

Equipment Required

<ul style="list-style-type: none"> • 4542PC Xenon-filled, End-Window Proportional Counter. • PC-STAND-AX Proportional Counter stand with source and absorber foil holders. • 556 High Voltage Power Supply. • 142PC Preamplifier. • 575A Amplifier. • 4001A/4002D NIM Bin and Power Supply. • EASY-MCA-2K including USB cable and MAESTRO software (other ORTEC MCAs may be substituted). • TDS3032C Oscilloscope with bandwidth ≥ 150 MHz. • C-36-12 RG-59A/U Coaxial Cable with SHV Female Plugs, 12-ft. (3.7-m) length. • C-36-0.5-S RG-59A/U 75-Ω Coaxial Cable with SHV Female Plugs, 0.5-ft. (15-cm) length. • Two C-24-4 RG-62A/U 93-Ω Coaxial Cables with BNC Plugs, 4-ft. (1.2-m) length. • C-24-12 RG-62A/U 93-Ω Coaxial Cable with BNC Plugs, 12-ft. (3.7-m) length. 	<ul style="list-style-type: none"> • C-29 BNC Tee Connector. • Foil-Al-5 10 each 1/2" diameter Aluminum foils, 0.005" thick (1.27 cm dia. x 0.0127 cm thick). • Foil-Ni-3 10 each 1/2" diameter Nickel foils, 0.003" thick (1.27 cm dia. x 0.00762 cm thick). • GF-241-M-10* 10 μCi ^{241}Am (433-y half life). • GF-137-M-5* 5 μCi ^{137}Cs (30.2-y half life). • GF-109-M-10* 10 μCi ^{109}Cd (463-d half life). • GF-057-M-20* 20 μCi ^{57}Co (272-d half life). • GF-055-M-10* 10 μCi ^{55}Fe (999-d half life). • ZN65S* 1 μCi ^{65}Zn (244-d half life). • Personal Computer with USB port and a recent, supportable version of the Windows operating system. • Small, flat-blade screwdriver for tuning screwdriver-adjustable controls.
<p>*Sources are available direct from supplier. See the ORTEC website at www.ortec-online.com/Service-Support/Library/Experiments-Radioactive-Source-Suppliers.aspx</p>	

Purpose

In this experiment, the techniques for operating a thin-window proportional counter are explored, and some typical X-ray spectra are obtained. The proportional counter is employed to measure the mass absorption coefficients of aluminum and nickel at 22 keV.

CAUTION

The thin beryllium window built into the proportional counter is very fragile. DO NOT allow any material to contact the window and DO NOT TOUCH IT.

Relevant Information

As discussed in Experiments 3 and 7, the photoelectric interaction is the most pronounced type of photon interaction for energies below 100 keV. This experiment utilizes the proportional counter to detect X-ray energies below 60 keV.

The typical proportional counter is basically a metal cylinder with a concentric wire stretched along the center of its longitudinal axis (ref. 1 and 8). The tube is filled with a counting gas mixture (e.g., 760 Torr of 90% Xenon and 10% CH_4), and a positive high voltage of ~ 1700 V is applied to the central electrode. In the most common configuration, a thin beryllium window is built into the cylinder wall to allow low-energy X rays to enter into the counting region with minimum absorption. Proportional counters are also available with the beryllium window mounted at one end of the cylinder. Beryllium is used because it is a malleable metal, and it has a low atomic number ($Z = 4$) that minimizes absorption in the window. The low atomic number is advantageous, because the photoelectric absorption cross section varies as Z^5 (see Experiments 3 and 7). When an X ray enters the tube, it ionizes the gas via the photoelectric interaction. The photon disappears, while transferring its energy to the electron ejected from the ionized atom. As the electron travels through the gas, it loses its energy by causing further ionization. At the end of the ionization process, the number of electron-ion pairs, n , is proportional to the original energy of the X-ray photon.

$$n = \frac{E}{\epsilon} \quad (1)$$

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Where E is the energy of the X ray, and ϵ is the average energy required to create one electron-ion pair, typically 21.5 eV for Xenon.

