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Recent Advances in Gas Scintillation Proportional Counters

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Summary

Various geometrical configurations for gas scintillation proportional counters have been investigated in order to determine which is best for use in a large volume, high efficiency counter for measuring low energy gamma and x-rays. A xenon filled counter having a rod anode inside a cylindrical cathode appears to provide the best configuration for providing a uniform field and the best resolution over the total volume of the counter. The details of construction and operating characteristics of various shaped counters are described.

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I. Introduction

A very significant improvement in resolution of low energy photons was recently obtained in gas scintillation proportional counters by replacing the center wire anode with a spherical anode.[1] When this type of counter is used with pure xenon gas and an electric field which is slightly lower than that required for secondary ionization, the energy resolution of the light pulses is much better than the resolution obtained from an ordinary center wire proportional counter. With good light collection efficiency, the light obtained per unit of absorbed x-ray energy is about 100 times that from NaI(Tl) detectors and a full width at half maximum of 500 eV (8.5%) for 5.9 keV photopeak was obtained.[1]

If large volume gas scintillation proportional counters could be built which have energy resolutions as good as or better than that described above,

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such counters would have many applications because their energy resolutions would be at least two times better than proportional counters and their detecting areas would be many times larger than existing germanium and silicon solid state detectors. The detection of ^{239}Pu in humans is just one of many examples where such a counter could provide increased counting sensitivity for gamma and x-ray energies up to about 100 keV.

Three different counter configurations were studied for use as large volume counters. These include the spherical anode inside a short cylindrical cathode, such as that used by Policarpo, et al;(1) a series of transparent parallel plates;(2) and a rod anode inside a long cylindrical cathode. Pure xenon gas was used in all counters with an attached hot calcium, convection flow purifier. The surfaces of the cathodes were covered with MgO by exposure of the surface to smoke from burning magnesium ribbon. A $\leqq 100\ \mu g/cm^2$ layer of p-quaterphenyl wave length shifter was vacuum vaporized onto the magnesium oxide surface and onto the inside of the quartz windows. The wave length shifter is necessary since most of the scintillation light from xenon is emitted in the ultraviolet region beyond the region of photomultiplier sensitivity.

II. Experimental Results

Spherical Anode Counters

The results of Policarpo, et al,(1) were confirmed at our laboratory using a counter of the same size and also with a counter 2-1/2 times larger which used 12.5 cm diameter EMI 9530 QR quartz photomultiplier tubes. A photograph of the counter in a dismantled state is shown in Figure 1.

With the large counter, several sizes of ball anodes made from machined and polished aluminum balls were tried in an effort to increase the light production and resolution of the counter. Ball sizes up to 2.5 cm in diameter were tried. The larger ball sizes required correspondingly higher anode voltages and produced more light over a larger volume of gas, but the resolution obtained was not better than that obtained using the smaller 0.6 mm ball anode.

Because the electric field is not uniform in the counter due to the insulator holding the ball and the closeness of the nonconducting windows, the best resolution is obtained only with a collimated source of x-rays which approach the ball on the side opposite that attached to the insulator. A spectrum obtained with this counter from collimated x-rays from a ^{55}Fe source is shown in Figure 2. The resolution of the 5.89 keV photopeak is 9.7% fwhm which is somewhat poorer than that obtained from the smaller counter (8.5%) using 5.08 cm diameter photomultiplier tubes but much better than that from a regular proportional counter. The poorer resolution in the larger counter is probably due to the poorer resolution of the large 12.5 cm photomultiplier tubes. Because of the nonuniformity of electric field in this type of counter, it does not appear to be a good configuration for a large volume, high resolution counter for practical use in measuring low level activity samples.

Transparent Parallel Plate Counters

From the experiments with the large ball anodes, it became apparent that a large ball anode operating inside a cylindrical cathode begins to approach the conditions of a parallel plate chamber. This suggested that a parallel plate counter with transparent grid anode and cathode might result in an improved counter due to the uniformity of the voltage between the parallel plates, the ease with which very large detectors can be constructed, and the more favorable source geometry which can be obtained.

A sketch of a 5 cm diameter counter which was constructed for testing the use of parallel plates for gas scintillation proportional counting has been previously described[2] and is shown in Figure 3. The walls of the counter were constructed from ordinary laboratory glass tubing. Nickel mesh was stretched onto both ends of section B of the counter wall. This mesh had a wire thickness of 0.0137 mm, 7.87 wires per cm, and was 97% transparent. The three sections of the counter wall were then cemented together with Torr seal, a low vapor pressure epoxy manufactured by Varian Associates, Palo Alto, California. A quartz window coated with $\leq$100 μg/cm^2 p-quarterphenyl was cemented to one end of the tube and a brass plate containing a small beryllium window and tubes leading to a hot calcium purifier was cemented to the opposite end. High voltage connectors were attached to the grids and supported by the epoxy. The brass end plate is maintained at ground potential. An RCA-4523, 5.08 cm diameter photomultiplier tube was coupled to the quartz window with Dow Corning 20-057 optical coupling compound.

