ABSOLUTE CALIBRATION AND USE OF A SOFT X RAY SOURCE OF CHARACTERISTIC CARBON RADIATION

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ABSTRACT

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A measurement of the absolute photon yield of characteristic carbon K radiation produced by direct electron bombardment of a target is described. The carbon K emission is produced by a simple and economical source. The radiation is detected with a commercially available proportional counter, using both commercially available windows and thinner windows made at this laboratory. A method for determining the gas absorption efficiency of the counter and transmission of the counter window is described. The pulse height distributions obtained from the proportional counter vary in shape with target voltage indicating the presence of a bremsstrahlung continuum as well as characteristic K radiation. The continuum contribution is subtracted from the total counting rate to obtain the photon yield of characteristic K radiation as a function of target voltage. The results of this determination are used in the calibration of a grazing incidence grating spectrometer at 44A.

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INTRODUCTION:

The determination of the absolute photon yield of a soft x ray source requires a detector with a known quantum efficiency or one for which the quantum efficiency can be determined. Several types of detectors are available such as the flow type Geiger and proportional counters and the open end photomultipliers. The selection of the proportional counter is appropriate because the amplitude of its output pulses can be analyzed to obtain information on the spectral characteristics of a radiating source.

The purpose of this paper is to describe a method, utilizing a proportional counter, for determining the absolute photon yield of carbon K radiation from a simple and economical source, designed, built, and used at this laboratory for calibrating soft x ray instrumentation. The results of this experiment have been applied to the calibration of a grazing incidence spectrometer at 44A.

DESCRIPTION OF APPARATUS:

A schematic diagram of the system employed in this experiment is shown in Figure 1. The x ray source has a simple configuration consisting of an elliptically shaped anode (disc) and v-shaped wire cathode. Figure 2 is a photograph of the x ray source showing the placement of the cathode and anode relative to the mounting plate. The anode, made of tantalum, has dimensions of 3/4" for the major axis, 9/16" for the minor axis and 2 mil in

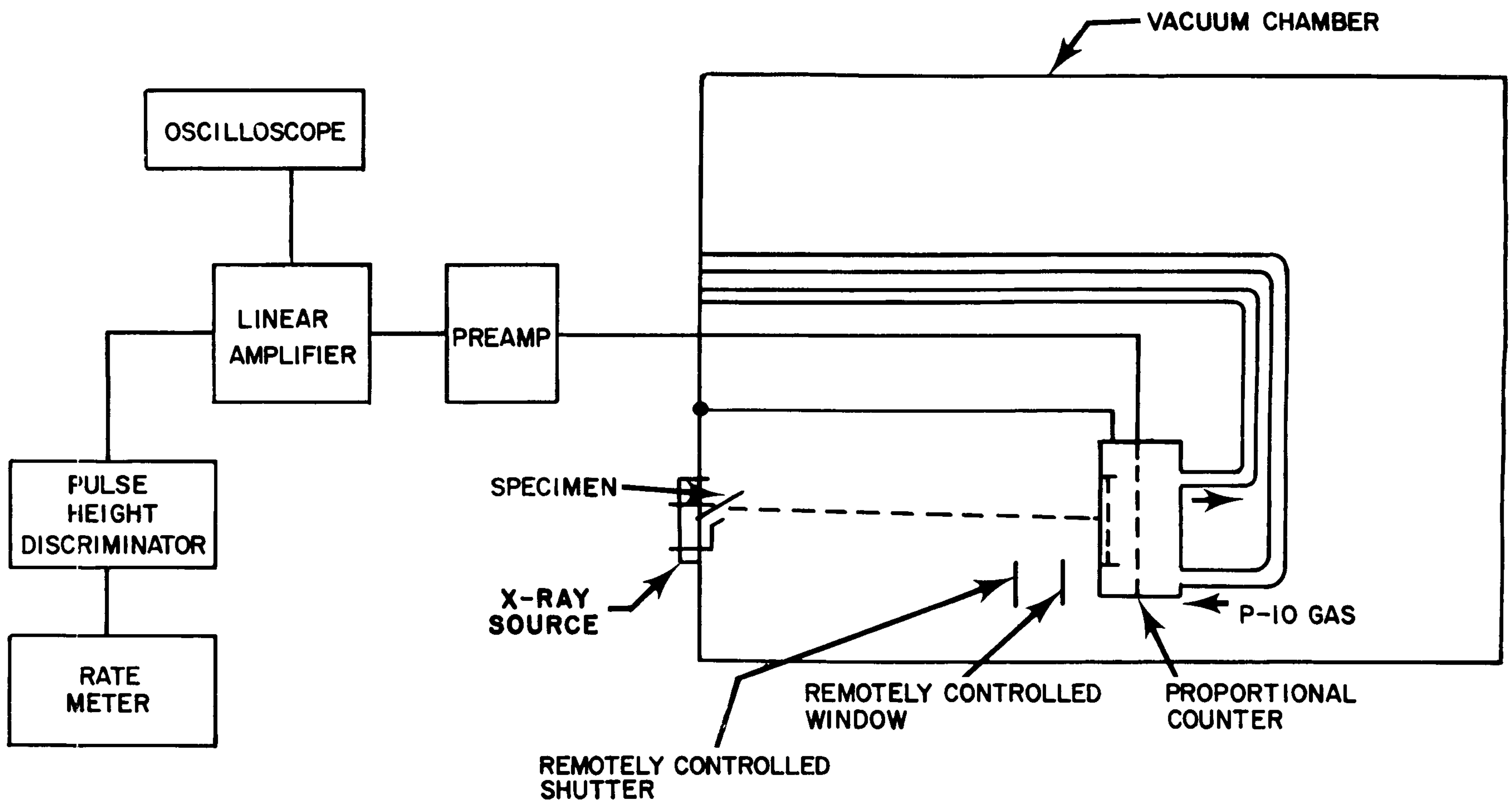

Figure 1 - Schematic Diagram of Apparatus Used to Determine the Absolute Photon Yield of Carbon K Radiation (44A)

