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An alpha tagged X-ray source for the calibration of space borne X-ray detectors

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ABSTRACT

Calibration of X-ray detectors is very important to understand the performance characteristics of the detectors and their variation with time and changing operational conditions. This enables the most accurate translation of the measurements to absolute and relative values of the incident X-ray photon energy so that physical models of the source emission can be tested. It is a general practice to put a known X-ray source (radio active source) in the detector housing for the calibration purpose. This, however, increases the background. Tagging the calibration source with the signal from a simultaneously emitted charge particle (like alpha particle) can identify the X-ray event used for calibration. Here in this paper, we present a new design for an alpha-tagged X-ray source using Am^{241} radio active source and describe its performance characteristics. Its application for the upcoming Astrosat satellite is also discussed.

1. Introduction

The characterization and measurement of X-ray emission from the astrophysical sources require well calibrated X-ray detectors. Parameterizing the energy scale and monitoring the variations in the performance of X-ray detectors can be done by using an internal calibration source which emits continuous calibration lines at certain energies. The overall performance can further be verified by analyzing the data recorded from the observations of any standard X-ray source in the sky. One commonly used radio active source is Americium-241 (Am^{241}), which provides a continuous source of calibration lines with energies between 13 and 60 keV. For example, the calibration of the Proportional Counter Arrays (PCA) onboard the Rossi X-ray Timing Explorer (RXTE) is done using a Am^{241} source embedded in a proportional counter [1,2]. Similarly, a tagged Am^{241} source is used to calibrate and stabilize the gain in the High Energy X-ray Timing Explorer (HEXTE) of the RXTE satellite [3,4]. The calibration source establishes the energy scale and its variation with time and other parameters along with the relative variation of the efficiency. The broadband performance and the flux calibration, however, is usually done by observing a few standard X-ray sources in sky such as Crab Nebula which provide a bright stable broadband source with a well-characterized spectrum.

Americium is a human-made radio active element with atomic number of 95. Americium-241 (Am^{241}) can be produced by bombarding plutonium-234 with alpha particles. Am^{241}, with a half-life of 432.2 years, decays primarily by alpha particle emission (at 5485 keV—84.5% and 5443 keV—13%) to Neptunium-237 which has a half-life of 2.144×10^6 years. These decays are accompanied by low energy gamma radiation with the 59.5 keV gamma emission (35.9%) being the most important one along with 26.35 keV (2.4%) and 13.9 keV (42%) emission. The radio active source Am^{241} is commonly used for testing and/or calibrating the majority of hard X-ray detectors specifically because of the presence of the prominent 59.54 keV X-ray emission.

To detect the alpha particles simultaneous to the X-ray emission, the Am^{241} source is embedded in a radiation detector which detects the alpha particles but is transparent to the X-rays. It can be done by using proportional counters (as was done for the PCA detectors [2]) or thin scintillators viewed by a Photo-multiplier tube (PMT), as was done for HEXTE [3]. Both these methods, however, require the generation and use of high voltages (a few hundred volts) which is cumbersome and heavy. For the Astrosat satellite [5], a large area hard X-ray detector of area 1000 cm^2 using an array of Cadmium Zinc Telluride (CZT) detectors is being developed with a overall mass budget of 50 kg. To calibrate these detectors (called

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CZT-Imager or CZTI), we have developed a compact low mass alpha-tagged X-ray source.

In this paper, we present the design of a new method of using Am^{241} as an alpha-tagged X-ray source and discuss its efficiency as a calibration source for the CZTI of the Astrosat satellite.

2. Design of the alpha-tag X-ray source

We have designed a very simple compact system for detecting the alpha particle coming from the Am^{241} radio active source. In addition to the detection of alpha particles, the system also transmits the 59.54 keV X-ray photons emitted by Am^{241} which can be used for the purpose of calibration of any radiation detector. In this detector system, the principal components used are (i) the radio active source Am^{241} which emits the alpha particles as well as the 59.54 keV X-rays, (ii) a CsI(TI) crystal which detects the alpha particles and also transmits the 59.54 keV X-rays, (iii) a Si-PIN photo-diode for the detection of the light output from the CsI(TI) crystal (due to the interaction of the alpha particle) (iv) a charge sensitive pre-amplifier (CSPA) mounted right behind the photo-diode. This whole system, called the Alpha Module, is light weight (~ 3 g) and requires only a low voltage supply (+12 V) with a power dissipation of 130 mW.