The thickness of gas in section C of Figure 3 is more than enough to absorb essentially all 5.9 keV x-rays which enter the small beryllium window. For the best results, the potential of the grid between sections B and C should be such that all primary electrons will drift to the grid without gaining enough energy to cause excitation in section C. The grid between sections A and B is operated so that the field in section B is just below the value at which secondary ionization occurs. If secondary ionization occurs, the resolution of the counter reverts back to that of an ordinary proportional counter. The optimum grid voltages for the best resolution for the new counter were found to be at 1900 and 8500 volts which produced an electrical field of 600 v/cm in the photon absorption and electron drift region, section 3, and 3470 v/cm in the excitation and light producing region, section B.

Volume A of the counter was added because the counter became noisy and unstable when the higher voltage grid was placed directly on the quartz plate which had been coated with p-quaterphenyl. This may have been due to electrons striking the p-quaterphenyl layer between the wires of the grid and building up a negative charge which would then discharge to the grid. By placing the high potential grid away from the quartz plate, the electrons which pass through the grid are drawn back to the grid before they strike the quartz plate. Volume A also allows a more uniform distribution of light over the entire photocathode of the photomultiplier tube.

The pulse height spectra of an ^{55}Fe source measured with this counter is shown in Figure 4. The resolution of 8.4% is slightly better than that obtained with the spherical anode counters. The best resolution of 8.5% for a spherical anode counter was obtained with ^{55}Fe x-rays passing through a chromium filter to reduce the intensity of the K_β x-ray of 6.49 keV.[1] The best unfiltered source spectra from a spherical anode counter has an estimated resolution of 8.86%. The 8.4% resolution which we obtained for an unfiltered source spectra from the parallel plate counter represents a 5% improvement.

A larger 12.5 cm diameter parallel grid counter was constructed which had a spacing of 10.16 cm for section C, 2.5 cm for section B and 1.25 cm for section A. The resolution of the counter using a 12.5 cm diameter photomultiplier was poorer than that of the smaller parallel grid counter and about the same as the larger spherical anode counter. This poorer resolution is again thought to be due to the poorer resolution of the larger photomultiplier tube.

In an attempt to use a smaller better resolution photomultiplier tube with a larger volume parallel grid counter, a 12.5 cm diameter counter was constructed as shown in Figure 5. The electrons formed in the absorption and drift region were focused onto and through a small grid similar to that in a 12.5 cm photomultiplier tube and then accelerated between two small diameter grids which were viewed by a 5.08 cm RCA-4523 photomultiplier tube. The counter appeared to function, but the pulses obtained were extremely long which indicated that the nonuniform electric fields in the absorption and drift region were not allowing the electrons to reach the focusing grid at the same time. The pulses varied in time length up to 0.1 to 0.15 milliseconds which are too long to be analyzed properly by conventional multichannel analyzers. The total amount of light produced for a single event appeared to be proportional to the energy absorbed, but the time distribution of the light varied according to where the event took place in the counter and the direction of the path length of the ionization. Due to the large effort which would be required to overcome the nonuniform field effects, work on this focusing type counter was not continued.

There are three problems which presently exist with the parallel grid type of counter. First, there is a small amount of sparking which occurs between the accelerating grids which form section B. This sparking occurs along the MgO covered walls of the counter and although it does not significantly reduce the resolution of the counter it does provide a high background count which makes counting of low activity samples very difficult. This type of sparking does not occur in the ball anode counter discussed above or in the rod anode counters described below unless a grid is placed between the cathode and anode to provide sharp separation of the electron drift and accelerating regions.

Secondly, since the counter walls were nonconducting, the electric fields near the walls were not the same as in the center of the counter. Therefore, the resolution of broad beam radiation entering the counter was much poorer than that of radiation collimated in a narrow beam into the center axis of the counter. Efforts to provide a uniform field from the center of the counter to the walls by painting a spiral of low conducting Aquadag on the walls was unsuccessful because of sparking which occurred between the spiral lines at high voltage.

The third problem occurs with higher energy radiation which passes through section A of the counter and is absorbed in section B, the accelerating region, and thus giving a lessor amount of light than that where the ionization is accelerated over the total distance between the two grids. If the radiation is low in energy such as x-rays 10 keV or lower, this does not present a problem but an increasingly significant fraction of x-rays or gammas above this energy can penetrate through section A and be partially absorbed in section B. This reduces the resolution of the counter. If a uniform electric field could be obtained in the focusing type of counter shown in Figure 5, this problem would be minimal since the volume of section B is only a few percent of volume A.

