Neutron Counting

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Contents

1 Abstract

Throughout the course of this lab, neutrons were counted using two different detectors: the BF_3 tube and the boron-lined tube. Using the BF_3 tube, a differential pulse height spectrum with distinct features was able to be obtained. Using a cadmium sleeve, it could be seen that the paraffin moderator thermalized the neutrons by observing the cadmium ratio drop from 117.889 to 4.805 when the neutron source was removed from the paraffin. Using the boron-lined tube, a differential pulse height spectrum was obtained, but it lacked the definition of the BF_3 tube. The relative counting efficiencies of the two detectors was compared; the boron-lined tube was 2.3653 times more efficient than the BF_3 tube.

2 Introduction & Objectives

In order to detect neutrons, it is important to get them to interact with other particles because neutrons are neutral and do not have charge that a detector can pick up. The easiest way to do this is to moderate neutrons into thermal neutrons. After being thermalized, the neutrons would interact with boron, producing an α-particle and a lithium ion. These charged particles could easily be detected by the proportional gas in the detectors. The ability to detect neutrons accurately is extremely important due to the effects that neutrons have on materials. When neutrons are deposited into a material, that material often becomes radioactive.

3 Equipment List

The following equipment was used in the laboratory:

- Ortec 4001 A bin Power Supply
- Ortec 994 Dual Counter / Timer
- Ortec 551 Timing SCA
- Ortec 572 Amplifier
- Dell OptiPlex GX100 running Maestro
- RG58u Polyethylene Coaxial Cable

4 Setup & Settings

For the entirety of this experiment, the equipment was in the setup that is shown in Figure 4.1.

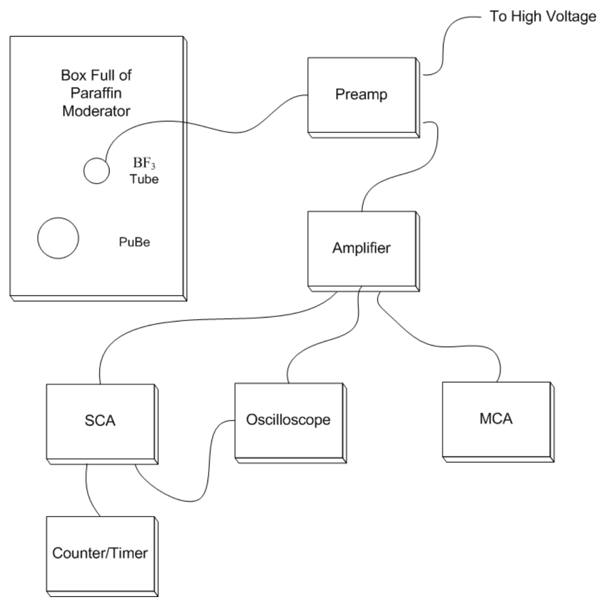

Figure 4.1: The equipment diagram for the neutron counting experiment.

The settings that were dialed in the equipment that was described in Section 3 were as follows:

Ortec 551 Timing SCA

- Int Mode
- ULD = 3.2
- POS OUT
- Delay = 0

Ortec 572 Amplifier

- Fine Gain = 1.0
- Coarse Gain = 100
- Shaping Time = 0.5 [μs]
- POS OUT
- Unipolar

4.0.1 Experiment Part 1

The ^{239}Pu-Be source[1] is first placed in the paraffin moderator. The detection tube, the BF^3 tube, was then inserted into the paraffin moderator via the access hole. The count rates and pulse heights for every 100 [V] were recorded. From this data, the counting curve was plotted and a usable operating voltage was chosen. Using the MCA, the differential pulse height spectrum was then recorded.

Next, a 10 [μCi] gamma source was placed on top of the paraffin near the tube and the effects on the system were observed and recorded. The gamma source was removed and the cadmium sleeve was placed over the tube. Count rates both with and without the cadmium sleeve were made. After doing this, the neutron source and the tube were removed from the paraffin and placed on the lab bench at a distance that was approximated the same as the distance they were separated by in the paraffin. Maintaining a constant operating voltage and that same separation distance from the paraffin box, the differential pulse height spectrum was recorded. Count rates were again measured with and without the cadmium sleeve.

Next, the tube was placed on top of the paraffin box in a position that is shown in Figure 4.2. The neutron source was returned to the paraffin. The count rate was measured.

