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A Payload to Evaluate Photodiodes for the Detection of Soft and Hard X-rays in a Space Environment Using a Get Away Special

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Abstract

We propose to use the Get Away Special (GAS) facility to evaluate P-intrinsic-N (PIN) detectors and avalanche photodiodes (APDs) for the detection of both solar and non-solar soft and hard x-rays. We would like to fly both types of silicon detectors for the direct detection of the x-ray photons in the energy range from 1 to 30 keV with an energy resolution of about 1 keV. We would also like to use both types of photodiodes viewing CsI(Tl) scintillators to extend the energy range up to 1 MeV with ~6% resolution at 660keV. Solar flares would be detected with this instrumentation during periods of solar pointing providing high energy resolution spectra with high time resolution. Similar data would be obtained in the scanning mode on non-solar transient and steady x-ray sources with the same instrumentation. A commandable door over the detectors would be required to allow measurements to be made as low as 1 keV.

Introduction

The Get Away Special offers a unique opportunity to evaluate state-of-the-art technologies for scientific satellite instrumentation. This is particularly true for the evaluation of new detectors in a space environment. The new solid-state silicon photodiodes now becoming available offer the capability of high-resolution x-ray detection with significant reductions in weight, volume, and power requirements compared to those of conventional detector systems. New detector systems can now be incorporated for soft and hard x-ray measurements of both solar and non-solar sources. PIN photodiodes and the recently developed APDs offer significant advantages over presently used detector systems. For soft x-rays (1 to 20 keV), the conventional detectors used in space research are gas-ionization chambers, proportional counters, scintillation counters, or solid-state detectors. The ion-chamber and proportional counters have been used very successfully. They offer large area, good efficiency, good spectral resolution and imaging capability but do not offer long-term stability. Their response time also is limited. Scintillators have been used in conjunction with photomultipliers and they have characteristics similar to those of the ion-chamber proportional counters. Among the solid-state detectors (conduction counters) lithium-drifted silicon detectors (Si(Li)) have significantly improved energy resolution and high counting rate capability, but they need to be cooled to 100K.

In 1980, Kemmer[1] reported the fabrication of silicon radiation detectors by the plannar process using photoengraving. He also used oxide passivation to significantly reduce detector noise caused by surface leakage currents and achieved low reverse-bias diode leakage currents of ~10nA. Another technique used was ion-implantation which achieved a good yield in detector fabrication with uniform characteristics. Detectors fabricated with this technology were marketed in France in the early 1980's, but their high cost and high power requirements constrained their use.

The availability of large-area, low-cost PIN diodes and low-noise, low-power, charge-sensitive pre-amplifiers from various vendors have triggered new interest in PIN silicon diodes for their use in soft x-ray investigations[2]. Avalanche-mode operation of large-area silicon photodiodes has also stimulated new interest in the use of silicon detectors for soft and hard x-rays.[3] For low energy x-rays (1 to 20 keV), the silicon diodes offer simplicity, low power and high spectral resolution and they operate at room temperature. Furthermore, their fast response time (~50ns) offers a high counting rate capability.

For hard x-rays (20 to 500 keV), scintillators viewed by photomultipliers have been used in space-borne instruments. The low-noise, high-gain capability of the photomultiplier and high detection efficiency of conventional scintillators (NaI, CsI) have proved very useful. However, even the ruggedized photomultipliers need careful packaging and handling, they are sensitive to external magnetic field variations, they need highly stable high voltage supplies, and they are bulky. Avalanche silicon photodiodes offer the possibility of replacing the photomultiplier for viewing NaI or CsI scintillators. The optical frequency response of silicon PIN diodes and APDs is wide (350 to 1100 nm) and matches very well with the CsI(Tl) scintillator emission spectrum. They have a much higher quantum efficiency (~60-70%) compared to photocathode quantum efficiency (~10-15%). Thus photodiodes have much better spectral resolution capability than photocathodes. Their usage as a replacement for photomultipliers would offer significant reductions in weight, volume, and power, with improved long-term stability for space-borne x-ray instrumentation.

