Laboratory Performance of the Proportional Counter Array Experiment for the X-ray Timing Explorer

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1. Abstract

In this paper we briefly describe the design and initial laboratory performance of the Proportional Counter Array (PCA) for the X-ray Timing Explorer (XTE). The PCA consists of 5 identical, sealed and collimated (1^oFWHM), xenon/methane multi-anode proportional counters sensitive to x-rays with energies between 2 and 60 keV. Each detector has an effective area of approximately $1,250cm^2$. The data system can tag the relative time of arrival of each event with an accuracy of $1\mu s$. The overall absolute time accuracy will be maintained by the spacecraft to better than $1ms$. Following the design principles of the HEAO-1 A2 HED detectors, the PCA adopts the interleaved anode connection scheme with an active propane anti-coincidence layer in the front and a similar anti-coincidence xenon/methane layer on three other sides of the detector. The interleaved anode connection scheme and the anti-coincidence layers reject background events caused by charged particles with high efficiency, thus significantly reducing the background event rate at lower energies. As of 1 June 1993, the fabrication and assembly of all five detectors had been completed. Their performance evaluation and characterization are currently under way. XTE is scheduled to be launched with a Delta-II rocket in the summer of 1995.

2. Detector

The Proportional Counter Array (PCA) consists of 5 identical Proportional Counter Units (PCU). Each PCU is a xenon/methane proportional counter with a mechanically collimated 1^0 (FWHM) field of view. The PCU design is based on the successful HEAO-1 A2 detectors (Rothschild et al. 1979; Boldt 1987) and employ a double gas volume system, anode interleaving connection scheme, a live anti-coincidence shield layer and a passive graded mechanical shield in order to achieve stable, low background, performance. The PCA is sensitive from 2-60 keV with microsecond timing capabilities. The PCA will be co-aligned with the High Energy X-ray Timing Experiment (HEXTE) (Bradt, Swank, and Rothschild, 1989) aboard the X-ray Timing Explorer (XTE) satellite and the two experiments will provide simultaneous spectroscopic coverage from

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2-200 keV. Figure 1 shows an exploded view of a PCU. We describe the components from the top. Each PCU is covered by a thermal shield consisting of aluminized 1/3 mil Kapton. The thermal shield is part of the passive thermal design of the PCA; each detector is thermally connected to the XTE spacecraft. The thermal shield will not be illuminated by direct sunlight except for observations which are < 45 degrees away from the sun. (The baffles which accomplish this are part of the spacecraft.)

The collimator consists of 5 individual modules, each of which is epoxied into the collimator housing. The collimator housing flange provides the mounting surface to the spacecraft and it is necessary that the individual modules be aligned with this interface. Each module is formed from 3 mil beryllium-copper sheets which are tin coated, stamped into half-hexagonal form, stacked, and heated. The tin coating solders the sheets together. Each module is a rectangular cube about 8 inches on a side and each hexagonal cell is about 1/8 inch across the flats. Each module has a 1 square cm mirror bonded to the front surface. The direction of peak transmission is measured in a parallel light beam and the interior surface of the module is machined normal to the direction of peak transmission. The interior surface is polished and coated with a small amount of uralane in order to protect the mylar window. Individual modules are then epoxied into the collimator housing; typically the 5 peak throughput directions are within 30 arc-seconds of each other. The net detector optical axis, calculated by averaging the axes of the 5 cubes and verified via measurement in the parallel light beam, is < 1 arcminute off from the normal to the mounting surface for 4 of the 5 detectors and < 2 arcminute off for the 5th detector. The mechanical alignment is better than the budgeted amount for all detectors in order to offset any possible in-orbit distortion caused by temperature variations.