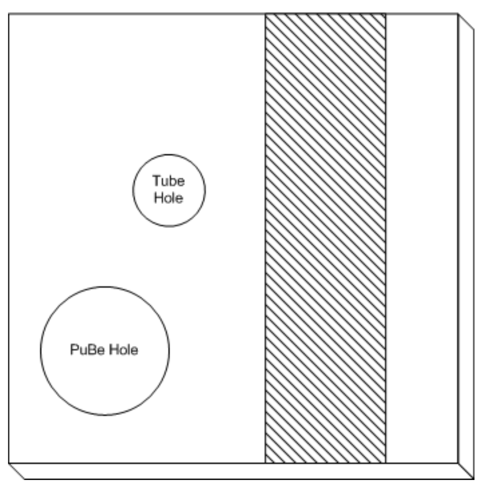

Figure 4.2: A diagram of the paraffin box. The shaded region represents the area that the tube was placed each time such that the solid angle was preserved between measurements.

The tube was then returned to the paraffin box. The operating voltage was reduced to 100 [V] and a counting curve was recorded.

[1] See Appendix A for more information about this source.

4.0.2 Experiment Part 2

The boron-lined tube was placed in the same reproducible geometry from part one (see Figure 4.2). From this geometry, a counting curve was obtained. A single count rate was taken at an operating voltage of 250 [V].

5 Data & Analysis

5.0.3 Experiment Part 1

Table 1 is the data that was collected in the lab for the BF_3 tube counting curve.

High Voltage [V]	Counts	Count Rate [s^{-1}]	Pulse Height [mV]
0	0	0	0
100	49886	831.433	437.5±15
200	103996	1733.27	550±15
300	136613	2276.88	625±15
400	158563	2642.72	703±15
500	172081	2868.02	750±15
600	174148	2902.47	821.5±15
700	176496	2941.60	890.6±15
800	177658	2960.97	984.4±15
900	177754	2962.57	1156±15
1000	178336	2972.27	1391±15
1100	179087	2984.78	1766±15
1200	179341	2989.02	2250±15
1300	178988	2983.13	325±15
1400	178635	2977.25	4750±15

Table 1: BF_3 tube counting curve measurements. All counts were taken over a counting period of 60 [s].

Using this data from the lab, a counting curve plot could be produced. Figure 5.1 shows the count rate of the BF_3 tube versus applied voltage.

After observing the plateau of the counting curve, an operating voltage of 800 [V] was chosen. At this voltage, the differential pulse height spectrum was obtained using the MCA. Figure 5.2 shows this spectrum with all it's features identified.

There are five regions of interest in Figure 5.2: The peak all the way on the left, the two plateaus in the middle of the spectrum, and the two peaks on the far right of the spectrum. The peak on the left of the spectrum represent electronic noise and low level gamma-rays. Most of these gamma-rays

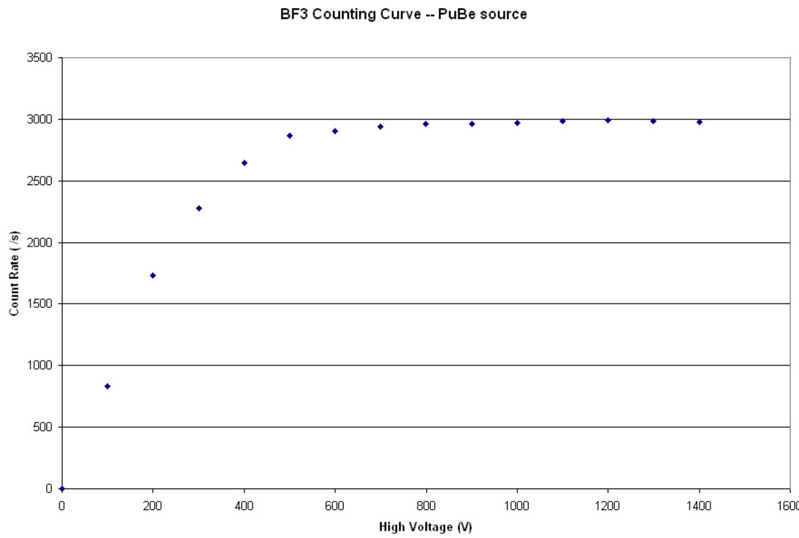

Figure 5.1: The counting curve for the BF_3 tube.