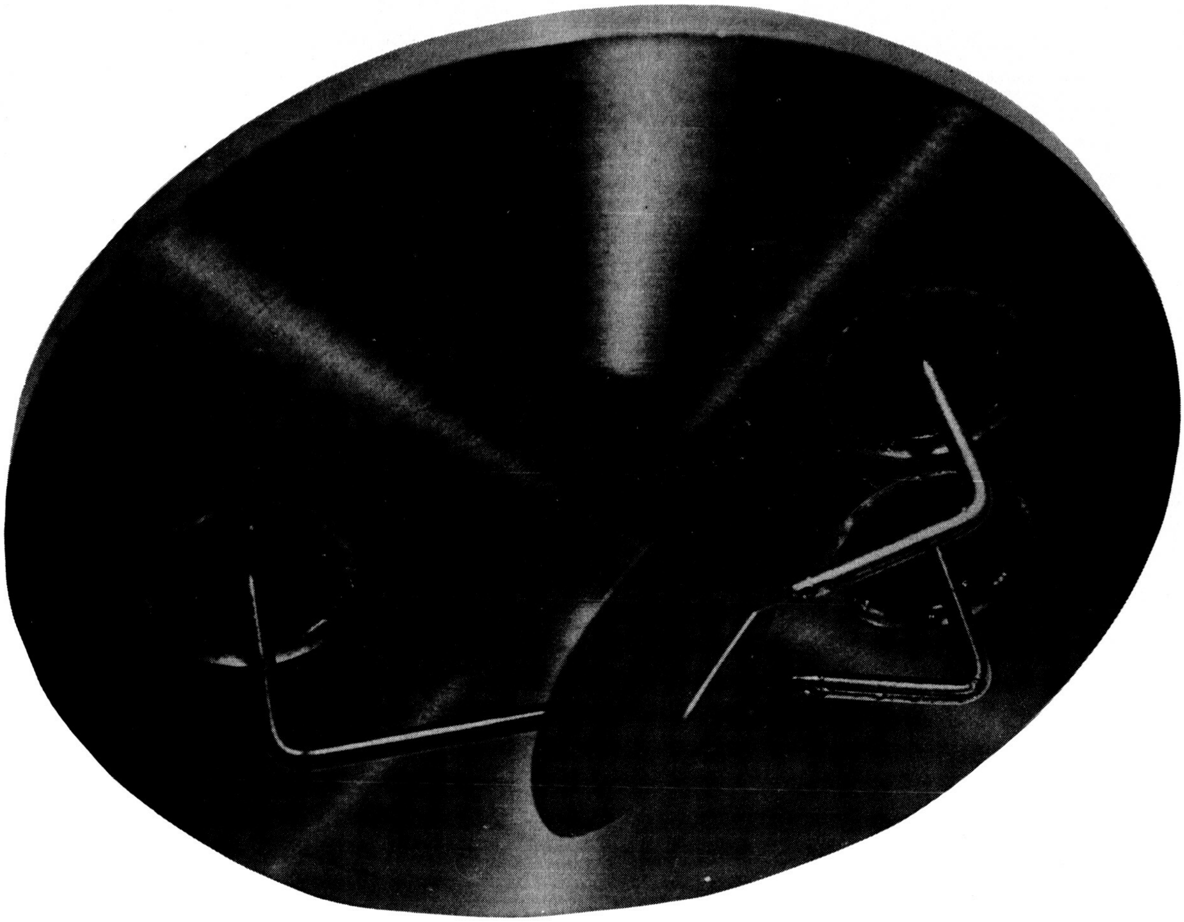

Figure 2 - X-ray Source Showing the Mounting Plate, Anode and Filament

thickness. It is spot welded at its center to a nickel electrode and positioned at an angle of 45° with respect to its mounting plate. The v-shaped cathode (5-mil tungsten wire) with its vertex at the center of the anode, is 1/4" from the anode and parallel to it. This configuration results in an electron beam, approximately 1/8" in diameter directed normally to the anode surface of the x ray source. This source was attached to the main chamber with an o-ring seal and operated at beam currents as high as 1.0 ma at a chamber pressure of 3.0×10^{-6} mm Hg. It was found that the photon emission was stable to within 2.0% over long periods of operation and that the target required no cooling at these low currents. Carbon K band radiation, obtained by painting the target with aquadag, was detected within a solid angle of 3.67×10^{-5} steradians at a takeoff angle of 45° to the target face.

The detector* is a side window proportional counter 6.0 cm. long and 2.52 cm inside diameter with an anode wire diameter of 0.0466 mm. The commercially available counter window material supplied with the counter is mylar 6 μ thick with one side covered with a thin layer of aluminum to provide conduction for electrical charges.

* This is a commercially available flow type counter made by the Seimens Co. in Germany and distributed in the U.S.A. by the Eastern Scientific Co., Cherry Hill, N.J.

An aluminum disc with an aperture 0.252 mm wide and 16.16 mm high is placed over the counter window. P-10 gas (90% Argon and 10% Methane) flows through the counter at atmospheric pressure.

The counter is connected to a preamplifier which drives a linear amplifier having a rise time of about 0.2 μsec and a minimum input sensitivity of about 5 mv. The output of the linear amplifier is fed into a single channel pulse height analyser. The output of the analyser is connected into a ratemeter and scaler circuit.

EFFICIENCY OF COUNTER:

The optimum gas pressure at which one can operate a counter is dependent on the strength of available window material, the counting stability as affected, for example, by the shortening of the plateau characteristic as the counter pressure is reduced, and the pressure at which the radiation is no longer completely absorbed in the gas path. Figure 3-F is a curve showing counting rate as a function of counter voltage, with the counter gas flowing at atmospheric pressure. This curve was obtained with an amplifier gain setting such that non x radiation background pulses were just below counting threshold. The proportional region is from about 1950 v to 2100 v and the Geiger region from about 2200 v to 2400 v. Beyond approximately 2430 v the counter goes into a continuous discharge. At atmospheric pressure the counter performs with excellent stability, having a good plateau in the Geiger region.

Other curves shown in Figure 3 illustrate the shortening of the plateau characteristic in the Geiger region as the counter pressure is reduced. At a counter pressure of 76 cm. of Hg one observes the plateau region extending from a counter voltage of approximately 2200 v to 2400 v while at a counter pressure of 40 cm. of Hg the plateau region is from approximately 1700 v to 1750 v. At 17.5 cm. of Hg the counter goes from proportional operation almost directly into a continuous discharge. These data indicate that if one wishes to operate at low counter pressures a very stable high voltage power supply is required. This requirement is even more stringent if one wishes to operate the counter in the proportional region.

Since the primary object of the experiment is to measure the absolute photon yield of characteristic carbon K radiation it is necessary to know, among other factors, the gas absorption efficiency of the counter. This can be obtained from a study of the counting rate as a function of counter gas pressure. The results are shown in Figure 4. The fact that the counting rate does not increase for pressures above 40 cm. of Hg indicates that complete absorption of the radiation has taken place at the higher pressures. The absence of a decrease at higher pressures indicates the absence of a dead region in the counter(7). Below 40 cm. of Hg the counting rate does decrease, indicating that the gas path is not optically thick and hence, that the gas absorption efficiency of the counter is decreasing from 100%.

