Proportional Counters

MANE- 4370

Rensselaer Polytechnic Institute

Nuclear Engineering Laboratory

Group 4

Fall 2015 Semester

Group Member	Contribution
Michael Ishida	
others	

Abstract

Proportional counters utilize a gas chamber inside of an electric field to detect the products of the primary ionizing radiation (i.e. ions and freed electrons) with the gas. By varying the magnitude of the electric field by way of changing the applied voltage of the detector when examining a known source, detector efficiency at different Alpha and Beta particle energies can be determined along with the detector unit's Alpha and Beta crosstalk (counts incorrectly identified) values. A Protean counting system was utilized to examine Carbon 14, Strontium 90, Chlorine 36, Promethium 147, and Lead 210 samples. Energy dependencies for all measured values were observed. Alpha efficiencies of the detector ranged from 0% to 0.00162% +/- 0.000165% across the six observed samples. The Beta efficiencies varied by a much wider margin, between 6.16% +/- 0.292% to 44.81% +/- 4.97%. The alpha crosstalk values fell within the range of 21.47% 8847400%. Beta crosstalk was much smaller than the alpha crosstalk. The beta crosstalk values ranged from 0.00113% 465.8% for the Am-241 sample. Experimental uncertainty was determined to stem from the number of recorded alpha and beta counts, the provided initial activity of the sources, and the time between the initial measurement of the sources and the date of the experiment.

Commented [MI1]: Background of the lab – what is a proportional counter? What is the goal of the experiment? Determining the detector efficiency and crosstalk.

Commented [MI2]: Experiment methods – what experiments did we do and how did we perform them?

Commented [MI3]: Major experimental results. What are the results of the experiments, with what uncertainty?

Conclusions we can draw from the results = beta crosstalk was smaller than the alpha crosstalk.

Motivation

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Proportional counters can be used to determine the activity of sources emitting both alpha and beta radiation. By observing the alpha and beta plateaus as well as the counting efficiencies for both types of samples, proportional counter behavior can be better understood. This knowledge has practical application as proportional counters are commonly used in laboratories.

Theoretical Background

Commented [MI5]: Technical background needed to understand the experiments and results. How do proportional counters work?

Proportional counters utilize a gas chamber to detect radioactivity. When Alpha, Beta, and Gamma radiation interacts with the gas in the counter, ions are created in the gas. By subjecting the gas chamber to an electrical field, some of the resultant ions (and freed electrons) migrate to the anode and cathode of the detector (figure 1). By increasing this electric field (via increasing the applied voltage), the energy of the free traveling electrons can be grown high enough to cause additional ionization in the gas chamber, known as ion cascades (or Townsend avalanches).

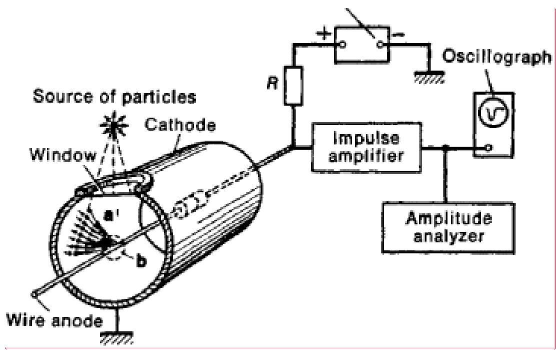

Figure 1: Simplified model of generic Proportional Counter [1]

Across a range of voltages, these detectors have several characteristic response regions (figure 2). The lowest voltage region, the recombination region, is characterized by an electric field that is not strong enough to prevent the initial ion pairs (produced from the direct interaction with radiation) from recombining. The ion saturation region, recombination of initial ion pairs occurs at an almost negligible rate. Only the initial ion pairs travel to the anode and cathode and contribute to the observed pulse; voltage changes in this region do not affect the amplitude of the collected pulse because the electrical field is not strong enough to induce an ion cascade. The third region, known as the proportional region, gas amplification (i.e. ion cascades) occur. In this region, the charge collected on the anode and cathode are proportional to the number of initial ion pairs. The limited proportional region the pulse amplitude is not directly proportional to the number of initial ion pairs, leading to observed non-linear changes in pulse heights. The Geiger-Mueller (GM) region is characterized by an electrical field that is strong enough to cause a large ion cascade cause a decrease in the electric field strength so that the ion cascade cannot continue. This weakening of the electric field is due to the very large number of positive ions created.

