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High resolution small gamma cameras for SPET applications

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Abstract- SPE (Single Photon Emission) detector response is studied with respect to the scintillating crystal type and of the electronic signal elaboration method with the aim of achieving a good spatial and energy resolution and a proper linearity response on the whole detection area. Two kind of scintillating crystal matrices are analysed: YAP:Ce and CsI(Tl).The imaging system shows a better spatial homogeneity when using the YAP:Ce matrix whereas when it is coupled to the CsI:Tl matrix it shows a spatial discretization that depends on the matrix septa thickness and on the pillar length but it can be corrected by means of a counts correction procedure. However, the CsI matrix allows a better energy resolution than YAP:Ce one. The linearity response mainly depends on the signal elaboration method: on the border the detector shows a better position linearity when the charge is collected independently by each anodic wire. These results point out the importance of using the CsI matrix when a very good energy resolution is needed, as in scintimammography applications, whereas the YAP matrix, together with the independent wire charge readout, has to be preferred when a high spatial resolution and homogeneity are required, as in radiotracer distribution studies in small animals.

I. INTRODUCTION

The use of scintillating crystal matrices coupled to PSPMT's Hamamatsu has achieved very promising results, especially for high resolution SPE (Single Photon Emission) technique system [1]. Up to now a small gamma camera has been accurately studied with a (40 x 40) mm^2 field of view, particularly suitable for radiotracers distribution studies in small animals [2] and another imaging system has been assembled with a (100 x 100) mm^2 FOV dedicated to scintimammography applications [3]. Accurate analysis have been dedicated to the YAP:Ce scintillating crystal assembled in multipillars structures [4], which is an interesting crystal also for PET applications[5]. The imaging system with the smaller FOV gives high quality biological images in comparison to the Anger Camera [6]; moreover the SPEM is presently undergoing a series of clinical tests.

II. EQUIPMENT AND METHODS

The small gamma camera (YAPCAM) head is composed by a scintillating crystal array which can be chosen between a YAP:Ce matrix 1 cm thick or a CsI(Tl) matrix 0.3 cm thick, with a (40 x 40) mm^2 FOV, coupled to a 3 inch diameter PSPMT Hamamatsu R2486 with a crossed-wire anode [7]. The YAP:Ce matrix is composed by pillars having a 0.6 x 0.6 mm^2 cross section and covered by 5 μm thick reflective-diffractive multilayers that grant a light transmission between adjacent pillars less than 5 % [7]. The YAP:Ce, supplied by Preciosa Crytur (Czech Republic) has a light yield of about 50 % relative to NaI(Tl) when considering the planar crystal, whereas it is reduced to 11% for a single pillar; the other basic properties have been extensively illustrated in other papers [8]. The CsI(Tl) matrix, supplied by Hilger Analitycal (Great Britain), is composed by pillars of the same dimensions of the YAP pillars, but they are 3 mm thick and are covered by a diffusive white epoxy layer 115 μm thick.. The CsI(Tl) properties are well known [9]; the planar crystal light yield is about 45 - 50 % relative to NaI(Tl) (measured with a bialkali photocathode).

The SPEM (Single Photon Emission Mammography) detector is composed by a scintillating CsI(Tl) 3 mm thick array, covering a total 10 x 10 cm^2 FOV, coupled to a 5 inch diameter PSPMT Hamamatsu R3292 with a crossed-wire anode. The single crystal pillars have a 2 x 2 mm^2 cross section and an optical isolation diffusive layer of 170 μm thickness. More information about the CsI(Tl) matrix characteristics and about the PSPMT can be found elsewhere [10, 3].In order to study the performances and physical characteristics of this kind of detector, a YAP:Ce matrix was also used; it is composed by pillars of 2 x 2 mm^2 cross section and 10 mm thickness.

Both imaging systems (YAPCAM and SPEM) are provided with adequate lead collimators that well match the intrinsic characteristics of the relative detectors; the two collimators characteristics are reported in table 1.