Devices

Over the last two years we have procured and evaluated several PIN and APD devices for the direct detection of soft x-rays and as photomultiplier replacements in scintillation hard x-ray detectors. Table 1 lists the devices that we have tested and their manufacturers. We have used commercial charge-sensitive pre-amplifiers and monitored the spectral response of some of the devices.

Figure 1 shows the response of a typical PIN device. The resolution at the 5.94 keV ^{55}Fe line is ~1 keV at room temperature. For PIN devices, the energy threshold can be set at ~2 keV when operated at room temperature and used with a commercial charge-sensitive preamplifier.

Figure 2 shows the spectral response of an APD (1 cm x 1 cm) to the ^{55}Fe line. Figure 3 shows combined ^{55}Fe and ^{241}Am spectra taken with both APD and PIN devices. The internal gain of APD's result in a very low noise level allowing the energy threshold to be set as low as ~1 keV when operated at room temperature. Figure 4 shows the spectrum from an APD coupled to a CsI(Tl) scintillator exposed to a ^{137}Cs source. We get ~6% resolution at 662 keV with an energy threshold of ~30 keV at room temperature.

Payload Concept

We propose to fly silicon PIN and APD devices to evaluate them in a space environment. For soft x-rays (1 to 20 keV) we would need direct exposure to space without material absorption, i.e. we would need a lid which could be opened on command. We would also need to know the view direction (to within a few tenths of an arcsecond) of the payload with time so that we could correlate our observation. Ideally, we would like to have coarse pointing capability to a few degrees to allow us to investigate specific x-ray sources such as the Crab Nebula, Cygnus X-1 , and the galactic center region in addition to x-rays from the Sun, etc. For our first GAS can instruments, this capability is not a necessity since the primary purpose would be to evaluate the performance of the solid-state devices in a space environment. We would also like to fly an optical camera for star field identification of our field of view. We will have solid-state memory to record data. Transient events will be recorded in a similar way to study their light curves. The payload would be completely self-contained.

References

1) Kemmer, J. *"Fabrication of Low Noise Silicon Radiation Detectors By the Plannar Process"* Nuclear Instruments and Methods. Vol. 169, pp.499-502 (1980).

2) Gramsch, E. et al *"Silicon PIN Photodetectors in High Resolution Nuclear Spectroscopy"* Nuclear Instruments and Methods Vol. A311, pp.529-538 (1992).

3) James, K. M. et al *"Performance Evaluation of New Large Area Avalanche Photodiodes for Scintillation Spectroscopy"* Nuclear Instruments and Methods Vol. A313, pp.196-212(1992).

Table 1:

device	dimensions (mm)	type	manufacturer
S2840	0.8 (dia.)	PIN	Hamamatsu
S1223	2.4 x 2.8	PIN	Hamamatsu
S1223-01	3.6 x 3.6	PIN	Hamamatsu
S 1722-01	4.1 (dia.)	PIN	Hamamatsu
S 1723-06	10 x 10	PIN	Hamamatsu
S 3590-01	10 x 10	PIN	Hamamatsu
S 3590-03	10 x 10	PIN	Hamamatsu
S 3590-05	10 x 10	PIN	Hamamatsu
F171A	11 x 11	PIN	Siemens
SH25R	25 (dia.)	APD	RMD
SX10R	10 x 10	APD	RMD
SX8R	8 x 8	APD	RMD