Commented [MI6]: Figure to explain the experimental setup. Note that all parts are labeled.

It is often much easier to understand the system using a labeled schematic rather than a labeled photo and does not always have to be drawn realistically or to scale. For example, in this figure we see a schematic similar to the device itself in conjunction with a block circuit diagram.

Note the caption and citation – always create a caption to adequately describe the figure and include a citation only for images you did not generate yourself.

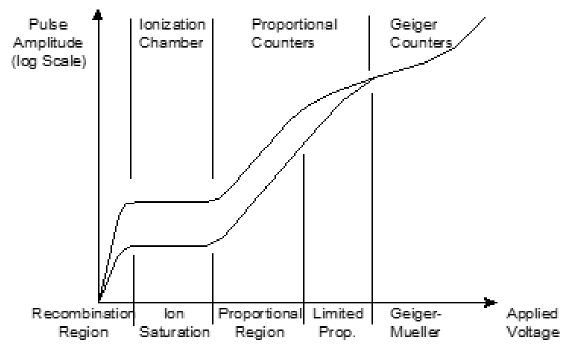

Figure 2: Pulse-height vs Voltage in a gas filled detector [2]

As has been established, charged particles that deposit energy into the gas chamber of proportional counters generate electrical signals; these detectors can be used to differentiate between alpha and beta particles based on the known common characteristics of the particles. This differentiation can only take place below the GM operational region. Because alpha particles are typically mono-energetic, the Differential Pulse Height Spectrum (DHPS) is a single, narrow peak. This DHPS peak translates to a plateau, due to the low penetrating power of the alpha particles and the relatively large dimensions of the detector's gas chamber. Conversely, beta particles have a wide range of energy distributions and a large penetrating range. These characteristics lead to a DHPS peak that is much wider (and have a smaller maximum amplitude) than observed for alpha particles and a secondary plateau that is shorter and has a greater slope that the alpha plateau (figure 3). These plateaus can be used to identify operating voltages for the proportional counter, as these plateaus show regions where observed count rates will be stable. In general, a detector will be set to operate in the beta plateau when counting a sample with a composition that is unknown. A pulse height discriminator (pulses above a specified threshold value are sorted as beta particles, those below the threshold are sorted as alpha particles) can be used to differentiate between alpha and beta radiation. Source contamination and the possibility of multiple interactions can breed crosstalk-some alpha particles counted as beta particles. This crosstalk can be eliminated by counting in the alpha plateau.

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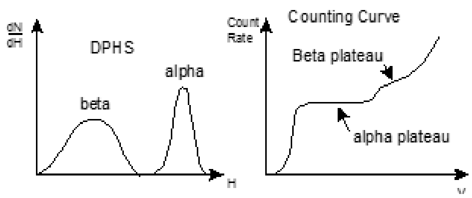

Figure 3: Curves for both alpha and beta particle. LEFT: Differential Pulse Height Spectrum (DHPS) RIGHT: Counting Curve. [2]

Additionally, activity of a source can be determined by equation 1 below.

$$A(t) = Ae^{-\lambda t} \quad (1)$$

Where *A(t)* is the activity of the source at time *t, A(0)* is the initial activity, and λ is the isotope's decay constant (where λ = ln(2)/(half-life of isotope)). The counting efficiency of the detector can be shown to be:

Efficiency = [(cpm - background)/dpm] x 100% (2)

Where counts per minute (cpm) come from the detector output and disintegrations per minute (dpm) are determined from the source (via Equation 1).

Experimental Procedure

This laboratory utilized the Protean counting system to make measurements and was operated by the console and computer monitor. To begin start up the sample changer track was occupied by a white plastic end plate and two carriers marked "Skip" on front. The samples were always loaded into the left-hand stack and the right-hand stack was never touched during the experiment. The mode on the console was set to PICNET mode with enabled communications.