Immediately behind the collimator is a 20 mil beryllium-copper shoe which duplicates the footprint of the first grid. A 1 mil mylar window with 700 angstroms of sputter deposited aluminum on each side is held in place between the shoe and the first grid. A second window is held between the first and second grids. The two windows and the first grid form the boundaries of a 1.3 cm deep volume which is filled with propane and which serves, primarily, as an electron veto region and front anti-coincidence shield. The first grid has twenty anodes on 1.3 cm centers and separated by aluminum walls which support the second window. The propane nominal pressure is 1.05 atmospheres; the double-gas-volume design requires that this pressure be less than or equal to the pressure behind the second window at all times during the construction and operation of the detector. Behind the second window are four more grids, each with twenty anodes and the same spacing as in the first grid. The anodes are separated by wire wall cathodes and this volume is normally filled with xenon plus 10% methane mixture at a total pressure of 1.10 atmospheres. The anode and cathode wires are all made from gold coated, 2 mil diameter, stainless steel wire. The wires are installed under tension (~110 gram) sufficient to stay taut at the lower survival temperature of $-25^0 C$, but low enough not to yield at the highest temperatures considered for baking out the detectors $(80^0 C)$. Wire tension is checked after installation by measuring the fundamental acoustic frequency of each wire.

Behind the last grid is a beryllium-copper back plate which provides the ground for the rear layer and some shielding from events which are created in the dead (i.e. non-instrumented) xenon volume at the rear of the counter. Mounted on this plate is an Americium 241 source which provides a continuous energy calibration as discussed below. A detector housing and a rear cover complete the detector volume. Mounted on the rear cover is a pressure transducer and a getter pump which

