COAXIAL ANODE FOR BACKGROUND SUPPRESSION IN X-RAY PROPORTIONAL COUNTERS

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We have devised, constructed and tested in flight a scheme which permits the ends (near the anode seals) as well as the bottom and sides of an X-ray astronomy proportional counter to be protected by anti-coincidence guard counters. A rocket-borne test has shown that the non-X-ray background is reduced by an additional factor of about 30 when the end guard counter feature is added.

Most current observations in X-ray astronomy are made with proportional counters. Directionalility is provided by some sort of mechanical collimator or grazing incidence reflector. The detected rate in a given pulse height or X-ray energy interval is composed of two parts — the "signal", due to cosmic X-rays incident upon the instrument and the "noise" or non-X-ray background. The non-X-ray background is primarily caused by incident charged particles (cosmic rays and sometimes particles of the radiation belts) and charged particles that are the progeny of gamma rays which interact in the body of the counter or other nearby material. In any case, given a background-limited measurement, the minimum detectable signal under a wide range of criteria is proportional to $\sqrt{F_B/At}$ where A is the effective area of detection, t is the observation time, and F_B is the non-X-ray background rate per unit area. A factor 10 reduction in F_B is equivalent to a factor 10 increase in the product At and since area and time represent basic limitations in rocket or satellite investigations, significant reductions in F_B are worth considerable effort.

The pulse shape discrimination scheme for background rejection is remarkably effective in the X-ray region above 1 or 2 KeV [1, 2]. The charged particles responsible for the background have trajectories that include a range of distances from the counter anode and the resulting long anode pulse rise times are distinguishable from the shorter rise time pulses produced by the localized ionization due to X-rays. In low energy (100-300 eV) X-ray investigations the number of ion pairs is small (3-10) and the corresponding charged particle path lengths required to produce the small amount of ionization are likewise small. For example, a minimum ionizing singly charged particle loses 200 eV in 0.5 mm of P-10 at 1 atmosphere and in 2 mm of CH_4 at 0.5 atmospheres. These distances are small fractions of the anode-cathode distance in typical proportional counters and for these reasons the pulse shape discrimination scheme loses effectiveness rapidly with decreasing energy.

A large portion of the low as well as higher energy non-X-ray background can be eliminated with veto counters. We have found that veto counters that are part of the same gas volume as the X-ray counters are especially effective since there are no walls and little other material in which the offending charged particles can come to rest. In a typical rectangular counter these veto counters are electrically separated from the X-ray counter volume by fine (0.01 cm) wires spaced every 0.4 cm or so and they run parallel to the veto and X-ray counter anodes.

In very low energy X-ray investigations, veto counters of the type described above can be easily arranged to protect 3 or 4 of the 6 sides of and X-ray counting volume. (The top or window side is usually not protected because a top veto counter must have an X-ray transmission near 1, and the X-ray counter itself, perforce using the same gas, must be essentially opaque. Anyway, the top <u>corners</u> of the X-ray counter are protected by the side veto counters.) Soft X-ray counters of the type described above have been used by the University of Wisconsin group in a number of rocket-borne soft X-ray investigations [3]. The non-X-ray background in these investigations has been negligible and for the small observation times the measurements have not been background limited. In the soft X-ray instrument we are preparing for flight on the Orbiting Solar Observatory (OSO-I), however, observation times will be much longer and ultimately the measurements will be background limited. Various laboratory tests have convinced us that a large portion of the residual non-X-ray background of our rocket counters has its origin in the unprotected (by veto counters) ends of the X-ray counters where the anode wire is terminated. This was the motivation for the development of the coaxial anode scheme to be described below.

Description and Operation

We wished to provide sensitive volumes connected in anti-coincidence on the two ends as well as on the two sides and bottom of an X-ray-sensitive counter volume. Anodes were therefore fabricated as shown in Figure 1. C is a solid inner conductor (0.0025 cm tungsten) that runs the entire length of the counter and is electrically accessible exterior to the counter at both ends. "Isonel" is enamel insulation of such thickness that the diameter of the coated tungsten is about 0.0027 cm and A is evaporated gold which in fact is the counter anode. (Isonel is manufactured by Schenectady Chemicals, Inc., Schenectady, N. Y. Wire with Isonel insulation is available from many suppliers.) The X-ray counting portion of the evaporated anode, A_2, is connected electrically near the middle of the counter to the center conductor C. Near the ends of the anode there are gaps (0.1 cm) in the evaporated gold layer and the two isolated sections A_1 and A_3, which are also accessible electrically exterior to the counter provide the anodes for the "end-veto" portions of the volume.

All three portions of the anode run at the same positive high voltage. Charge sensitive amplifiers connected to C and to (A_1, A_3) detect ionization that occurs in the three well-defined regions of gas which surround A_1, A_2 and A_3.

The measured pulse height distributions are similar in all respects to the distributions obtained with normal solid-wire anodes. The channel number of the peak of a Fe^{55} (5.9 KeV) pulse height spectrum as a function of distance along the counter is shown in Figure 2. The data were taken with the X-rays collimated into a fan beam which illuminated the entire width of the counter but only 0.05 cm along its length. During the measurements on $\underline{A_2}$, the end-veto sections ($\underline{A_1}$ and $\underline{A_3}$) were grounded through large blocking capacitors and during the measurements on the end-veto sections, $\underline{A_1}$ was grounded similarly. As is evident from the data, the sensitive volume is separated into three parts and the width of the transition region between volumes is about as expected from the finite source collimation and size of the gap between anode sections. The 10-20% enhanced pulse height response near the gaps in the anode and near the center of the counter where $\underline{A_2}$ was connected electrically to $\underline{C}$ are the result of the perturbed electric field pattern near the wire in these regions. Of course, when the counter window is uniformly bathed in an X-ray flux, as it is in use, these relatively small regions of non-uniform response broaden the resolution somewhat, but are of little or no real consequence.

