An efficient method and system for simultaneously measuring the performance of vast scintillating materials

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Abstract A method and system for automatically and simultaneously measuring the light output of multiple scintillators, or each scintillating unit of an array, were developed. Using a large area flat panel PSPMT H8500, the light output and energy resolution were obtained automatically by comparing with reference scintillators or array using an Energy Table, Look-up Table and energy spectrum data. The aim of developing an efficient performance evaluation of scintillators was achieved. Using the method, a scintillator performance testing system was set up and six LYSO crystals and a 3×3 LYSO array were measured. The results showed that the light output and energy resolution were accurately measured automatically. The deviation of repeat measurements for the same sample was not more than 2%, and the nonlinear deviation of the system was not more than 3%. The system is suitable for measuring the performance of crystals, especially where the mass measurement of crystals and arrays is required.

Key words Scintillating materials**,** Light output, Energy resolution, Measurement

1 Introduction

Scintillating materials are widely used as nuclear detectors. The measurement and evaluation of their light output, energy resolution and other performance indicators are of importance for detector designs. With the rapid development of nuclear imaging and position-sensitive detection, an instrument may have a large number of scintillators or scintillator arrays. For example, hundreds of detector modules and tens of thousands of scintillating units are used in a position emission tomography (PET). Measurement of the light output and energy resolution of such a large number of different scintillators and arrays is an arduous task, which shall be alleviated bya convenient and efficient method.

There are several methods to measuring light output[1-6], but they are of measurements of just a single scintillator, and can hardly be used to evaluate the performance of each scintillating unit in an array. Therefore, alternative ways shall be explored. In this paper, we report a method for precisely, and efficiently measuring light output of multiple scintillators or scintillating units of an array automatically, and the experimental result a system we constructed, including the system's performance in measuring six LYSO samples and a 3×3 LYSO array. The results of a simultaneous measurement of 169 LSYO crystals indicate that the method and system are suitable for widespread use for performance evaluation of vast scintillating materials or arrays.

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2 Principles and methods

The methods to measure light output of a scintillator include silicon photodiode measurements[1], photomultiplier measurements[2,3] and photomultiplier measurements in photodiode mode[4]. Each of them measures accurately, but not rapidly and efficiently. With the wide use of large area position sensitive photon multiplier tube (PSPMT), a comparative method[3] that employs some reference crystals or an array and a calibrated PSPMT was developed. With the established Look-up Table and Energy Table, the method is based on comparing the position of full energy peak of 662 keV γ-ray by the crystal or array in test with that measured by the reference crystal or array (Fig.1).

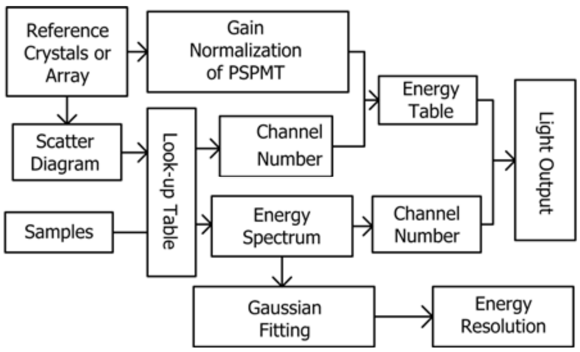

Fig.1 Flow chart for measuring light output and energy resolution.

2.1 Establishment of the Look-up Table

The Look-up Table in this work defines each (*x, y*) location of a two-dimensional (2-D) flood histogram for which the (*x, y*) data are histogrammed into a 256×256 image corresponding to the crystal. The relation between the signal location of a detected event and the corresponding crystal is matched. The energy spectra and channel number (Ch_{ij}) of a full-energy peak are obtained by counting all events within the boundaries ($x_{j,i}$,$y_{j,i}$) of a crystal with the Look-up Table.

Much research has been conducted on how to establish a more precise Look-up Table[7-9]. Here, the Look-up Table for 36 reference LYSO crystals was established quickly and accurately by using the flood histogram in Fig.2, which clearly shows that the points on each row along the *x*-axis are nearly in a straight line, as are the points in each column along the *y*-axis. Accordingly, both the *x*-coordinates of the crystal centers in the same column and the *y*-coordinates of the crystal centers in a row are the same. The Look-up Table was established in four steps:

1) The distribution curve (Col_i) of the flood histogram in the *x*-axis direction was obtained by adding the data of different rows from the flood histogram array into Eq.(1).

$$Col_i=\sum Histo_{j,i} \quad (1)$$

where $Histo_{j,I}$ is the matrix of the flood histogram. The positions ($x–Peak_i$) of the peaks of the curve are the *x*-coordinates of the center of the crystals.

2) The *y*-coordinates ($y–Peak_j$) of the centre of the crystalsare obtained with the same method.