The imaging system readout has been accurately studied in order to optimize the detector performances.

Table 1. Collimators characteristics

	YAPCAM	SPEM
Holes diameter	0.5 mm	1.7 mm
Septa thickness	0.15 mm	0.2 mm
Thickness	20 mm	35 mm

The first YAPCAM detector prototype has a single wire readout with 32 independent electronic chains, each of which is composed by a preamplifier and an amplifier. For each interaction event the output signals are multiplexed, digitized by two ADC and then sent to a FIFO. From the FIFO data is transmitted to a PC486, where the interaction position of the event is calculated as the centroid of the charge distribution sampled by the anodic wires [7].

Successively some modifications have been applied to the system readout in order to reduce construction costs and to achieve a faster count rate: the single wire readout has been changed in a resistive chain readout with an integrated acquisition electronics[6]. This type of readout has been applied both to the PSPMT's Hamamatsu R2486 and R3292. Briefly, the crossed anode wires have four output terminations: Xa, Xb, Ya, Yb. For each interaction event these four signals have to be summed in order to achieve the total energy information, while the position determination is calculated out by the means of the "resistive chain" algorithm [6].

III. RESULTS AND DISCUSSION

The spatial resolution of the detector depends on many factors as the physical characteristics of the scintillating crystal, the pillars dimensions and the electronic readout. Previous works have demonstrated that the detector shows a spatial discretization [7]. In this condition, when the intrinsic spatial resolution is smaller than the matrix step (pillar cross section plus matrix septum) the spatial resolution is equal to the smallest distance between two sources distinguished by the detector, that is the interaxis distance between two adjacent pillars. Whereas, when the intrinsic spatial resolution is comparable with the matrix step the total spatial resolution depends on the number of pillars involved by the irradiation spot, so it follows a specific formula [7]. Considering that the collimators holes are comparable with the pillars dimensions, only one or at least two crystals can be involved. In Table 2. the spatial resolution values for different detector configurations are reported; the values relative to one pillar involved correspond to the measured intrinsic spatial resolution. These results together with other intrinsic measurements show that the resistive chain readout do not critically worsen the detector performances[6] so it has been applied also to the SPEM detector.

The energy resolution has been measured in flood field condition in order to analyze the overall energy response, and the results are reported in Table 2. The discrete structure of the matrix produces an energy resolution degradation, due to the different pillars energy responses [8]. The CsI:Tl matrix shows better energy resolution values because of its higher light yield: the 3 mm thick CsI pillar has 44% light yield whereas the 10 mm thick YAP pillar has 11% light yield; confirming the previous consideration also the energy resolution value is not affected by the simplified electronic readout.

Different procedures have been proposed to recover the uniformity of the pillars energy response. They are substantially based on the subdivision of the detector active area in small elementary zones, consisting of few pillars; the energy spectrum of each area is recorded and then it is renormalized respect to a calculated mean value, by doing so we recover the energy response homogeneity. More details about these energy correction procedures can be found elsewhere [8,6]. The energy resolution values obtained with the energy correction are reported in Table 2. Since the Compton scattering events blur the acquired images, a good energy resolution is a basic precondition to improve the image contrast, allowing the application of a narrower energy selection window. The 22 % energy resolution value achieved with SPEM detector is particularly important for scintimammography applications where the Compton events have a significant weight on the total energy spectrum. On the contrary, for YAPCAM applications (i.e. in vivo studies on small biological specimens), a 40 % energy resolution is not a real limitation because the Compton source is small and because the detector has an intrinsically high image signal to noise ratio due to its good spatial resolution [8].

Table 2 - Total spatial resolution and energy resolution of different detector configurations. The energy resolution values are achieved with a Tc-99m flood field irradiation.
(*)Discretization effect: the spatial resolution is calculated as the interaxis distance between two adjacent pillars.

