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Evaluation of flat panel PMT for gamma ray imaging

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Abstract

The first position sensitive PMT, Hamamatsu R2486, developed in 1985, represented a strong technological advance for gamma-ray imaging. Hamamatsu H8500 Flat Panel PMT is the last generation position sensitive PMT: extremely compact with 2 in. active area. Its main features are: minimum peripheral dead zone (1 mm) and height of 12 mm. It was designed to be assembled in array to cover large detection area. It can represent a technical revolution for many applications in the field of gamma-ray imaging as for example nuclear medicine. This tube is based on metal channel dynode for charge multiplication and 8×8 anodes for charge collection and position calculation. In this paper we present a preliminary evaluation of the imaging performances addressed to nuclear medicine application.

To this aim we have taken into account two different electronic readouts: resistive chain with Anger Camera principle and multianode readout. Flat panel PMT was coupled to CsI(Tl) and NaI(Tl) scintillation arrays. The results were also compared with the first generation PSPMT.

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1. Introduction

The first 3 in. position sensitive PMT, Hamamatsu R2486, developed in 1985 [1,2], represented a strong technological advance for gamma-ray imaging. The first generation was based on proximity mesh dynode by which the charge was

multiplied around the original position of light photon striking photocathode. The charge shower had a wide intrinsic spread. Such tubes were characterized by large detection areas (5 in.) [3] useful for a number of applications in physics, but not large enough for medical imaging where small organs like breast and brain need at least 20 cm FoV. Furthermore large PSPMT peripheral dead zones (1 cm or more) did not allow to assemble arrays of tubes like in Anger camera. The second PSPMT generation was based on metal channel

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dynode for charge multiplication by which the intrinsic spread is reduced down to 0.5 mm FWHM. A further technological improvement consists of metal housing that allows very compact size (about 1 in.³) [4,5]. Hamamatsu H8500 Flat Panel PMT [6] is the last generation position sensitive PMT: extremely compact with 2 in. active area. Its main features are: minimum peripheral dead zone (1 mm) and height of 12 mm. It can represent a technical revolution for many applications in the field of gamma-ray imaging as for example nuclear medicine. This tube consists of metal channel dynode for charge multiplication and 8×8 anodes for charge collection and position calculation. It is designed to be assembled in array to cover large detection area with an improved effective area up to 97%. Solving limitations due to a large photocathode glass window thickness associated to a large PMT area. Flat Panel photocathode glass window (3 mm) could be the best trade-off between anode size (6 mm), effective area (packing density), spatial resolution and position distortion. In this paper we present a preliminary evaluation of the imaging performances addressed to nuclear medicine application. To this aim we are taken into account two different electronic readout: resistive chain based on Anger Camera principle and multianode readout for R2486 PSPMT and Flat Panel PMT, respectively. Tubes were coupled to a number of CsI(Tl) arrays and to a NaI(Tl) scintillation array. The comparison with the results of the first generation PSPMT Hamamatsu R2486 allowed to evaluate the image intrinsic improvement introduced both by metal channel dynode charge multiplication and by 64 anodes.

2. Equipment

The sample of H8500 Flat panel PMT utilized in this work, has very compact size with metal envelope thickness of 0.25 mm. The external size are 51.7 mm $\times$ 51.7 mm $\times$ 15.4 mm, the photocathode is bialkali and 12 stages metal channel dynode are used as electron multiplier. The overall PMT active area of 49.7 mm squared corresponds, not including the external dead zone, to anode area consisting of 8×8 matrix in which each individual anode has 6.5 mm size. This should match the light broadening produced by photocathode glass window.

Geometrical configuration of scintillating arrays utilized in this work to evaluate the imaging performance of Flat Panel Tube are detailed in Table 1. CsI(Tl) arrays have a pixel side ranging between 1 and 3 mm, each CsI(Tl) individual is coated in a white diffusive epoxy reflector 0.2 mm thick. CsI(Tl) and NaI(Tl) array were manufactured by Hilger Crystal and Bicorn Crysmatec respectively. NaI(Tl) array has a 2 mm pixel side and white powder is used to optically insulate each individual, giving a total dead zone of 0.200 mm. Due to its hygroscopicity the crystal has an aluminum housing with 3 mm thickness glass window. The thickness and pixel size of scintillation crystals have been specifically chosen for clinical applications.

