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Gaseous Detector Spectroscopy, Energy Calibration and Statistical Analysis

*Abstract*— Gaseous detector spectroscopy is an important aspect of nuclear sciences. A gaseous proportional detector filled with P-10 gas was tested to determine energy calibration and spectra peak identification. Co-57, Fe-55, and Cd-109 sources were used for testing. The associated energy calibration equation is The full energy peaks and X-ray escape peak were identified on the spectra. The Co-57 source was further tested for radioactive statistics. Trials of five seconds of counting show that the experiment follows a Poisson distribution for low counting times. The Chi-square for the Co-57 testing to a Poisson and Gaussian distribution are 0.30 and 0.31, respectively.

*Index Terms*—Radiation Detection, Gaseous Detector, Spectroscopy, Chi-square, Escape Peak, P-10

# INTRODUCTION

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pectroscopy of low energy photons is the primary application of gaseous proportional counters [1]. Proportional counters can be used for the detection and spectroscopy of photons that interact with the detector. Pressurized gas proportional counters are most suited to detect lower energy photons. The low density gas and absorption cross section do not permit detection of high energy photons, approximately greater that 100 keV [1].

The principal interactions that take place for a gaseous proportional counter include the photoelectric effect and Compton scattering [2]. The nature of the incident radiation can be evaluated by a calibrated pulse height spectrum from the detector and electronics.

Fluxuations occur in radioactive counting experiment data because of the stochastic nature of radioactive decay [3]. Counting experiments can be represented by statistical models. It is important to analyze the standard deviation, Chi-square for a predicted count, and frequency distribution of count rates for an experiment.

# Theory

Proportional counters have pulse amplitudes proportional to the incident radiation over a range of radiation energies [2]. Gaseous proportional counters are more sensitive to lower energy photons and soft x-rays [2]. Sources can be used to map pulse height amplitudes (PHA) to the channel in the multi-channel analyzer (MCA). The channel number can be fit using a least-square fitting of a polynomial. The degree of nonlinearity is usually small, so the fitting can be accomplished with a linear fit with an error of under 5% if high precision is not required [1].

The absorption of the incident radiation creates a full energy

peak (FEP), where nearly all of the radiation is converted to signal. A typical gas produces an ion pair for every 25-35 eV of incident energy deposited [1]. The low energy photon may be accompanied by a characteristic K X-ray that follow the photoelectric absorption off the main radiation. The Kα X-ray for argon is 2.97 keV [1]. Aside from the main FEP, an escape peak with energy of the FEP minus the K-shell X-ray energy of the fill gas [1].

Statistics for radiation experiments is characterized by the Binomial distribution, where there is a probability of occurrence for a particular outcome [3]. The Poisson and Gaussian distributions approximate a Binomial distribution for counts above 20 [4]. The standard error of the mean counts is given by the mean divided by the square root of the number of counts. From the distribution of counts, a certain amount can be rejected with Chauvenet’s criterion. Chauvenet rule states that outliers can be rejected if the expected counts at least as bad as the outlier is less that 0.5 [3]. The Chi-square distribution can be used to test the probability distribution fit quality [3]. The Chi-square test is:

# Experiment

A gas filled ionization detector was used for experiment with a standard NIM counting system electronics and a MCA. The MCA emulated with an ORTEC 926 ADCAM multichannel Buffer and a laptop with GammaVision [2].

The detector uses P-10 gas, which is a mixture of 90% argon and 10% methane [1]. The flow rate for the gas is set to 10 cubic feet per minute. The system was tested with a pulser to ensure operation. A counting curve was created to determine the optimal bias voltage for the detector. A bias of 1700 V is on the plateau of the counting curve and within the operational range of the detector.

Three sources were used for the experiment, Fe-55, Co-57, and Cd-109. The three sources span a range of gamma-ray energies from approximately 5 to 25 keV, which are all detectable by the gaseous detector. Other energy gamma-rays are present at higher energies; however, they are not detectable with smaller gaseous detectors at low pressure. The energies of the FEP expected are 6.4 keV and 14.4 keV for Co-57, 22.16 keV for Cd-109, and 5.89 keV for Fe-55. There are less intense emissions near these energies that will slightly skew the data; however, these energies are about an order of magnitude above the nearby emissions.