For initial plateau generation, carriers 1 and 2 were loaded with Am-241 and Cl-36 and placed in the left=hand stack. The white plastic end plate was placed on top of the stack. To begin calibration, the "CAL" button was pressed and "Detector Voltage Determination" was selected. The count time was set to 30 seconds. The stack was advanced to acquire the data from the Am-241 source. When the data collection cycle was complete, the "PIC Communicator" program was opened on the desktop computer. The instrument address was set to "PIC 1"

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input, and the input type was set to "Plateau Data". The plateau data for Am-241 was saved to the computer desktop. The plateau generation procedure was repeated for the Cl-36 source.

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Next data was collected for beta counting efficiency. The previous stacking arrangement was reset and loaded with the following order of samples: Routine 7, Carrier 1 (Am-241), Carrier 2 (Blank), Carrier 3 (Pm-147), Carrier 4 (C-14), Carrier 27 (Sr-90), Carrier 17 (Pb-210). Then the white end plate was placed on top of the stack. Counting began by pressing the count button on the main screen of the Protean counting system console. The counting machine cycled through the entire stack and began counting the samples for 2 minutes each. The "Data Buffer" results were saved as output.

Data Analysis

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The values from the counts as a function of applied voltage were graphed in Figures 4 and 5. These figures show the alpha and beta plateau energies. For example, in Cl-36 the difference in between the different beta emissions are shown in the step structure of the spectrum. However, for Am-241 the two alpha energy emissions 5.486 and 5.44 MeV are impossible to distinguish, and therefore appears as a smooth curve.

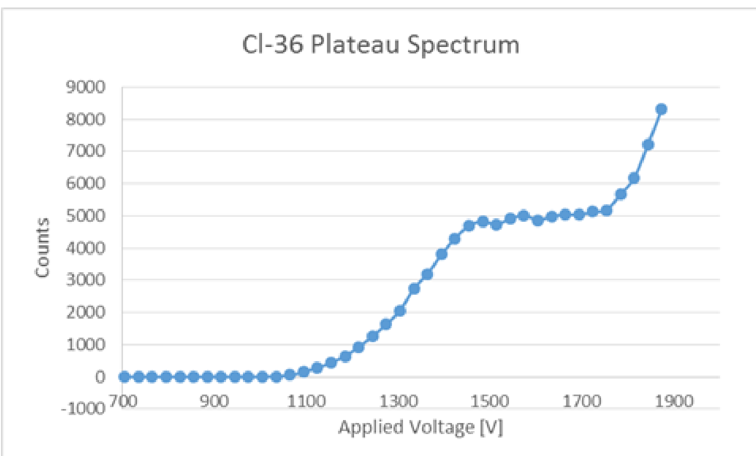

Figure 4: Cl-36 Plateau

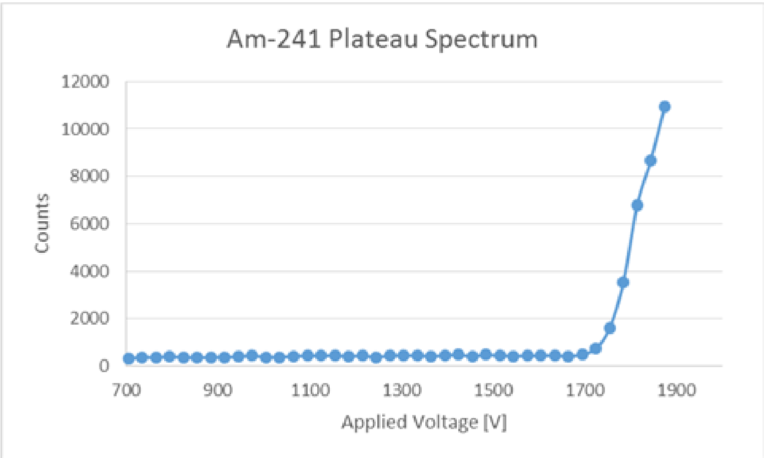

Figure 5: Am-241 Plateau

The output values of the alpha and beta counts from the Protean Counting System were used to generate the values for the alpha and beta efficiency for each sample as shown below in Table 1. The efficiency values were generated from equation 2.

