Development of Input Function Measurement System for Small Animal PET Study

JongGuk Kim [a], Byung-Su Kim [a], Jin Su Kim [a], Sang-Keun Woo [a], Ji Ae Park [a], A Ram Yu [a], Young Sub Lee [a], Wonho Lee [a], Tae Hyun Choi [a], Chang Woon Choi [a], Sang Moo Lim [a], Gi Jeong Cheon [a], Kyeong Min Kim [a]
[a] *Korea Institute of Radiological and Medical Sciences, Seoul, Rep. of Korea*
[*] *Corresponding author: jgkim@kirams.re.kr*

1. Introduction

For quantitative measurement of radioactivity concentration in tissue and a validated tracer kinetic model, the high sensitive detection system has been required for blood sampling. With the accurate measurement of time activity curves (TACs) of labeled compounds in blood (plasma) enable to provide quantitative information on biological parameters of interest in local tissue. Especially, the development of new tracers for PET imaging requires knowledge of the kinetics of the tracer in the body and in arterial blood and plasma. Conventional approaches of obtaining an input function are to sample arterial blood sequentially by manual as a function of time. Several continuous blood sampling systems have been developed and used in nuclear medicine research field to overcome the limited temporal resolution in sampling by the conventional method [2]. In this work, we developed the high sensitive & unique geometric design of GSO detector for small animal blood activity measurement.

2. Methods and Results

2.1 Description of Detector

The proposed blood sampling system consists of four GSO scintillation crystals, photomultipliers (PMTs) assembly with lead shield, and plastic tube guide as shown in figure 1. The total dimension of detector unit is 14 cm x 18 cm x 6 cm. Two paralleled GSO detectors with PMTs are facing to another two paralleled detectors, and polyethylene tube line of a continuous blood flowing is introduced to acryl guide at the detection position. The PMTs are having 15mm diameter of effective window area with a gain of 2.0 x 10^6. The distances from detection windows to sampling tubes are determined with consideration of gammas efficiency and minimizing outer shielding.

The system description follows the block diagram shown in Figure 1. The GSO crystal used has the dimensions of 17 x 17 x 20 mm^3. The scintillator is optically and mechanically attached to a PMT, operating at 11.5 to 15.5 input control voltages. The blood sample is carried to the four detectors in standard polyethylene tubes (Inner diameter of 0.5 mm~ 2 mm), and the tube is held in a reproducible fixed position by plastic tube guide panel. The detector output current signals from the photomultipliers were connected to modules and four serial interfaces at the other electronics control unit.

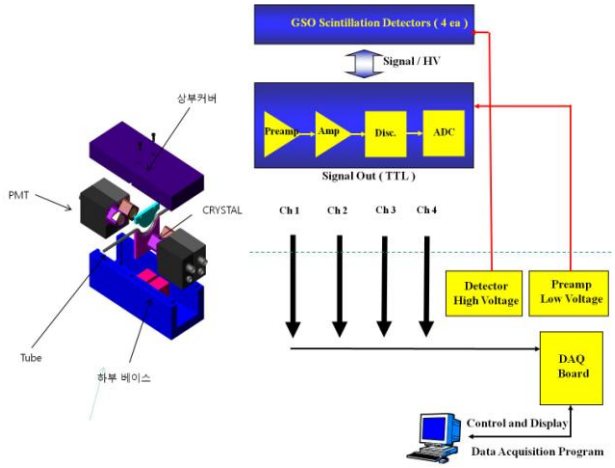

Fig. 1. A Schematic of the Blood Activity Measurement System.

The detector output current signals from the photomultipliers are all summed to produce energy signal. They are integrated with electric circuit and A/D converted to digital signal. All voltages are generated by the power supplies in electronics control unit.

2.2 Photon Transport Simulation Using GATE (Geant4 Application for Tomographic Emission) and Detector Energy Calibration.

The sensitivity of each detector to gammas depends on (1) the size of the scintillator, (2) the amount of energy deposited in the GSO crystal - Thickness, and (3) the efficiency for detecting the scintillation light. As shown in Fig. 2(a), the GATE simulation result of optimal thickness (20 mm) has been determined for crystal dimension [3].

