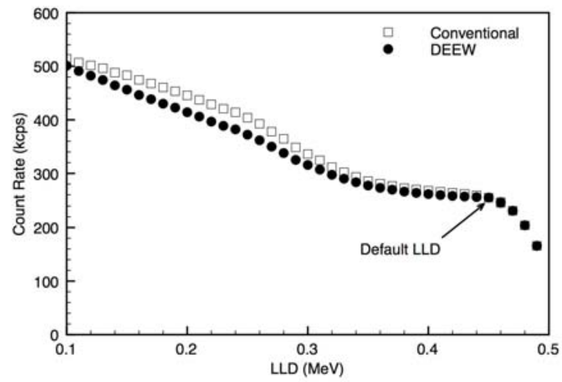

Fig. 3. True count rates with different LLDs of the DEEW and conventional energy window methods.

The NECR test is done simulating four energy windows as shown in Fig. 5. The energy window of DEEW2 deletes events deposited at 350-450 keV by the $LaBr_3$ layer from DEEW1 because events of this area are mainly patient scatter as shown in Fig. 2. Fig. 6 shows the NECR curves with four energy windows for the DOI-PET scanner. Peak NECR of the conventional energy window is 245 kcps and peak NECR of DEEW2 is 311 kcps. Peak NECR of the wide conventional energy window is about 123 kcps for each DOI-PET scanner.

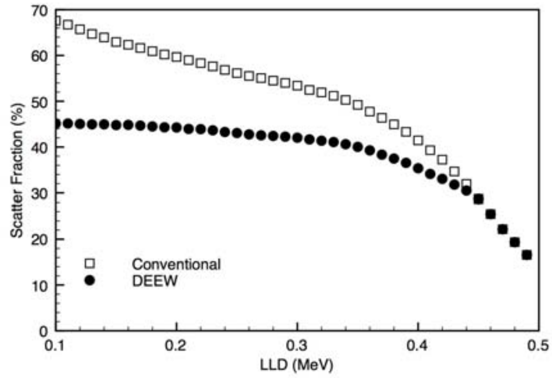

Fig. 4. SF with different LLDs of the DEEW and conventional energy window methods.

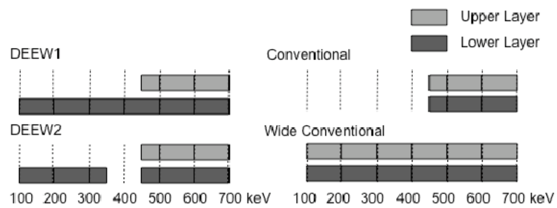

Fig. 5. Illustration of four energy windows

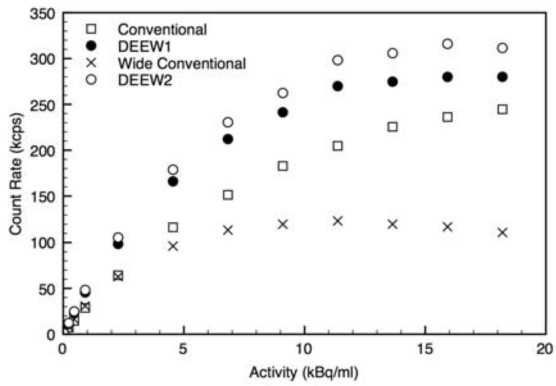

Fig. 6. NECR curves with four energy windows.

Fig. 7 shows improved NECRs of the DEEW method. At lower activity, the DEEW method can provide higher NECR than the conventional energy window method. Also, the NECR of DEEW2 is 10 % larger than the NECR of DEEW1.

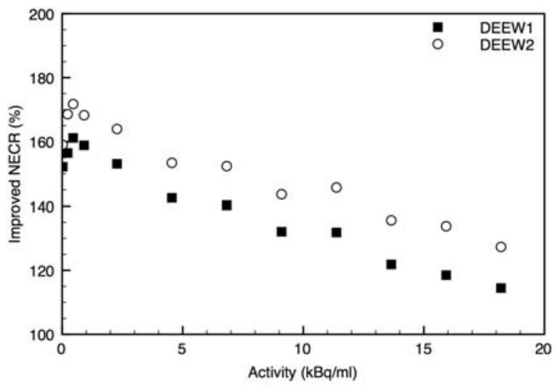

Fig. 7. Improved NECR of the DEEW method

4. Discussion and Conclusion

From simulation results, the number of true coincidences can be increased while keeping low SF and low random coincidences by using the DEEW method. As deposited energy decreases from the Compton edge, the number of detector scatter events is increased in the $LaBr_3$ layer. Therefore, LLD of the $LaBr_3$ layer should be set at the lowest level possible.

In this work, crystal length of the LSO layer was 5 mm for the best NECR. Crystal length of the upper layer must be optimized for not only scatter reduction capability but also effect of parallax error. If GSO is used in the upper layer, crystal length must be longer than 5 mm for the best NECR.

NECR can be increased by 20-60 % for the whole-body DOI-PET scanner with LSO/$LaBr_3$ detectors using the DEEW method. Also, the NECR of DEEW2 can be increased by more than 10 % of the NECR of DEEW1. In our previous report [5], simulation showed NECR was increased by 10-25 % for the whole-body DOI-PET scanner with GSO/GSO detectors. Sensitivity of the whole-body DOI-PET scanner with scintillators which have low effective atomic number can be especially improved.

Acknowledgments

We wish to thank Dr. I. Kanno of NIRS for his encouragement. This study was supported by Grant-in-Aid for Scientific Research from the Ministry of Education, Culture, Sports, Science and Technology of Japan.

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