$$\text{Efficiency} = [(\text{cpm} - \text{background})/\text{dpm}] \times 100\% \qquad (2)$$

Table 1: Alpha and Beta Efficiencies

Sample	Beta Efficiency %	Alpha Efficiency %
Carrier 3: Pm-147	6.15913	0
Carrier 4: C-14	12.8951	0.00014437
Carrier 16: Cl-36	44.8133	0.0029705
Carrier 17: Pb-210	9.8746	0
Carrier 27: Sr-90	37.1206	0.001621

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In this example, calculations for nuclear engineering require a high degree of precision.

The spillover of alpha counts registered wrongly as a beta count is known as “crosstalk”. This value was calculated for each sample by equation 3 and listed in Table 2. The value of beta crosstalk was also calculated for each source. For sources that there were no registered alpha counts the values for alpha crosstalk were not calculable. In Table 2, only the Am-241 source has a considerable crosstalk because the alpha and beta peak energies are so close to each other that it is harder to distinguish.

$$\boldsymbol{Alpha\ Crosstalk} = [\boldsymbol{beta\ counts/alpha\ counts}] \times \mathbf{100}\% \tag{3}$$

$$\boldsymbol{Beta\ Crosstalk} = [\boldsymbol{alpha\ counts/beta\ counts}] \times \mathbf{100}\% \tag{4}$$

Table 2: Alpha and Beta Crosstalk

Sample	Beta Crosstalk %	Alpha Crosstalk %
Carrier 1: Am-241	465.8486708	21.46619842
Carrier 4: C-14	0.001130276	8847400
Carrier 16: Cl-36	0.006584796	1518650
Carrier 27: Sr-90	0.004401796	2271800

Error Analysis

The sources of uncertainty in this lab are the alpha count, A, the beta count, B, the initial activity, and the time from the measurement of initial activity to the experiment. The uncertainty in A and B is the square root of said counts. These uncertainties can be found in table 3 below.

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HOWEVER, it is indeed important to discuss sources of uncertainty, relative magnitude of the sources, and how we might mitigate those sources if we (or someone else) were to do this experiment again in the future.

Table 3: Uncertainty in A and B

Carrier	Source	A	B	ΔA	ΔB
1	Am-241	2278	489	47.7284	22.1133
2	blank	0	50	0.0000	7.0711
3	Pm-147	0	1933	0.0000	43.9659
4	C-14	1	88474	1.0000	297.4458
16	Cl-36	2	30373	1.4142	174.2785
17	Pb-210	0	4388	0.0000	66.2420
27	Sr-90	1	22718	1.0000	150.7249

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The uncertainty in the initial activity is one half the smallest unit of measurement used, or .000005 uCi. Converting this to disintegrations per minute, the uncertainty in initial activity is 11.1 dpm. The uncertainty in time between the initial measurement of activity and the experiment is also one half the smallest unit of measurement, or 30 seconds.

The propagation of error equation is given by equation 5 below.

$$Error\ in\ f(x_1, x_2, \ldots, x_n) = \sqrt{\left(\frac{\partial f}{\partial x_1}\right)^2 (SE(x_1))^2 + \left(\frac{\partial f}{\partial x_2}\right)^2 (SE(x_2))^2 + \cdots + \left(\frac{\partial f}{\partial x_n}\right)^2 (SE(x_n))^2} \quad (5)$$

The count adjusted for background is found by subtracting the count by the count of the blank sample. Therefore, the equation for uncertainty in the count adjusted for background is:

$$\Delta A_{true} = \sqrt{\left(\frac{\partial}{\partial A}(A - A_B)\right)^2 \Delta A^2 + \left(\frac{\partial}{\partial A_B}(A - A_B)\right)^2 \Delta A_B{}^2}$$

and

$$\Delta B_{true} = \sqrt{\left(\frac{\partial}{\partial B}(B - B_B)\right)^2 \Delta B^2 + \left(\frac{\partial}{\partial B_B}(B - B_B)\right)^2 \Delta B_B{}^2}$$

or

$$\Delta A_{true} = \sqrt{\Delta A^2 + \Delta A_B{}^2}$$

and

$$\Delta B_{true} = \sqrt{\Delta B^2 + \Delta B_B{}^2}$$

The uncertainties in the true alpha and beta counts can be found in table 4 below.