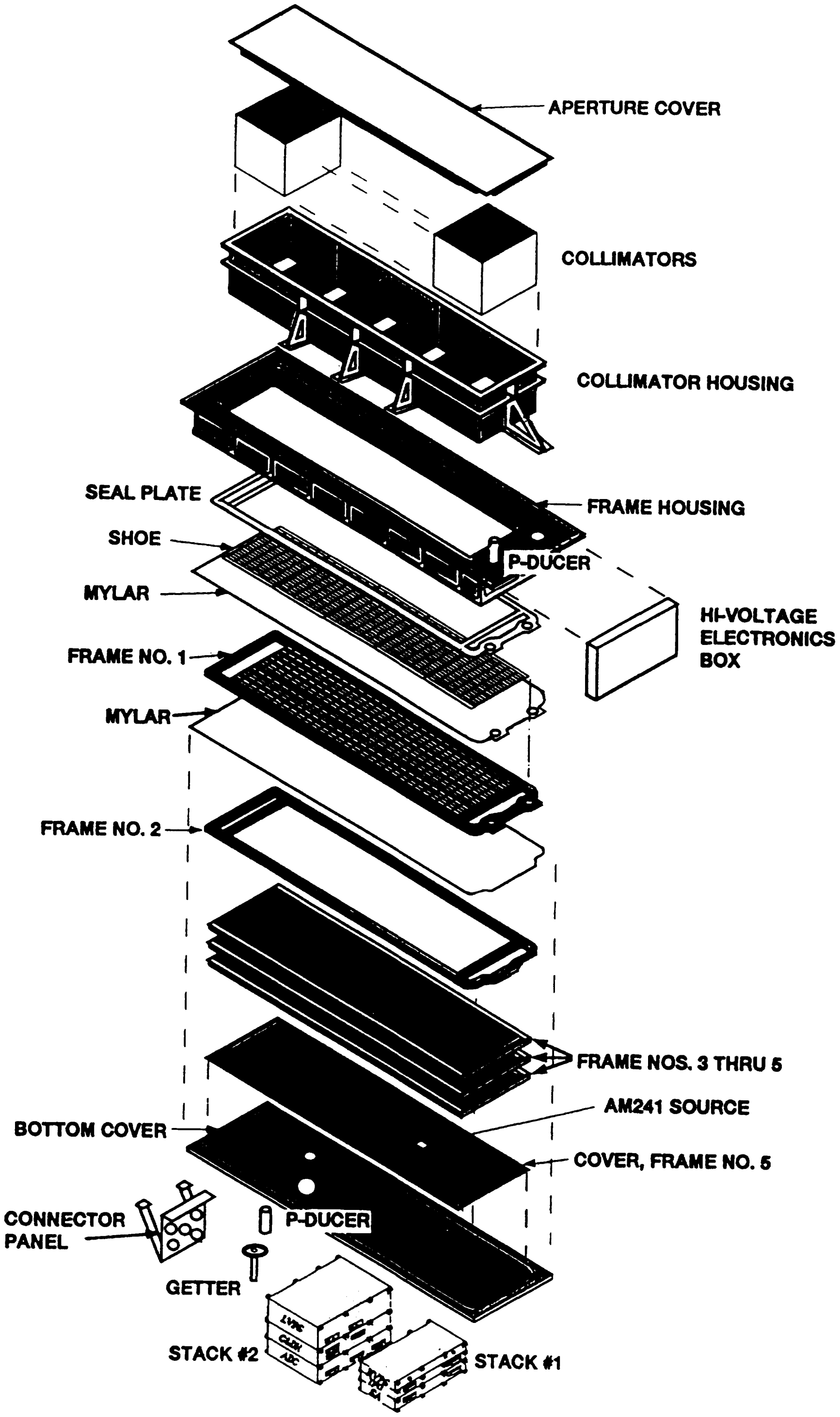

Fig. 1 Exploded view of a PCU. The function of various components are discussed in the text from top to bottom.

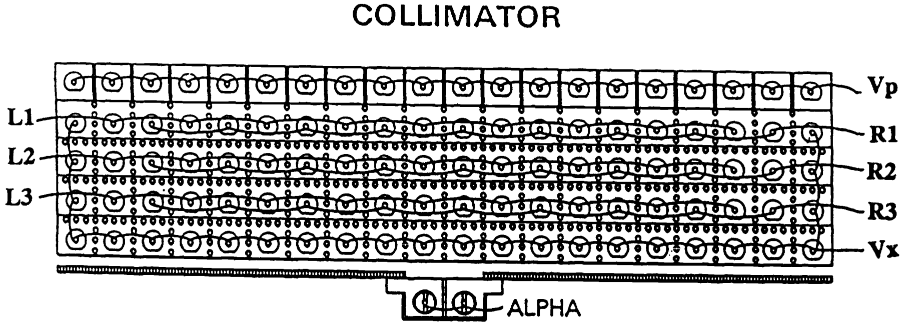

Fig.2 The interleaved anode connection scheme for maximum background rejection. Each PCU has 9 independent channels of analog electronics.

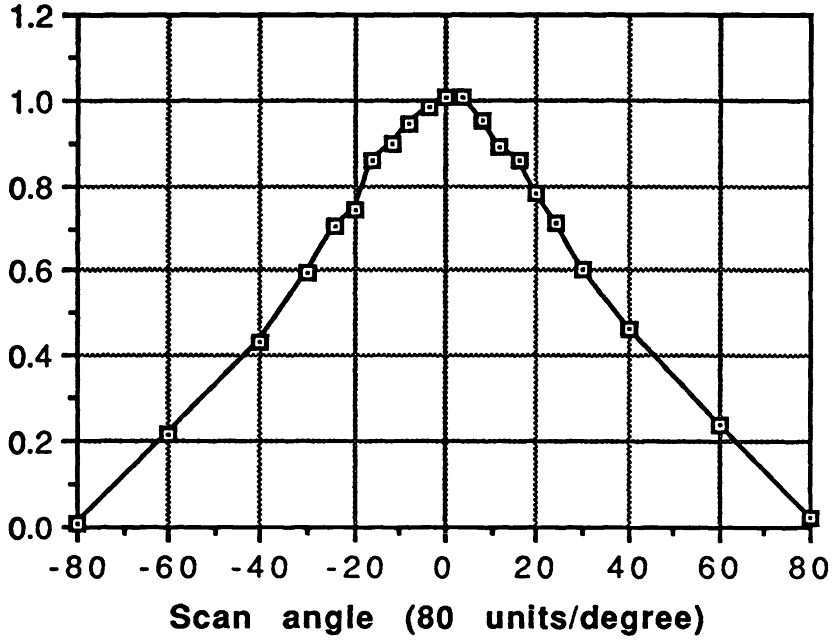

Fig. 3 Collimator transmission as a function of angle. The plateau around zero is caused by the divergence of the beam and reflection effects.

is filled with a zirconium/vanadium/iron alloy which is activated by external heating just before the detector is filled. The detector is covered by a graded tantalum (60 mil) and Tin (20 mil) shield. The tantalum thickness is chosen to keep the event rate due to the diffuse cosmic photon flux above 60 keV which penetrates the detector walls less than the expected flux due to the cosmic X-ray background flux which enters the detector through the collimator. The tin thickness is chosen to absorb escape photons generated from interactions in the tantalum.

