Proceedings of the Korean Nuclear Society Spring Meeting
Cheju, Korea, May 2001

Development of Integrated Code for Gamma Camera Design (INCOGAM)

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Abstract

So as to develop a gamma camera for functional imaging, which consists of a collimator, a scintillation crystal, an optical guide, PMT array and position determination circuit, the total response of this system has been estimated using several simulation programs. MCNP4B, DETECT97, and Anger program were used to investigate the response of each component. A collimator for general purpose, 12”×12”×3/8” NaI(Tl) crystal, and 23 PMTs for charge amplification with each 5” diameter were considered as the components of gamma camera detector in this work. Interactions of gamma photons in the collimator and crystal were simulated using MCNP4B for estimating the distribution of energy absorption in crystal and interactions of optical photons in the crystal and optical guide were simulated using DETECT97 for estimating the distribution of optical photons out of crystal. The position determination of source was investigated using our own Anger program, which was developed to calculate positions of incident photons in the gamma camera. The main code which is integrated three simulation codes, named INCOGAM (Integrated Code for Gamma Camera Design), automatically creates each inputs and analyzes each outputs. INCOGAM provides 2-D digital image of source finally. The proto-type gamma camera has been developed based on the simulation results. The two images of planar source, acquired by simulation and experimental measurement with Co-57 source, are agreed well to each other. INCOGAM may be used to estimate total response of gamma camera as well as other imaging systems having similar detector structure.

Introduction

Due to the ability of functional imaging and relatively easy production of radioisotopes, the gamma camera is the most widely used in nuclear medicine. The detector of gamma camera system typically consists of a collimator, a thin, large, single crystal of NaI(Tl) and an array of photo-multiplier tubes (PMTs). The outputs of the PMTs are fed into an electronic position logic circuit, called Anger logic, which determines the location of incident gamma ray. The coordinates of the interaction point are provided to a cathode-ray tube (CRT) display and the image is formed as a result of the summation of thousands of these coordinates [1,2]. (Fig.1)

The collimator plays a vital role in image formation, and allows only the gamma photons traveling in certain directions to enter the scintillation crystal for image formation. This is achieved in collimator design by using an array of holes separated by thin septa. The collimator affects on the sensitivity and spatial resolution of gamma camera. A compromise must be reached in collimator design to maximize geometric efficiency for a given spatial resolution while minimizing penetration and scatter.

The scintillation crystal absorbs gamma ray energy and the emitted optical photons from the scintillation crystal are reached at PMT photo-cathode through the optical guide. Optical photons experience in crystal before reaching PMT photo-cathode such as absorption, scattering, reflection and refraction. These optical properties are determined by crystal itself, surface treatment, physical properties of bonding material between crystal and PMT, and geometric component.

The response of gamma ray interactions with the collimator and crystal was simulated by many research groups [3,4]. But there is no simulation tool which estimate the total response of gamma camera including interactions of optical photons and position determination.

In this study, we developed the integrated code to design the detector of gamma camera using Monte Carlo method, the gamma camera detector head and acquired 2-D digital images.

Materials and Methods

1. Simulation of Gamma Camera Response

For gamma camera detector, a collimator, crystal, and PMT structure are optimally designed by simulation. The schematic diagram of integrated code is shown in Fig.2 and estimates response of gamma camera.

The number of optical photons generated in the crystal is directly proportional to the total absorbed energy in a given crystal. In order to determine the distribution of energy absorption within the crystal, MCNP4B code was used [5]. For the incident gamma ray, the Cobalt-57 planar source incident perpendicularly on the crystal was considered. Locally distributed energy absorption was estimated in cubic box of crystal by Monte Carlo simulation.

To fully characterize the detector behavior it is necessary to have a specific model of optical photon transport out of the crystal. It is assumed that the optical photon generated in the center of a small cubic box is proportional to the total absorbed energy in the box and then propagates isotropically. In order to determine the optical photon distribution out of the crystal, DETECT97 code which simulates interactions of optical photon such as absorption, scattering, reflection, and refraction, was used [6]. In the DETECT97, six types of optical surface treatments are allowed for various optical materials, namely DETECT, METAL, PAINT, POLISH, GROUND, and UNIFIED. For the each cubic box, the optical photon distribution out of the crystal was calculated. The geometrical shape, size and surface condition of the NaI(Tl), and optical properties of all materials were considered as the input parameters of the DETECT97. Accounting for the sufficient statistical error-reduction, 100,000 histories, the number of emerging optical photons was generated and expected to reach into PMT photo-cathode surface.