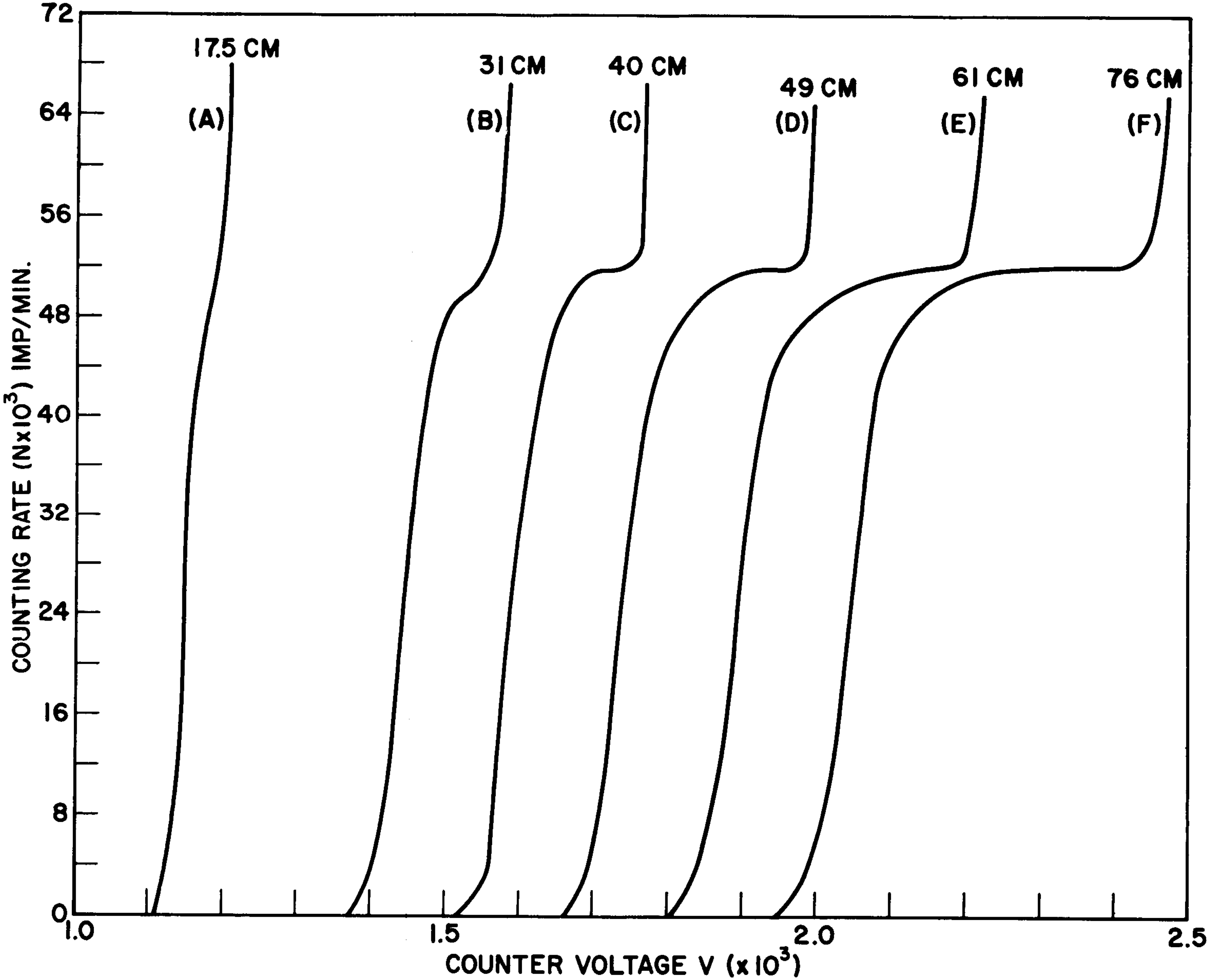

Figure 3 - Family of Curves Showing the Decrease in Width of the Plateau Region as the Counter Pressure is Reduced at Constant Intensity of Radiation.

