A POSITION SENSITIVE PHOSWICH HARD X-RAY DETECTOR SYSTEM

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ABSTRACT

A prototype position sensitive phoswich hard X-ray detector, designed for eventual astronomical usage, has been tested in the laboratory. The scintillation crystal geometry was designed on the basis of a Monte Carlo simulation of the internal optics and includes a 3mm thick NaI(Tl) primary X-ray detector which is actively shielded by a 20mm thick CsI(Tl) scintillation crystal. This phoswich arrangement is viewed by a number of two inch photomultipliers. Measured values of the positional and spectral resolution of incident X-ray photons are compared with calculation.

1. Introduction. The use of the coded aperture mask is rapidly becoming a well established technique for the imaging of high energy X/gamma-ray photons (10 keV $\lesssim E_\gamma \lesssim$ 1 GeV) [1,2]. The successful application of this technique and the imaging quality of the final telescope system are related to the development of a suitable position sensitive photon detection plane. The performance of this element must be optimised with respect to a number of factors in order that a high quality astronomical telescope can be constructed. First and foremost, the detection plane must have the best possible positional resolution for the incoming photons so that high definition images can be made. However, to ensure that sophisticated astrophysical information may be extracted from the imaging data it is also important that the detector has good spectral resolution for the detector photons and that the background noise level is reduced to a minimum level in order to maximise the sensitivity of the overall system.

A number of position sensitive detector systems are currently under development for astronomical use in the hard X/gamma-ray region of the electromagnetic spectrum ranging from the thick inorganic scintillators for gamma-ray photons to xenon gas proportional counters at the lower end ($E_\gamma \lesssim$ 100 keV) of this spectral range [3,4,5,6]. At the present time the most effective detection system to cover the hard X-ray spectral range $\sim$15-300 keV comprises a thin (few mm) NaI crystal which is actively shielded. The phoswich/collimator arrangement has been extensively used to accumulate hard X-ray astronomical information. Here we describe the development of a prototype position sensitive phoswich system. Apart from eventual use as an imaging syystem such a device has the additional advantage of potential operation as an X-ray polarimeter.

2. The Detector System and Associated Tests. A prototype NaI(Tl)/CsI(Tl) phoswich system was constructed as shown in Fig.1. The dimensions of the assembly were 262mm x 62mm x 33mm. The NaI(Tl) and CsI(Tl) crystals were 3mm and 20mm thick respectively. A thin aluminium entrance window enabled the system to be studied with X-ray photons down to $\sim$15 keV. The 'bottom' face of the arrangement was covered in glass to enable the scintillation light to be detected by a suitable array of photomultiplier tubes which were optically coupled by means

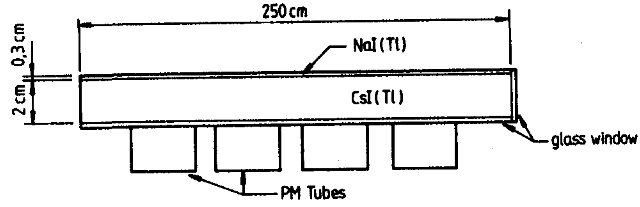

Fig.1. A prototype NaI(Tl)/CsI(Tl) position sensitive phoswich system.

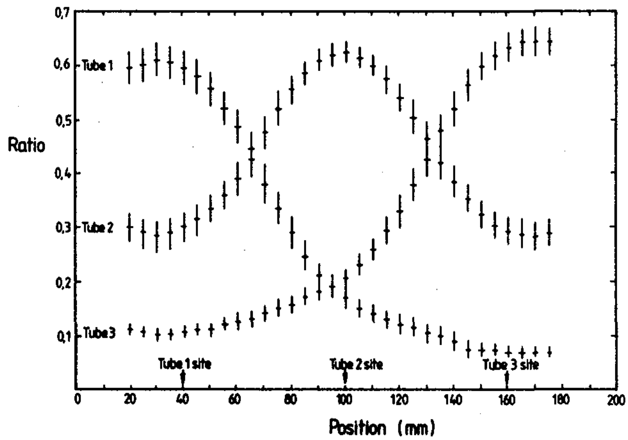

Fig.2. The ratio of individual photomultiplier signals to the total signal as a function of position along the length of the detector.

of a highly transparent silicon grease. The photomultiplier signals were processed by a Harshaw NC25A pulse shape discrimination unit and in conjunction with a CAMAC/PDP-11 computer system in order to select genuine X-ray events and record the various signal amplitudes for individual X-ray events. A highly collimated Am 241 source was used to irradiate a well defined (<2mm) position on the surface of the NaI crystal.