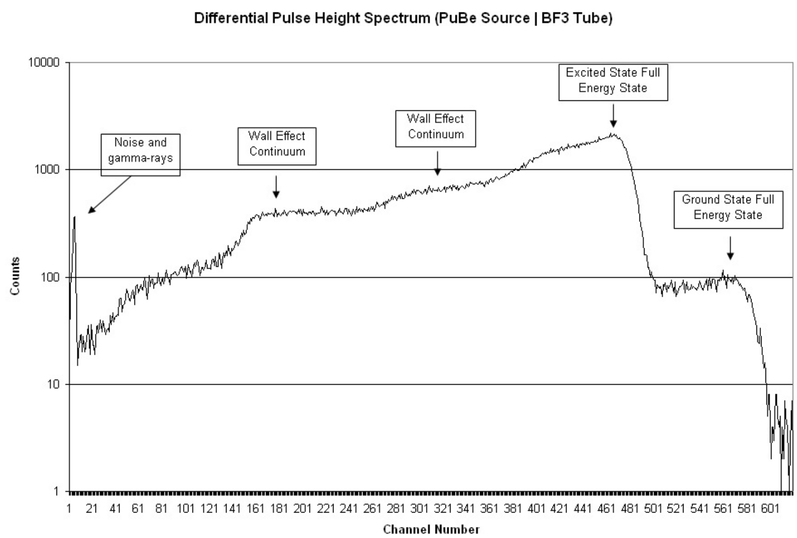

Figure 5.2: The differential pulse height spectrum for the BF_3 tube.

interact with the wall.

The two plateaus in the middle of the spectrum are a direct result of wall interactions. The reaction that the neutron undergoes in the gas is B(n,α)Li. Because of the energetics of this reaction (the neutrons are thermal neutrons), the α-particle and the lithium ion are ejected anti-parallel to each other. Because of this, one particle is ejected toward the center of the gas where it is likely to deposit its energy. The other particle is ejected toward the wall. If the particle interacts with the wall, it cannot deposit its energy into the system. The output pulse will be smaller than expected by a static amount because of this wall interaction. Both particles have an equal probability of being ejected towards the wall, and thus there are two different wall effect continuum that are produced. The continuum on the left represents the range of energies that is created by the Li nucleus (the less energetic of the two particles) depositing its energy within the detector. The right part of the continuum is the superposition of the lithium ion continuum and the range of energies produced by the α-particle interacting with the wall. The result of this superposition are the plateaus that are visible in Figure 5.2.

The last two peaks on the right of Figure 5.2 are the full energy peaks. There are two peaks because the thermal neutrons in reaction that occurs in the proportional gas create two different types of Li nuclei: one in the ground state and one in the first excited state. Due to this, it is obvious that two different peaks would appear on the spectrum. The branching ratio for thermal neutrons is such that about 6% of the reactions lead to the ground state and 94% to the first excited state. Therefore, the ratio of the areas under the excited full energy peak and the ground state full energy peak is 94:6.

By observing the ratio of peaks between the excited and ground state peaks of the measurements made in the lab, a ratio of 95:5 is observed. This value agrees very well with literature values.

Next, a 10 [μCi] source (Cd^{109}) was placed on top of the paraffin box next to the tube. Another spectrum measurement was made via the MCA but no marked difference in the spectrum was noted. This is exactly as expected. The low level gamma energies would do nothing but contribute to the noise peak at the beginning of the spectrum.

Using the cadmium sleeve that was provided, measurements were made and placed in Table 2.

Shielding	Voltage [V]	Count	Count Rate [s^{-1}]
None	800	177658	2960.97
Cadmium Sleeve	800	1507	25.1167

Table 2: BF_3 tube counting curve measurements with different shielding methods with a moderator. All counts were taken over a counting period of 60 [s].

The cadmium ratio, the ratio of the unshielded count rate to that with the cadmium cover has a value of 117.889. The cadmium ratio is an indication of the degree to which a given neutron field has been thermalized. The unshielded count rate includes both thermal and resonance neutrons, while the count rate with the sleeve consists of only the resonance contribution. The ratio measured in lab implies a good level of thermalization in the neutrons emitted from the source.

After removing the PuBe source from the paraffin and placing it on the lab bench at the same distance apart that they were inside the moderator, more cadmium ratio measurements were made.