The three sources used allow for the system energy calibration where the MCA channels are mapped to photon energy levels. A spectrum of all three sources individually and combined was acquired for analysis. The spectra were taken for approximately 300 seconds, and the combined spectra was taken for 45 minutes, 15 minutes with each source.

The Co-57 source was used to test counting statistics. The timing single channel analyzer (TSCA) was used to select the full energy peak (FEP) of Co-57 at 14.4 keV.

The source was placed 9 cm from the detector to achieve a count rate of 3-8 counts in 5 seconds. 300 trials of 5 second collection times were taken. The source was adjusted to 1 cm distance to the detector and an additional 300 trials of 5 seconds was collected with the source at a 5 cm distance to produce approximately 125 counts per 5 seconds. An additional test of 10 100 s count times was collected. The background count rate was collected for each position for 10 trials.

# Results and Discussion

The sources were used to calibrate the energy of the MCA. The four data points were used to create a linear fit line, which has good fit with the data. Figure 1 shows the channel to energy calibration curve. The associated equation for the curve is:

Fig. 1. Energy Calibration Curve for P-10 Filled Gaseous Detector at AFIT. The equation to map channel to energy is 0.612\*Channel +0.9134 = Energy in keV.

Figures 2 though 4 show the spectrum for Co-57, Fe-55, and Cd-109. Various details are present in the spectrums. The FEP were used to map the channel to the energy for calibration. Higher energy gamma-rays, such as the 88 keV from Cd-109 were not present in the spectrum. The gaseous detector has low efficiency at higher incident energy.

Co-57 and Fe-55 show an X-ray escape peak. This escape peak is approximately 3 keV less than the FEP, which is expected for P-10 fill gas. There is no visible escape peak for Cd-109. It is likely hidden within the spread of the FEP.