3. Data System

Each PCU has 9 analog signal chains: a front one consisting of all the anodes in the propane volume (Vp); a back one consisting of the outer layer of anodes in the xenon volume (Vx); a calibration flag indicator (alpha flag, see the section on Energy Calibration); and 6 main signal chains which are formed by alternate anodes on each of the xenon grids (L1, R1, L2, R2, L3, and R3). The inter-connections are shown in the cross section view of figure 2. All of the signal chains except Vp are supplied from a common high voltage supply with a nominal setting of 2050 V and commandable in 20 V increments. The Vp layer has a separate supply with nominal setting 2800 V and commandable in 20 V increments. The signal from each anode chain has a pre-amplifier and shaping amplifier. The alpha chain merely provides an indication of an event; the Vx chain provides a 3 channel pulse height; the other channels are gated into a single analog to digital convertor. An event consists of an 8 bit pulse height, a two bit Vx pulse height, 8 lower-level discriminator (LLD) flags, and a saturating event flag. If two or more LLD flags are set the origin of the 8 bit pulse height is ambiguous; however, such events are primarily due to particles which leave tracks in the detector (and which we desire to reject) and secondarily to events which are split between two anodes due to the initial photo-electric absorption occurring near an anode boundary or to the re-absorption of a xenon K-escape photon. While these effects will cause us to reject some bona fide X-ray events, they can be compensated for in the detector response function. Sufficient sensitivity does remain at the higher energies in order to overlap with the HEXTE bandpass (which starts at 15 keV). The total rate of activity on each anode chain is recorded in the housekeeping telemetry every 8 seconds as well as the total rate of 2 or more LLDs in coincidence and the number of saturating events.

Every event detected in the PCU is passed to the Experiment Data System (EDS) as a 19 bit serial data stream. The EDS, designed and built at MIT, serves as a flexible telemetry processor for the PCA and as a control and data processing unit for the All Sky Monitor which completes the XTE instrument complement. The functionality of the EDS allows us to consider its PCA functions independently. Within the EDS there are 6 Event Analysers (EA), each of which receives the entire PCA data stream from all 5 PCU's and can be programmed to process the event stream in various ways. The EDS front end receives PCA event data asynchronously, adds 3 bits to identify the PCU, and latches the spacecraft supplied time with microsecond resolution. This information is supplied to each EA which can be programmed to bin the data with good energy resolution and coarse time resolution, coarse energy resolution and high time resolution, to pass some or all of the bits directly to telemetry, or to perform more complicated functions such as fourier transforms, auto-correlations, or phase binning. Two of the EAs will be devoted to standard modes with the intention of producing some data products which are uniform for all the observations throughout the mission. The current plan is to collect spectral data for each anode chain with a resolution of 16 seconds and total rates in 1/8 second intervals in several broad energy bands. This will require the use of ~3 kbps of telemetry out of an average available telemetry of 32 kbps.

Telemetry will be the limiting factor. Since the overall background activity rate in each PCU may be ~400/sec, and 48 bits are required to send all of the information, including time, for each event, the required telemetry for a complete description of the background is ~100 kbps for the PCA.

4. Energy Calibration

A PCU's gain and resolution are monitored using several atomic and nuclear x-ray lines accompanying alpha decays of an Am241 source. This source is located inside a parasitic small proportional counter, referred to as the alpha counter hereafter, at the bottom of the main counter (see Fig. 1). When a disintegration occurs, the alpha particle is detected by the alpha counter while the x-rays are detected as if they were normal x-rays coming in through the collimator. The coincidence between the alpha detection and the x-ray detection serve as a flag to indicate that this particular event is a calibration event. During a normal observation run, pulse height spectra of these flagged events are accumulated. With the Am source activity of 5 nCi, we get an event rate of 0.5 counts/sec in each of the six active layers. This rate ensures that we can get a statistically sufficient data set for each layer everyday. Since not all the alpha particles can get out of the source holder as all the x-rays do, a small fraction of the x-rays associated with the Am source do not get flagged, thus becoming part of the background. These events create some line features identical to the calibration spectrum. This rate can be measured accurately and can be subtracted out from the real observational data. A typical alpha tagging efficiency is about 80%.

5. Performance Characteristics

In this section we will briefly report on the performance characteristics we have obtained so far and our tentative plan to further characterize all PCU's.