Table 4: uncertainty in A and B adjusted for background

Carrier	Source	adjusted A	adjusted B	ΔA	ΔB
1	Am-241	2278	439	47.7284	23.21637
3	Pm-147	0	1883	0.0000	44.53089
4	C-14	1	88424	1.0000	297.5298
16	Cl-36	2	30323	1.4142	174.4219
17	Pb-210	0	4338	0.0000	66.61832
27	Sr-90	1	22668	1.0000	150.8907

To find the activity at the time of the experiment, equation 1 was used. As stated previously, the initial activity and time from measurement of initial activity to experiment both have associated uncertainties. Therefore, the equation for uncertainty in activity is given by:

$$\Delta A(t) = \sqrt{\left(\frac{\partial}{\partial A_0}\left(A_0 e^{-\lambda t}\right)\right)^2 \Delta A_0^{\,2} + \left(\frac{\partial}{\partial t}\left(A_0 e^{-\lambda t}\right)\right)^2 \Delta t^2}$$

or

$$\Delta A(t) = \sqrt{\left(e^{-\lambda t}\right)^2 \Delta A_0^{\,2} + \left(-\lambda A_0 e^{-\lambda t}\right)^2 \Delta t^2}$$

The uncertainties in activity found using this equation can be found in table 5 below.

Table 5: uncertainty in activity at time of experiment

Carrier	Source	A(0) [dpm]	t [min]	A(t) [dpm]	ΔA(t) [dpm]
3	Pm-147	23887.2	4236480.8	10190.722	4.7354654
4	C-14	228660	4236480.8	228570.84	11.0956717
16	Cl-36	22555.2	4236480.8	22555.033	11.0999176
17	Pb-210	21445.2	21045601	14643.513	7.57945797
27	Sr-90	22510.8	4236480.8	20355.258	10.0371096

To find the count rate, the count adjusted for background is divided by the experimental time, which is assumed to have no uncertainty. Therefore, the equation for uncertainty count rate is:

$$\Delta \mathrm{CR} = \sqrt{\left(\frac{\partial}{\partial C}\left(\frac{C}{t}\right)\right)^2 \Delta C^2}$$

or

$$\Delta \mathrm{CR} = \frac{\Delta C}{t}$$

The count time in this experiment was three minutes per sample. The uncertainty in count rates can be found in table 6 below.

Table 6: uncertainty in A and B count rates

Carrier	Source	A count rate [counts/min]	B count rate [counts/min]	ΔA count rate [counts/min]	ΔB count rate [counts/min]
3	Pm-147	0	627.6666667	0	14.84362939
4	C-14	0.333333333	29474.66667	0.333333333	99.17661015
16	Cl-36	0.666666667	10107.66667	0.471404521	58.1406341
17	Pb-210	0	1446	0	22.20610527
27	Sr-90	0.333333333	7556	0.333333333	50.2968963

The efficiency is found using equation 2. The uncertainty in the efficiency is given by:

$$\Delta\text{eff} = \sqrt{\left(\frac{\partial}{\partial\, CR}\left(\frac{CR}{A(t)}\right)\right)^2 \Delta CR^2 + \left(\frac{\partial}{\partial\, A(t)}\left(\frac{CR}{A(t)}\right)\right)^2 \Delta A(t)^2}$$

or

$$\Delta\text{eff} = \sqrt{\left(\frac{1}{A(t)}\right)^2 \Delta CR^2 + \left(-\frac{CR}{A(t)^2}\right)^2 \Delta A(t)^2}$$

The alpha and beta efficiencies can be found in table 7 below.