In normal use, the anode section $\underline{A_2}$ and the paralleled sections $\underline{A_1}$ and $\underline{A_3}$ are connected to separate charge sensitive amplifiers. A limitation of the usefulness of the scheme results from the distributed capacitance, C_d, between $\underline{A_2}$ (the main anode) and the paralleled $\underline{A_1}$ and $\underline{A_3}$ (end-veto anodes). This capacitance causes cross-talk between the main and end-veto channels. Cross-talk into the main channel from large pulses in the end-veto channel is of no consequence. The large end-veto pulse eliminates all pulses from consideration anyway. But cross-talk into the end-veto channel from large pulses in the main channel is undesirable because all pulses in the main channel above some threshhold or critical amplitude will veto themselves. The useful dynamic range of the X-ray counting channel is thereby limited.

With ideal charge sensitive amplifiers the amount of cross-talk would be small. Charge induced on the main anode, for example, will return to ground through the main and veto amplifier branches in proportion to the capacitance of the two branches. Since the stray capacitance C_d is of order 100 pf and coupling capacitors and charge sensitive amplifiers can have nominal capacitances of $\sim 10^4$ pfs each, only 2% of the charge deposited on a main anode should appear at the end-veto amplifier terminals. In practice, finite response time effects result in charge sensitive amplifiers having much less than the nominal input capacitance during the early part of a transient, and the resultant cross-talk is several times that estimated above. J. Sitzman of the University of Wisconsin Space Science and Engineering Center has shown, however, that the objectionable cross-talk can be greatly reduced if a small portion of the leading edge of the main amplifier signal is inverted and mixed with the end-veto simplifier signal. A cross-talk of about 3% is acceptable in our application, and we have not attempted further improvement, though it is no doubt possible.

Laboratory Performance

In the discussion that follows, the logic in both the end-veto and surrounding bottom and side veto channels was set to trigger on a pulse height corresponding to about 300 eV X-ray energy.

Figure 3 shows the pulse height distribution obtained with the main anode volume exposed to a Fe^{55} source of 5.9 keV X-rays. The gas was P-10, 90% argon - 10% methane. In part a the veto logic was disconnected. In part b only the bottom and side veto channels were connected and in part c the end veto as well as the bottom and side were connected. A comparison of the figures demonstrates that few, if any, of the large Fe^{55} X-ray pulses were rejected by the cross-talk phenomena discussed earlier.

We interpret the background level to the right and left of the argon escape peak in a (but not in b or c) as the result of X-ray-ejected electrons that deposit only part of their energy in the X-ray volume, the remainder in the veto volume. When the veto logic is operative, most of these are rejected.

The X-rays entered the gas through an aluminum window, and aluminum Kα fluorescent radiation is evident at about 1.5 keV.

We have used Co^{60} as a convenient laboratory source in evaluating the merit of background rejection schemes. There result more low energy electrons than in a normal space environment and, of course, there are no protons or other heavy particles. Figure 4 shows the pulse height distribution response of one of our counters to Co^{60}. Here the gas was again P-10. Curve a was taken with no veto logic, for curve b only the bottom and side channels were operative, and for curve c the end veto channel as well as the bottom and side channels were operative. The bottom and side veto arrangement under these conditions reduces the Co^{60} induced background a factor of 10 to 30, and the end veto scheme provides an additional factor of 2 to 4.

P-10 is not a suitable filling gas for thin window counters on a small satellite. Differential diffusion would result in a time dependent gas mixture. We have therefore been forced to use a one-component gas, and have chosen methane. Figure 5 is entirely equivalent to Figure 4, but the gas is methane at 400 Torr instead of P-10 at 1 atmosphere. The energy scales are the same and the two sets of data were taken under identical conditions with regard to counter geometry, source location, etc. The fast particle energy loss per cm of path is of course less for methane than it is for argon, and this accounts for the displaced peaks (curves a). But the overall response and quality of Co^{60} induced background rejection is similar.

Performance in Flight

The Co^{60} tests described in the previous section strongly suggested but did not prove that the end-veto scheme was worth including as part of the OSO-I satellite instrumentation. We therefore arranged to fly the counter as part of the payload of one of our X-ray astronomy sounding rocket investigations. The normal side and bottom veto counters were operative during the entire flight, but the end veto scheme was alternately turned on and off for 10 second periods. The scheduled view directions included a slow scan through the Earth in order to provide a realistic evaluation of the non-X-ray background. Data were also acquired during the rest of the flight when directions well above the horizon were viewed. The data are shown in Figures 6 and 7 in the form of telemetered pulse height spectra. Figure 6 shows the non-X-ray background data with the end-veto scheme off, as well as the similar data with the end veto scheme on. There are too few non-X-ray counts for an accurate evaluation of the (end-veto off)/(end-veto on) ratio, but the ratio is clearly of the order of 30 to 1 or greater. Figure 7 shows X-ray data taken during a sky-viewing portion of the flight. It is included to demonstrate that inclusion of the end-veto provision and logic does not disturb the X-ray response of the system.