Table 3 shows these measurements.

Count Rate Without Cadmium Shield	Count Rate With Cadmium Shield
27.067 [s^{-1}]	5.633 [s^{-1}]

Table 3: BF_3 tube counting curve measurements with different shielding methods without a moderator. All counts were taken over a counting period of 60 [s] at 800[V].

From the data in Table 3, the cadmium ratio is measured to be 4.805. We can see a marked decrease in this number. This decrease corresponds directly to the decrease in thermal neutrons due to the source being without a moderator. Due to the fact that the neutrons were not thermalized, no differential pulse height spectrum was obtained because the detector couldn't get a decent read on the source at all.

After laying the tube on top of the paraffin, as is seen in Figure 4.2, the neutron source was returned to the moderator and a count rate of 122.383 [s^{-1}] was measured at a voltage of 800 [V].

The differential pulse height spectrum was then measured with the tube voltage at 700 [V] and again at 900 [V]. These spectra are in Appendix B and Appendix C, respectively.

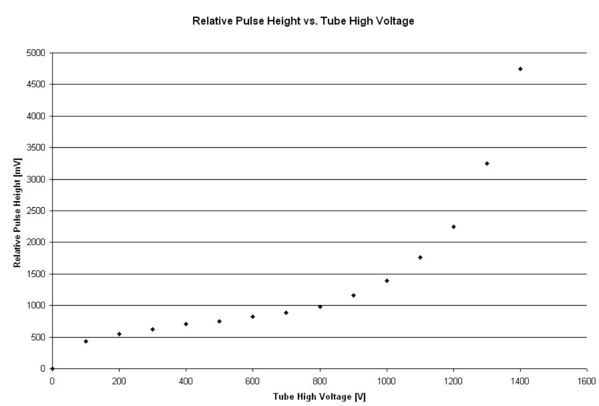

Figure 5.3: Relative Pulse Height vs. Tube High Voltage

Figure 5.3 shows the relative pulse height plotted against the tube high voltage. From this plot it can be observed that for the lower regions of voltages, the pulse heights increase linearly with voltage. At 700 [V] the pulse heights are no longer linear and start to grow exponentially as applied voltage is increased. From this plot, it can be inferred that it is best to operate the BF_3 counter within this linear region.

Figure 5.4 shows the count rates of the features identified on the three differential pulse height spectra that were captured in the lab[2]. The count rates were used instead of the energies because

[2]The numbers for these plots are listed in Appendix D.

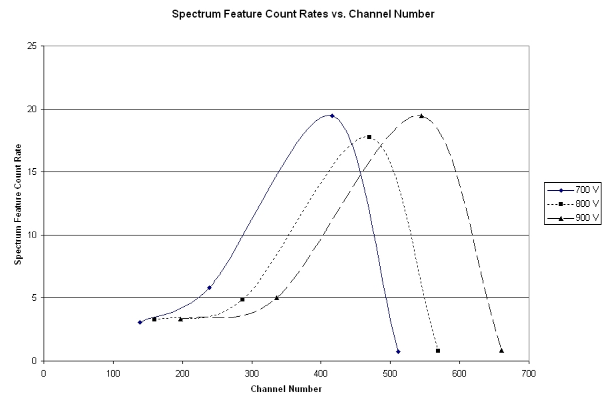

Figure 5.4: Spectrum Feature Count Rates vs. Channel Number

all the spectra were not measured over the same time period. From Figure 5.4 it can be seen that the tube is truly proportional at the operating voltage. As operating voltage is increased, the features and energies merely shift to the right, signifying a shift to higher channel numbers. The count rates of the features at differing voltages are within reasonable error of each other.

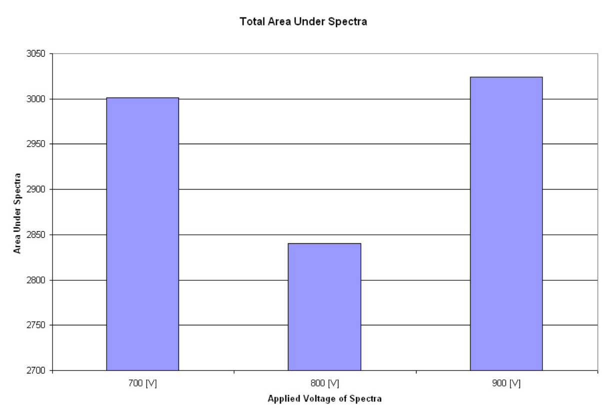

Figure 5.5: Area Under the Spectrum (Total Count Rates) For All Cases.