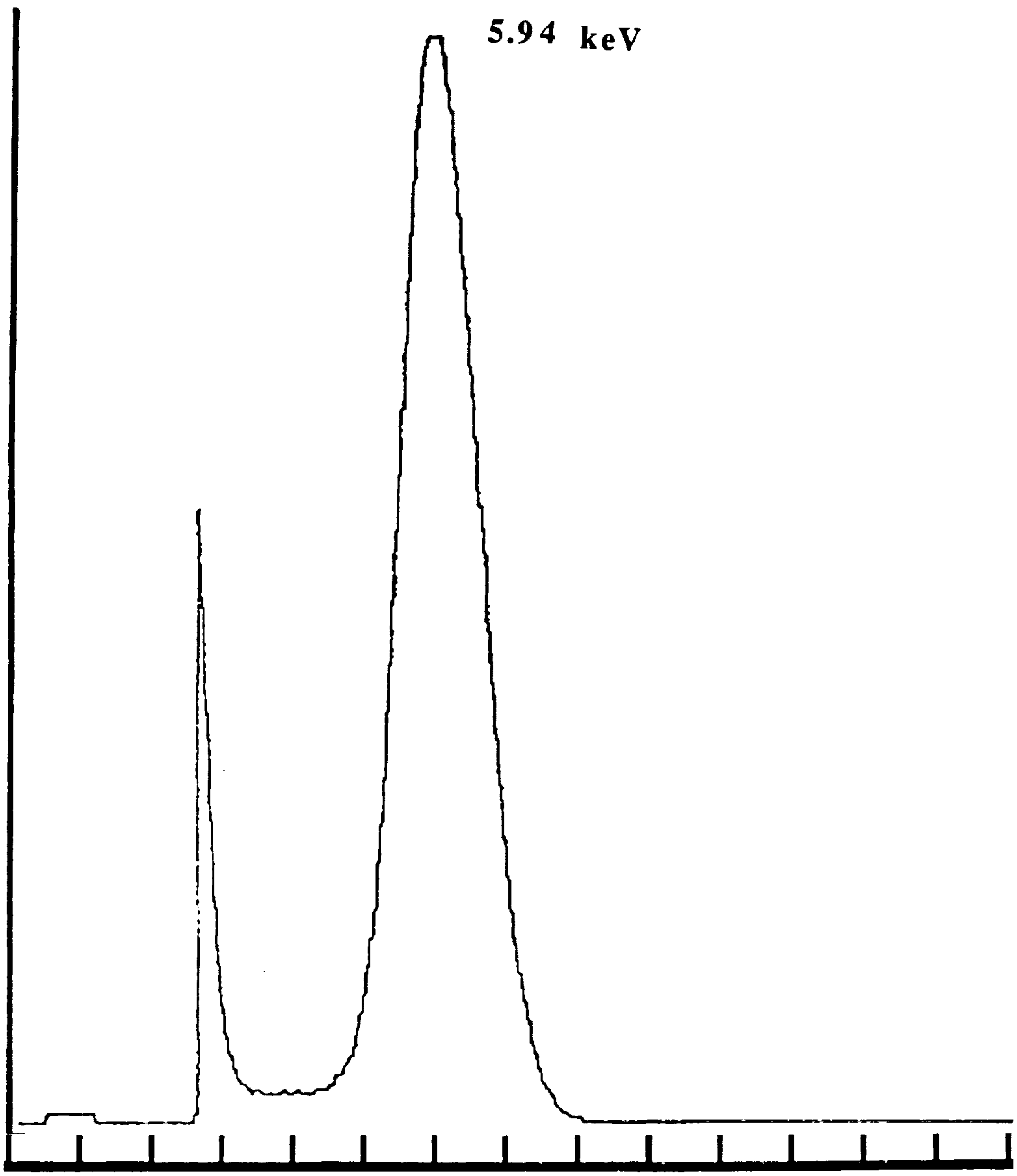

Figure 1. X-ray detection using a pin photodiode connected to the AMPTEK A250 charge-sensitive amplifier exposed to ^{55}Fe at room temperature.