We conclude that since a factor 30 reduction in non-X-ray background is equivalent to a factor 30 increase in area in background limited X-ray astronomy investigations, the scheme is worth flying.

Acknowledgements

We appreciate the able skills of Gene Buchholtz in the development of the various techniques used in fabricating the anodes. This work was supported in part by the National Aeronautics and Space Administration under grant NGL 50-002-044 and contracts NAS5-11282 and NAS5-11361.

Appendix: Miscellaneous Construction Notes

1. The anodes we use are 0.001" tungsten coated with Isonel to make the total diameter 0.0015". Somewhat thicker enamel insulation would be desirable, were it available, in order to reduce capacitance and uncompensated cross-talk.
2. In our gold evaporation procedure we mount six parallel anode wires equidistant (about 4") from a twisted bundle of electrically heated tungsten wires that carry the molten and evaporating gold. The anode wires rotate about their own axes once per 5 seconds to insure a uniform evaporated layer. A finished anode has a resistance of 15 - 30 ohms per inch. The gaps in the wire that separate the main and end-veto sections are provided by shadowing during the evaporation process. A small section of the Isonel insulation near the center of the anode is removed before the evaporation process. The gold then deposits over this section to provide the needed connection between the main anode and the inner tungsten wire. Electrical connection to the end-veto section of the anode is made by a short piece of 0.001" Kovar wire that is Indium-soldered to the evaporated gold.

References

1. E. Mathieson and P. W. Sanford, Proceedings of the International Symposiun on Nuclear Electronics, Paris, 1963 (ENEA; 1964), p. 65.
2. P. Gorenstein and S. Mickiewicz, Rev. Sci. Instr. 39, 816 (1968).
3. A. N. Bunner, P. L. Coleman, W. L. Kraushaar, and D. McCammon, Ap. J. 167, L3 (1971).

Figure Captions

Figure 1 Schematic diagram of the coaxial anode wire. Mechanical support and exterior electrical connection to the main or X-ray counting section is provided by the inner tungsten wire.

Figure 2 Relative gas gain along the length of a counter equipped with the coaxial anode scheme. The black dots refer to the main or X-ray portion and the open circles refer to the end-veto sections.

Figure 3 Measured pulse height distributions for Fe^{55} (5.9 KeV) X-rays. The spectra were taken a) with no veto logic connected, b) with only the bottom and side veto logic connected, and c) with the end-veto as well as the bottom and side veto logic connected.

Figure 4 Pulse height distributions for Co^{60} gamma rays taken under the three indicated veto logic combinations. The counter gas was P-10 at one atmosphere.

Figure 5 Pulse height distribution for Co^{60} gamma rays taken under the three indicated veto logic combinations. The counter gas was methane at 400 Torr.

Figure 6 Non-X-ray background pulse height spectra observed during the rocket flight. The side and bottom veto counter logic was operative continuously, but the end-veto logic was turned on and off for 10 second periods. During this portion of the rocket flight the counter viewed the Earth.

Figure 7 Cosmic X-ray (diffuse background) pulse height spectra observed during the rocket flight while the counter was viewing the sky. The effective counter area and collimation were approximately 80 cm^2 and 8° FWHM, respectively. The window was 2-μ polycarbonate coated on its inside surface with 15 μg cm^{-2} of colloidal carbon. The counter gas was methane at 273 Torr. The broad peak centered near 200 eV is the expected counter response and is the result of the high window transmission just below the carbon K-edge at 284 eV.

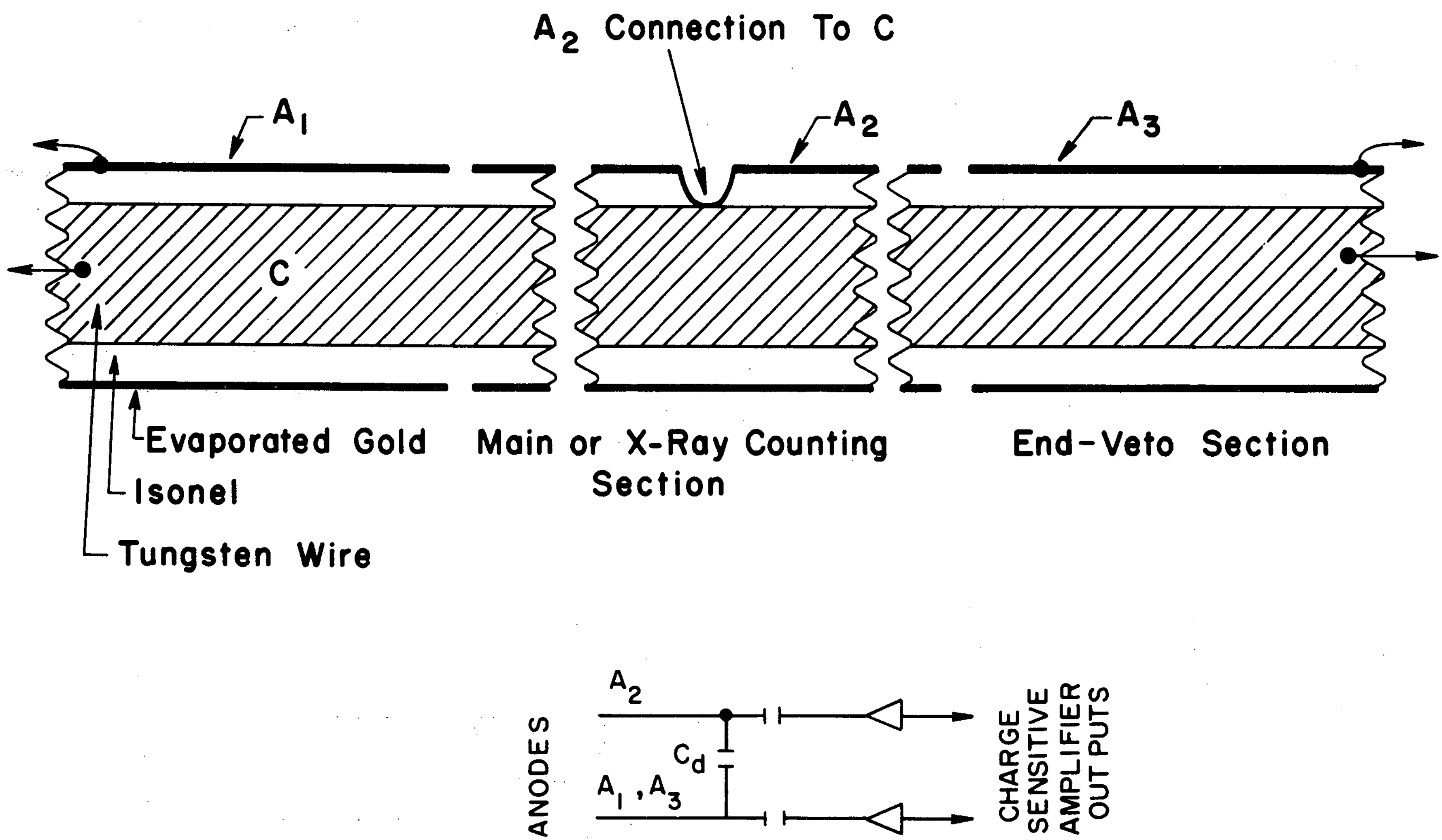
A2 Connection To C
A1
A2
A3
C
Evaporated Gold
Isonel
Tungsten Wire
Main or X-Ray Counting Section
End-Veto Section
ANODES
A2
Cd
A1 , A3
CHARGE SENSITIVE AMPLIFIER OUT PUTS