Table 7: uncertainty in efficiency in alpha and beta detection

Carrier	Source	eff A	Δeff A	eff B	Δeff B
3	Pm-147	0.00000E+00	0.00000E+00	6.15920	0.29167
4	C-14	1.45834E-04	1.62468E-05	12.89520	1.43081
16	Cl-36	2.95573E-03	3.28749E-04	44.81335	4.97425
17	Pb-210	0.00000E+00	0.00000E+00	9.87468	0.74845
27	Sr-90	1.63758E-03	1.65179E-04	37.12063	3.72584

The alpha crosstalk was found using equation 3, and the beta crosstalk was found using equation 4. So, the uncertainty in alpha crosstalk is given by:

$$\Delta\text{A crosstalk} = \sqrt{\left(\frac{\partial}{\partial A}\left(\frac{B}{A}\right)\right)^2 \Delta A^2 + \left(\frac{\partial}{\partial B}\left(\frac{\text{B}}{A}\right)\right)^2 \Delta B^2}$$

or

$$\Delta\text{A crosstalk} = \sqrt{\left(-\frac{B}{A^2}\right)^2 \Delta A^2 + \left(\frac{1}{A}\right)^2 \Delta B^2}$$

and the uncertainty in beta crosstalk is given by:

$$\Delta\text{B crosstalk} = \sqrt{\left(\frac{\partial}{\partial A}\left(\frac{A}{B}\right)\right)^2 \Delta A^2 + \left(\frac{\partial}{\partial B}\left(\frac{A}{B}\right)\right)^2 \Delta B^2}$$

or

$$\Delta\text{B crosstalk} = \sqrt{\left(\frac{1}{B}\right)^2 \Delta A^2 + \left(-\frac{A}{B^2}\right)^2 \Delta B^2}$$

The alpha and beta crosstalks can be found in table 8 below.

Table 8: alpha and beta crosstalks

Carrier	Source	alpha crosstalk	∆alpha crosstalk	beta crosstalk	∆beta crosstalk
1	Am-241	21.46619842	0.01069864	465.84867	0.23218
3	Pm-147	und	und	0	0.00000
4	C-14	8847400	88474.500	1.13028E-03	1.13028E-05
16	Cl-36	1518650	10738.831	6.58480E-03	4.65631E-05
17	Pb-210	und	und	0	0.00000
27	Sr-90	2271800	22718.500	4.40180E-03	4.40189E-05

Results and Discussion

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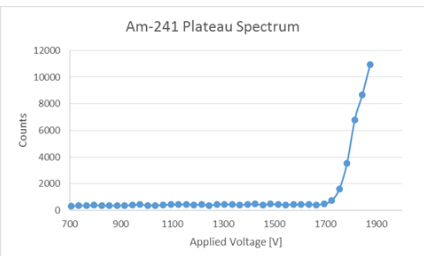
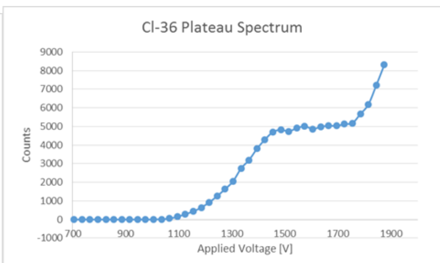
The initial plateaus generated in the first part of the experiment are as expected - the Am-241 results indicate only alpha radiation emitted while the Cl-36 results show an extra plateau because it is a beta emitter.





The calculated alpha efficiencies are very low, none more than 0.01%. The calculated beta efficiencies are much higher, with none less than 6%. When compared to the beta max energies, no clear trend appears. These values are depicted in the following table:

Table 9: Beta Max Energies

Sample	**Beta %**	**Beta Max [MeV]**
C-14	12.89	0.157
Sr-90	37.12	2.28
Cl-36	44.81	0.709
Pm-147	6.16	0.224
Pb-210	9.87	1.162

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These are displayed in the following Figure 6.