When the proper bias voltage is applied between the center wire (anode) and the outer cylinder (cathode), the cloud of electrons released in the initial ionization process is accelerated towards the center wire, while the positive ions drift towards the outer cylinder. As the electrons accelerate towards the anode, they acquire sufficient energy to ionize additional atoms. The result is an avalanche of electrons impinging on the center wire.

The difference between a Geiger Counter and a Proportional Counter lies in the bias voltage. The voltage applied to a Geiger Counter is high enough so that the number of electrons reaching the anode wire is always the same, independent of the energy of the detected photon. For a Proportional Counter, the voltage is lowered to the point where the number of electrons reaching the anode, n_A , is proportional to the energy of the detected photon.

$$n_A = A n = A \frac{E}{\epsilon} \quad (2)$$

Where A is the proportionality constant, which is the ratio of the number of avalanche electrons to the number of initial electrons. In other words, A is known as the gas gain. Happily, the gas gain significantly increases the amount of charge collected by the preamplifier for each detected X ray. That reduces the importance of the preamplifier noise, enabling the analysis of very low X-ray energies.

The gas gain of the proportional counter is sensitive to the applied bias voltage. Consequently, a power supply that delivers a very stable bias voltage is essential. Also the bias voltage must be selected within the normal operating range of the detector. Figure 11.1 illustrates the operational characteristics of a cylindrical, gas-filled detector as a function of the applied bias voltage. Some voltage is required to separate the electron-ion pairs and drift the negative and positive charges to their respective electrodes, where they are collected by the preamplifier to form a pulse. V_i is the minimum bias voltage required to collect all the electron-ion pairs before some of them recombine. As the voltage is increased from V_i to V_p , the detector functions as an ionization chamber, i.e., the number of electron-ion pairs collected is independent of the voltage.

Beginning at V_p , the electrons pick up enough energy on their trip to the anode to cause further ionization. Thus the value of the gas gain is greater than unity. Because of the coaxial cylindrical geometry, the electric field strength is highest near the anode wire, and decreases towards the wall of the cylinder. Thus, it is only when the electrons get close to the anode that they pick up sufficient energy to cause an avalanche of ionization. As the bias voltage increases, the field strength increases, and electrons receive sufficient acceleration further from the anode to cause an avalanche of ionization. Thus the gas gain, A , increases with increasing bias voltage.

The vertical scale in Figure 11.1 is logarithmic. Consequently, the parallel, diagonal lines for low-energy and high-energy photons reflect the increasing gas gain as the bias voltage increases. Above V_{ip} , the gas gain for high-energy photons does not increase as strongly as the gain for low-energy photons. Therefore, the pulse-height spectrum begins to compress at higher energies. This is the limited proportional region.

If the bias voltage is increased above V_g , all pulses will exhibit the same pulse height, and this is the Geiger Counter region. Even with a Geiger Counter, the region above V_c must be avoided because of the destructive continuous discharge in the detector.

The normal operating range for a proportional counter is in the proportional region between V_p and V_{ip} . For the 4542PC Proportional Counter, these limits are from 1600 to 1850 Volts.

Typically the charge collection time for electrons is less than 500 ns. However, the charge collection time for the positive ions is quite long, of the order of tens of microseconds. Therefore, a 0.5 μ s shaping time constant is

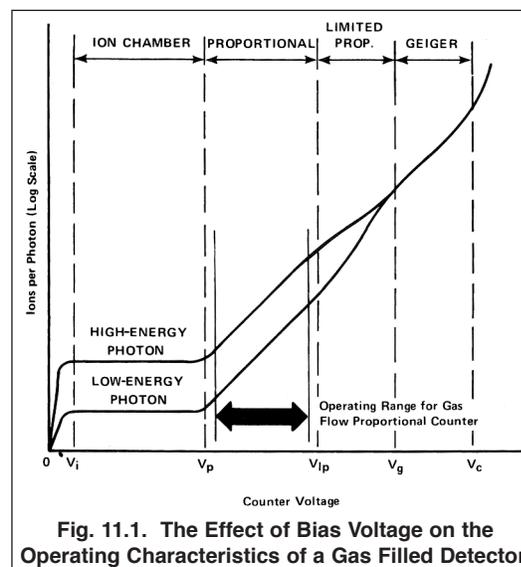


Fig. 11.1. The Effect of Bias Voltage on the Operating Characteristics of a Gas Filled Detector