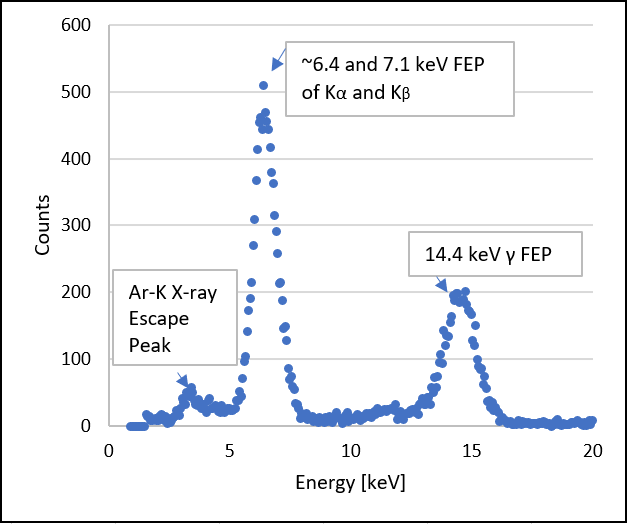


Fig. 2. Co-57 Spectrum Showing FEP and Escape Peak

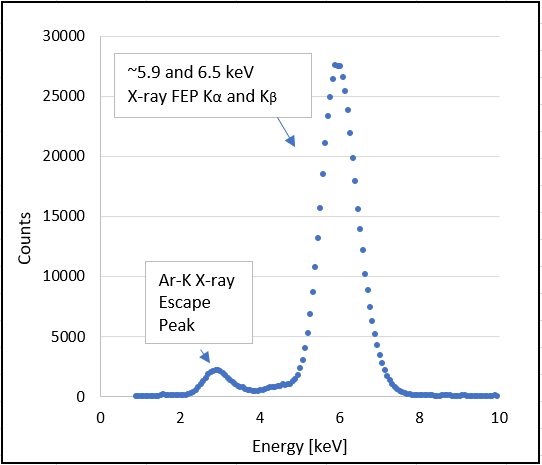


Fig. 3. Fe-55 Spectrum Showing FEP and Escape Peak

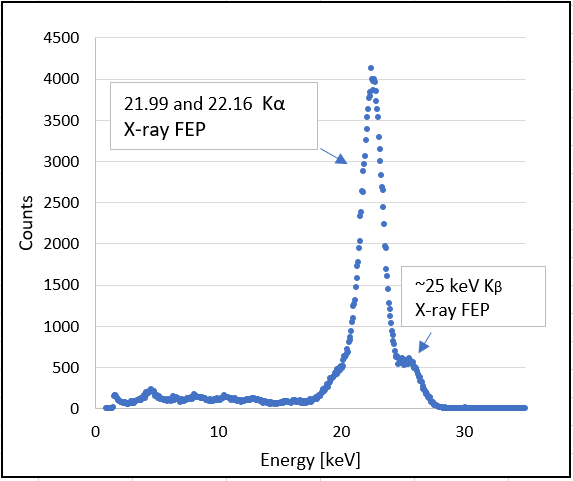


Fig. 4. Cd-109 Spectrum Showing FEP

The result for the three sources for 15 minutes each in one spectrum is shown in Figure 5. The large peak near 6 keV from Co-57 and Fe-55 combine to form a very large peak. Spectroscopy with this gaseous detector cannot differentiate between Co-57 and Fe-55 because of lower resolution. Cd-109 is individually identifiable. The escape peak is formed by a combination of Co-57 and Fe-55.

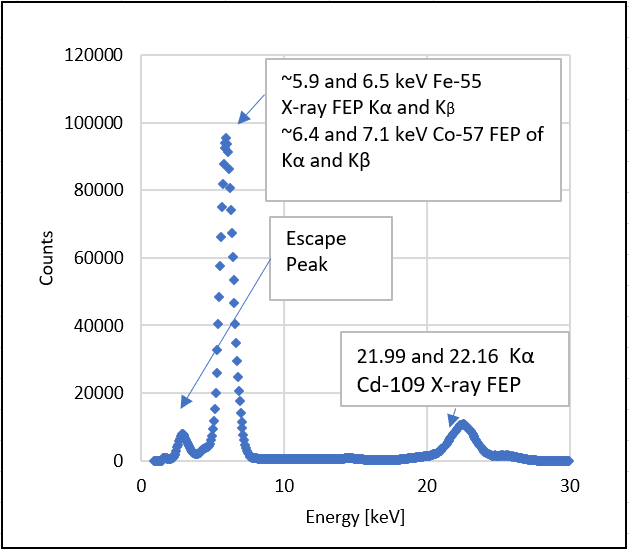


Fig. 5. Co-57, Fe-55, and Cd-109 Spectra. Each source was collected for 15 minutes to create the spectrum.

The Co-57 300 trial sample was fit to a Gaussian and Poisson distribution based on the frequency of events. A plot of the frequency distribution and the fits is shown in Figure 6.

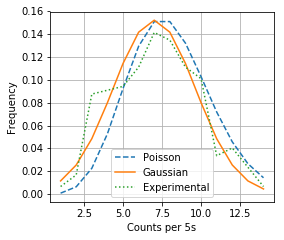


Fig. 6. Poisson and Gaussian Fits to Experimental Data.

The χ2 of the Poisson and Gaussian fit are 0.30 and 0.31, respectively. The Poisson distribution is a slightly better fit as the average count is below 20 [3]. After 20 counts, the Gaussian distribution becomes a better fit for radioactive frequency distributions. No data was thrown out as outliers from the Chauvenet test.

The gross, background, and net count rate are 28±0.53, 0.3±0.05, and 28±0.54 counts per second, respectively, for the first trial of the 100 second counting data for Co-57. The background count rate is significantly lower than the gross count rate, which minimizes error from background. The uncertainty in the background and gross count rate sum in quadrature to form the uncertainty in the net count rate.

The gross, background, and net count rate are 28±0.17, 0.27±0.02, and 28±0.17 counts per second, respectively, for the entire 10 trials of the 100 second counting data for Co-57. A ten-fold increase in counts theoretically should decrease the relative error by 1/. The relative error from uncertainty decreased by a factor of 0.314 with ten times more counts, which matches the theoretical number.

# References

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