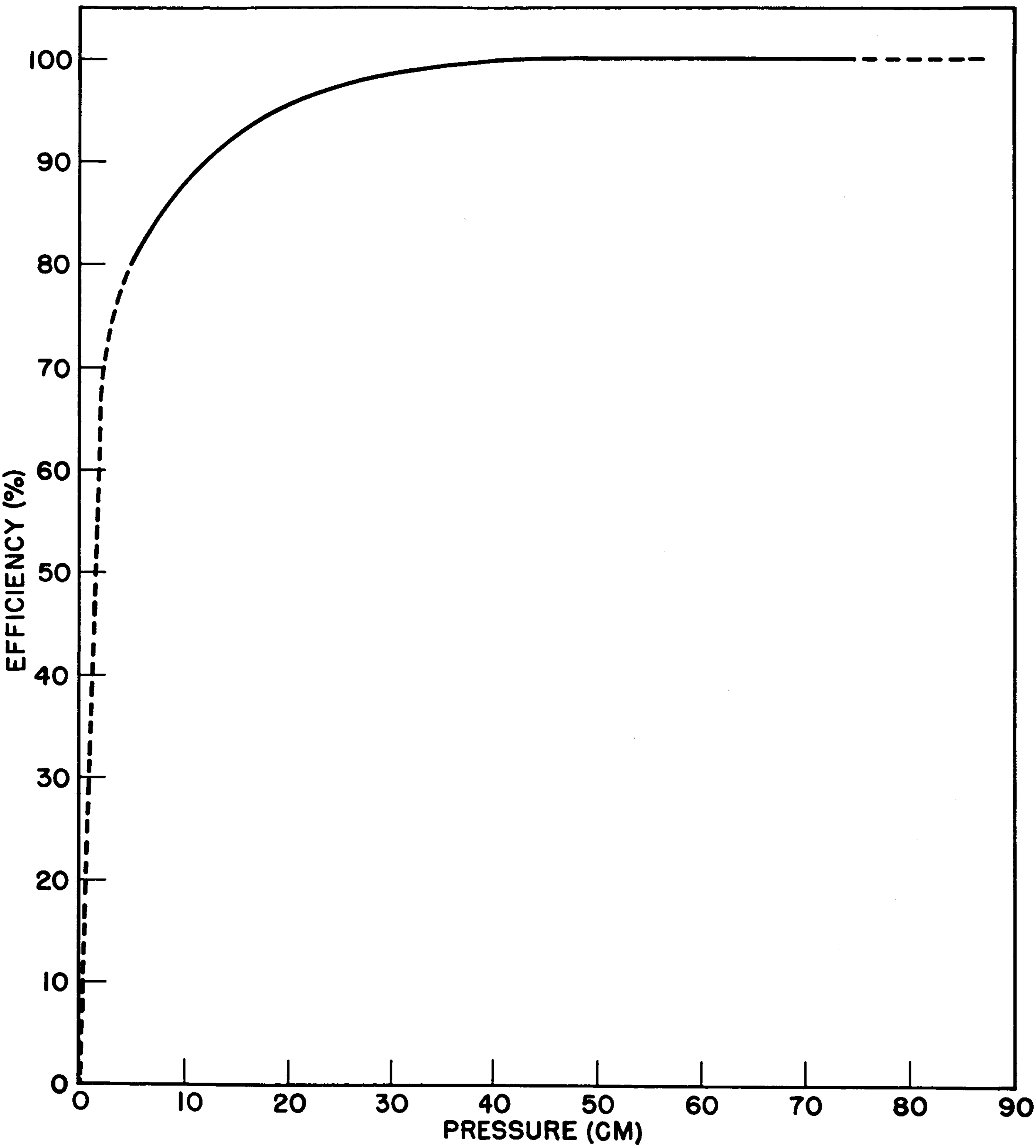

Figure 4 - Counter Gas Absorption Efficiency As A Function of Counter Pressure For Constant Intensity of Radiation

In order to identify the origin of soft x rays produced by the source, it was necessary to operate the counter in its proportional region thereby obtaining a degree of energy resolution. The extent to which proportional operation was achieved was checked by comparing the pulse height distributions of counts obtained from a carbon and from an aluminum target. Using a counter voltage of 2100 v, the electronics were set such that the peak for characteristic carbon K radiation occurred for 10 v pulses. Under these same electronic conditions, a peak was observed for characteristic aluminum K radiation at 57 v. The values obtained for carbon and aluminum were plotted against their respective K band x ray energies. These points lay on a straight line passing through the origin thus showing that the counter, at 2100 v, was operating in the proportional region.

Figure 5 shows the pulse height distributions of carbon K band radiation with constant current and various target voltages using the commercially available counter window material. The curves show a secondary maximum which increases rapidly as the target voltage is increased. This secondary peak has been attributed to bremsstrahlung radiation. The pulse height distribution of carbon K band photons occurs between 5 v and about 35 v while that due to continuum photons ranges from 35 v to beyond 105 v depending on the target voltage. In Figure 5 one observes that at a target voltage of 1000 v no observable continuum is present.

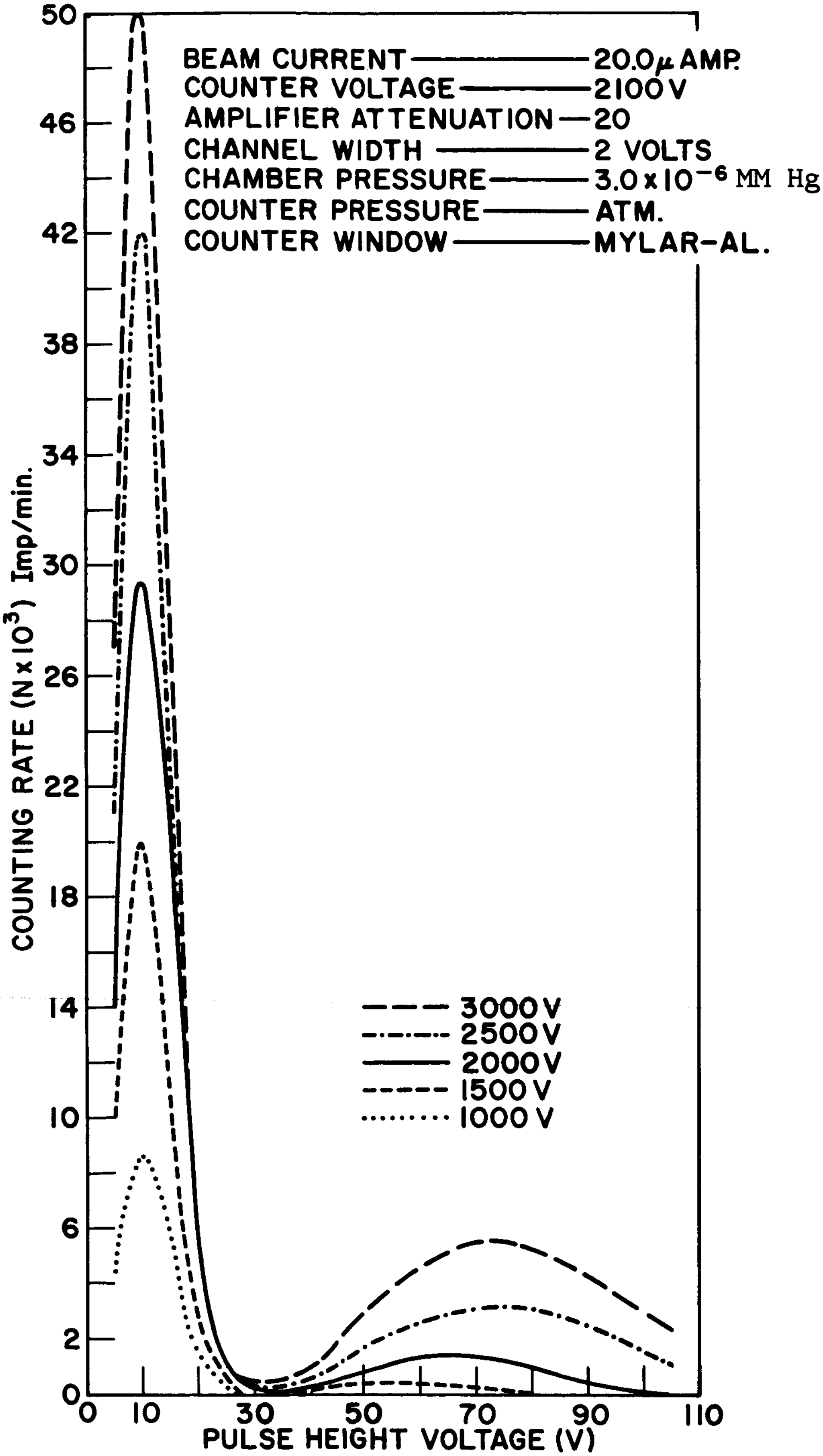

Figure 5 - Pulse Height Distribution Curves For Various Target Voltages with Constant Beam Current Using An Aluminum-mylar Window

As a target voltage is increased to 1500 v the continuum begins to be detected in the pulse voltage range from 40 to 80 v. At 1500 v the continuum radiation was 9.3% of the total count rate (carbon + continuum) whereas at 3000 v it was 44.0% of the total count rate. The percentages stated are valid only for the particular counter window which was used since the transmission of the window is the dominant factor. The results above clearly show that the continuum must be taken into consideration when determining the absolute photon yield of carbon K band radiation, especially when using thick counter windows.