3) The coordinates of each crystal were determined by:

$$x_{j,i}=x–Peak_i \quad (2)$$

$$y_{j,i}=y–Peak_j \quad (3)$$

4) The boundaries of each crystal are obtained by $x_{j,I}$ and $y_{j,i}$ from Ref.[10].

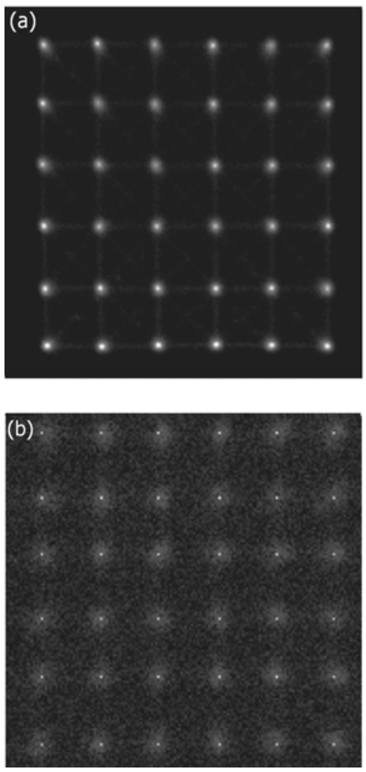

Fig.2 Flood histogram (a) with the white points, which are the coordinates of the center in (b), with the gray points being the boundaries of the crystals.

2.2 Establishment of the Energy Table

In practice, the gain of each position on the PSPMT is not uniform. The window of PSPMT H8500 was equally divided into 36 positions (P_{ij}, $i, j\in$ [1, 6]) and the channel number (Ch_{ij}) of the full-energy peak of the 36 reference crystals at 5120±50 phe/MeV on the 36 positions was calculated. The gain of P_{ij} position of PSPMT H8500 is proportional to the channel number, because the light output of the 36 reference crystals is the same. The gain normalization factor of each position, in terms of a comparison of each channel number with the maximal channel number (=277), is shown in Fig.3, where the gains differ from each other. Consequently, the 36 reference LYSO crystals were used to calibrate the PSPMT H8500 and the number of photons (n_{ij}) passing the window of P_{ij} position on the PSPMT H8500 per channel was obtained by:

$$n_{ij}= 5120/Ch_{ij},\ i, j\in [1, 6] \tag{4}$$

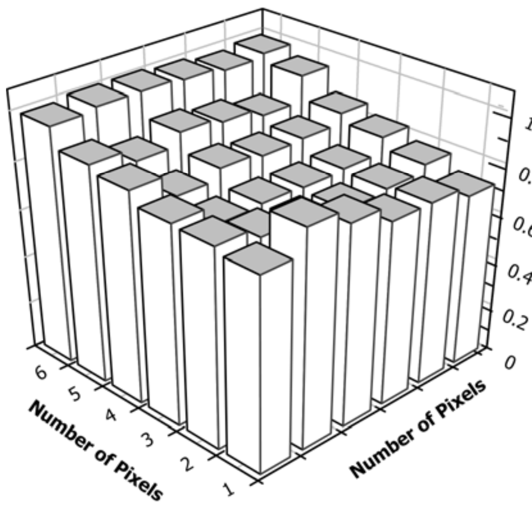

Fig.3 Uniformity of the gains of the 36 positions on the PSPMT H8500.

The n_{ij} measured in the same position on the PSPMT H8500 for different crystals is fixed under the same experimental conditions. In accordance with this principle, the Energy Table for the 36 positions of the PSPMT H8500 was established from n_{ij} (Fig.4).