The collimator response to x-rays has been measured at a beam facility at Goddard. This beam, because of its 8-arcmin divergence, can only serve to qualitatively characterize the collimator response. Fig. 3 shows the transmission efficiency as a function of the angle. The plateau around the maximum is caused by the divergence of the beam and reflection effects. With the current beam conditions we have not yet measured the response degradation related to the alignment errors of individual collimator cells. Further measurements will be made of this curve at different energies for each detector. Fig. 4 shows the xenon/methane layer gain as a function of time measured with a Cd109 source. We have found that the xenon/methane gain rise during the first 60 days is related with the loss of methane due to the absorption/adsorption of methane by the detector interior surfaces. The magnitude of the rise is directly proportional to how long the detector is baked and pumped before filling. But at any rate, this rise in gain is transitory. About 100 days after each filling the gain stabilizes.

Fig. 5 shows the energy resolutions of the xenon/methane layer as functions of time at two different energies. It can be seen that the resolution is quite stable over the entire monitoring period. Two procedures have been used to maintain the purity of the proportional gas: the baking and pumping prior to each filling and the presence of two getter pumps with Zr-V-Fe alloy.

A primary goal of XTE is to detect source variations on microsec time scales. The variations with

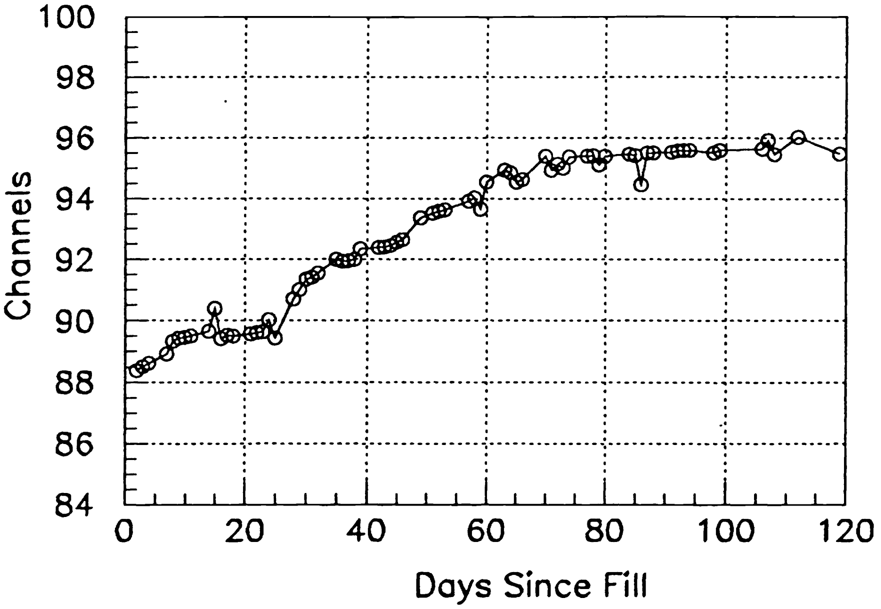

Fig. 4 Gain as a function of time since fill from a typical PCU. The steady rise during the first 100 days is due to the absorption/adsorption of methane by the detector inner surface.