Rod Anode Counters

The use of a center rod in a cylindrical shaped counter with collimated radiation can provide the same excellent resolution as that obtained with the spherical anode or parallel grid counters. The spectrum of a beam of radiation from an ^{241}Am source collimated into the counter midway between the two ends is shown in Figure 6. The counter chamber is 5 cm in diameter and 7.5 cm long and has a 0.3 mm diameter polished aluminum rod anode.

The resolution of the 14 and 17.8 keV photopeaks are 6.4% and 7.6%, respectively, and this compares to 11.8% and 10.9% obtained by Yanin, et al,[3] in a regular proportional counter chamber with dimensions of 5.08 x 5.08 x 35.6 cm and filled with a 90% xenon - 10% methane gas mixture. The resolution should be better in a larger diameter gas scintillation counter since much of the 14 and 17.8 keV radiation penetrates into the light production region of this small diameter counter which results in poorer resolution.

Rod anodes of both 3 mm and 6 mm diameter have been used and both resulted in the same degree of resolution. The 3 mm rod gives the best ratio of absorption volume to light production volume and, therefore, is preferred for the higher energy radiation.

Due to the nonuniform field at the ends of the counter, poor energy resolution is obtained for a broad beam of radiation. Efforts are currently being made to eliminate the end effects of the counter by using field shaping rings similar to that described recently by Horstman, et al.[4] Figure 7 shows a 12.8 cm diameter by 17.8 cm long counter of this type with a large beryllium window and Figure 8 shows the counter with one photomultiplier tube removed so that the field shaping rings can be seen. The rings consist of 0.35 mm diameter wire embedded with low vapor pressure epoxy into grooves cut into the quartz plates. Contacts to the wire rings and the center rod are made by 0.05 mm wires which run between two quartz windows which are bonded together by transparent epoxy. Holes in the inside plate allow the 0.05 mm wires to be attached to the rings and the center anode. Appropriate resistors are attached to the leads on the outside of the counter so that the proper voltage is applied to each ring according to its distance from the center rod. This technique eliminates almost all of the nonuniform fields at the ends of the counter and the major volume of the counter now insensitive to the location of the radiation absorption.

Although this counter configuration needs some further development, it appears to be the best of those tested so far. The uniformity of the electric field that can be obtained over the total length of the counter is better and the best ratio of absorption volume to light production volume is obtained. Large, thin window areas are possible with the curved surface. The 1 mm thick beryllium window has an area of 12.5 x 12.5 cm, is curved on a 7.3 cm radius and can easily withstand pressure or vacuum. The one existing problem is that of sparking between the center rod and the closest field shaping ring which is apparently caused by some sharp places on the wire which were caused during construction. With special care or a greater distance between the rod anode and the first field shaping ring this problem can probably be overcome.

III. Conclusions

These gas scintillation proportional counters have proved to be rugged and reliable. Some of the counters described above have been in operation for nearly a year and have not shown any deterioration in resolution or counting sensitivity. When not in use for extended periods, the calcium furnace can be turned off during that time and when heated again just prior to use the gas quickly becomes purified. After several days of gas purification the counter will operate for several days without the hot calcium furnace turned on.

The gas scintillation proportional counters in their current state of development have much better resolution than ordinary proportional counters and for very low x-ray energies the resolution exceeds that of the Ge and Si solid state detectors.[5] For higher energies the Ge and Si detectors have superior resolution but the larger detecting areas and the room temperature operation are favorable characteristics of the gas scintillation proportional counter.

These studies have only been concerned with the development of large pure xenon counters. There are many other potential applications of gas scintillation proportional counters which use other noble gases and gas mixtures.[1,6] Other papers in this session will discuss some of these. This field, although not new, is presently undergoing a rapid expansion in new techniques and knowledge and promises to provide significant advances in several areas of radiation detection. These areas include x-ray fluorescence studies, low level, low energy radiation detection, radiation dosimetry, analysis of radiation in space, and the detection of trace atmospheric contaminants.