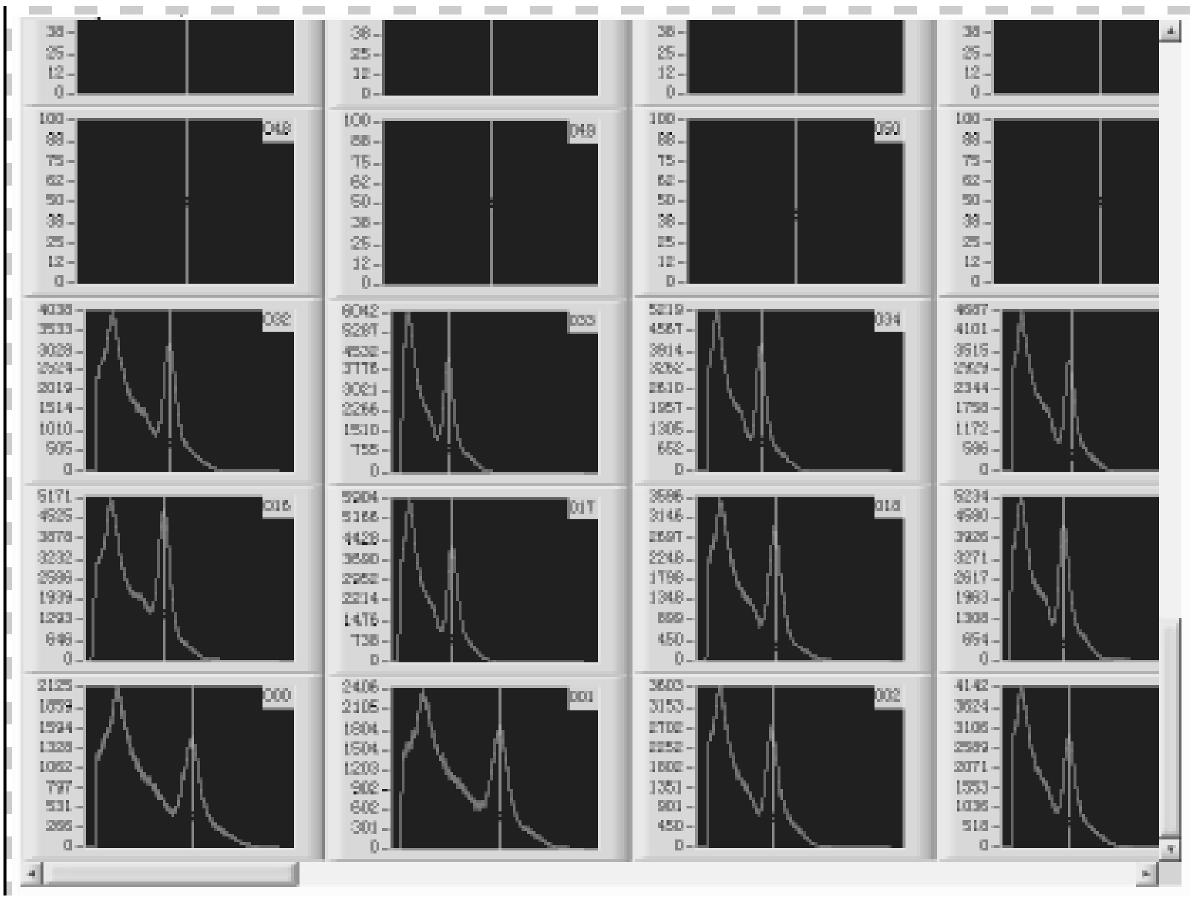

Fig.5 Energy spectra and the Ch_{ij} of each scintillator, obtained automatically.

3 System description and results

The apparatus and electronic setup used in the system are shown schematically in Fig.6. The 64 anode outputs of the H8500 are read out into a DPC circuit[11]. After amplification and shaping, the four signals and the time information from the dynode signal (Dy12) are processed by Leading Edge Triggering (LET) and fed into the CSM board[12]. The Look-up Table and Energy Table can be established using CSM and a PC with Lab-Window software. Finally, the light output and energy resolution are obtained.

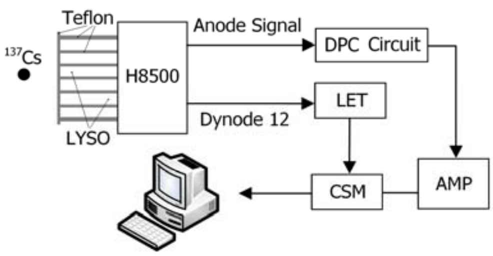

Fig.6 Schematics of the apparatus and electronic setup.

To minimize photon loss, the reference crystals and the LYSO samples) were mounted onto the PSPMT H8500 with optical grease and placed in a light-tight box and kept stationary, and the adjacent crystals were separated with Teflon. To ensure the accuracy of the measurement, a mechanical fixed tool is designed to ensure that all crystals were placed on P_{ij} position. The source of the 662 keV gamma rays was a 10μCi^{137}Cs (37 kBq). All of the reference crystals of 5120±50 phe/MeV were used to calibrate the PSPMT H8500. The light output of the reference crystals was considered to be the same because the difference among them less than 1% and they were all 3.5 mm ×3.5 mm ×20.0 mm polished LYSO crystals. The nine tested sample crystals (including the array) were 4.0 mm× 4.0mm×10.0mm polished LYSO crystals.

3.1 Light output

Table 1 lists the light output and deviation for the six LSYO samples from eight repeat tests under the same experimental conditions. The results show that the relative deviation was not more than 1% for the same sample.

To verify accuracy of the method, light output of the six LYSO samples was measured with traditional method (*T_L*)[3]. The results were compared with those obtained with the proposed method (*N_L*). From Table 2, the discrepancy between the two methods was not more than 2%.