In order to obtain a complete imaging characterization of Flat Panel PMT, a ‘multi-anode’ read out technique has been used; the charge on each anode is individually read out and digitized. The subsequent position calculation is performed by software. The READ system, developed at

Table 1
Geometrical characteristics of scintillating arrays

Scintillator	Pixel size (mm ²)	Height (mm)	Glass window height (mm)	Dead zone (μ m)	Number of pixels	External size (mm ²)
CsI(Tl)	1 $\times$ 1	5	—	200	5 $\times$ 5	6.2 $\times$ 6.2
CsI(Tl)	1.4 $\times$ 1.4	5	—	250	16 $\times$ 16	26.65 $\times$ 26.65
CsI(Tl)	2 $\times$ 2	3	—	200	22 $\times$ 22	48.6 $\times$ 48.6
CsI(Tl)	3 $\times$ 3	5	—	250	15 $\times$ 15	49 $\times$ 49
NaI(Tl)	1.8 $\times$ 1.8	6	3	200	24 $\times$ 24	48.2 $\times$ 48.2

Southampton University, is able to read the anode values and to calculate the event position. The READ system electronic consists in HX2 multi-channel amplifiers and the control logic [7]. The HX2 chip is a 16-channel integrating amplifier

array with data storage and multiplexed outputs. These chips are controlled by common logic so that their outputs may be read out sequentially on a single channel. The serial output from the HX2 board is subsequently read by a 1.5 MHz National Instruments AT-MIO Analogue to Digital Converter (ADC) mounted on host PC [8,9].

The 3 in. Hamamatsu R2486 has been used to compare the results with the previous generation PSPMT. In this case an electronic read-out based on conventional resistive-divider technique is used for position calculation [10]. Four preamplifiers read out the four ends of the two resistive chains connected to the X and Y wires, respectively. The pulses are acquired in list mode through a multi-parameter Comtek FAST MPA/PC. In order to evaluate imaging performances of the detector a collimated Co^{57} source was used. Collimator holes were 40 mm in length and 1 mm in diameter. The characterization of the PSPMT was also performed by flood-field measurements with an uncollimated Co^{57} source at a distance of approximately 7 m from the detector. When the intrinsic spatial resolution of tube results better than pixel size, the scintillating array works like an array of optical fibers irradiating photocathode area with light spots. From these measurements it was possible to evaluate intrinsic spatial resolution and position linearity as a function of scintillation material and pixel pitch.

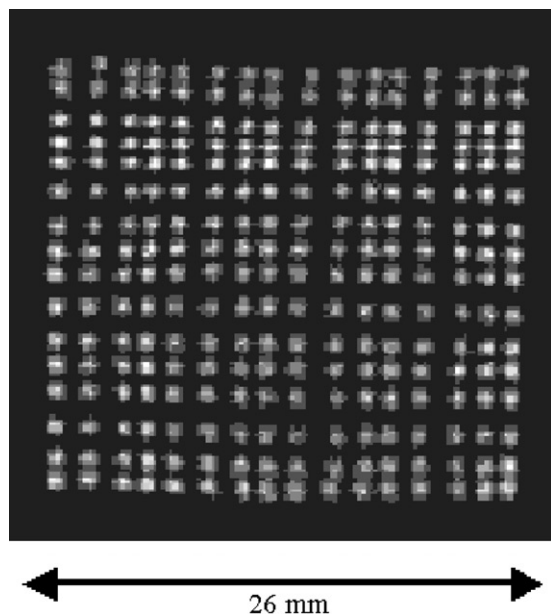


Fig. 1. H8500 Flat Panel PSPMT Multi anode read-out: ^{57}Co flood field irradiation raw image of 16×16 CsI(Tl) scintillation array— $1.4 \times 1.4 \text{ mm}^2$ pixel size.