Based on the results from the above simulation with MCNP4B and DETECT97, the position of incident gamma ray was estimated by using our own ANGER program [7], which determines the spatial localization of the source position by Anger algorithm. As shown in **Fig.3**, PMT signals in each interaction are weighted according to the position of the PMT and then signals from each PMTs are combined to form directional +X, -X, +Y, and –Y signals. These four signals subsequently make a single X and Y coordination.

The hexagonal hole collimator made of lead has lots of 2.5 mm-diameter and the septal thickness is 0.3 mm. NaI(Tl) having 30 X 30 cm^2 field of view and thickness of 0.95 cm is used as a scintillation crystal. The 1 cm-thick pyrex glass is used as an optical guide [7]. The array of 23 PMTs, having hexagonal closed pack, with 5 cm-diameter is used.

The INCOGAM can simulate MCNP4B, DETECT97, and Anger program with order, and finally generate 2-D image at once. The properties of source, collimator, crystal, optical guide, and PMT array are necessary for INCOGAM input. As input parameters, material and shape for source, hole diameter, septal thickness, shape, and length for collimator, shape, material, and surface treatment for crystal, thickness and refractive index for optical guide, and diameter and packing shape for PMT array are needed. The INCOGAM creates inputs of MCNP4B, DETECT97, and Anger program and runs these codes automatically. And then using each output of codes, the 2-D image of incident gamma source is estimated. Fig.4 shows the block diagram of INCOGAM.

2. Development of Gamma Camera

In order to capture the gamma ray images, a prototype gamma camera have been developed based on the calculation results. The collimator for low energy and general purpose, which is parallel-, hexagonal-, multi-hole type, is fabricated. As a gamma ray detector, NaI(Tl) with 30 X 30 X 0.95 cm^3 bonded onto an 1 cm-thick optical guide is used. The detector is viewed by 23 PMTs (Hamamatsu R6231) having hexagonal close-pack structure. Position determination circuit is developed using resistor network based on the Anger logic. These all the components were placed in the light tightened housing. Signal is processed by NIM electronics, and the PCI-MIO-16-E board (National Instrument) is used for data acquisition. Data acquisition and image formation is operated by LabView program. Fig.5 shows the developed gamma camera head. Using both the planar Cobalt-57 source and the 2.5 cm-diameter Co-57 disc source, the preliminary images were acquired during 1 minute per image.

Results

Fig.6 shows finally acquired image of planar source by INCOGAM simulation. The images show the decreased field of view at the edge of crystal. Generally, about 5 cm from the field of view is eliminated because the side surfaces of crystal are treated as absorption materials and the defect of Anger logic [8].

Fig.7 and Fig.8 show acquired images by experimental measurement with various positions of disc source and planar source. The proto-type gamma camera can distinguish each position of source as we expect. However, the distortions of image were observed such as the image non-linearity and non-uniformity caused by the detector and electronics. These distortions can be corrected by correction algorithm such as matrix multiplication, count skimming methods and etc [9-11]. Application of correction algorithm for these distortions is not performed in this study.

Conclusion

The INCOGAM, integrated code for designing gamma camera, was developed using MCNP4B, DETECT97 and Anger program and the proto-type gamma camera was successively developed. The total response of gamma camera was estimated by INCOGAM simulation and verified by the experimental measurements. The two images, acquired from simulation and experimental measurement with planar source, are agreed well to each other.

This INCOGAM code may be used to estimate response of gamma camera as well as other imaging systems having the similar detector structure.

Acknowledgement

This work has been supported in part by a nuclear technology program of ministry of science and technology in 2001.

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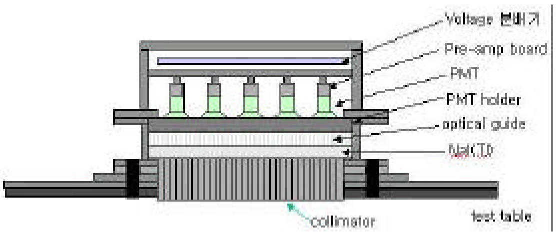

Fig.1. Schematic diagram of gamma camera detector which consists of collimator, scintillator, optical guide, position computing circuit and lead shied.

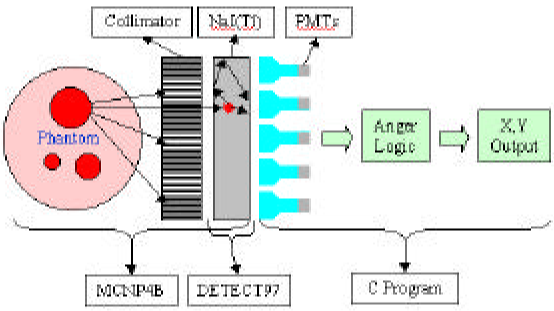

Fig.2. Schematic diagram of integrated simulation code for gamma camera design using MCNP4B, DETECT97 and Anger program.