Table 1 Light output of the six LYSO crystals across eight tests.

Crystal	1	2	3	4	5	6	7	8	%deviation
1#	4950	5002	4956	4912	4911	4936	4891	4890	0.77
2#	5220	5177	5202	5158	5199	5240	5130	5121	0.82
3#	5101	5085	5082	5093	5049	5104	5032	5001	0.73
4#	4470	4454	4423	4448	4407	4442	4389	4372	0.77
5#	4888	4788	4826	4837	4806	4789	4760	4772	0.86
6#	4978	4937	4961	4918	4958	4997	4892	4884	0.82

Table 2 Light output results using the traditional and proposed methods.

Crystal	*T_L*	*N_L*	Error /%
1#	4853	4932	1.6
2#	5081	5184	2.0
3#	5005	5069	1.3
4#	4351	4426	1.7
5#	4747	4808	1.3
6#	4868	4941	1.5

3.2 Nonlinear deviations

The nonlinear deviation of the system was measured by testing the channel number (67, 210, 312, 410 and 807) of a LYSO crystal with known energies (122, 356, 511, 662 and 1274 keV) using different sources (^{57}Co, ^{33}Ba, ^{22}Na and ^{137}Cs).

Figure 7 shows the results of the linear fitting, and demonstrates the nonlinear deviation of the entire system was less than 2%.

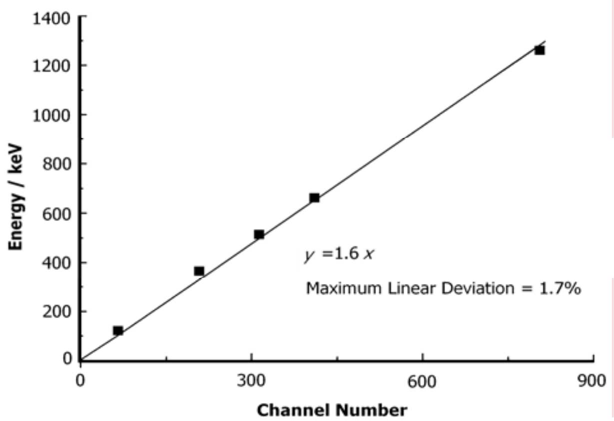

Fig.7 Linear equation *f*.

3.3 Energy resolution

After the measurement, the software automatically saved the energy spectrum date for each tested crystal. The energy resolutions(FWHM) of the $1^{\#}$–$6^{\#}$crystals are 13.1%, 11.2%, 12.7%, 14.3%, 12.4% and11.7%, respectively.

3.4 Measurement results of the 3×3 array

A sample 3×3 array constructed from the $1^{\#}$–$6^{\#}$ LYSO crystals, and three other LYSO crystals ($7^{\#}$–$9^{\#}$), was measured. The averaged L_{out} of the $1^{\#}$–$9^{\#}$crystals are 4987, 5222, 5074, 4444, 4821, 5001, 4842, 4502 and 4665, respectively, and their energy resolutions (FWHM)are 12.9%, 11.7%, 13.1%, 13.6%, 12.1%, 12.0%, 12.1%, 13.4% and 12.7%, respectively.

Based on above results of the light output and energy resolution, the six LYSO crystals tested show that the maximum deviation is far less than 1%.

4 Conclusion

This work proposes and confirms a method and system that allows the light output and energy resolution of multiple scintillators or scintillating unit of an array to be measured automatically, precisely, and simultaneously by using the new flat panel type PSPMT with a Look-up Table and Energy Table. The performance of six LYSO crystals samples and a 3×3 array were measured using this system. The crystals and array were re-measured several times and the results show that the deviation was not more than 2% and the light output of the LYSO crystals agreed well (generally within ±2%) with measurements taken using the traditional method. The nonlinear deviation of the entire system was less than 2%. The automatic, rapid and accurate measurements of the light output and energy resolution for a mass of scintillators or arrays obtained with proposed method and system can be applied to the development and production of scintillation crystals and scintillation detectors, especially the measurement of vast scintillator. At the same time, the method should also serve as a valuable reference for nuclear imaging techniques.

The system was calibrated using several reference LYSO crystals. However, LYSO crystal may not be the best material for reference crystal because of their high level of self radiation. Each surface of each crystal (all crystals and crystal units) was separated by a Teflon reflector except for the exit surface toward the PSPMT. The crystals were coupled the PSPMT by means of optical grease, but there is also a chance that the light penetrated the Teflon and entered the other crystals[6]. This would inevitably have affected the light output (generally between 1% and 2%, as shown in Table 2). Table 2 shows that the *N_L* results were larger than the *T_L* results. Better results might be achieved if more appropriate reference crystals such as BGO were used, and if further improvements made to reduce the light crosstalk among the crystals.

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