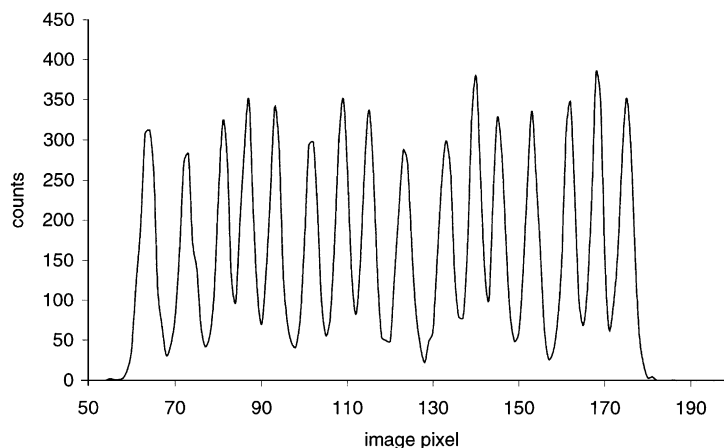


Fig. 2. H8500 Flat Panel PSPMT: raw image cross section of ^{57}Co flood field irradiation of 16×16 CsI(Tl) scintillation array— $1.4 \times 1.4 \text{ mm}^2$ pixel size.

3. Results and conclusions

A Flat Panel PMT gain calibration was performed at first because of the large gain non uniformity response. Gain anode variations were found ranging between 27 and 100. Each crystal pixel produces a charge distribution on anodes depending on pixel size, light guide thickness,

photocathode glass window thickness and on its relative position with respect to the anode lattice, as a consequence a specific calibration procedure was carried out for each crystal array. In order to evaluate its best spatial resolution value, Flat Panel PMT was coupled to the CsI(Tl) scintillation

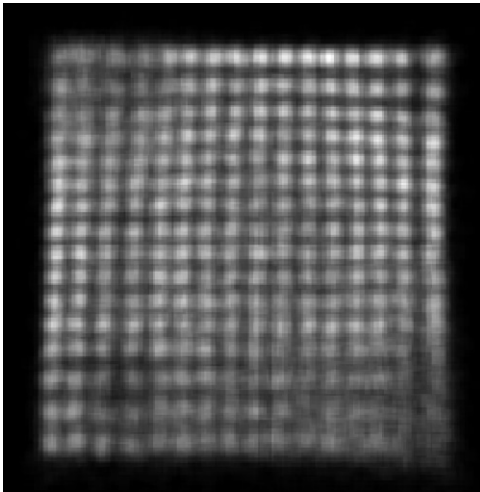


Fig. 3. R2486 PSPMT resistive chain readout- ^{57}Co flood field irradiation raw image of 16×16 CsI(Tl) scintillation array— $1.4 \times 1.4 \text{ mm}^2$ pixel size.

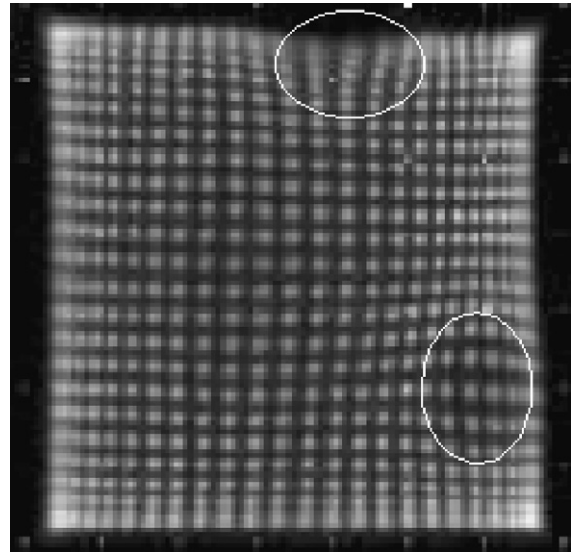


Fig. 5. ^{57}Co flood field irradiation image of H8500 Flat Panel PSPMT coupled to 24×24 NaI(Tl) scintillation array— $1.8 \times 1.8 \text{ mm}^2$ pixel size—circles show disconnected anodes.