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FIGURE 1

UNASSEMBLED LARGE SPHERICAL ANODE COUNTER

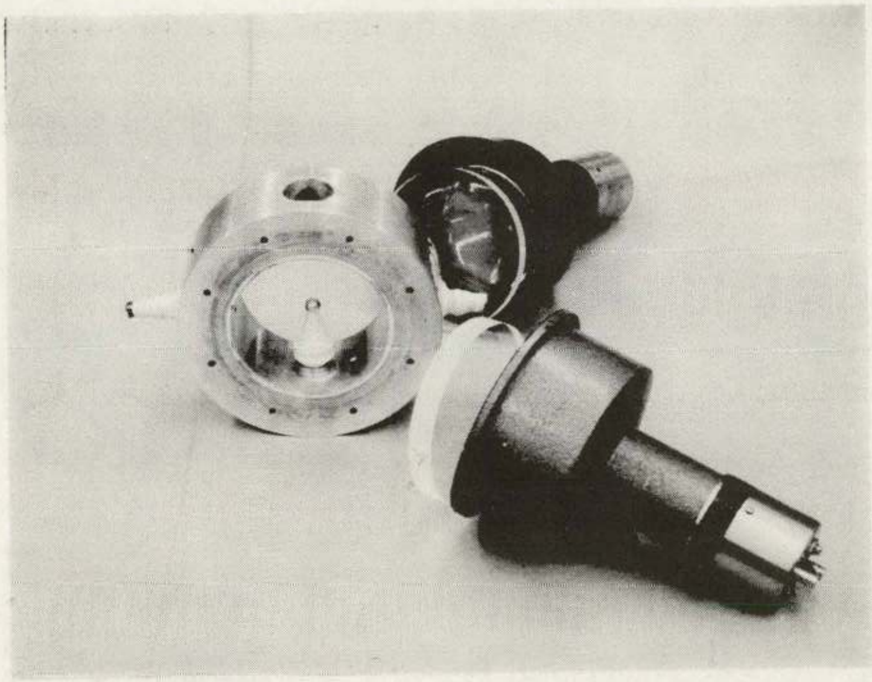

FIGURE 2

X-RAY SPECTRUM FROM ^{55}Fe SOURCE COUNTED ON A 12.5 cm DIAMETER SPHERICAL ANODE GAS SCINTILLATION PROPORTIONAL COUNTER (ANODE DIAMETER = 1.27 cm)