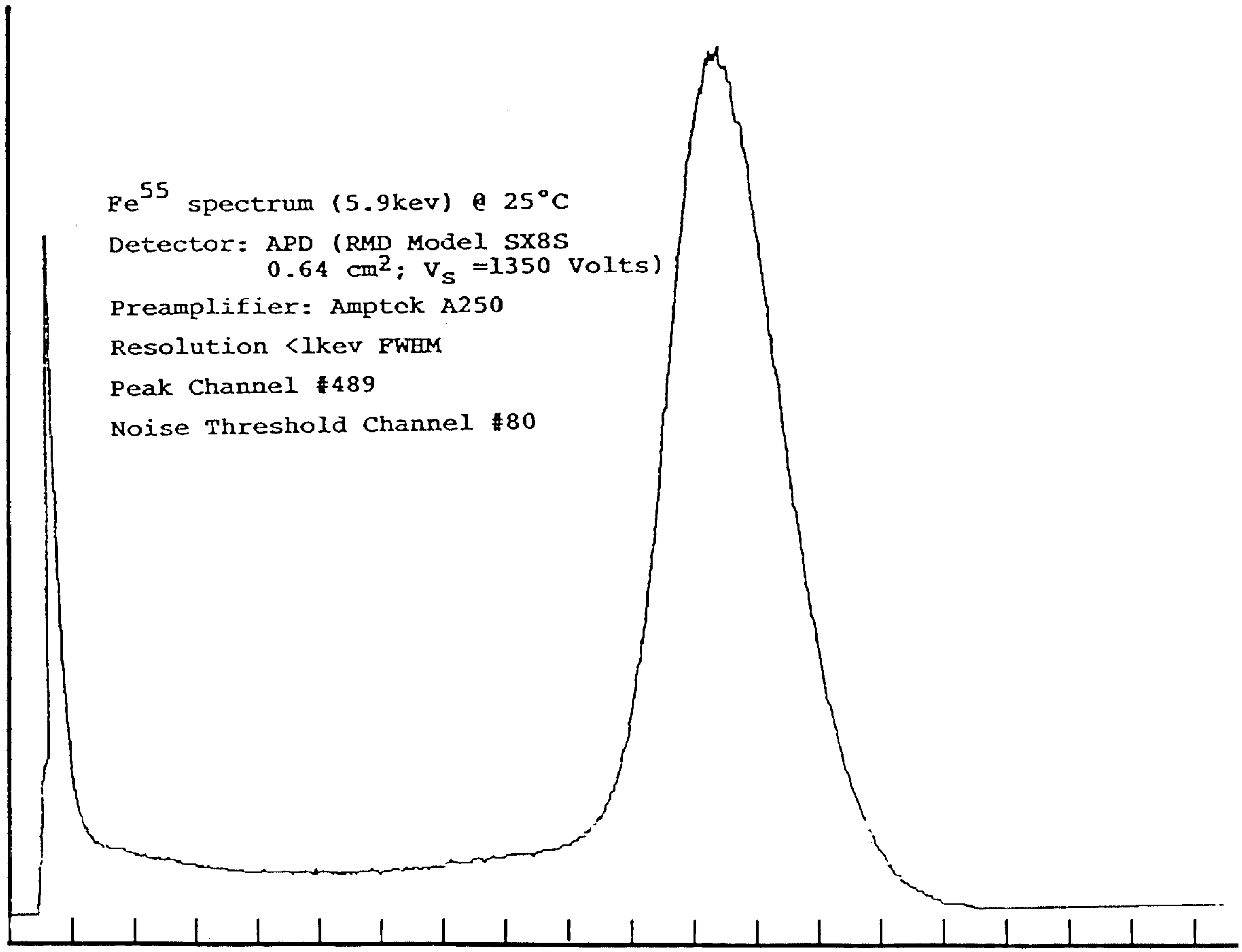

Figure 2. X-ray detection using avalanche photodiode (APD) connected to the AMPTEK A250 charge-sensitive preamplifier.