The transmission of the counter window to be used for intensity measurements in the carbon K band wavelength region was directly measured using a remotely controlled solenoid which placed the window between the x ray source and the counter having a window of unknown transmission. A solenoid controlled shutter could also be introduced in the x radiation path to check that the counter was counting only photons from the source. The transmission of the window was measured using only counter pulses produced by K band photons. This was done by first recording the total x ray counting rate (continuum and K band) with the window in and out of the radiation path. The same procedure was followed, with the appropriate changes in electronic setting, to determine the counting rate due to the continuum alone. The difference between the total counting rate and that due to the continuum gave the counting rate of the carbon K band radiation. The ratio of the carbon K band counting rates with the window in and out of the x radiation path gave the transmission of the window. This procedure was followed for target voltages of 1.0, 1.5, 2.0, and 3.0 KV. The average transmission of the window at the carbon K band was calculated to be 2.43% ±0.05%. This window was then placed in the counter and the intensity measurements were made.

INTENSITY MEASUREMENT:

It was necessary to discriminate between counter pulses produced by characteristic K radiation and pulses produced by continuum photons in measuring the absolute K band photon yield of the source. The electronics were first set so that the counting rate due to the carbon K band plus continuum radiation was recorded. Then the electronics were set so that only the counting rate due to the continuum radiation was recorded. The difference between the total counting rate and that due to the continuum gave the counting rate of the carbon K band. This procedure was followed for target voltages in steps of 0.5, 1.0, 1.5, 2.0, 2.5 and 3.0 KV.

The absolute number of carbon K band quanta was obtained with a knowledge of the counter gas absorption efficiency, count rate, beam current, transmission of the counter window and the solid angle. Curve A in Figure 6 shows the absolute quanta per electron per unit solid angle as a function of target voltage for an aquadag target.

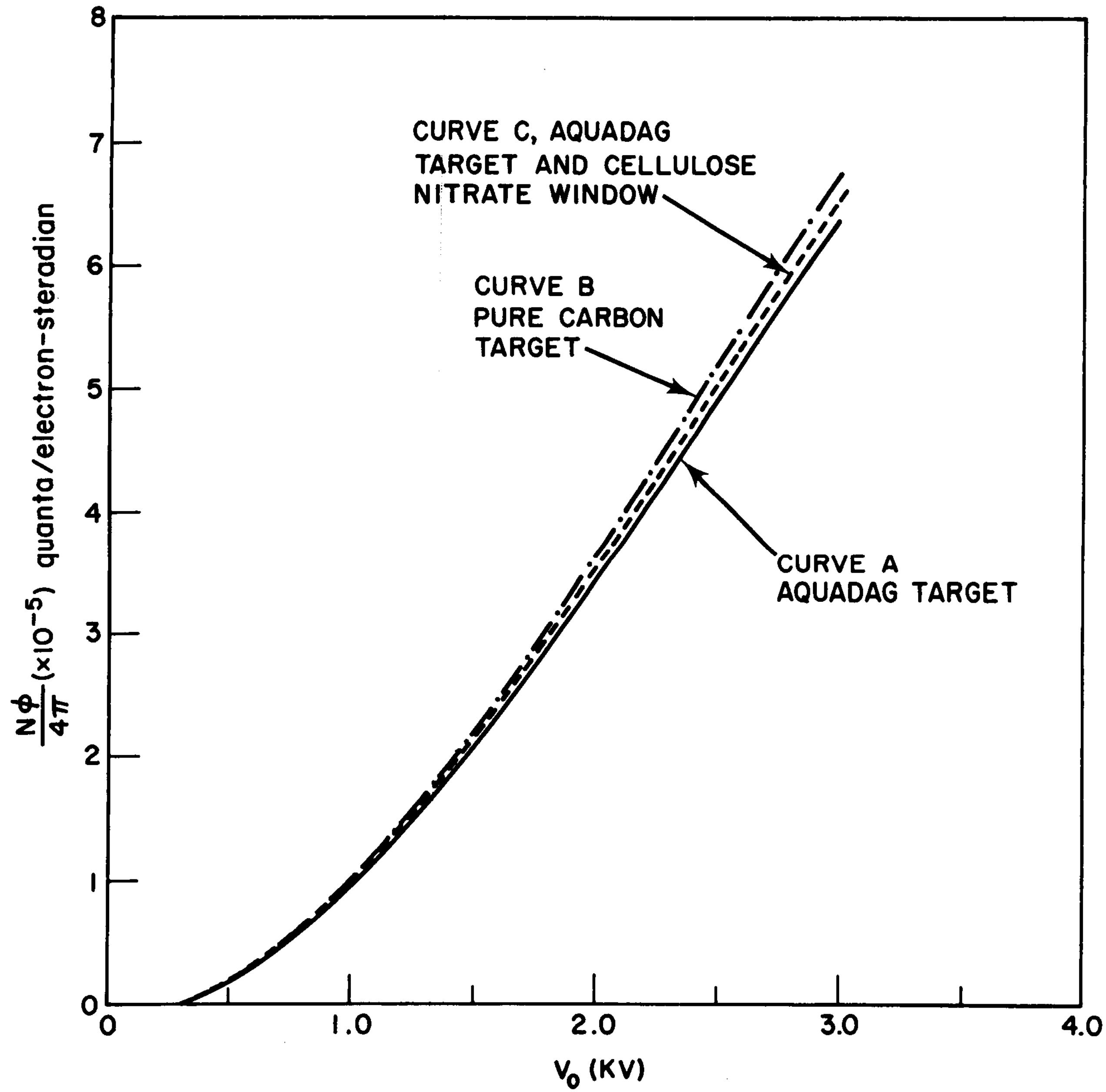

Figure 6 - The Absolute Photon Yield of Carbon K Band Radiation as a Function of Target Voltage Vo.

Another experiment was carried out utilizing spectroscopically pure carbon as the target material. The source configuration was the same as the one for aquadag previously described (the target in this case being a circular carbon disc one half inch in diameter and one-eight inch thick.) The target was filed to smooth its surface to some extent. Absolute photon yield measurements were made under the same conditions as those in the experiment with aquadag. The results, shown in Figure 6, curve B, indicate that the photon yield for pure carbon is slightly higher than for aquadag.