Fig. 1

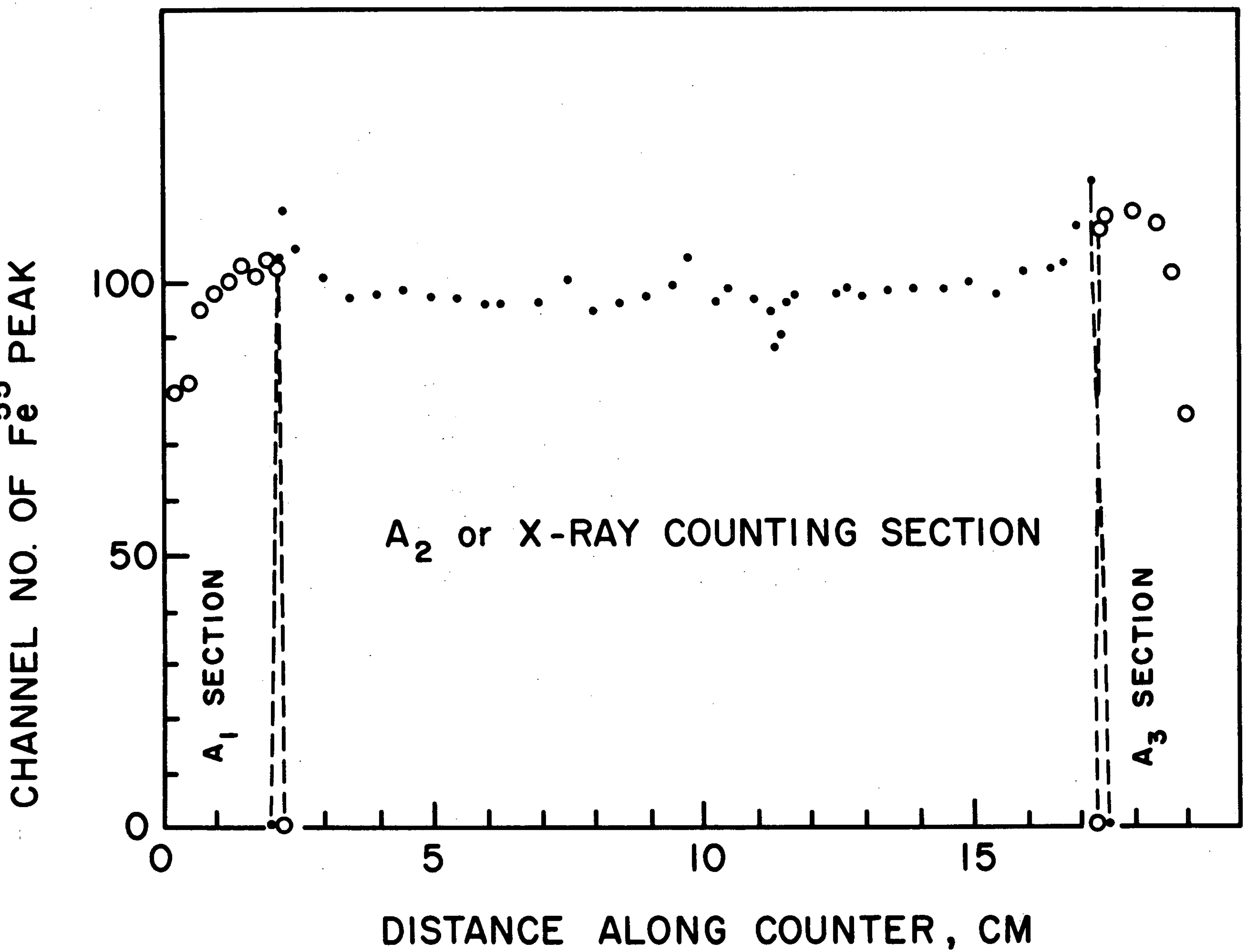
CHANNEL NO. OF Fe55 PEAK
100
50
0
0
5
10
15
A1 SECTION
A2 or X-RAY COUNTING SECTION
A3 SECTION
DISTANCE ALONG COUNTER, CM