The Alpha Module (see Fig. 1) is a small $10 \times 10 \times 0.3\,mm^3$ of CsI (Tl) crystal (wavelength = 550 nm) with Teflon reflective material coupled to a Si-PIN photo-diode of the same area. It contains a small pallet of Am^{241} with a low strength of about 2000 Bq which is mounted on a 0.15 mm steel template. This radioactive source is kept in contact with a 0.3 mm CsI(Tl) crystal that detects the alpha particles and also transmits the 59.54 keV X-rays with a transparency of 35%. The Si-PIN photo-diode detects the light output from the CsI(Tl) crystal (due to the interaction of the alpha particle). This photo-diode has a broadband response in visible spectrum (average efficiency of 50%) with higher sensitivity and low dark current. Incident energy from the alpha particle is converted into light in CsI(Tl) whereas the light seen by the photo-diode is converted into an electrical pulse, which is amplified by the charge sensitive pre-amplifier (CSPA). The CsI(Tl) along with photo-diode and CSPA, as a whole structure, is called the Alpha Module, which is rugged, compact, reliable and does not need a high voltage supply for biasing purposes. This whole compact system is procured from M/s Scionix, Holand. Since the photo-diode output impedance is high (10 M Ω) and signal level is of the order of a few milli volts, a low noise CSPA is used to process the signal. This CSPA is placed just behind the photo-diode, so as to reduce noise. The pre-amplifier is wired on a $10 \times 10\,mm^2$ PCB (printed circuit board) and it is an integral part of the Alpha Module.

We have designed a simple electronics circuit to read out the pulses from the Alpha Module. The signal from the CSPA is passed through a pre-amplifier circuit with appropriate integration to achieve bipolarity with a gain of 900. The sharp pulses (rise time 0.5 μs) resulting from the detection of ionizing radiation (signal from the CsI(Tl) crystal through the photo-diode) are processed in the amplifier to have suitable shape and amplification. This amplified signal is passed through a comparator having a fixed LLD (lower-level discriminator) bias to cut off noise. This whole scheme is shown in Fig. 1, along with the Alpha Module. The module can be used as a source of X-rays from Am^{241} and the Alpha pulse output from this device can be used as a tag for the X-rays. The Alpha Module, mounted on a PCB, along with the electronics, is called the Alpha-tag source and it is used in the CZTI payload of Astrosat for in-flight calibration.

The amplifier output is fed to a Multi Channel Analyzer (MCA) and the results are shown in Fig. 2. A peak corresponding to the 5.5 MeV alpha particles is clearly seen in the figure. A count rate corresponding to 720 counts/s is noted.

3. X-rays from the Alpha-tag source and the alpha-tagging methodology

We made an experimental set up to study the alpha-tagged X-ray source characteristics. Our experiment consists of a NaI(Tl)/CsI(Na) Phoswich scintillator detector on the top of which the Alpha-tag source was mounted. The scintillators are coupled to a PMT which multiplies the current produced by the incident light by as much as 100 million times (i.e. 160 dB), in multiple dynode stages, enabling individual photons to be detected. The current signal from PMT for every incident energy is converted to voltage and then passed through an amplifier having a gain of around 20.

The alpha particles from the Americium source in the Alpha Module generates pulses in the Alpha-tag source electronics (the circuit diagram of which is shown in Fig. 1 along with the Alpha Module) and the 59.54 keV X-rays, if they interact with the Phoswich detector, generates signal in the PMT electronics. The signal from PMT was then gated with the Alpha pulse and plotted on computer using a pulse height analyzer (PHA) software. It was found that there was a delay of approximately 5–15 μs in the Alpha pulse with respect to the X-ray pulse, due to the different electronics characteristics. This delay was accommodated by adding a peak detector circuit in the path of the PMT signal. The amplified signal was then connected directly to a MCA and/or an oscilloscope. The pocket MCA (MCA 8000A from AMPTEK) was used in the experiment, which was again connected

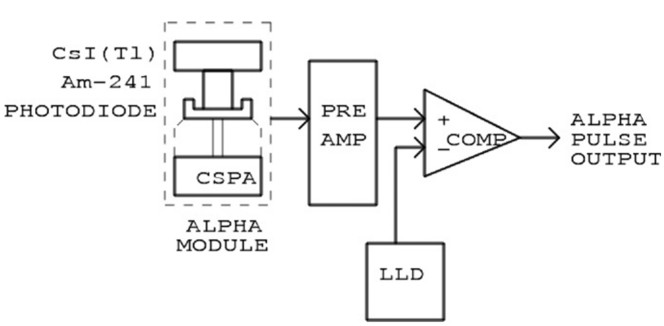

Fig. 1. The block diagram of Alpha-tag source with the Alpha Module and the electronics for generating Alpha pulse output for tagging the X-rays.