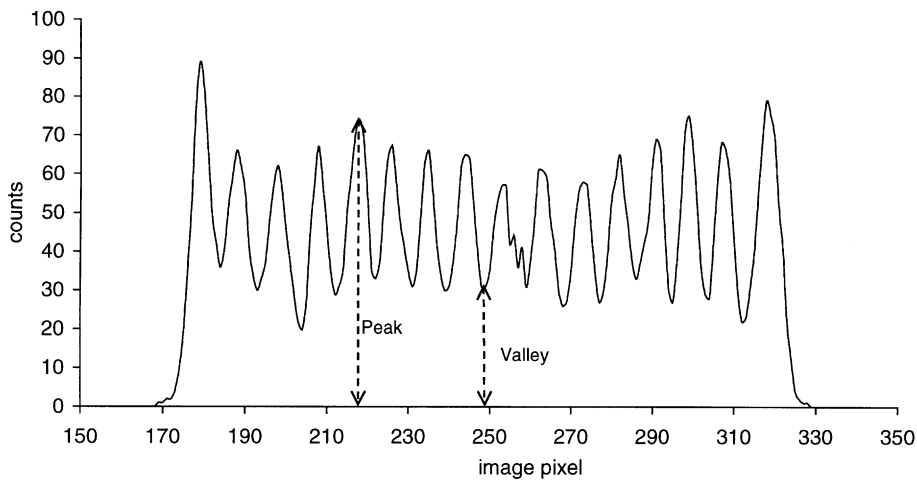


Fig. 4. Raw image cross-section of ^{57}Co flood field irradiation of R2486 PSPMT coupled to 16×16 CsI(Tl) scintillation array— $1.4 \times 1.4 \text{ mm}^2$ pixel size.

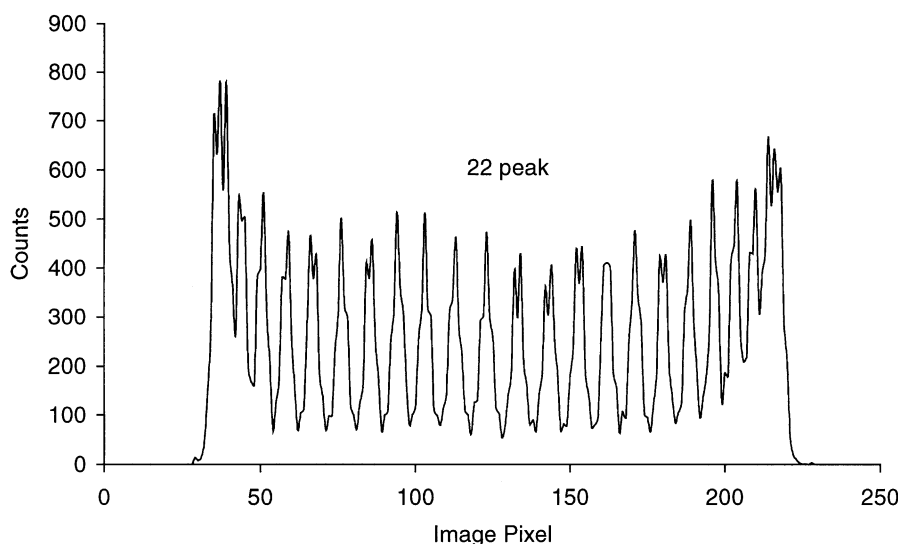


Fig. 6. H8500 Flat Panel PSPMT: 24×24 NaI(Tl) scintillation array— $1.8 \times 1.8 \text{ mm}^2$ pixel size— ^{57}Co flood field irradiation cross-section.

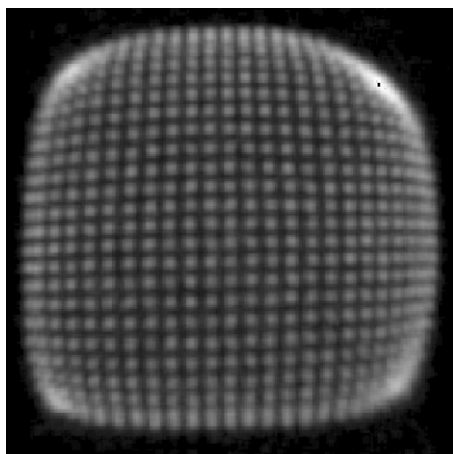


Fig. 7. R2486 PSPMT: 24×24 NaI(Tl) scintillation array— $1.8 \times 1.8 \text{ mm}^2$ pixel size— ^{57}Co flood field irradiation image.