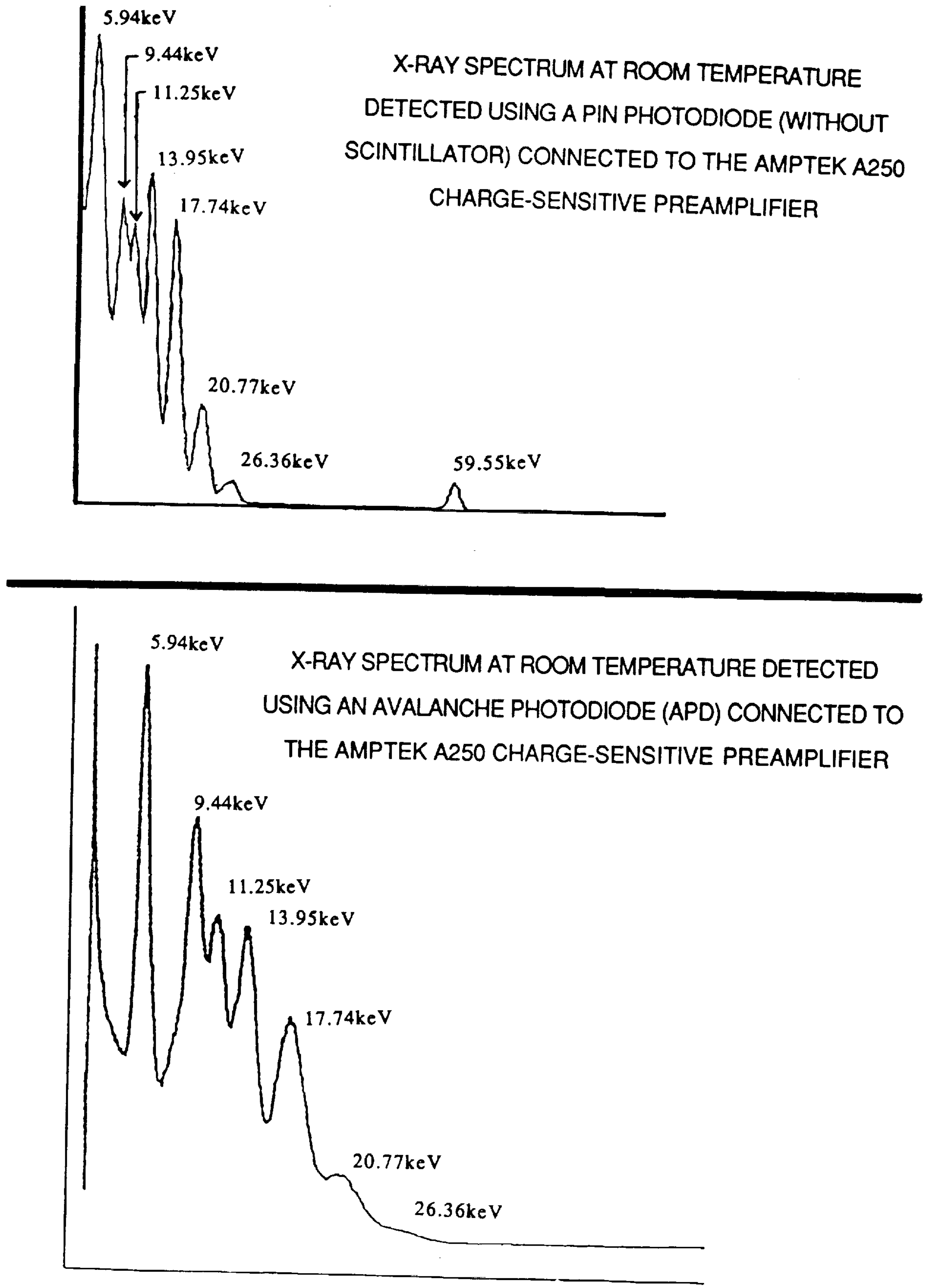
5.94keV
9.44keV
11.25keV
13.95keV
17.74keV
20.77keV
26.36keV
59.55keV
X-RAY SPECTRUM AT ROOM TEMPERATURE DETECTED USING A PIN PHOTODIODE (WITHOUT SCINTILLATOR) CONNECTED TO THE AMPTEK A250 CHARGE-SENSITIVE PREAMPLIFIER
5.94keV
X-RAY SPECTRUM AT ROOM TEMPERATURE DETECTED USING AN AVALANCHE PHOTODIODE (APD) CONNECTED TO THE AMPTEK A250 CHARGE-SENSITIVE PREAMPLIFIER
9.44keV
11.25keV
13.95keV
17.74keV
20.77keV
26.36keV

Figure 3.