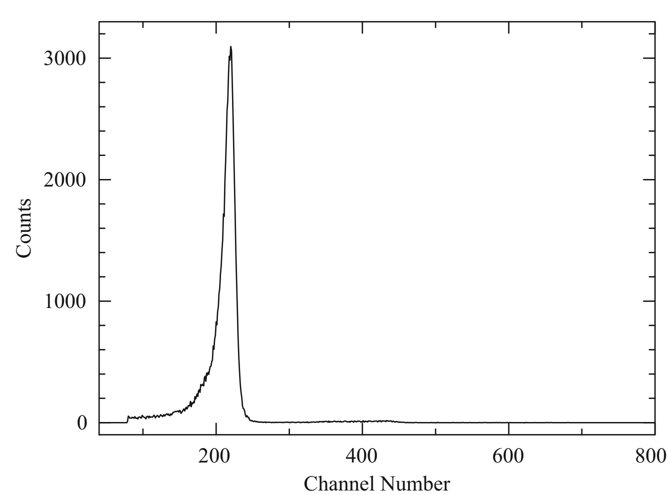

Fig. 2. The pulse height distribution from the Alpha-tag source. The peak corresponds to the 5.5 MeV alpha particles.

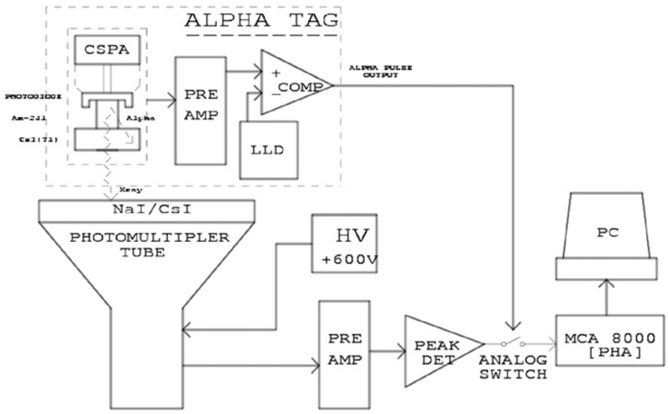

Fig. 3. The experimental set-up to tests the alpha tagging efficiency of the Alpha-tag source.

to a computer for data acquisition and storage. The experimental set-up is shown in Fig. 3.

To reduce external noise, necessary care was taken to block extraneous light entering the PMT. A thick lead sheet with a small hole at the center was used as a collimator on the top of the Phoswich detector to block X-rays coming from other directions to reduce the background. An arrangement was also made to block the X-rays from the Alpha-tag source so that background could be measured from the Phoswich detectors without actually removing the Alpha-tag source. With this set-up, the data were recorded by blocking the X-rays from the alpha source to measure the ambient background. The MCA was calibrated by shining a bright Am^{241} source directly onto the Phoswich detector and measuring the peak corresponding to the 60 keV X-rays. The Alpha-tag source was then kept on the Phoswich set-up and the spectrum was taken by repeating the above procedure. Excess counts were seen near the 60 keV peak and we note a count rate of 23 counts/s due to the Am^{241} source. The 2000 Bq source gives about 720 count/s and (we estimate about 50% efficiency for the detection of alpha particles in the CsI detector, based on the fact that the Am^{241} source is mounted on a steel template). The expected number of 60 keV counts are reduced by a fraction α where $\alpha = \varepsilon\Omega/(2\pi)t$ where ε is the fraction of 60 keV X-rays emitted for each alpha particle (~ 0.35), $\Omega/(2\pi)$ is the fractional solid angle subtended by the Phoswich detector to the alpha source (~ 0.3) and t is the transmission of CsI detector for the 60 keV X-rays (~ 0.35) giving α to be 0.036 which agrees with the observed number of X-rays.

For the background estimation, the alpha-tag source was kept out of the experimental set-up and necessary care was taken to avoid any X-ray photons from the alpha-tag source entering the PMT. The photon spectra were accumulated for 100 s of exposure and collected using the MCA. This count spectrum are considered as the background spectrum. This is shown in Fig. 4. After collecting the background spectra, the alpha-tag source was kept on the Phoswich set-up and the corresponding spectra were taken. This photon spectra are shown in Fig. 5.

Following these observations, the Alpha-tag detector was placed on the PMT with the necessary experimental connections as shown above (Fig. 3). The observations were repeated several times and the count spectrum for one such observation is shown in Fig. 6. We can see that the X-ray peak is enhanced considerably. Comparing the 80–120 keV count rates in Figs. 5 and 6, we estimate that less than 10% of background X-rays are registered due to the tagging process. The total counts in <80 keV region in Fig. 6 is $27\,s^{-1}$. If we assume that the background in this region too is reduced by 90%, we can estimate that by the alpha-tagging method, more than 95% of the 60 keV X-rays impinging on the Phoswich detector are registered. This is somewhat higher than the 50% estimated earlier for the detection of alpha particles in