array with the smallest pixel size. The image obtained by Co^{57} flood field irradiation of 16×16 array with a pixel pitch of 1.6 mm is shown in Fig. 1. In this image all pixels are clearly identified, demonstrating the good intrinsic spatial resolution of the tube. Some position distortions are also visible due to the large anode size with respect to the close light distribution emitted by crystal

pixels. In this case the under sampling of scintillation light distribution produces on the image a grouping of spots inside the individual anode (see Figs. 1 and 2). Comparing the flood field image with the analogous one obtained coupling the same scintillating array to R2486 PSPMT, the latter shows a worsening of the intrinsic spatial resolution but a better position linearity response. The poorer pixel identification of the R2486 PSPMT image (Figs. 3 and 4) is mainly due to the wider intrinsic spread of charge (7 mm FWHM). At the same time a thin sampling of the overall charge distribution from the anode pitch (3.75 mm) contributes to a better position linearity response. Imaging results obtained from NaI(Tl) array are shown in Figs. 5–7, respectively for Flat Panel and R2486 PSPMT. The flood field image cross sections obtained irradiating NaI(Tl) show comparable characteristics as in spatial resolution as in position linearity response (see Figs. 6 and 8). The response agreement is surely determined by the thick photocathode glass window and by an additional NaI(Tl) glass optical guide that, spreading the scintillation light distribution, obscure the strong difference of intrinsic charge distribution (7 and 0.5 mm FWHM for R2486 and Flat Panel, respectively). In Table 2 all

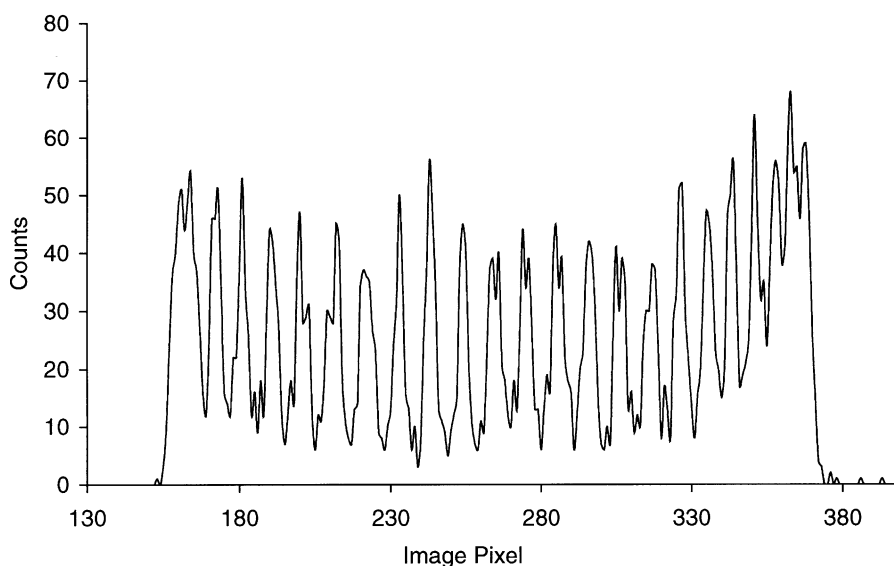


Fig. 8. Raw image cross section of ^{57}Co flood field irradiation of PSPMT R2486: 24×24 NaI(Tl) scintillation array.

Table 2

Comparison of spatial resolution values and valley on peak ratios of Flat panel PMT and R2486 PSPMT, respectively, coupled to scintillation array

Scintillator	Pixel size (mm ²)	Spatial resolution (mm)		Valley/peak ratio	
		R2486	H8500	R2486	H8500
CsI(Tl)	1×1	0.90 ± 0.09	0.62 ± 0.06	0.80 ± 0.06	0.580 ± 0.008
CsI(Tl)	1.4×1.4	1.27 ± 0.11	0.80 ± 0.07	0.46 ± 0.04	0.14 ± 0.03
CsI(Tl)	2×2	1.09 ± 0.09	0.63 ± 0.06	0.31 ± 0.03	0.051 ± 0.009
CsI(Tl)	3×3	1.53 ± 0.13	0.86 ± 0.07	0.068 ± 0.007	0.032 ± 0.005
NaI(Tl)	1.8×1.8	1.00 ± 0.08	1.16 ± 0.09	0.10 ± 0.01	0.15 ± 0.03

results obtained from scintillating arrays are summarized. Spatial resolution values as well as valley to peak ratios are reported to compare the imaging performance of both tubes. The final results show a strong improvement in spatial resolution and in pixel identification of Flat Panel PMT. In particular CsI(Tl) scintillating arrays show always sub-millimeter spatial resolution values. Better values are also foreseen for NaI(Tl) array reducing crystal glass window thickness. The first conclusion of this work is that Flat Panel shows very good image performances, generally better than the previous generation of PSPMT. Compactness makes it attractive for a number of applications in nuclear medicine.

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