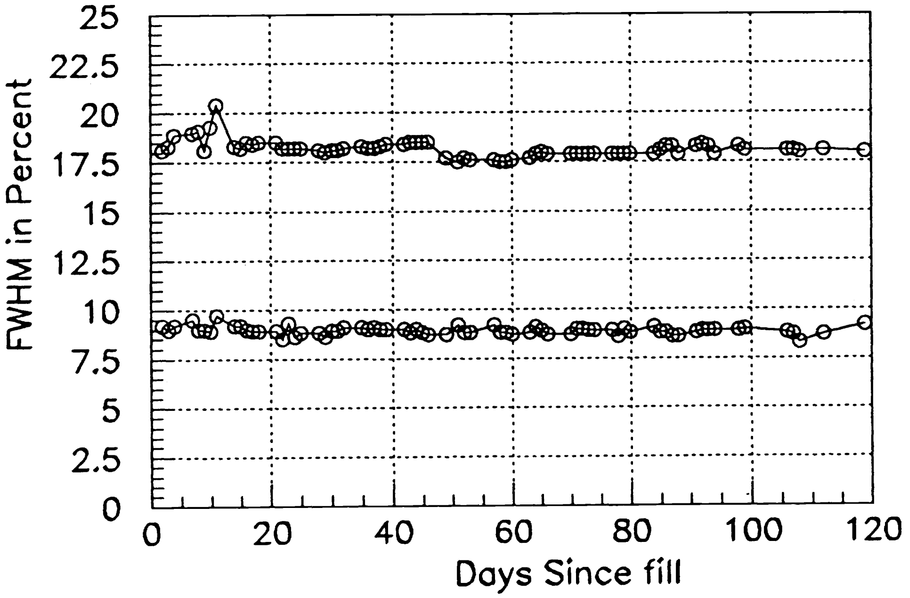

Fig. 5 Energy resolution of the xenon/methane layer as a function of time. The upper points are for Fe55 x-rays and the lower ones for Cd109 x-rays.

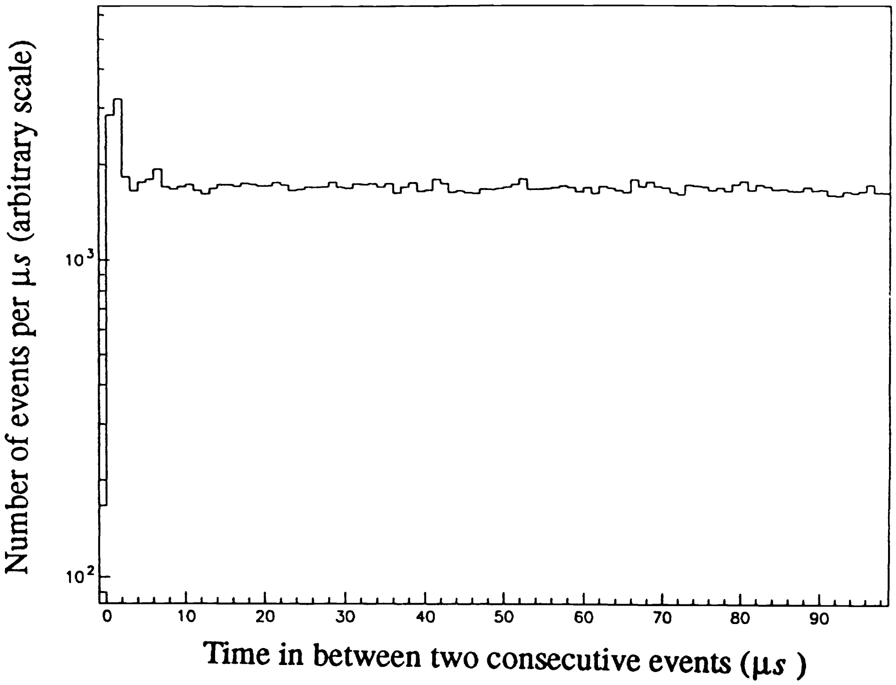

Fig. 6 Histograms of time intervals in between two consecutive events. The events occurring in the zero bin are due to cosmic ray showers triggering two detectors simultaneously. This figure establishes the microsec timing capability of the EDS.