At a later date the photon yield measurement was repeated using a thin window (cellulose nitrate) made at this laboratory. Employing the same geometry and source of radiation, the transmission of the cellulose nitrate window in series with an electroformed mesh was determined to be 44.0% ±2.0%. This is an increase in transmission by a factor of 18 over the 6 μ thick mylar-aluminum window.

Figure 7 shows the pulse height distribution curves obtained using the cellulose nitrate window. It is evident from figures 5 and 7 that the counting rate is lower with a mylar-aluminum window and beam current of 20.0 μa than with the cellulose nitrate window and a beam current of only 2.0 μa. The shapes of the pulse height distribution curves in Figures 5 and 7 are similar except that the secondary maximum, attributed to the continuum, is more pronounced with the thicker counter window. The reason for this is that the thin cellulose nitrate window has practically

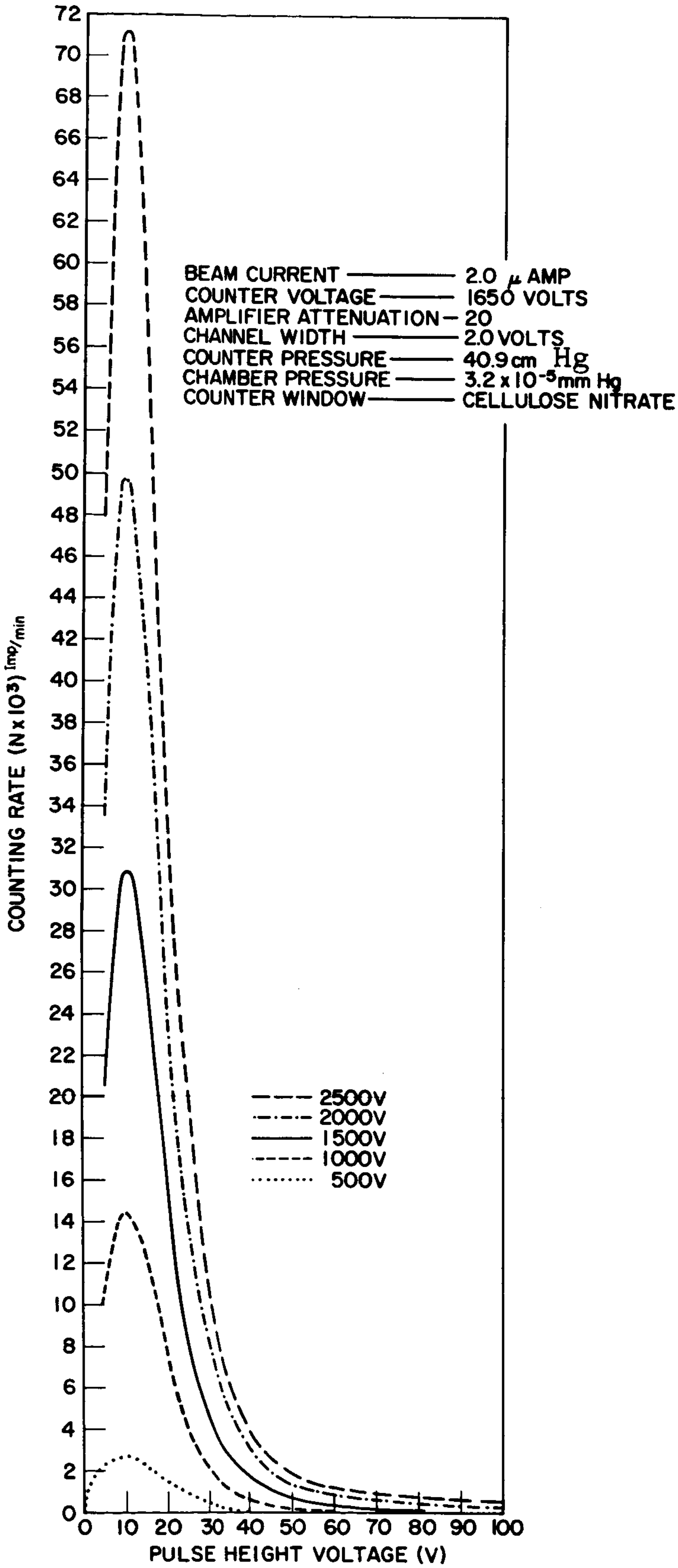

Figure 7 - Pulse Height Distribution Curves For Various Target Voltages With Constant Beam Current Using A Cellulose Nitrate Window

the same transmission for the carbon K band as it has for the continuum radiation whereas the mylar-aluminum window has a much lower transmission for the carbon K photons than it has for the continuum.

Curve C in Figure 6 shows the absolute photon yields measured with the cellulose nitrate counter window. The results are within 5% of those photon yields obtained with the 6 μ thick mylar-aluminum window. This check indicates that the measurements made with both window materials agree within experimental error.

DISCUSSION:

The following corrections have been made in the observed photon yield measurements: Continuum radiation, counting rate in the low energy tail of the pulse height distribution and transmission of the counter window.

No corrections have been made for spurious effects due to back scattering electrons because the target has a low back scattering coefficient and only a small proportion of back scattered electrons have energies sufficiently high for carbon K excitation[(2)]. No correction was made for surface condition of the target material. Errors due to analysis and apparatus have been calculated to be less than 10%. The results of this experiment may be compared with experimental work done by Dolby[(2)]. His absolute photon yield measurements are higher by a factor of about 1.7. For example, at a target voltage of 1.0 KV Dolby's measurement is 1.7 x 10^{-5} quanta per electron per unit solid angle, before a surface condition correction was made as compared to 0.98 x 10^{-5} obtained in this experiment. Brown and Ogilvie[(14)] found Dolby's measurements for aluminum to be higher by a factor of 2. It is not clear why Dolby's measurements are higher for carbon or aluminum; however Campbell[(13)] discusses possible experimental errors.

CALIBRATION OF SCANNING SPECTROMETER AT 44A

The foregoing calibration technique has been applied in the calibration of a grazing incidence grating spectrometer designed to measure solar soft x ray and extreme ultraviolet radiation (Behring, Neupert and Nichols)[(11)]. Radiation is incident on the grating at an angle of 88°. The diffracted rays continue to the exit slit in front of the detector, which is a Bendix Magnetic Electron Multiplier (M-306). This detector is mounted on a carriage which moves on a circular rail so that the exit slit follows along the Rowland circle where the spectrum is in focus. The plane of the exit slit stays approximately perpendicular to the diffracted ray at all positions along the rail, thereby keeping the spectral passband nearly constant (to within one percent) for all angles of diffraction. Read out from the spectrometer was in analog-digital form, with the accumulation of each eight counts in the scaler circuit being reported as a change in voltage at the output of the electronics.