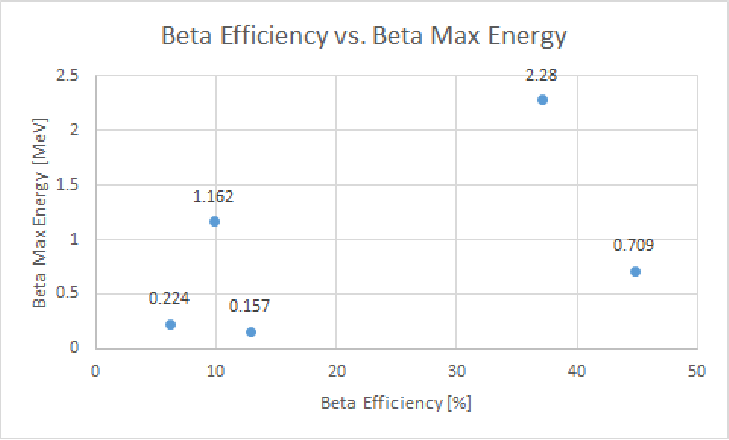

Figure 6: Beta efficiency vs. Beta max energy

The Protean Alpha/Beta Counter operates primarily in the plateau range, where gas amplification occurs; the gas multiplication is linear, so the charge collected is proportional to the number of ion pairs created by the incident radiation and the detector readings show a plateau from beta radiation and a plateau from alpha radiation. Below this region, all ions formed by the radiation interaction are already collected, which prevents any gas multiplication caused by the applied voltage field. Above this region, the multiplication is nonlinear and the charge collected is no longer proportional to the number of ion pairs created, which makes it more difficult to differentiate between counts of alpha and beta radiation. Operating within plateau region allows the use of a pulse height discriminator to distinguish between alpha and beta radiation detected and ensures that the count rates will be stable.

A proportional counter can be very useful in the field of radiation protection. A counter like the Protean Alpha/Beta Counter used in this lab is not portable and would not be taken out of a lab setting, but it could be used to be to measure the alpha and beta emissions of a something like a soil sample. It is important to be able to determine the radioactivity of soil before beginning construction to protect the health of people who will be working or living on that property. The counter can analyze the samples to determine the radiation emitted and to determine whether additional measures are needed to eliminate the radiation sources.

The sources of error in this lab are the error in counts measured, the error in the initial activity, and the error in the time between the activity measurement and the experiment. The error in the

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counts accounts for the probabilistic nature of the counts detected and corresponds to the standard deviation of the sample. There also some error in the activity of the samples measured by the lab staff and since the activity is used in calculations, the error in the activity will propagate to other values as well. There is also some error in the time between the activity measurement and the running of the experiment, which affects the calculations less than the other sources of error.

Conclusions

This experiment examined the use of a Protean Alpha/Beta proportional counter, which uses gas amplification in the proportional region to count and distinguish alpha and beta radiation. After first examining the Am-241 alpha source and the Cl-36 beta source to generate the plateaus, those two samples and four other samples were analyzed in this experiment and measurements of the alpha and beta radiation were taken. The alpha efficiencies found for the six different sources ranged from 0% for the Pm-147 and the Pb-210 samples to 0.00162% +/- 0.000165% for the Sr-90 sample. The beta efficiencies found for the six different sources ranged from 6.16% +/- 0.292% for the Pm-147 sample to 44.81% +/- 4.97% for the Cl-36. The alpha crosstalk values ranged from 21.47 for the Am-241 sample to 8847400% for the C-14 sample; the beta crosstalk values ranged from 0.00113 for the C-14 sample to 465.8% for the Am-241 sample. Sources of error in these experiments include the error in the counts detected, error in the calculated source activity, and error in the time between the activity measurement and the experiment, and these sources of error are included in the reported error values.

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References

[1] *7 Best Radiation Detection and Measuring Devices*. Get top tens.com. Accessed November 8th, 2015. http://gettoptens.com/wp-content/uploads/2013/05/Proportional-Counter.png

[2] *Nuclear Engineering Laboratory Manual 2015*. Rensselaer Polytechnic Institute, 2015

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