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normally employed in the amplifier to emphasize the fast signal from the electrons, while suppressing the slow, positive-ion signal (ref. 8). Because the detector is filled with a gas at a pressure circa 760 Torr, the proportional counter does not have a high detection efficiency above 50 keV. Two common, alternative fill gases are Argon and Xenon. Because of its higher atomic number Xenon is the better choice when energies above 20 keV must be measured. Moreover, an end-window is preferred over the side window geometry when high energies are important, because the end-window geometry provides the full length of the cylinder for stopping the photons, whereas the side window presents the much smaller diameter of the cylinder.

Figure 11.2 shows the typical intrinsic detection efficiency of an end-window proportional counter filled with Xenon at 760 Torr. The intrinsic detection efficiency specifies the number of photons that end up in the photopeak in the energy spectrum, expressed as a percent of the photons that are incident on the Beryllium window port. At energies below 8 keV, the detection efficiency declines because of absorption in the 0.25 mm thick Beryllium window. The abrupt jump in detection efficiency at 34.579 keV corresponds to the K absorption edge of Xenon. Photons above that energy can ionize the K-shell of Xenon, causing much stronger absorption than is provided by only L-shell ionization at slightly lower energies. When electrons refill the vacancy in the K shell, Xenon K-series X rays are emitted. If those K X-rays escape the detector, there will be a deficit of energy recorded by the detector. This is the source of the escape peaks in the energy spectrum approximately 29.7 and 33.8 keV below the original energy of the photon entering the detector.

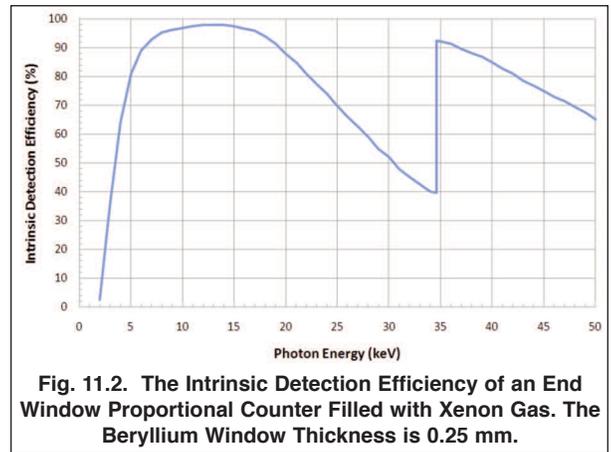


Fig. 11.2. The Intrinsic Detection Efficiency of an End Window Proportional Counter Filled with Xenon Gas. The Beryllium Window Thickness is 0.25 mm.

References 1 and 8 delineate the factors that contribute to the energy resolution of the proportional counter. Statistical variations in the number of original electron-ion pairs and statistical variations in the gas gain are the major contributors. Electronic noise in the preamplifier is usually small compared to these two contributions. For most applications, the energy resolution can be presumed to be proportional to the square root of the photon energy. A FWHM resolution of 2.2 keV is typical at 22.1 keV. This is much worse than obtained with a Si(Li) detector (Experiment 8).

Because of the relatively coarse resolution, it is convenient to use the weighted average of the $K_{\alpha 1}$ and $K_{\alpha 2}$ energies and similarly for the $K_{\beta 1,3}$ and $K_{\beta 2}$ peaks. Table 11.1 shows the resulting energies for the radioisotopes typically used for energy calibration.