Fig. 2

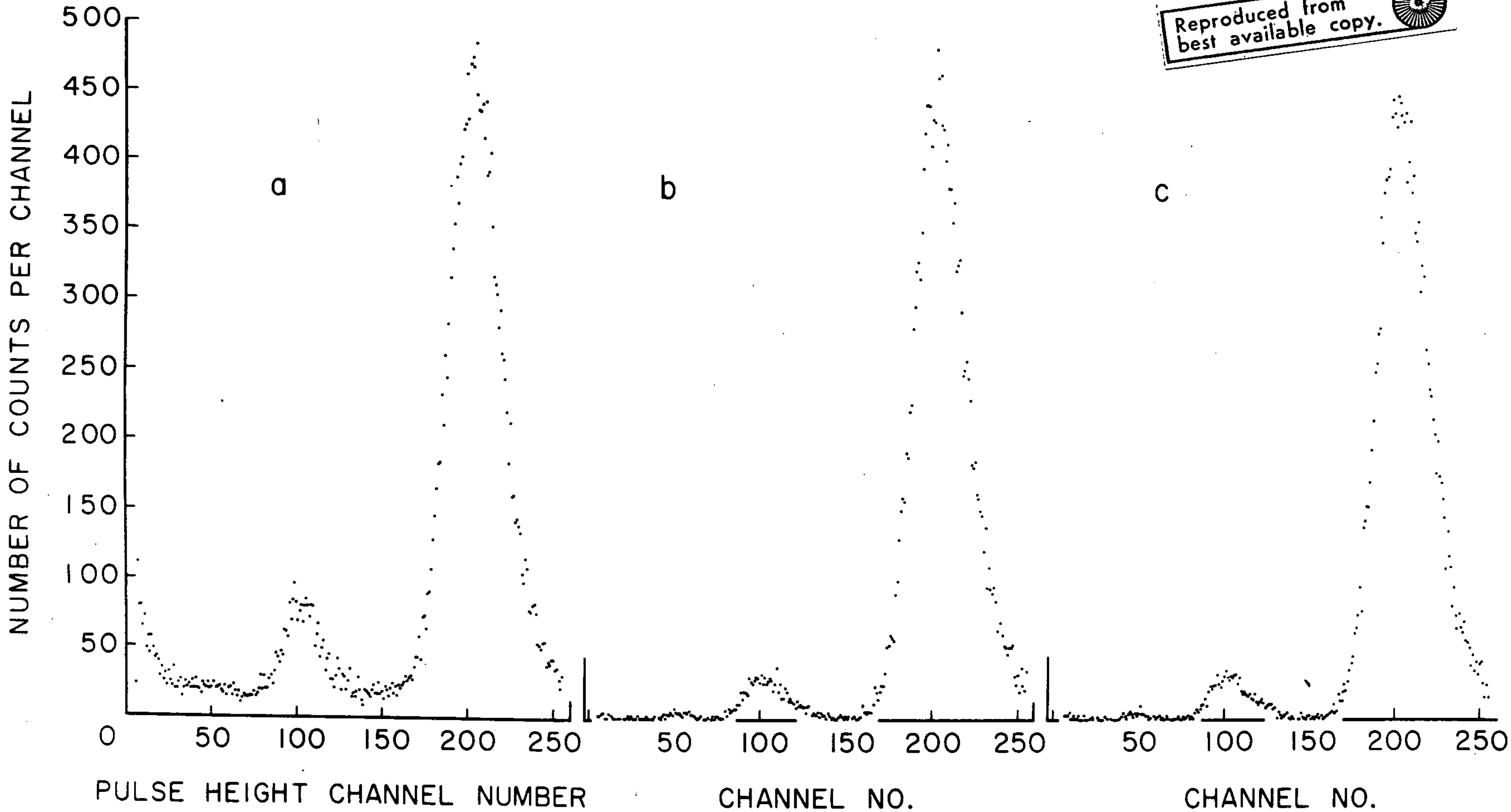
NUMBER OF COUNTS PER CHANNEL
0
50
100
150
200
250
300
350
400
450
500
a
b
c
PULSE HEIGHT CHANNEL NUMBER
CHANNEL NO.
CHANNEL NO.