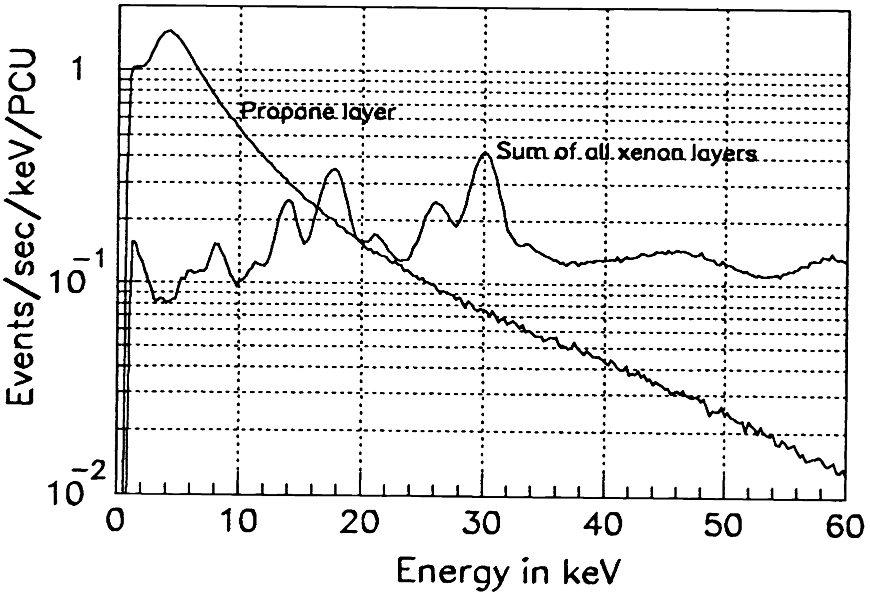

Fig. 7 Background spectra from the propane layer and the first xenon layer. The sources of the lines are under investigation. The propane background is caused by charged particles related to the collimators.

time scale larger than about 10 microsecs, which is the detector dead time, can be measured and characterized by a single detector. Other variations with time scales between 1 and 10 microsecs, need to be characterized by at least two detectors. Fig. 6 shows the distribution of time intervals between two consecutive events from two detectors. The excess in the 0 microsec bin in the case of two detectors, which is caused by showers of cosmic electrons/gamma rays, is clearly seen.

In addition to the typical response complications, such as absorptions of photoelectrons by the window and K and L escapes, associated with a typical proportional counter of this type, the multi-layer structure of the XTE/PCA counters necessitate some unique corrections. As a price for efficient background rejection, some of the bona fide x-rays are rejected as background events if their photoelectron clouds drift into and trigger two adjacent layers. The probability that an x-ray is rejected by this effect, referred to as charge division, is dependent upon the energy of the x-ray, ranging from a fraction of a percent for x-rays with energy below the xenon L edge to as much as 15 percent for those with energy above xenon K edge. This effect will be measured with precision with a monochromatic x-ray beam at different energies.

The dead time of each detector for each observation will be calculated using the various event rates. Since the front-end discriminator pulse width of each layer depends on the pulse height, with typical values of less than 10 microsecs for pulse height below 10 keV to 15 microsec for pulse height of 23 keV, in principle, the dead time of a detector caused by an event depends on its pulse height. But to the first order approximation, all the events will cause the same amount of dead time which is equal to the ADC busy time of about 10 microsecs. In addition, we have to take into account the dead time caused by the occurrences of the so-called very large events (VLE). VLE's are events which deposit more than 75 keV of energy in any one of the six active xenon layers or the propane layer. To eliminate the electronic noise pulses caused by these VLEs, the data transmission to the EDS is inhibited for a programmable amount of time ranging from 20 to 550 microsecs.

6. Background

The overall background event rate in a detector in the laboratory is about 160 counts/sec. This rate is dominated by cosmic rays traversing the detector. Of the 160 events, 125 are rejected by the anti-coincidence logic[aa]. The other 35 events, with 25 in the propane layer and 10 in the xenon layer constitute the raw background. Fig. 7 shows the pulse height spectra of these remaining events for the propane layer and various xenon layers. It should be pointed out that the lines near 13, 16 and 26 keV are close to the x-rays associated with the Am241 source, but their energies are significantly different. Thus they have not originated from the Am241 source. In particular, these lines remain even with the Am241 source removed from the detector. Preliminary investigation indicates that these lines come either from the radioactive contaminants in the collimator materials or come from the fluorescence of the collimators by cosmic rays. From the experience gained from HEAO-1 A2 detectors, the orbital background rate is typically two to three times as high as in the laboratory. By multiplying the above rate by a factor three, we find that the background rates of XTE/PCA are comparable to that HEAO-1 A2 on a per square cm per sec basis.

[aa] The charged particle rejection efficiency of a typical PCU has been measured to be 98%.

7. Summary

All the six (five flight detectors plus a spare) XTE/PCA proportional counters have been fabricated and assembled as of 1 June 1993. Their initial performance as described in this paper satisfies the mission requirements. Further tests and characterizations will be conducted on each of the six detectors in the next 6 months. Five flight detectors will be delivered to be integrated on the XTE spacecraft early next year.

8. Acknowledgment

We thank the many scientists, engineers, and technicians at the Goddard Space Flight Center who have contributed to the design and fabrication of XTE/PCA detectors. In particular, we thank E. Boldt and P. Serlemitsos and all the XTE Science Working Group members who have contributed significantly to XTE/PCA with their suggestions.

9. References

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