Radioisotope	Half Life	Daughter Isotope	K_{α} X-Ray (keV)	K_{β} X-Ray (keV)	γ -Rays (keV)
^{54}Mn	312.3 d	^{54}Cr	5.411	5.946	
^{57}Co	271.8 d	^{57}Fe	6.399	7.057	14.41
^{65}Zn	244.3 d	^{65}Cu	8.040	8.921	
^{85}Sr	64.8 d	^{85}Rb	13.374	15.012	
^{88}Y	106.6 d	^{88}Sr	14.141	15.892	
^{109}Cd	462.6 d	^{109}Ag	22.102	25.062	88.03
^{113}Sn	115.1 d	^{113}In	24.135	27.411	
^{137}Cs	30.17 y	^{137}Ba	32.059	36.582	

EXPERIMENT 11.1. Energy Calibration

Purpose

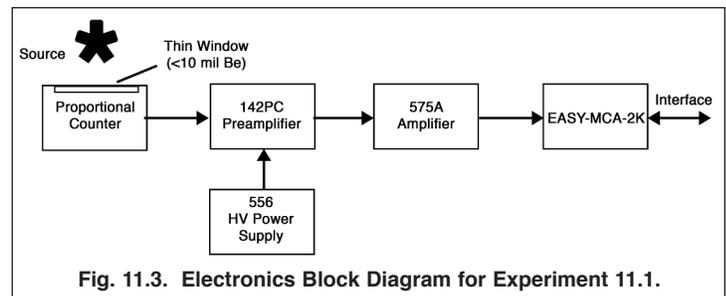
In this experiment the detector and its supporting electronics will be set up and calibrated. The dependence of energy resolution on energy will be explored. The spectrum from an ^{241}Am source will be examined to identify the X-ray lines and gamma-ray peaks. An unidentified source will be counted for the purpose of identifying the source via its energy spectrum.

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Procedure

1. Connect the instruments as shown in Fig. 11.3, being careful to prevent touching the Be window on the proportional counter. More specifically:
2. Turn off the power switches on the 556 Power Supply and the NIM Bin power supply. Install the modules in the NIM Bin.
3. Connect the proportional counter to the INPUT of the 142PC Preamp using the shortest possible coaxial cable having the appropriate connectors. If the proportional counter employs an MHV connector, the cable will be 75- Ω RG-59A/U with an MHV connector on the end for the proportional counter, and an SHV connector to accommodate the Preamp INPUT. If the proportional counter utilizes an SHV connector, the RG 59A/U cable will have SHV connectors on both ends.
4. On the 575A Amplifier, check that the switches accessible through the side panel have been set for a 0.5 μ s SHAPING TIME. Set the front-panel input polarity switch to POSitive.
5. Connect the 142PC Preamp power cord to the PREAMP POWER connector on the rear panel of the 575A Amplifier. Using the 3.7 m, 93- Ω , RG-62A/U coaxial cable, connect the ENERGY output from the preamp to the INPUT of the 575A Amplifier.
6. On the rear panel of the 556 High-Voltage Power Supply, check that the CONTROL switch is set to INTERNAL. Verify that the POLARITY switch is set to POSitive. Using the 3.7 m, RG-59A/U coaxial cable with SHV plugs, connect one of the high voltage OUTPUTS to the BIAS input on the 142PC Preamp.
7. Set the voltage controls on the front panel of the 556 High-Voltage Power Supply approximately half way between the manufacturer's recommended operating voltage and the minimum operating voltage specified by the manufacturer. For the 4542PC, the range of operating voltages is +1600 V to +1850 V, and the manufacturer's recommended operating voltage is +1700 V. Using a slightly lower bias voltage permits higher counting rates before peak shifting caused by the positive ion cloud sets in (ref. 8).
8. Using a 93- Ω RG-62A/U cable, connect the UNIpolar OUTput of the 575A Amplifier to the analog INPUT of the EASY-MCA-2K. Ensure that the EASY-MCA-2K is interfaced to the supporting computer via the USB cable, and MAESTRO is operating in the computer.
9. Via MAESTRO, set the MCA coincidence gate requirement to OFF. Select a 512-channel conversion gain. Set the Upper Level Discriminator to 512, and the Lower Level Discriminator to 10 channels.
10. Turn on the NIM Bin power and the 556 Power Supply.
11. Place the ^{241}Am source approximately 5 cm from the Proportional Counter window on the axial centerline of the detector cylinder.
12. Observe the UNIpolar OUTput of the 575A Amplifier on the oscilloscope.
13. Adjust the Amplifier gain to achieve a +8.5 V pulse height for the 59.5 keV gamma ray. Once the adjustment is complete, lock the FINE GAIN dial so that the gain cannot be accidentally changed.
14. Employing the procedure taught in Experiment 3, adjust the Pole-Zero (P/Z) cancellation on the 575A Amplifier to make the output pulses return to baseline as quickly as possible without undershooting. NOTE: The slow positive-ion charge collection in the proportional counter will cause a slower return to baseline than is experienced with NaI(Tl), Si(Li), silicon surface-barrier or ion-implanted silicon detectors (see the pulse shape pictures in ref. 8).
15. Reconnect the 575A Amplifier UNIpolar OUTput to the EASY-MCA-2K analog INPUT.
16. Temporarily remove all radioactive sources from the vicinity of the Proportional Counter and start an acquisition on the MCS. Observe the percent deadtime. If the dead time is greater than 1% adjust the Lower Level Discriminator on the EASY-MCA-2K to be safely above the noise level. This can be accomplished by lowering the discriminator