Figure 5.5 shows the total area (in count rates) under each spectrum. Again, count rates were used because the spectrum measurements were all taken over different time periods. From this graph, nothing conclusive can be drawn. It appears that the data for the 800 [V] is a statistical outlier. It is expected that the total area will remain relatively constant within the linear region of operating voltages and then will increase much more rapidly in the exponential region of operating voltages. More data would need to be taken in the lab to verify the response predicted by the literature.

5.0.4 Experiment Part 2

Figure 5.6 is the counting curve for the Boron-Lined tube[3].

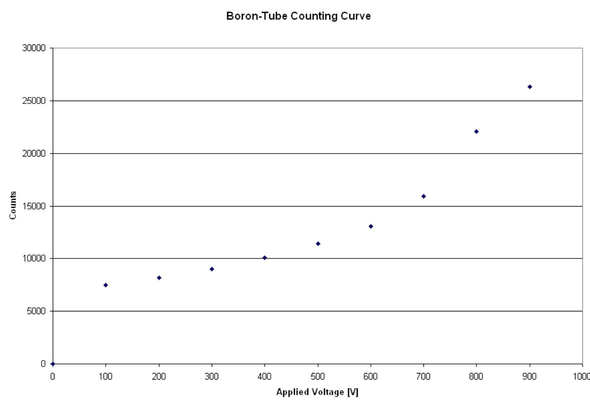

Figure 5.6: Counting Curve for the Boron-Lined Tube.

It should be noted that there is no plateau on this counting curve. The reason for this is that there are no full energy peaks that appear in the differential pulse height spectrum.

From this counting curve, it was decided that 250 [V] was the optimal operating voltage. At this voltage, the boron-lined tube had a count rate of 289.467 [s^{-1}]. A count rate of 122.383 [s^{-1}] was measured at a voltage of 800 [V] with the BF_3 Tube. It can be seen that the count rate for the boron-lined tube is over twice the magnitude than the count rate of the BF_3 tube. By dividing these count rates we can see the relative counting efficiencies of these detectors. Dividing the boron-lined tube count rate by the BF_3 count rate gives a value of 2.3653. This means that the boron-lined tube is 2.3653 times more efficient of a detector than the BF_3 tube. The down side to using this more efficient detector is that there is no plateau on the counting curve and that its gamma-ray discrimination ability is inferior to that of the BF_3 tube.

The tube was placed on top of the paraffin box as shown in Figure 4.2. At the optimal operating voltage, a differential pulse height spectrum was obtained.

Figure 5.7 is the measured spectrum. The boron-lined tube utilizes the same reaction that the BF_3 tube does. Because this reaction occurs in the wall, only one of the emitted particles deposits its energy in the proportional gas. Each particle has a distinct energy that is less than its maximum kinetic energy. Due to this fact, no full energy peak (for the excited or ground state) will appear on the spectrum. The ideal pulse height spectrum for this system would be the superposition of energy continuum for these two particles and would like a stair step going down from left to right. Unfortunately, particles can enter the tube with any amount of non-zero energy. The result of this

[3]The raw data for this experiment can be found in Appendix E.

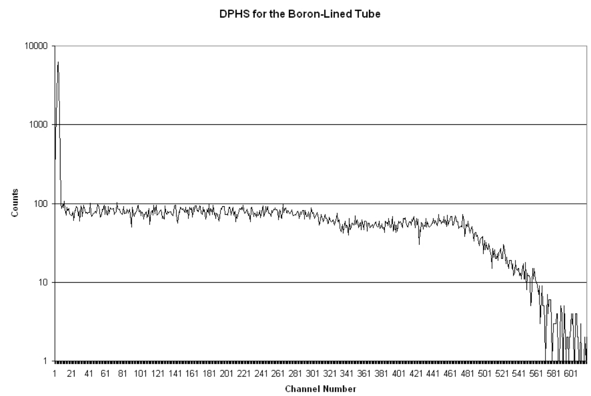

Figure 5.7: Differential Pulse Height Spectrum for the Boron-Lined Tube.

can be seen in Figure 5.7. The spectrum is fairly constant in height until it reaches the alpha particle maximum kinetic energy point, where the plot then drops to zero counts. This result is just as the literature predicts.