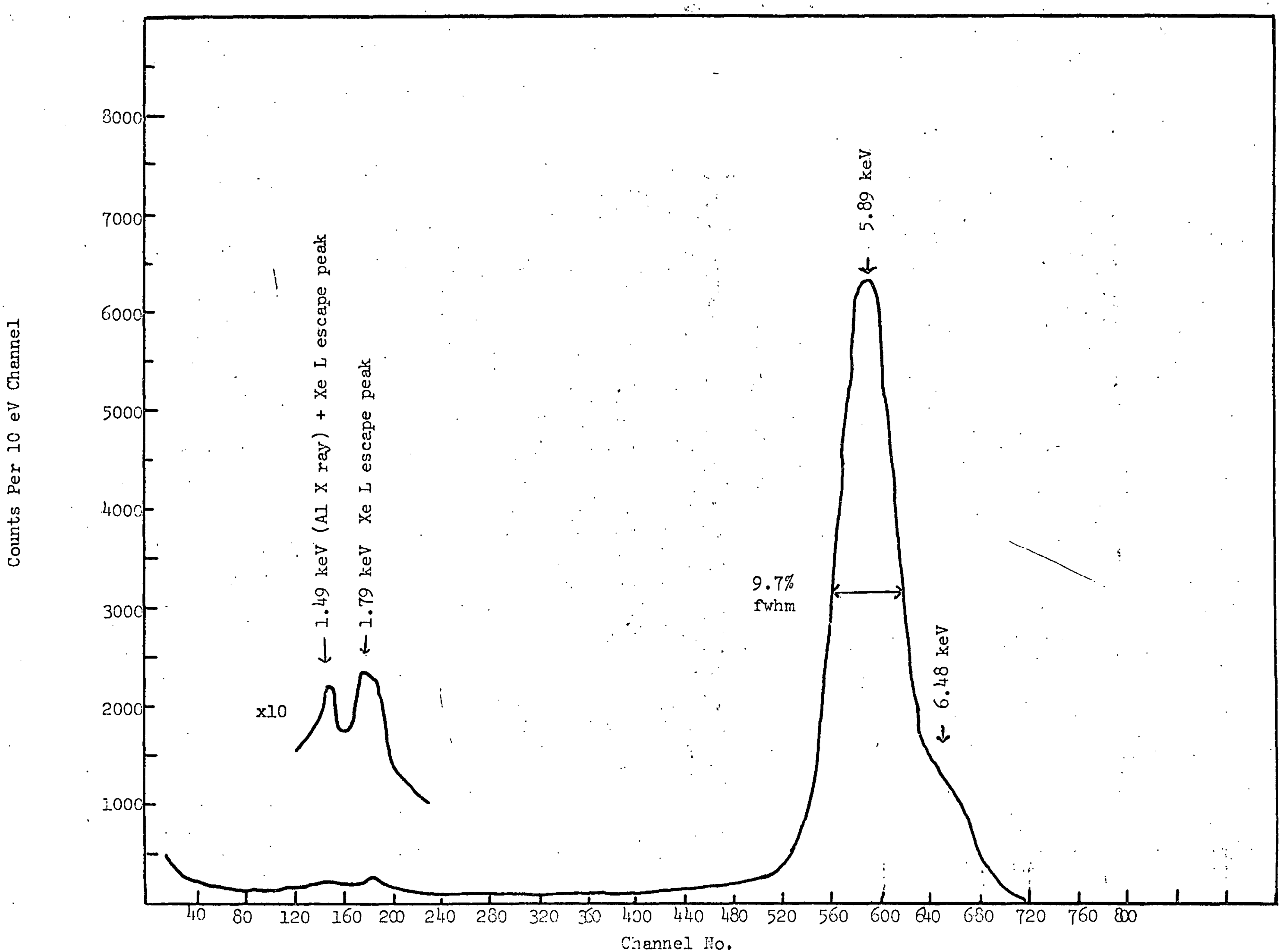

FIGURE 3

SKETCH OF 5 cm DIAMETER PARALLED PLATE GAS SCINTILLATION PROPORTIONAL COUNTER

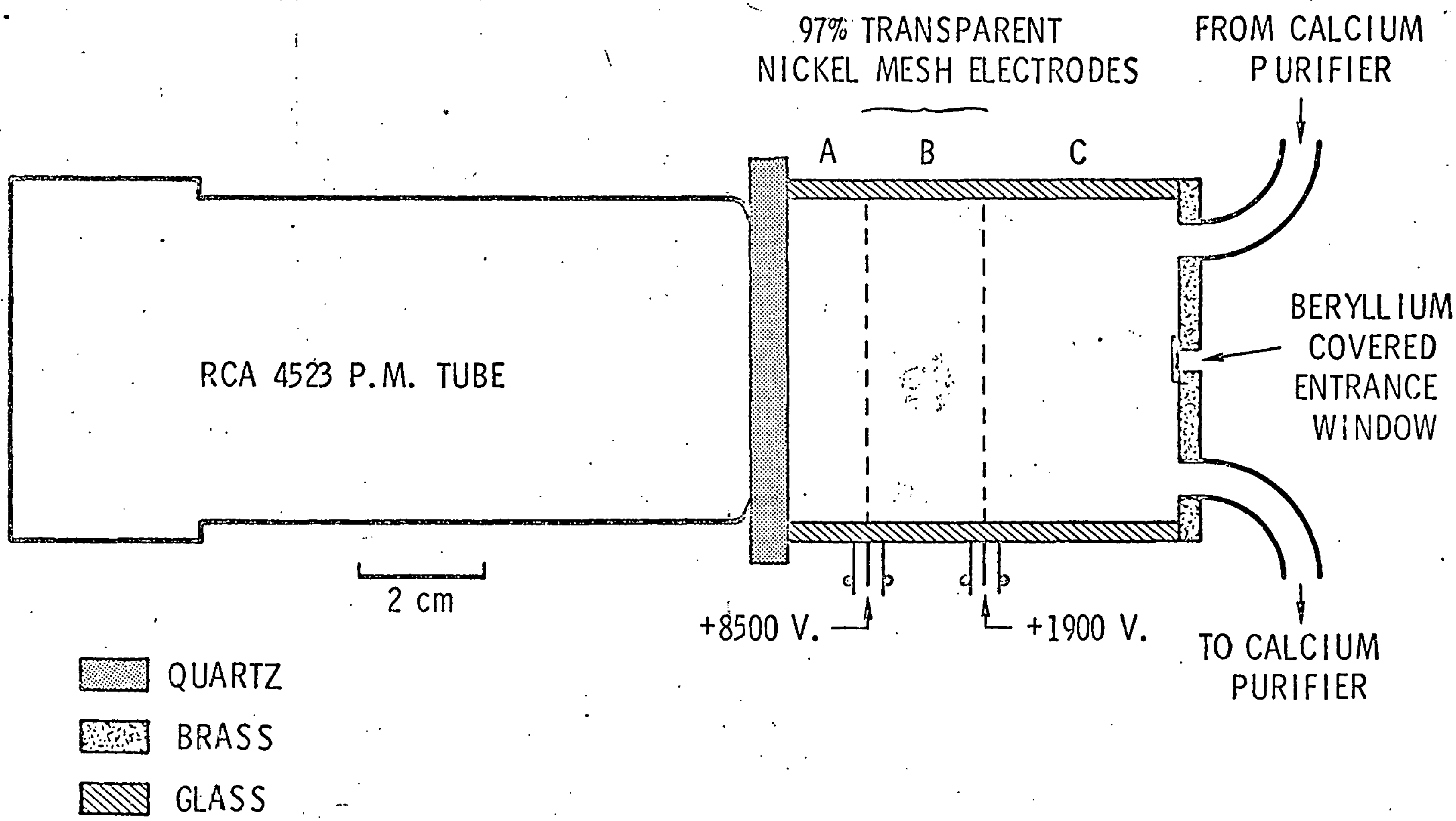

FIGURE 4