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level until the percent dead time increases drastically. Next, slowly raise the discriminator threshold until the dead time is just less than 1%. If the dead time does not exceed 1%, there is no need to adjust the lower level discriminator.

17. Place the ^{241}Am source on the axial centerline of the proportional counter, with a source to detector distance of approximately 5 cm. If the percent dead time exceeds 20% with any of the sources employed in this experiment, increase the source to detector distance to reduce the percent dead time below 20%.
18. Acquire a spectrum for a sufficient live time to obtain adequate statistical precision in the shape and location of the 59.5 keV gamma ray. If the gamma-ray is not centered on channel 426, adjust the amplifier fine gain to position the peak within ± 10 channels of channel 426. Lock the FINE GAIN dial so that the gain cannot be accidentally changed.
19. Using the features available in MAESTRO, determine the channel numbers corresponding to the centroid of the 59.5 keV peak. Measure the FWHM resolution of the gamma-ray peak. Record both numbers and save the spectrum for possible later reference.
20. Replace the ^{241}Am source with the ^{137}Cs source. Acquire a spectrum, and record the channel positions for the centroids of the K_α and K_β X-ray peaks. Measure and record the FWHM for each peak. Save the spectrum for possible later reference.
21. Repeat step 20 using the ^{57}Co source. Record the channel positions for the centroids of the K X-ray peak and the 14.4 keV gamma-ray peak. Measure and record the FWHM for each peak. Save the spectrum for possible later reference. Figure 11.4 illustrates a typical ^{57}Co spectrum.
22. Repeat step 20 with the ^{109}Cd source, recording the centroid channel positions and the FWHM resolutions of the silver K-lines, and saving the spectrum for possible later reference.
23. Using the spectra and centroids acquired in steps 19 through 22, and the calibration menus of MAESTRO calibrate the MCA cursor to read directly in keV.

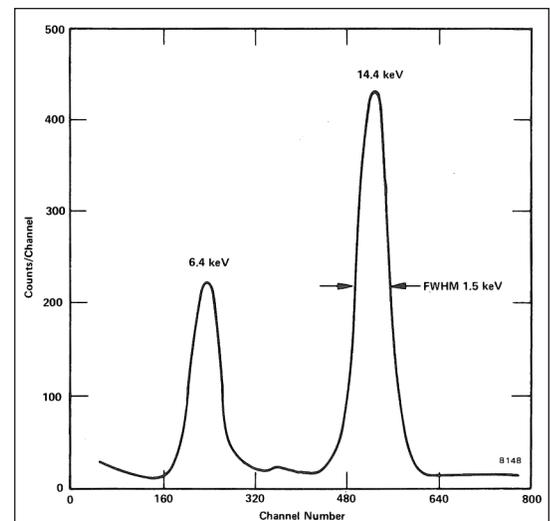


Fig. 11.4 A Typical ^{57}Co Spectrum Acquired with a Proportional Counter.