6 Conclusions

Throughout the course this lab, neutrons were thermalized and detected using two different counters: the BF_3 tube and the boron-lined tube. The boron-tube, though over twice as efficient as the BF_3 tube, lacked the discrimination between energies that the BF_3 tube has. The BF_3 tube produces excellent differential pulse height spectra, but at the cost of efficiency. This proves, once again, that there is no one detector that should always be used and that the choice of detector for a situation depends entirely on what type of information is desired from the detector. In all, the results from the lab were in agreement with the theory and the literature.

Appendices

Appendix A Neutron Source

The source for this lab was a ^{239}Pu-Be alloy that contains one Curie of ^{239}Pu. The alpha particles produced in its decay react with beryllium nuclei to form neutrons by the following reaction : ^{9}Be(α,n)^{12}C

These netrons are formed with a spread of kinetic energies ranging up to about 10 [MeV]. The detection reaction cross sections are large, however, only for neutron energies below about 1 [keV]. Consequently, a paraffin block is used to moderate and partially thermalize the neutrons to decrease their average kinetic energy.

Appendix B Differential Pulse Height Spectrum at 700 [V]

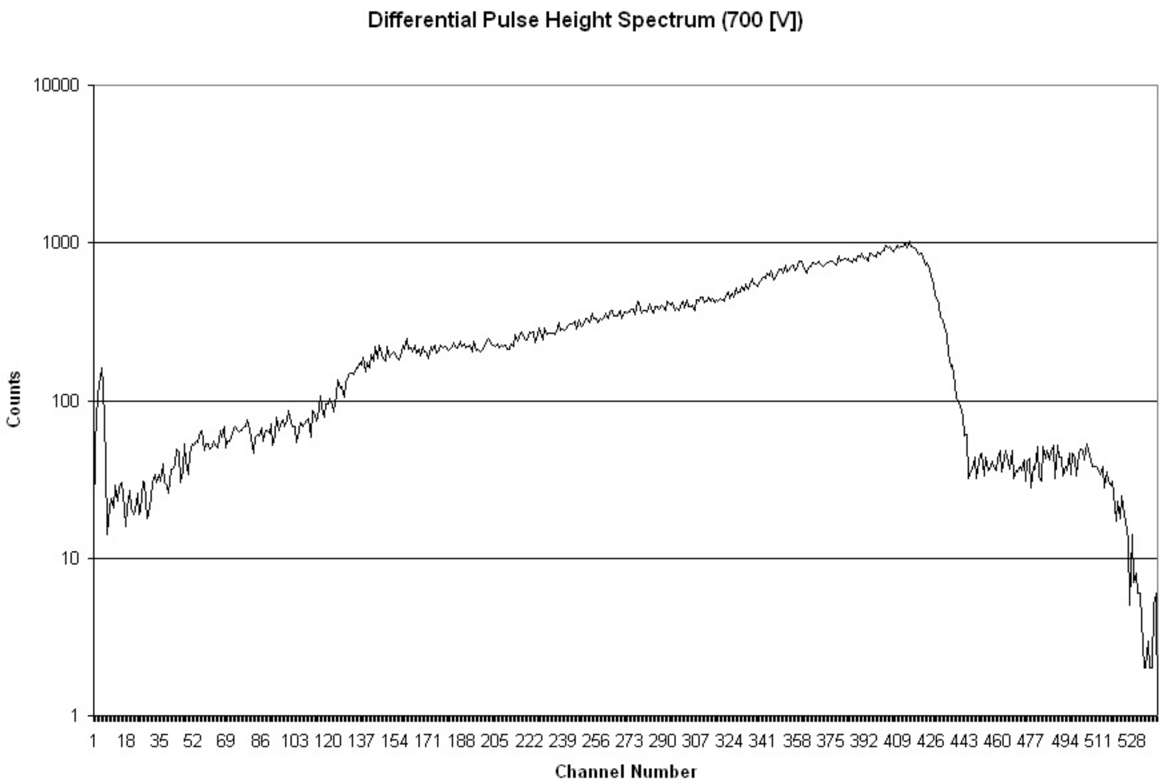

Figure B.1: The Differential Pulse Height Spectrum of the BF_3 Tube at 700 [V].