		YAPCAM				SPEM
Crystal:		YAP:Ce		CsI:Tl		CsI:Tl
Readout:		Single wires	Resistive chain	Single wires	Resistive chain	Resistive chain
Total Spatial Resolution	1 pillar involved	0.6 mm	1.1 mm	0.4 mm	0.8 mm	1.8 mm
	2 pillars involved	0.84 mm	1.25 mm	(*) 0.83 mm	(*) 0.83 mm	(*) 2.33 mm
Energy Resolution	Uncorrected:	57 %	57 %	49 %	42 %	39 %
	Corrected:	39 %	44 %	30 %	28 %	22 %

Another correction procedure has been carried out in order to recover the spatial homogeneity response of the imaging system.

For the YAPCAM detector, using the YAP:Ce matrix, the spatial non homogeneity mainly depends on the PSPMT structure (dynode bars [7]), whereas for the SPEM detector, using the CsI:Tl matrix, it is mostly affected by the relative large matrix septa [10]. The application of the counts correction procedure improves the SPEM spatial homogeneity, measured with a Tc^{99m} flood field irradiation, from 30% up to 18%.

The discretization effects of the CsI matrix are also visible in the detector spatial linearity results. The spatial linearity response is studied, for different detector configurations, by irradiating the matrices with a collimated Co^{57} source whose position is accurately determined by a mechanical system. The YAPCAM spatial linearity response has been already measured using the single wire readout: the achieved standard deviations from the linear behaviour were 0.52 mm and 0.64 mm for the YAP:Ce and the CsI:Tl matrix respectively [10].

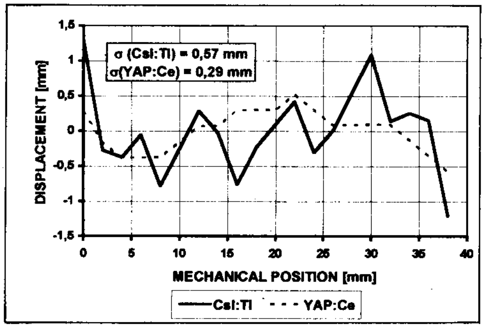
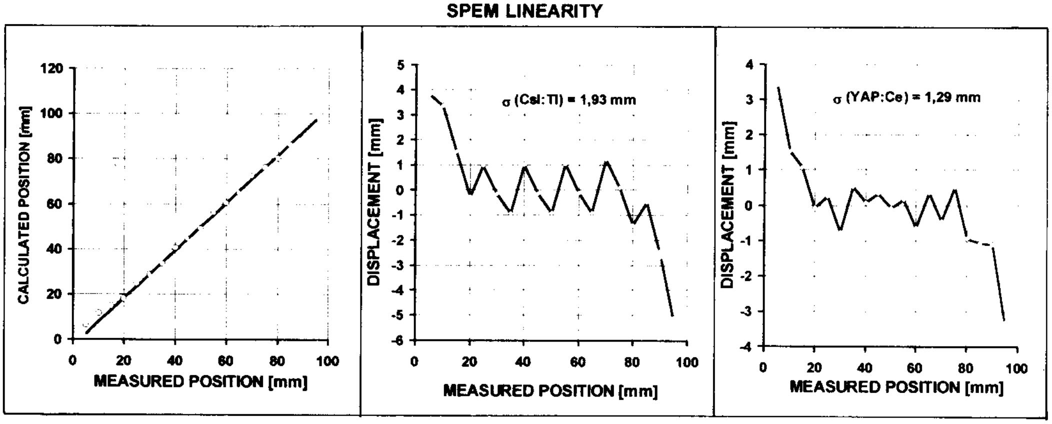