EXERCISES

- a. Plot an energy calibration curve for the data acquired above. Determine the slope of the calibration line in keV/channel. Using either the calibration curve or the MAESTRO features, convert the measured FWHM values for the peaks from channels to keV, and plot them on a linear graph.
 - b. Plot the FWHM in keV on a logarithmic scale versus the energy of the X ray or gamma ray on a logarithmic scale. Draw a straight line through the points and measure the slope. Does this line support the contention that the energy resolution is proportional to the square root of the energy?
 - c. For cases where the K_α and K_β peaks are not completely resolved, how does that complication affect the measured position and FWHM of the peak? Can you find any discrepancies in the energy calibration and the resolution graphs that are traceable to this resolution limitation?
-
24. Acquire a spectrum with the ^{241}Am source long enough to enable identification of the weaker peaks. Save this spectrum on a transportable medium such as a CD, memory stick or portable hard disk for later incorporation in your report. It should be exported to the transportable medium as an ASCII file. This file can be imported into an Excel spreadsheet using tab and space delimiters for plotting and inclusion in your report. Alternatively, the computer display of the spectrum can be photographed with a high-resolution digital camera, for transfer of the image into your report.

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EXERCISES

- d. Refer to Table 8.1 of Experiment 8, and identify the peaks in the ^{241}Am spectrum.
 - e. For the 59.5 keV gamma ray, forecast the location of the escape peaks caused by the Xenon K_{α} and K_{β} X rays escaping from the detector. Identify those escape peak locations in your spectrum. Are these escape peaks detectable in your spectrum?
-

- 25. From your Laboratory Instructor, obtain an X-ray source whose identity has been hidden. Acquire a spectrum.
-

EXERCISE

- f. Identify the unknown X-ray source from its spectrum and the information in references 6, 9 and 10.
-

EXPERIMENT 11.2. Mass Absorption Coefficients for 22 keV X Rays

Purpose

The mass absorption coefficients for the 22.1 keV Ag K_{α} X rays from ^{109}Cd will be measured for aluminum and Nickel. The results for aluminum can be compared to the value measured in Experiment 8.

Procedure

1. Continue with the system as set up and calibrated in Experiment 11.1.
2. Place the ^{109}Cd source on the axial centerline of the proportional counter approximately 5 cm from the detector window.
3. Acquire a spectrum for a preset live time of 100 seconds. Check the percent dead time. If the dead time is greater than 20%, increase the source-to-detector distance to reduce the dead time below 20%. If the percent dead time is less than 10%, reduce the distance to move the dead time into the 10% to 20% range. In any case, do not reduce the source-to-detector distance to less than 2.5 cm.
4. Once the distance has been adjusted, determine what preset live time is required to accumulate at least 4,000 counts in the area under the 22.1 keV peak. Use that preset live time for each acquisition in the remainder of the experiment.
5. Accumulate a spectrum for the selected live time with no metal foils between the ^{109}Cd source and the proportional counter. Set a region of interest (ROI) across the full extent of the Ag K_{α} peak, and record the total counts in the ROI on line 0 in Table 11.2.
6. Being careful to not change the position of the source, insert an aluminum foil between the source and detector, using the thickness specified on line index 1 of Table 11.2. Repeat the measurement of the counts in the Ag K_{α} peak using the same ROI and live time as in step 5. Record the measurement in Table 11.2.
7. Repeat step 6 for each foil thickness specified in Table 11.2.