Appendix C Differential Pulse Height Spectrum at 900 [V]

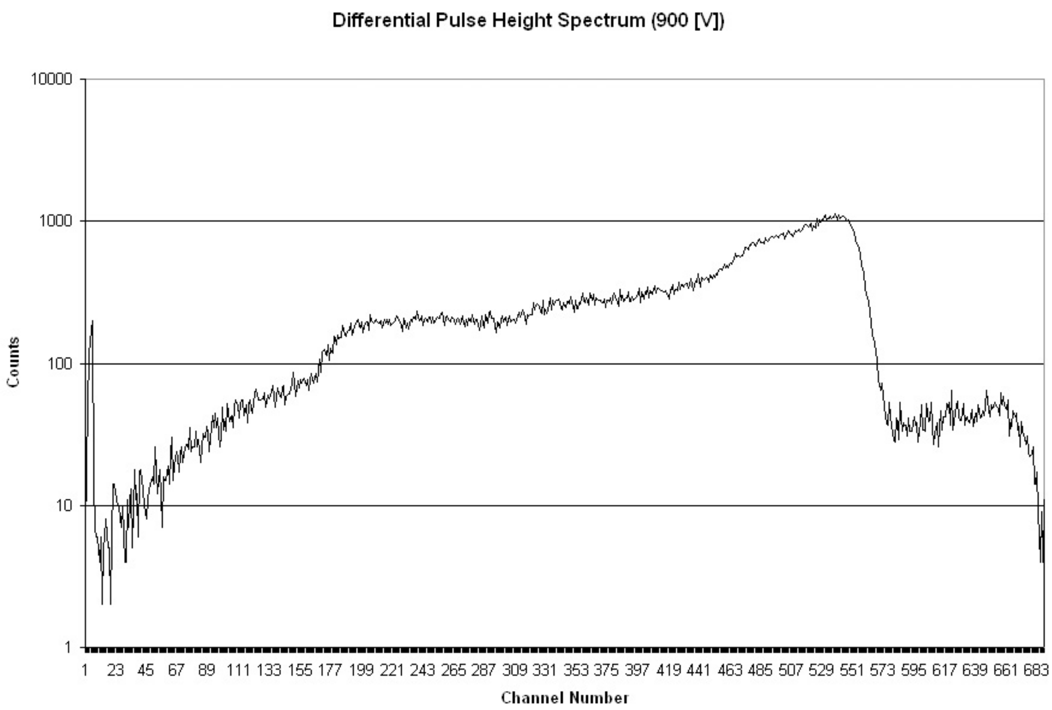

Figure C.1: The Differential Pulse Height Spectrum of the BF_3 Tube at 900 [V].

Appendix D Feature Information from Figure 5.4

Event	Channel	Peak (Counts)	Peak (Count Rate)
700 [V]			
α Loss	139	151	3.082
Li Loss	239	285	5.816
Excited Peak	416	952	19.429
Ground Peak	511	36	0.735
700 [V]			
α Loss	160	363	3.300
Li Loss	287	537	4.882
Excited Peak	470	1952	17.745
Ground Peak	569	87	0.791
700 [V]			
α Loss	197	183	3.327
Li Loss	336	276	5.018
Excited Peak	545	1069	19.436
Ground Peak	661	47	0.855

Table 4: Feature Data for the BF_3 Tube.

Appendix E Experiment 2 Raw Data

Using the PuBe source with a timing interval of 30 [s], the following data was obtained:

High Voltage [V]	Counts	Count Rate [s^{-1}]
0	0	0
100	7474	249.13
200	8199	273.30
300	8985	299.5
400	10090	336.33
500	11447	381.57
600	13088	436.27
700	15909	530.30
800	22096	736.53
900	26317	877.23

Table 5: Counting Curve Data for the Boron-Lined Tube.

References

[1] Glenn F. Knoll, Radiation Detection and Measurement. John Wiley & Sons, Inc., USA, 3rd Edition, 2000.

[2] Knolls Atomic Power Laboratory, Nuclides and Isotopes: Chart of the Nuclides. Lockheed Martin, USA, 16th Edition, 2002.

[3] Bernard Shleien, Lester A. Slaback, Brian Kent Birky, Ed., Handbook of Health Physics and Radiological Health. Williams & Wilkins, Baltimore MD, 3rd Edition, 1998.