Fig. 3

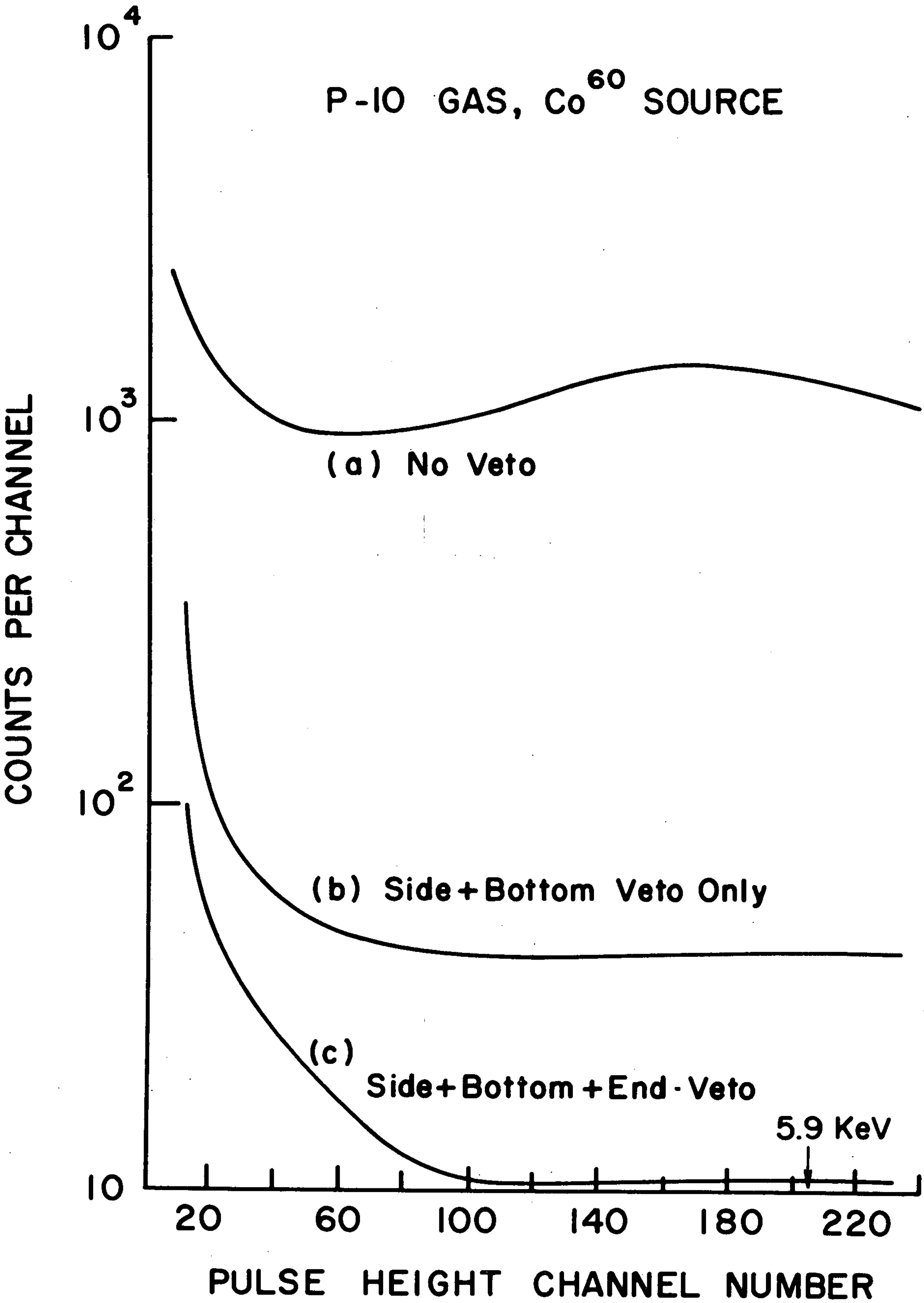
P-10 GAS, Co60 SOURCE
10^4
10^3
10^2
10
COUNTS PER CHANNEL
(a) No Veto
(b) Side+Bottom Veto Only
(c)
Side+Bottom+End-Veto
5.9 KeV
20
60
100
140
180
220
PULSE HEIGHT CHANNEL NUMBER