PULSE HEIGHT SPECTRA OF A ^{55}Fe SOURCE FROM PARALLEL PLATE GAS SCINTILLATION PROPORTIONAL COUNTER

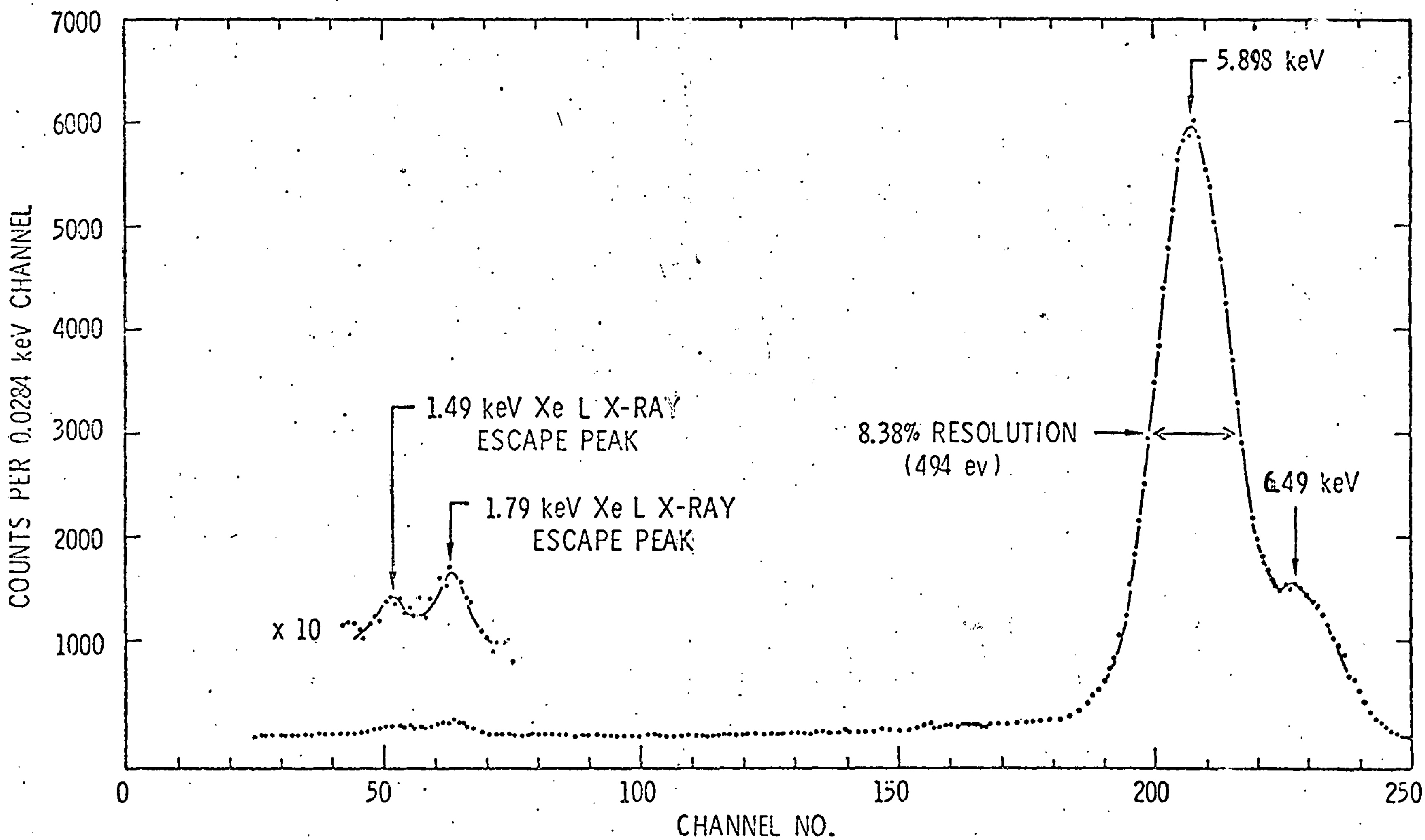

FIGURE 5

AN ELECTRON FOCUSING GAS SCINTILLATION PROPORTIONAL COUNTER