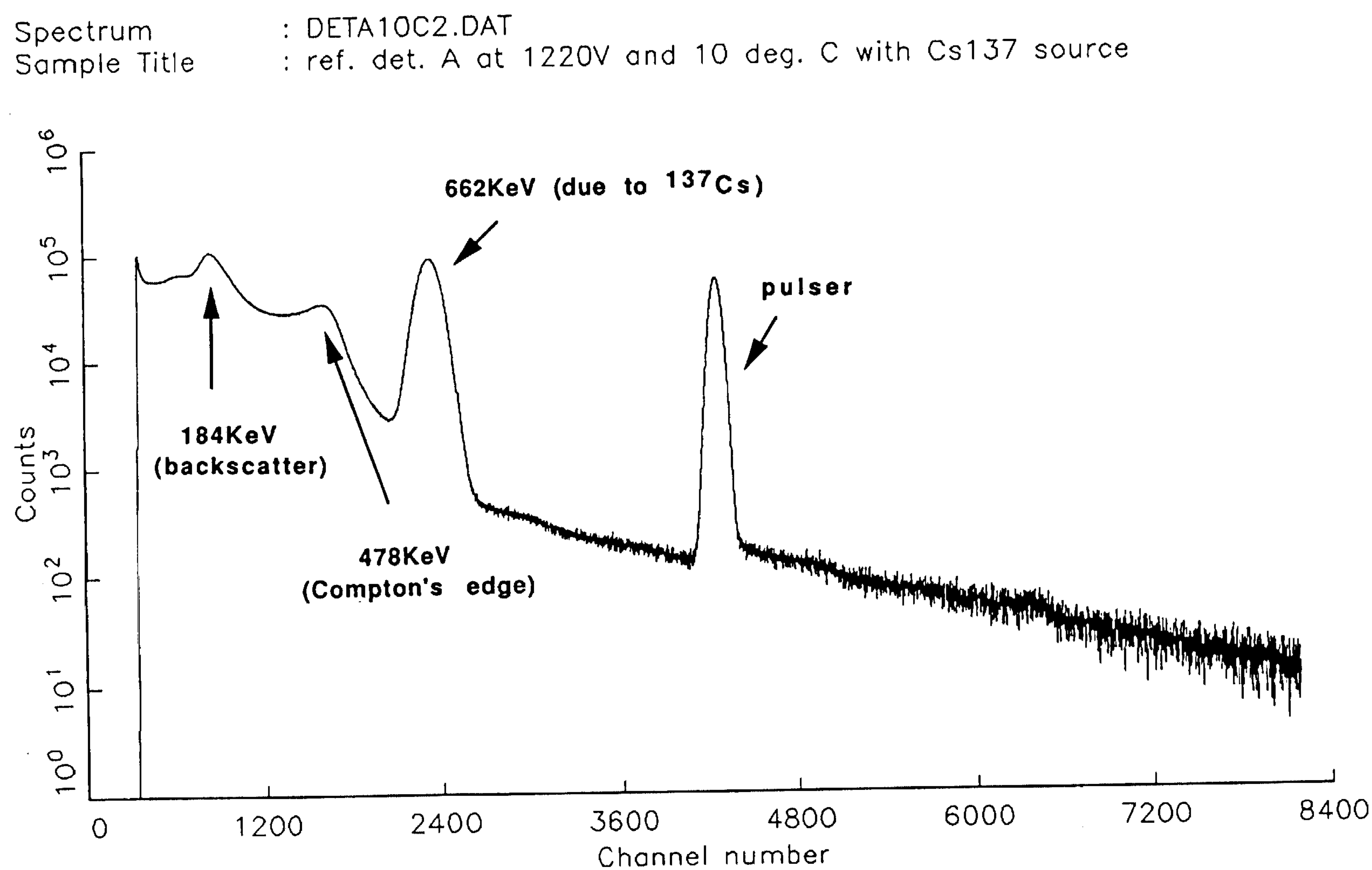

Figure 4. X-ray spectrum at 10 °C detected using an avalanche photodiode (APD) connected to a CsI (Tl) scintillator.