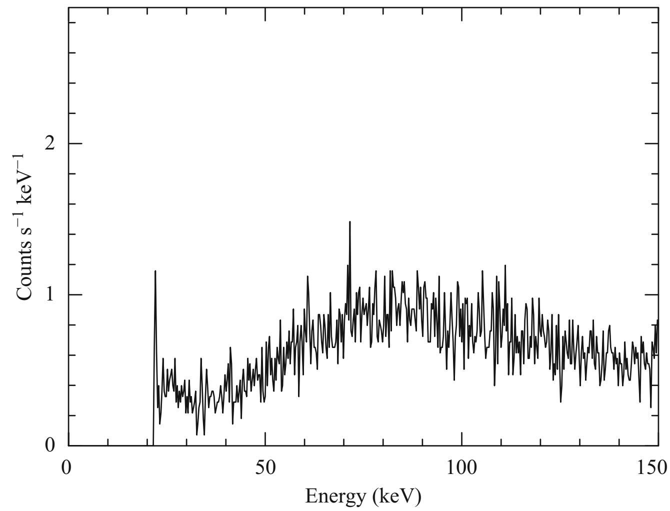

Fig. 4. The background spectrum from the Phoswich detector.

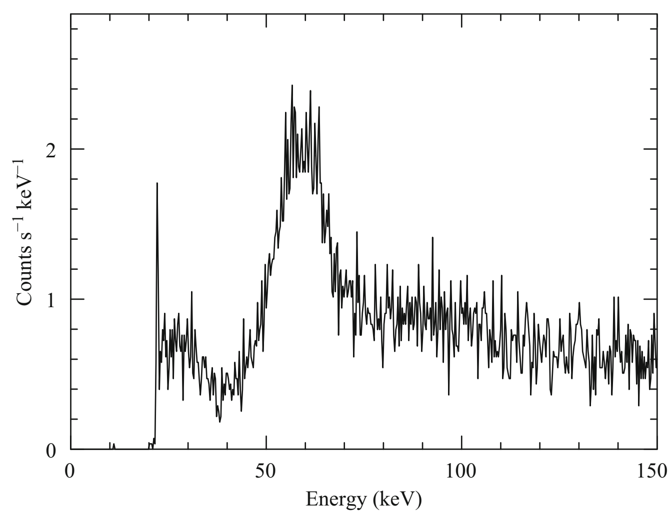

Fig. 5. The spectrum from the Phoswich detector with the alpha-source kept on it.

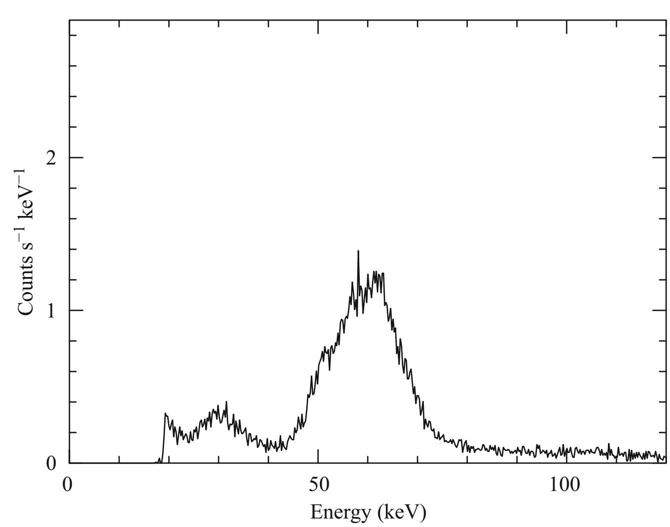

Fig. 6. The Phoswich detector output gated with Alpha-tag pulse.

the CsI detector. This discrepancy could be the result of (a) the pallet of Am^{241} could have a shape which enables a large fraction of alpha particles to impinge on the CsI crystal and/or (b) the reduction of background in the <80 keV region being higher than 10% due to some threshold effects. This experiment is done at somewhat higher background conditions (a total background of $177\,s^{-1}$). This alpha-tagged X-ray calibration source is proposed to be used in the Astrosat satellite where the onboard background is expected to be only about 20 counts/s and hence negligible leakage is expected.

4. Conclusions

We have developed a new alpha-tagged X-ray source for space application which is rugged, cheap and easy to operate. Though the count rate is low (23 counts/s), it is sufficient to make onboard calibration with an integration time of about 100 s. Currently, the leakage of background counts is about 10%. This would be improved in a low background environment and better tuning of the gate-width for the alpha detection. The alpha-tagging method selects only the calibration X-rays along with negligible contribution from the background, thus enabling the calibration with a low count rate source. Further, even if a small fraction of these X-rays enter the detector without getting tagged (a few count per second), they will have negligible impact on the overall background rates.

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