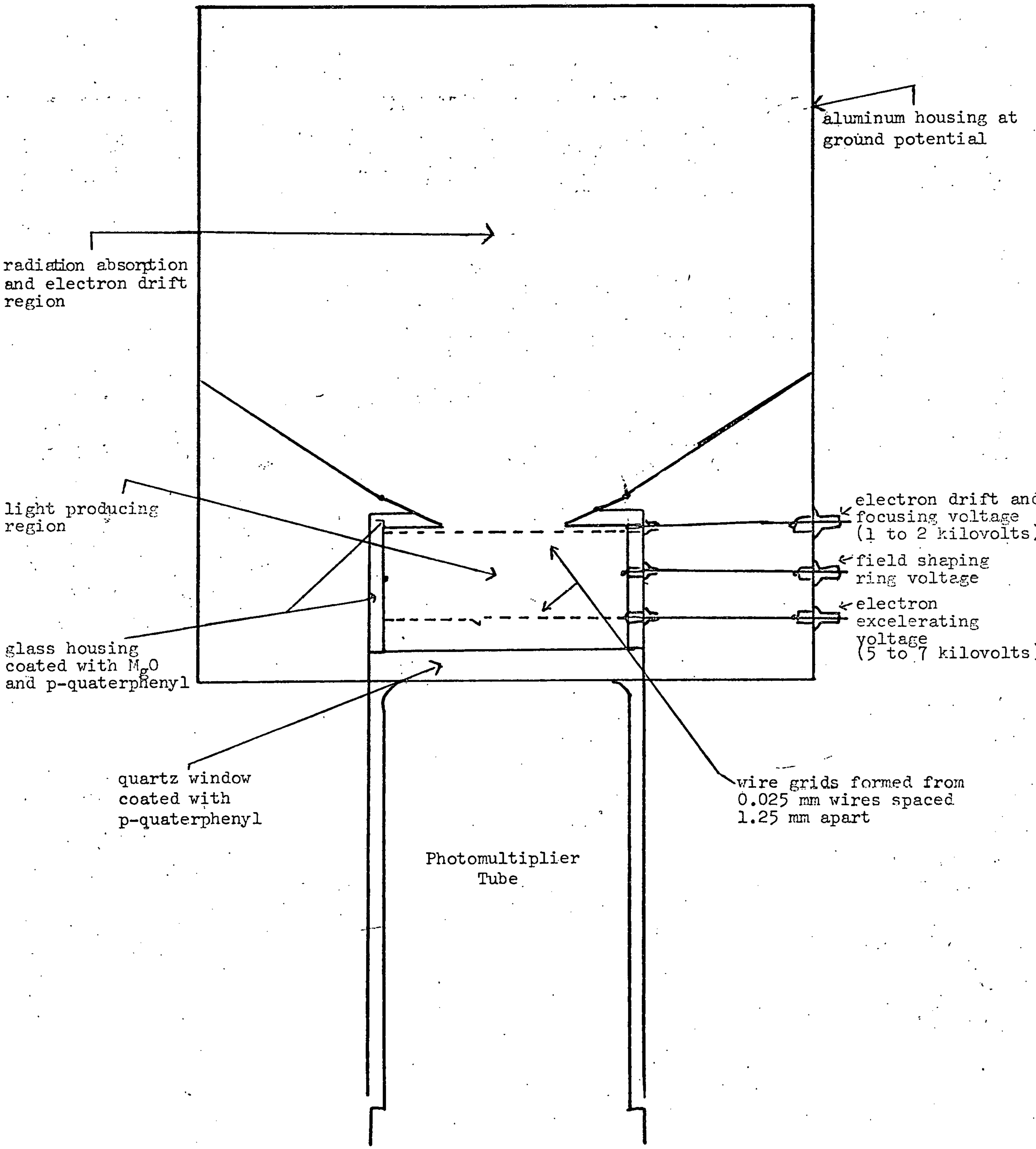

FIGURE 6

SPECTRUM FROM ^{241}Am SOURCE COUNTED ON A 5 cm DIAMETER, 7.5 cm LONG ROD ANODE GAS SCINTILLATION PROPORTIONAL COUNTER (ANODE DIAMETER = 3.2 mm)