Fig. 4

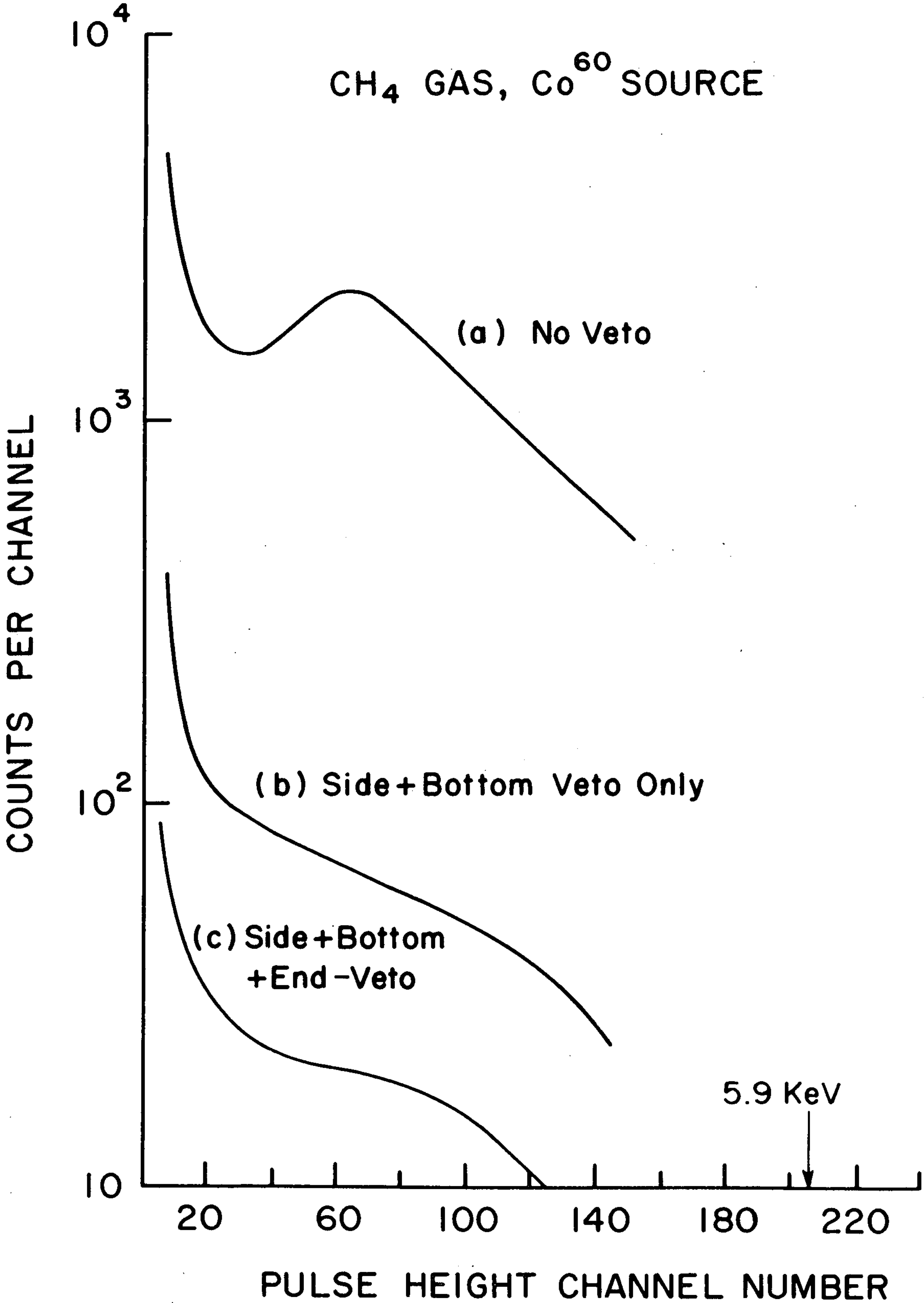
CH4 GAS, Co60 SOURCE
(a) No Veto
(b) Side+Bottom Veto Only
(c) Side+Bottom
+End-Veto
5.9 KeV
COUNTS PER CHANNEL
10^4
10^3
10^2
10
20
60
100
140
180
220
PULSE HEIGHT CHANNEL NUMBER

Fig. 5

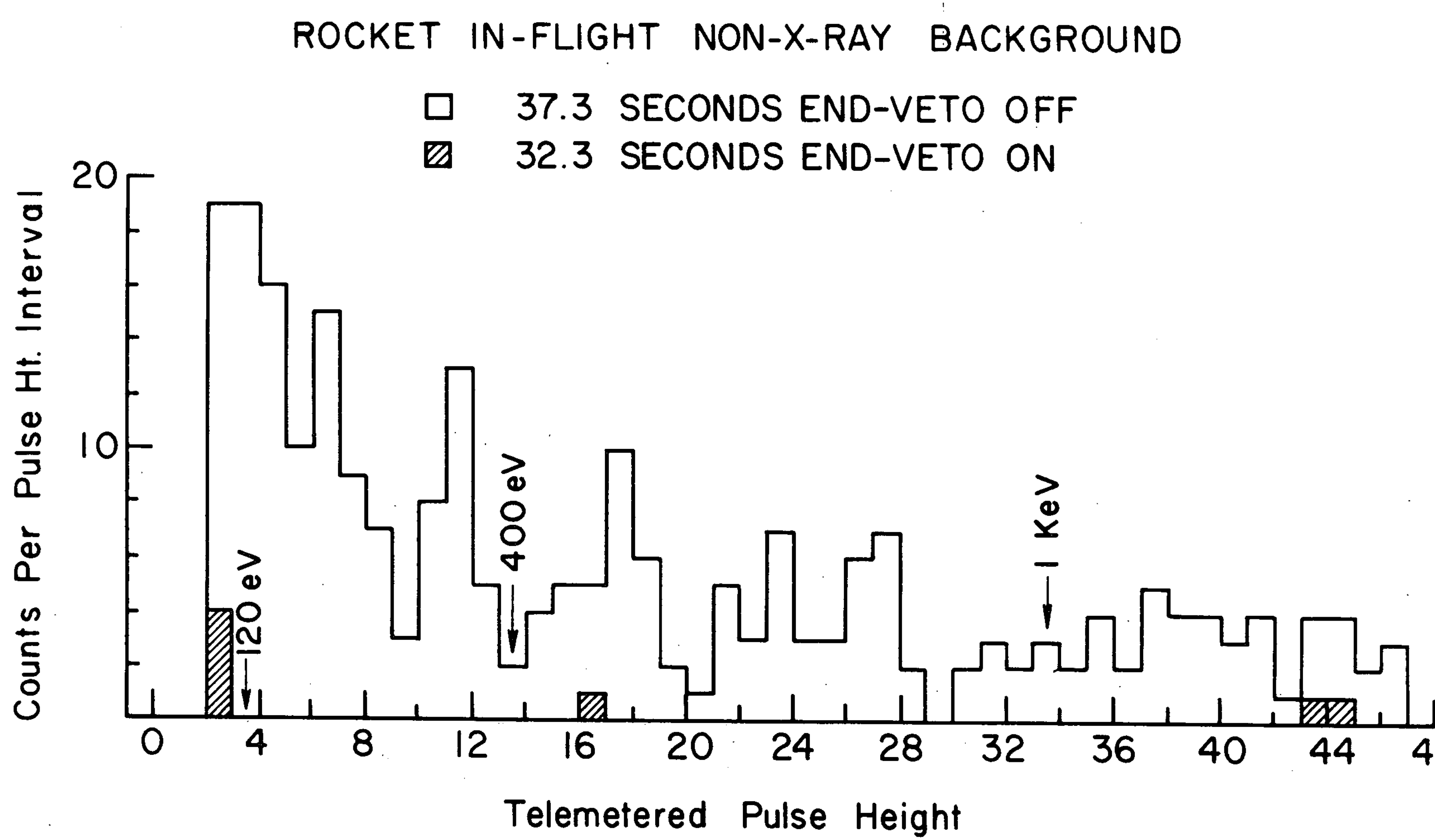
ROCKET IN-FLIGHT NON-X-RAY BACKGROUND
37.3 SECONDS END-VETO OFF
32.3 SECONDS END-VETO ON
Counts Per Pulse Ht. Interval
20
10
120 eV
400 eV
1 KeV
0
4
8
12
16
20
24
28
32
36
40
44
48
Telemetered Pulse Height