Accumulation of multiples of eight counts (128 and 2048 counts) was also reported by appropriate algebraic combinations of voltages from two additional taps on the scaler chain.

The source described in the first portion of this paper was used for operational tests of the instrument, the distance from source to entrance slit being adjusted to simulate, as closely as possible, the actual appearance of the sun in the direction parallel to the Rowland Plane. This requirement was compromised to some extent to obtain increased fluxes at the entrance slit. A distance of about twelve inches from source to entrance slit was chosen, sufficient to guarantee that radiation from all points on the source, passing through the entrance slit, would be intercepted by some exposed portion of the ruled surface of the grating. During observation of this source with the spectrometer a separate Bendix M-306 electron multiplier monitored the constancy of the beam which, as has been pointed out, remained stable to within 2 per cent over a period of several months.

The average of four scans through the carbon band is presented in Figure 8 together with mean deviations for each of the points which represent averages over uniform intervals of the spectrum. The large deviations are attributable to statistical fluctuations and also to error in measuring the time intervals over which the groups of eight counts were accumulated. The probable error of each point is of the order of 10%. A smooth curve (dashed line), compatible with the

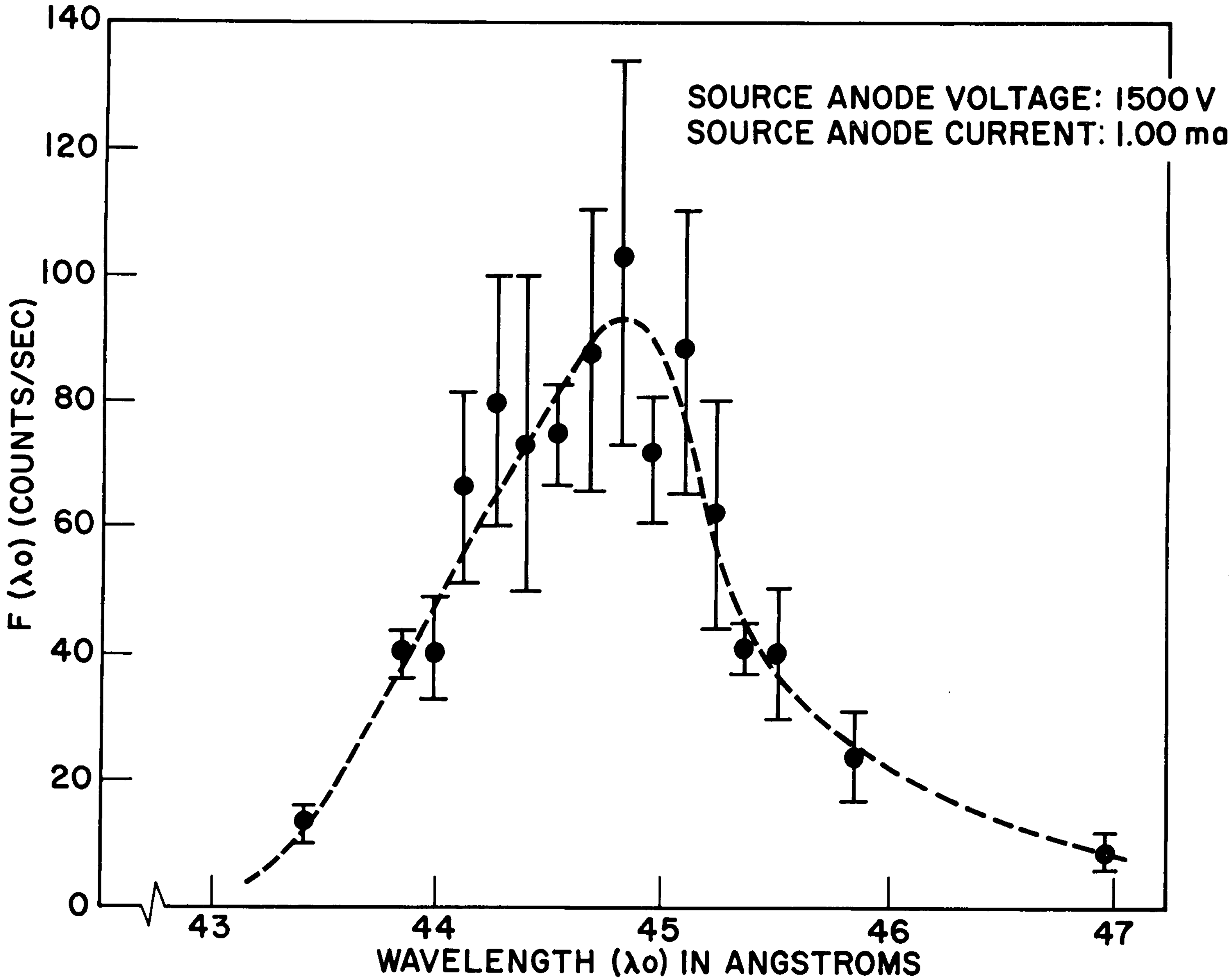

Figure 8 - First Order Carbon K Emission Band As Observed With A Grazing Incidence Spectrometer Using An X-ray Target Voltage of 1500 V And A Beam Current of 1.00 ma.

spectral passband, has been drawn through these points. This curve is also consistent with a previous observation of the carbon band made by Siegbahn[12]. The band was also observed in second order, appearing with reduced intensity, but still confirming the asymmetry which appears in first order. The entire nominal wavelength range of the spectrometer (10A - 400A) was scanned and showed no regions of increased counting rates other than those associated with three orders of the carbon band.

A calibration for the wavelengths of the band may be obtained even though the exact shape of the band is not known. One need only assume that the efficiency of the instrument, $\epsilon(\lambda)$, defined as the probability of recording one count for one photon having a wavelength λ entering the entrance slit, when the spectrometer is set on wavelength λ_o, be the same for all wavelengths in the band. In general, for a flux $I(\lambda)$ entering the instrument, one obtains, as an output from the spectrometer, a counting rate $F(\lambda_o)$ given by:

$$F(\lambda_o) = \int_{\lambda_1}^{\lambda_2} \epsilon(\lambda)\, I(\lambda)\, S(\lambda, \lambda_o)\, d\lambda$$

where $S(\lambda, \lambda_o)$, the instrumental transmission function, is defined as that fraction of the radiation of wavelength λ incident on the focal plane of the spectrometer which is admitted to the detector when the spectrometer is set on wavelength λ_o. Neglecting aberrations of the system, the function $S(\lambda, \lambda_o)$ in the present case may be taken to be an isosceles triangle with a half width specified as $\Delta\lambda$. The limits of integration are chosen so as to include all of the spectral output of the source.