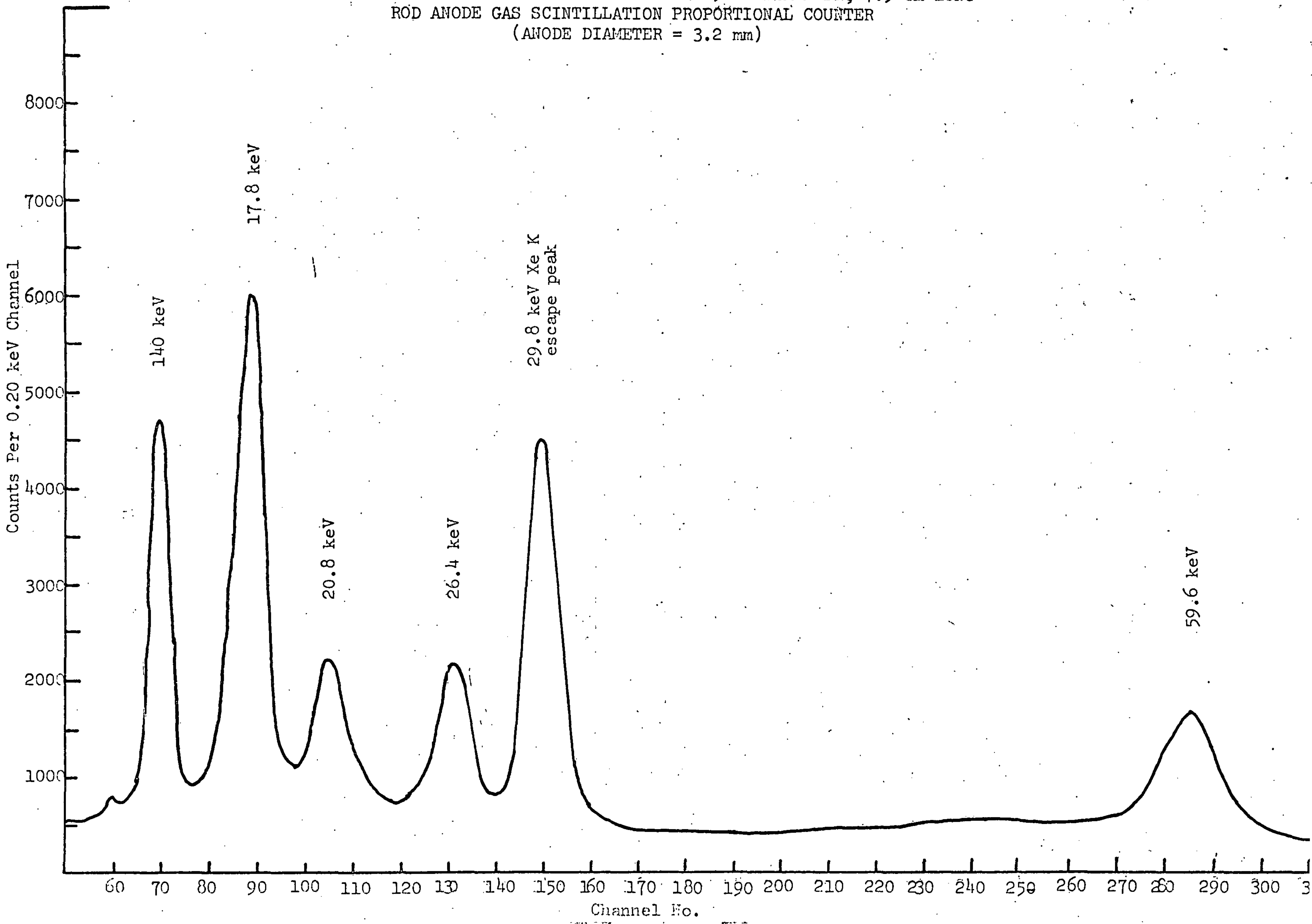

FIGURE 7

LARGE ROD ANODE COUNTER WITH LARGE
BERYLLIUM WINDOW

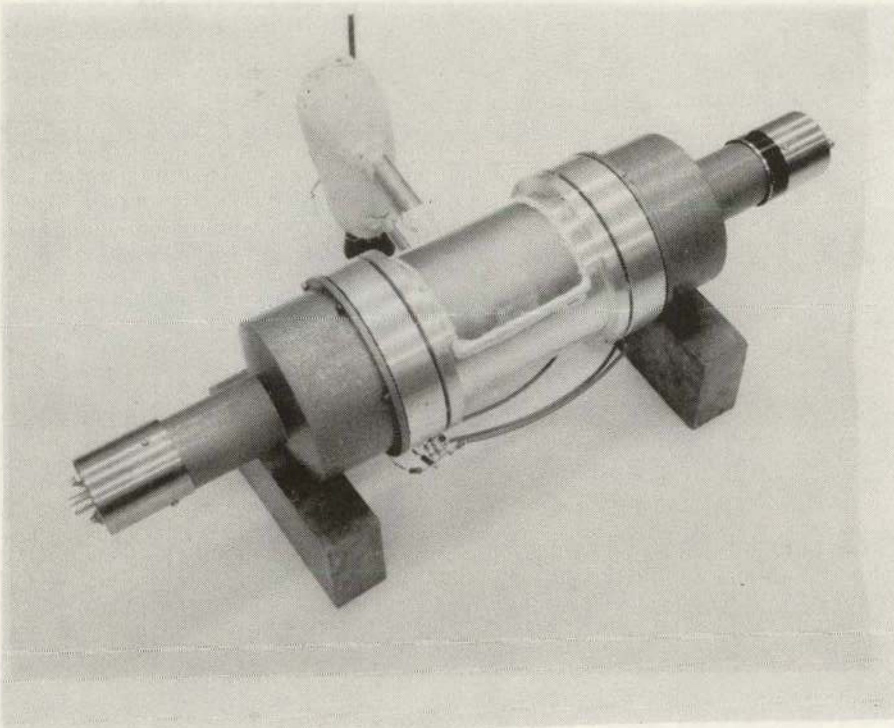

FIGURE 8

LARGE ROD ANODE COUNTER WITH A PHOTOMULTIPLIER
TUBE REMOVED TO SHOW FIELD SHAPING RINGS