Fig. 6

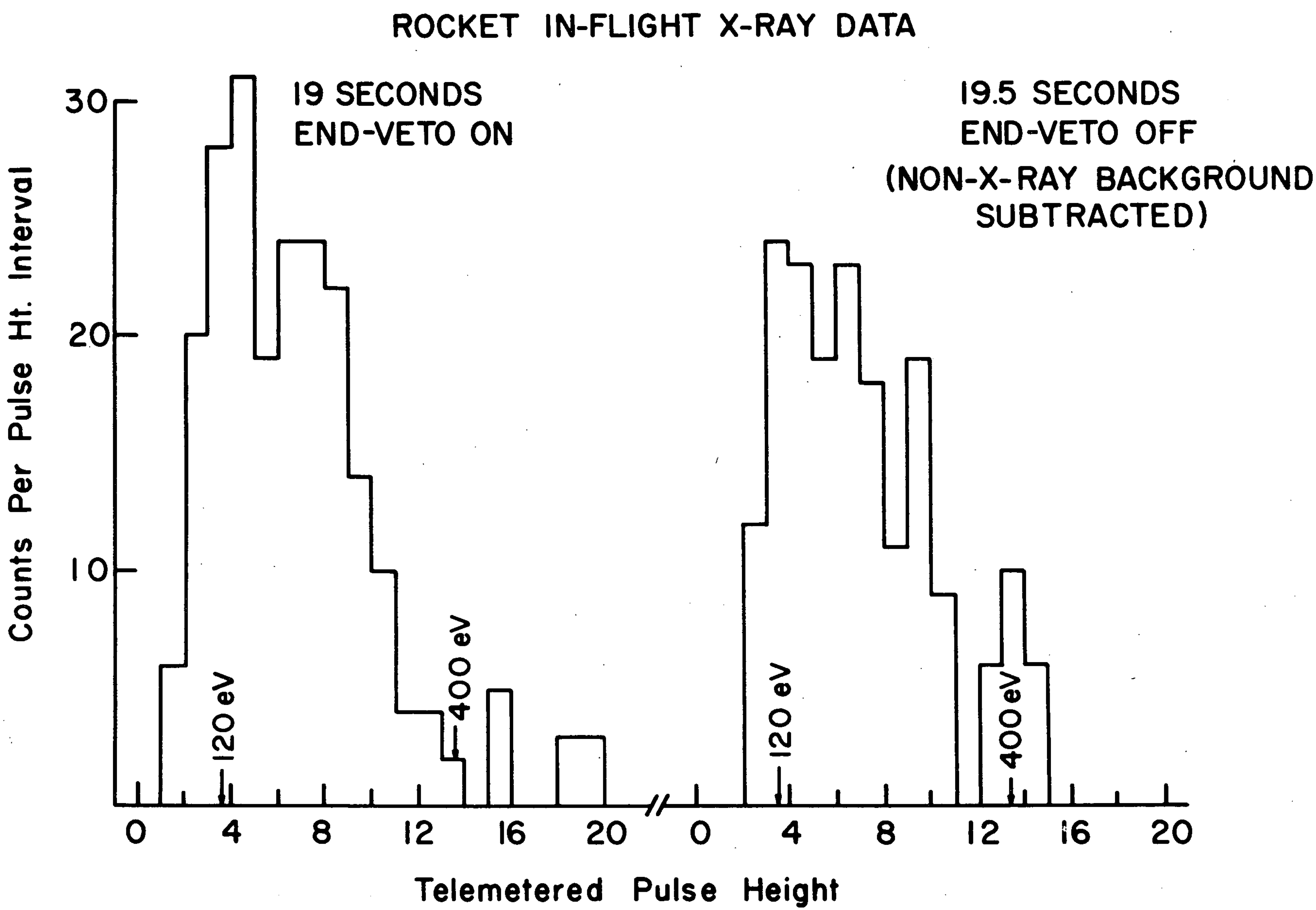
ROCKET IN-FLIGHT X-RAY DATA
19 SECONDS
END-VETO ON
19.5 SECONDS
END-VETO OFF
(NON-X-RAY BACKGROUND
SUBTRACTED)
Counts Per Pulse Ht. Interval
30
20
10
120 eV
400 eV
120 eV
400 eV
0
4
8
12
16
20
0
4
8
12
16
20
Telemetered Pulse Height

Fig. 7