Figure 2 shows the ratio of individual photomultiplier signals to the total signal, as a function of position along the length of the detector. The measurements were taken at 5mm intervals on a line which joins the centres of the phototubes. Approximately 10^4 events were recorded for each position. The positions of the photomultiplier tubes are indicated on the X-axis. The shape of the curves was found to be in excellent agreement with the prediction of a Monte Carlo simulation of the scintillation light collection efficiency for various X-ray interaction positions over the surface area of the detector system.

An appropriate event location algorithm was constructed on the basis of the above experimental data and subsequently used to calculate the position of interaction of incident X-rays. Figure 3 shows a graph of positional resolution versus position along the line joining the centres of the photomultiplier tubes. It can be

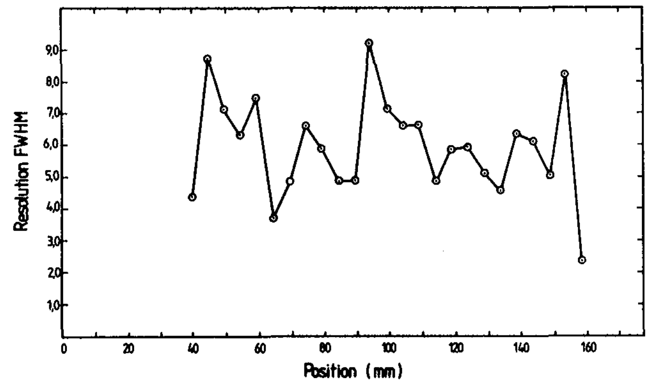

Fig.3. Positional resolution (FWHM) as a function of position using data from Fig.2.

seen for such a 'linear' case that the best positional resolution occurs in the region between the photomultiplier tubes where the gradients of the signal ratio versus position are at a maximum. The relatively poor resolution above the centres of the photocathodes leads to a 'spikey' response which is undesirable for coded aperture imaging.

Figure 4 demonstrates the improvement which may be gained by sampling the scintillation light over a two dimensional sample. In this case the photomultiplier signals (lighter lines) and positional resolution (heavy line) are taken along a line of symmetry between two rows of PM tubes. The positions of the individual photomultipliers are indicated along the X-axis. The great improvement in the uniformity of the positional resolution clearly demonstrates that a two dimensional must be employed as in the traditional gamma-camera.

The spectral resolution of the system was found to be competitive the best scintillation devices.

3. Conclusions. The above preliminary tests have demonstrated that a position sensitive phoswich detector can be made to operate in the hard X-ray region of the electromagnetic spectrum with a positional resolution of a few millimetres. For historical reasons the original attempt has been to develop a one-dimensional position sensitive counter. It was found that this device had an extremely non-uniform positional resolution function which is not suitable for the production of good quality coded aperture images. When operated as a two-dimensional device, in a similar manner to the gamma-camera, it was found that

a phoswich device could be made to operate with good spectral and positional resolutions for the incident hard X-rays.

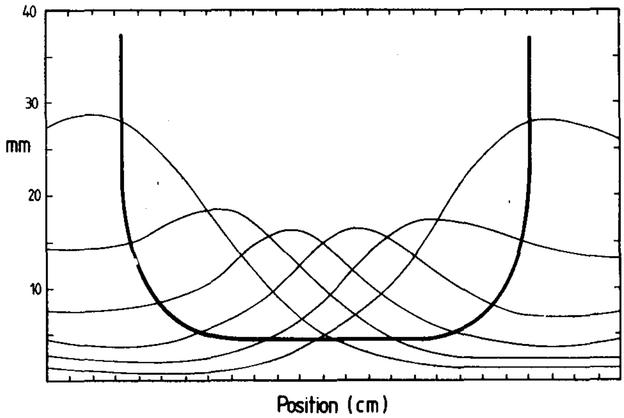

Fig.4. Ratio of individual photomultiplier signals as a function of position along a line equidistant between two rows of photomultipliers (light curves) and arbitrary units). Calculated positional resolution along this line (heavy curve)

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