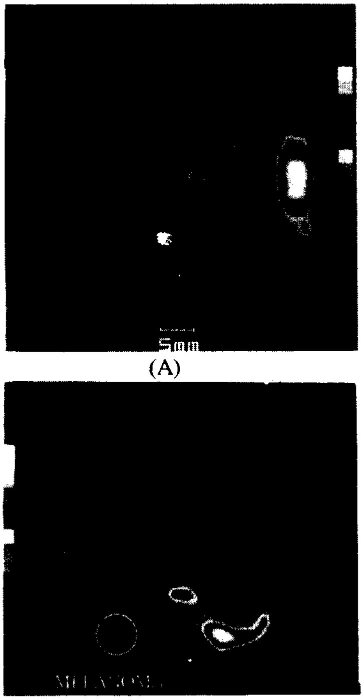
Figure 1 - YAPCAM: comparison between the measured displacements from the linearity response achieved with the YAP:Ce and CsI matrices and the resistive chain readout.

Figure 1 shows the displacements from the linearity behaviour measured by the YAPCAM, using a resistive chain readout: the standard deviations are 0.29 mm and 0.57 mm for the YAP:Ce and the CsI:Tl matrix respectively: the CsI:Tl matrix produces a more evident discretization effect. Moreover the resistive chain readout gives a better spatial linearity response; this result can be explained by the more precise event localization obtained with the single wire readout, that emphasizes the position displacements given by the discrete matrix. On the contrary the resistive chain readout gives a less precise event position determination and, by doing so, it blurs the discretization effect. Figure 2 shows the SPEM spatial linearity responses obtained with the resistive chain readout, using both the CsI and the YAP matrices; in figure 2 (A) and 2 (B) the linearity response achieved with a CsI:Tl matrix and the displacement from the linearity are reported. The SPEM linearity response, when using the YAP:Ce matrix is quite similar to the previous one, except for some minor differences that are highlight in figure 2 (C). The measured standard deviations are 1.29 mm and 1.93 mm for the YAP:Ce and the CsI:Tl matrix respectively. Figure 2(B) shows a spatial periodicity every 3 steps (15 mm) corresponding to 5 pillars step (septa included). The SPEM active area is extended to the PSPMT border, which is a critical zone for the spatial linearity, also because the compression effect is increased by the resistive chain readout, as shown if fig. 2(B) and 2(C). However, from a macroscopic point of view, the detector shows a good spatial linearity response on the whole detection area.



(A) (B) (C)

Figure 2 - SPEM linearity response: (A) CsI linearity response, (B) CsI displacement from the linear response, (C) YAP:Ce displacement from the linear response



(A)

(B)

Figure 3 - YAPCAM biological images achieved with a YAP:Ce matrix: (A) Tumour detected in a murin head, (B) Melanoma detected on a mouse dorsal region.

In order to show the high performances of the YAP Camera, using the YAP:Ce matrix, two images of murin models are presented both in single-wire and in resistive chain readout modality.

Figure 3 (A) shows the image of the head of the biological sample, where the melanoma had been injected: the tumour cells can be recognized, corresponding to the main radiotracer captation zone; this image has been obtained by using a single wire readout. On the contrary, in figure 3 (B) is shown an image obtained by using a resistive chain readout. It shows the internal organs of a mouse and a 3 mm size melanoma, that was injected on the mouse dorsal space, can be also recognize. In both the readout modalities the detector shows very good performances. Moreover, very promising clinical results has been obtained with the SPEM detector; they will be soon published in another paper.

IV. CONCLUSIONS

Extensive studies have demonstrated that the best "setup" and configuration of SPE detector depends also on the final application to which it is dedicated. The YAPCAM, due to its relative small FOV, is a valid instrument to study the tracers biodistribution studies on small animals; in this case the YAP:Ce matrix has to be preferred to the CsI:Tl one, in order to obtain a better spatial homogeneity and spatial resolution, and both the readout modalities can be applied to achieve good quality images. On the contrary, the SPEM detector benefits from the better energy resolution of the CsI:Tl matrix, so that a better image contrast can be achieved. Moreover the resistive chain readout together with the integrated acquisition electronics have to be preferred for SPEM detectors to achieve a faster count rate.

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