The problem of estimating ϵ is made more manageable, especially in the present case, by integrating $F(\lambda_o)$ over λ_o:

$$F = \int_{\lambda_1 - \Delta\lambda}^{\lambda_2 + \Delta\lambda} F(\lambda_o)\, d\lambda_o = \int_{\lambda_1 - \Delta\lambda}^{\lambda_2 + \Delta\lambda} \int_{\lambda_1}^{\lambda_2} \epsilon(\lambda)\, I(\lambda)\, S(\lambda, \lambda_o)\, d\lambda d\lambda_o$$

where F is now the area under the output curve of the spectrometer (Fig. 8) with units of A • counts/sec. The limits chosen for this integration are appropriate for the symmetric transmission function just described. If the source of radiation is monochromatic, or nearly so, one may assume that the efficiency ϵ is constant over the range of integration:

$$F = \epsilon \int_{\lambda_1 - \Delta\lambda}^{\lambda_2 + \Delta\lambda} \int_{\lambda_1}^{\lambda_2} I(\lambda)\, S(\lambda, \lambda_o)\, d\lambda d\lambda_o$$

The geometry of the spectrometer being calibrated is such that the double integral may be reduced to two measurable quantities, thereby making possible an estimate of ϵ. We must make use of the fact that, for a scanning spectrometer in which the plane of the exit slit remains always perpendicular to the diffracted ray, the integral $\int_{\lambda} S(\lambda, \lambda_o)\, d\lambda$ is independent of λ_o, the wavelength setting of the spectrometer. Indeed, we have the further result

$$\int_{\lambda} S(\lambda, \lambda_o)\, d\lambda = \int_{\lambda_o} S(\lambda, \lambda_o)\, d\lambda_o = \text{constant} = \Delta\lambda$$

where $\Delta\lambda$ is, as before, the half width of the instrumental transmission function. This half width is constant, to within 1%, over the entire range (10A to 400A) of the present spectrometer.

One may change the order of integration of the double integral, the mathematical requirements for this operation being obviously satisfied, to obtain:

$$F = \epsilon \int_{\lambda_1}^{\lambda_2} I(\lambda) \int_{\lambda_1 - \Delta\lambda}^{\lambda_2 + \Delta\lambda} S(\lambda, \lambda_o)\, d\lambda_o d\lambda$$

$$= \epsilon \int_{\lambda_1}^{\lambda_2} I(\lambda)\, d\lambda \int_{\lambda_1 - \Delta\lambda}^{\lambda_2 + \Delta\lambda} S(\lambda, \lambda_o)\, d\lambda_o \quad .$$

Hence

$$\epsilon = \frac{F}{\int_{\lambda_1}^{\lambda_2} I(\lambda)\, d\lambda \int_{\lambda_1 - \Delta\lambda}^{\lambda_2 + \Delta\lambda} S(\lambda, \lambda_o)\, d\lambda_o}$$

$$= \frac{F}{\Delta\lambda \int_{\lambda_1}^{\lambda_2} I(\lambda)\, d\lambda} .$$

The integral over the input flux in the denominator must be obtained by some means independent of the spectrometer. The proportional counter work supplied this measurement.

The result which has been obtained using a band of radiation is applicable to monochromatic inputs as well if one uses the peak output counting rate instead of the area under the output curve. For a monochromatic input $I(\lambda_1)$, one has

$$F_{max} (\lambda_o) = \epsilon (\lambda_1) I (\lambda_1) S_{max} (\lambda, \lambda_o).$$

Both $F (\lambda_o)$ and $S (\lambda, \lambda_o)$ are maximized by taking $\lambda_o = \lambda_1$. For the spectrometer being calibrated (exit slit equal in width and length to the entrance slit)

$$S_{max} (\lambda, \lambda_o) = 1 \quad ,$$

so that we obtain

$$\epsilon(\lambda_1) = \frac{F(\lambda_1)}{I(\lambda_1)} \text{ .}$$

In applying this calibration procedure to the calibration of the spectrometer we take

$$I(\lambda) = \omega\varphi(\lambda)$$

where φ (λ) is the flux from the source, per unit solid angle, and ω is the effective solid angle subtended by the spectrometer. The limiting apertures used in defining this angle were the width of the entrance slit and the length of the exit slit. Taking W and L as the width and height of the respective slits, and r_1 and r_2 their respective distances from the source, we obtain

$$I(\lambda) = \frac{WL}{r_1 \quad r_2} \varphi(\lambda)$$

$$\epsilon = \frac{F}{\omega \; \Delta\lambda \int \varphi(\lambda)\, d\lambda} = \frac{r_1 \; r_2 \; F}{WL \; \Delta\lambda \int \varphi(\lambda)\, d\lambda}$$

In examining a distant source such as the sun, one wishes to compute the average number of incident photons, per square centimeter, which will result in one output pulse from the spectrometer. This quantity, which we shall denote by S, is then given by

$$S = \frac{1}{\epsilon WL} = \Delta\lambda \frac{\int \varphi(\lambda)\, d\lambda}{r_1 \; r_2 \; F} .$$

During calibration of the spectrometer the target voltage of the source was 1500 V and the current 1.00 ma. yielding $\int \varphi(\lambda)\, d\lambda = 12.5 \times 10^{10}$ photons/sec per steradian. Under these circumstances we obtain

$$F = 147 \pm 15 \text{ A}^{\circ} \text{ counts/sec.}$$

Using $r_1 = 31.8$ cm, $r_2 = 43.2$ cm, and $\Delta\lambda = 0.85$ A, we obtain:

$$S = 5.2 \times 10^5 \text{ photon cm}^{-2} \text{ count}^{-1}$$

in the wavelength range from 43A to 46A. The probable error of this result is estimated to be 15%.

CONCLUSION:

This investigation of a commercially available proportional counter shows that it can be used as a detector for the absolute measurement of quanta in the soft X-ray region. Intensity measurements made with the mylar-aluminum and cellulose nitrate windows show that they agree well within experimental error. The counter can be used at wavelengths longer than 44A by making use of suitably thin windows having high transmission. Using X-ray sources having targets made of light elements, it is possible to obtain a calibration for a spectrometer, such as the one described here, at a sequence of discrete wavelengths in the soft x-ray region.

ACKNOWLEDGEMENT

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