Table 11.2. Data for Absorption Measurement with Al Foils.					
Aluminum Density = 2.70 g/cm ³					
Line Index, i	Absorber Thickness			Live Time (sec)	Counts in Ag K_{α} Peak
	Inches	cm	g/cm ²		
0	0.000	0.000	0.000		
1	0.005	0.013	0.034		
2	0.010	0.025	0.069		
3	0.015	0.038	0.103		
4	0.020	0.051	0.137		
5	0.025	0.064	0.171		
6	0.030	0.076	0.206		
7	0.035	0.089	0.240		
8	0.040	0.102	0.274		
9	0.045	0.114	0.309		
10	0.050	0.127	0.343		

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EXERCISES

- a. Make a plot on semilog paper of counts vs. absorber thickness (g/cm^2) for aluminum. Figure 11.5 shows some typical data taken at a lower energy with thinner foils.
 - b. From your plots and with reference to the discussion in Experiment 3, determine the half-value thickness and the mass attenuation coefficient for aluminum.
-
8. Repeat the sequence of measurements and the Exercises using the nickel foils instead of the aluminum foils. See Table 11.3 and Figure 11.6.

Table 11.3. Data for Absorption Measurement with Ni Foils.

Nickel Density = $8.90 \text{ g}/\text{cm}^3$

Line Index, i	Absorber Thickness			Live Time (sec)	Counts in Ag K_{α} Peak
	Inches	cm	g/cm^2		
0	0.000	0.000	0.000		
1	0.003	0.008	0.068		
2	0.006	0.015	0.136		
3	0.009	0.023	0.203		
4	0.012	0.030	0.271		
5	0.015	0.038	0.339		
6	0.018	0.046	0.407		
7	0.021	0.053	0.475		
8	0.024	0.061	0.543		
9	0.027	0.069	0.610		
10	0.030	0.076	0.678		

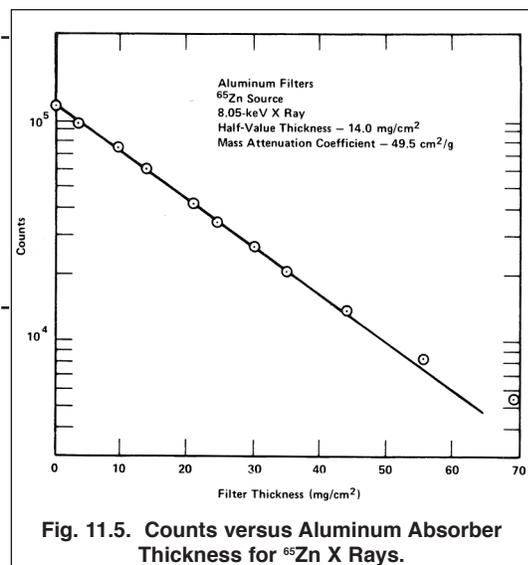


Fig. 11.5. Counts versus Aluminum Absorber Thickness for ^{65}Zn X Rays.

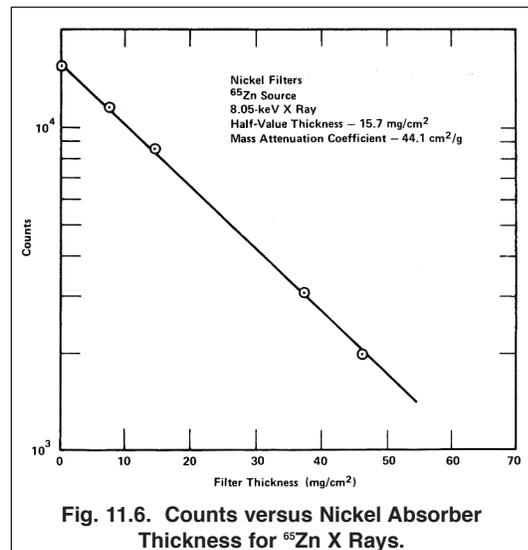


Fig. 11.6. Counts versus Nickel Absorber Thickness for ^{65}Zn X Rays.

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Specifications subject to change
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