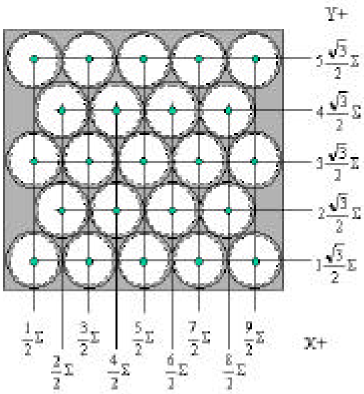

Fig.3. Schematic diagram of gamma camera position determination logic (Anger logic)

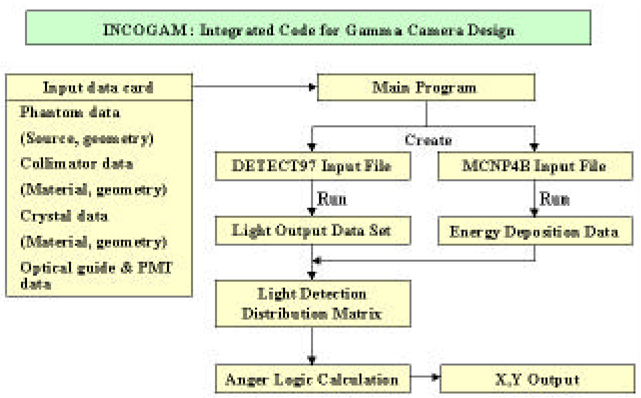

Fig.4. Block diagram of INCOGAM

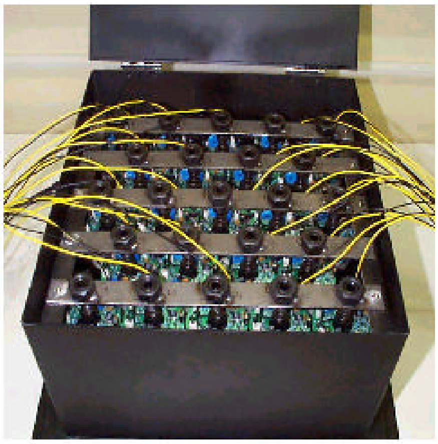

Fig.5. Developed gamma camera detector head.

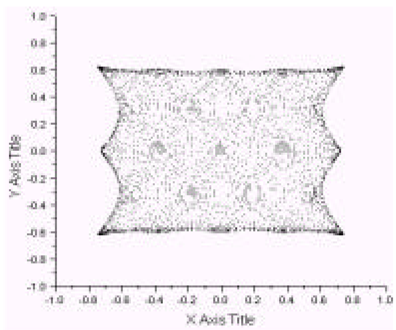

Fig.6. Finally acquired image by INCOGAM simulation with planar source.

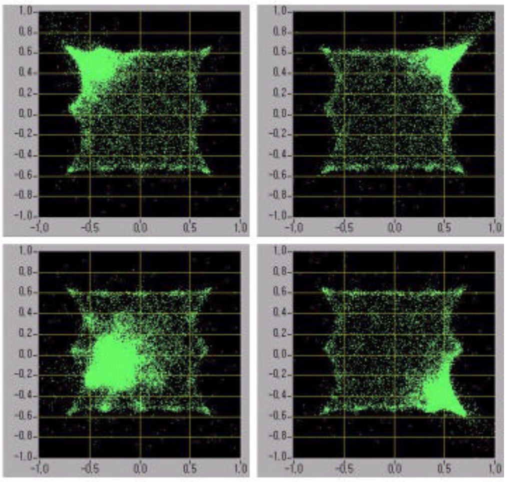

Fig.7. Acquired images by experimental measurement as positions of disc source.

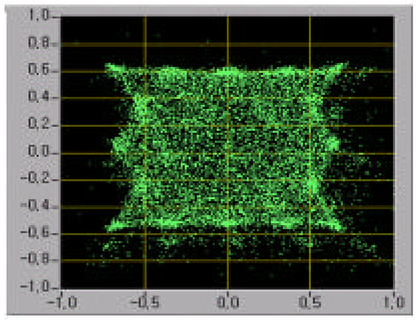

Fig.8. Acquired image by experimental measurement with planar source.