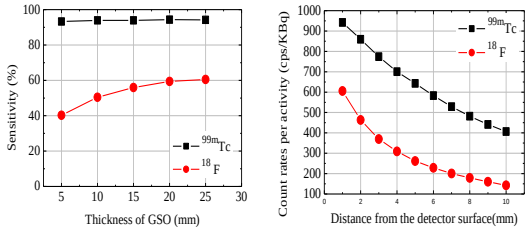

Fig 2. (a) Sensitivity as a function of GSO thickness, (b) Count rates as a function of the distance from the detector surface.

Distance from detector to blood sample is optimized. Fig. 2(b) shows the counting rate of the coincidence counting as a function of the distance from the detector surface. By placing Tc-99 and F-18 sources in the middle of detector, the count rates per activity show 94 % on single photons of 140 keV, and 60 % of 511

keV coincidence photons [4]. Significant reduction of count rates were observed as being away from the detector surfaces. The sensitivity estimated by Monte Carlo simulation were ~ 23 % for F-18 and ~ 61 % for Tc-99.

As seen in Fig 3, energy spectrum of a Ce-doped GSO detector measured with Na-22, Cs-137 showed the energy resolutions of 40% @511 keV, and 32% @662 keV respectively. The count rates were also measured with desired detection limit by adjusting threshold on preamplifier. Resolutions were relatively poor due to use of reflective coating on crystals for increasing sensitivity.

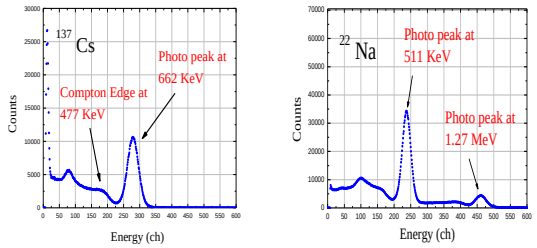

Fig 3. Pulse Height Spectra of Co-60, Cs-137, Na-22, F-18 sources obtained with detector of GSO for energy resolutions

2.3 Sensitivity and Time activity Curve (TAC)

Evaluation of sensitivity was performed using F-18 solutions with concentration ranged from 0.005 to 30 μCi. The baseline shift of the gamma ray energy peak at high counting rate was measured as a function of source to detector distance and activity rate of the F-18 source, and corrected with short time constant and pole zero cancellation

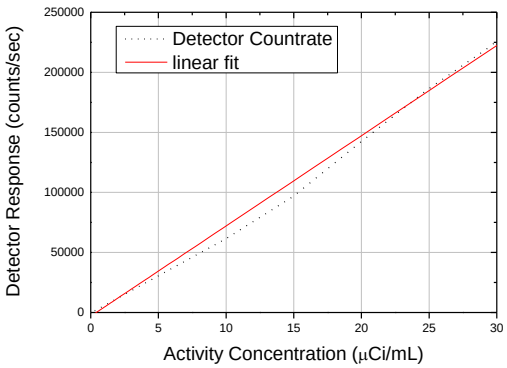

Fig 4. Linearity characteristics on Blood activity measurement system. The solid line represents a linear fit to countrate from 0.1 μCi/mL to 30 μCi/mL.

The pulse height position was degraded about ~4.8% at 30 μCi/ml of activity concentration, but total count rates were still preserved. The measured detection sensitivity was ~26.4% when F-18 solutions positioned ~1 mm from detector center.

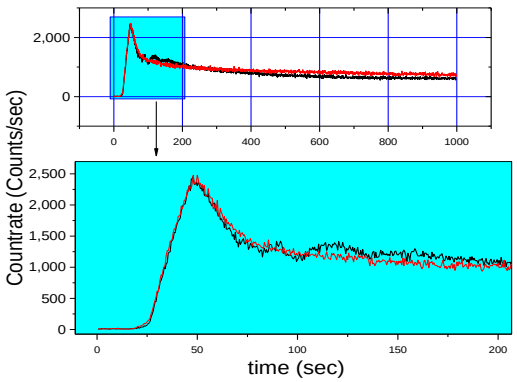

Fig 5. Time Activity Curve (TAC) for Small animal Arterial blood

3. Conclusions

Accurate information on the kinetics of administered tracers needs to be measured as the tracer uptake in the target organs as a function of time. The determination of the tracer concentration in arterial plasma is of importance for correct model predictions. The results from this investigation demonstrated that the GSO based detection system for small animal blood radioactivity measurement is capable of effectively detecting photons emitted by different radiotracers. The results indicate that GSO detector has promising sensitivity to be used in the measurement of radiotracer concentration.

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