NE 5742 Nuclear Radiations and Their Measurements

Lab 2 Report

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I. Introduction

The purpose of this lab was to familiarize students with a BF_3 proportional gas-filled counter, and to identify features of the detector's pulse amplitude spectrum that can be related to the physics of the overall detection process. This was accomplished through two related experiments; the first experiment sought to determine the operating voltage for the counter by taking a bias curve spectrum, and the second used the detector to obtain neutron counts and explore counting statistics.

II. Theory

Neutrons are conventionally detected with the use of a converter to generate measurable ion-pairs. For this particular experiment, the neutron interaction with Boron-10 in BF_3 was the source of such ions. The neutron detector used was a proportional counter, so called because incident ion-pairs cause secondary ionizations and so the output energy is equal to the input energy multiplied by a factor M. This process of charge multiplication is referred to as the Townsend avalanche, and is most pronounced near the detector anode (usually a thin wire). As the electrical field intensity drops rapidly even short distances from the anode most ionization in the detector occurs only in the path of incident particles. Proportionality is assured by using detectors where discrete Townsend avalanches are produced for every ionizing event, but this can only be done for a certain range of voltages applied. Additionally, each detector type has a certain voltage at which count-rates are most accurate, the bias voltage to be determined in this experiment.

The second section of the experiment is contingent on the fact that nuclear radiation is produced by the random process of radioactive decay, and therefore the laws of probabilities and statistical distributions apply to radiation counting data. Poisson's, Gauss's, and the Binomial laws are those this experiment was concerned with.

III.Experimental Setup

The instrumentation used is shown in Table 1 on the following page, and was set up according to Figure 1. The linear amplifier controls were set as follows: Coarse Gain 30, Fine Gain 4.16, Shaping 4 μsec, and Input Polarity +. The counter probe was placed inside the source shielding cylinder, and the computer and UCS-30 MCA were booted. The MCA software was set as follows: Live TIme 10 seconds, Region of Interest Start 5 and Stop 256, Vertical Axis Spacing Linear. The HVPS/Amplifier/ADC was set as such: Discriminator Low Channel 0, Discriminator High Channel 255, ADC Mode Direct In, ADC Conversion Gain to 256 Channels, High Voltage Off, Input Polarity Positive. After the equipment settings were all confirmed the external high voltage supply was set in 100-volt increments from 1200 to 2100 volts, with count rates and counts per 10 seconds determined for each voltage.

Table 1: Lab Instrumentation

Wood Counter Lab, Inc. Model G-10-5 BF3 proportional neutron detector
Tennelec Model TC 175 Preamplifier
Spectrum Techniques UCS-30 Pulse Spectrum Analyzer
Canberra 3002D High Voltage Power Supply
Canberra 2022 Linear Amplifier
Oscilloscope
550 mCi AmBe source, in polyethylene shield
Ortec 419 Precision Pulse Generator
Ortec 4006 Minibin and Power Supply
Toshiba Satellite Laptop (with UCS-30 DAC software)

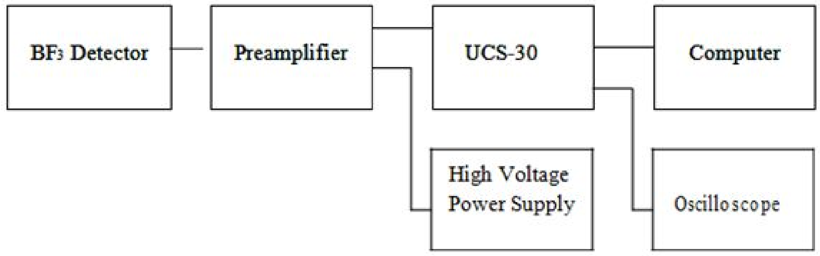

Figure 1: Detector Channel Setup Guide

For the second stage of this experiment, the detector channel was set for multichannel scaling (MCS), the UCS-30 operating mode to MCS-Internal, and the Dwell Time to 1 second. 100 one-second observations were recorded at a count rate of 500 cps, then another 100 were recorded at a rate of 10 cps. These measurements were graphed in histograms, to be compared to the Poisson and Gaussian distributions. A computer program was then written to simulate 500 coin tosses and record the number of heads, and to repeat this process 100 times. The results from the coin toss program were then compared to the binomial and Gaussian distributions.

IV. Results and Analysis

In order to determine the BF_3 detector bias voltage, counts were recorded for 10 seconds for voltages ranging from 1200 to 2100 V. Below is a figure graphing the results.

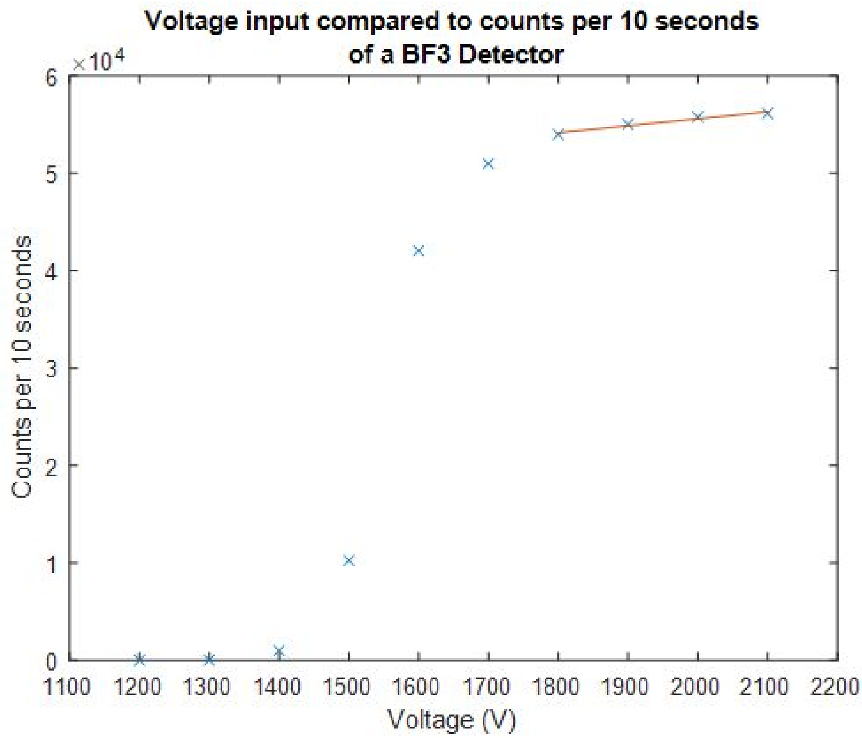

Figure 2: Comparing count rate to input voltage for determining bias voltage.

From the figure, it can be seen that the detector begins to level out its count rate at 1800 V. A linear best fit is shown between 1800 and 2100 V. The detector should be operated at the midpoint voltage of this line, corresponding to 1950 V.

Next, the energy spectrum was observed with a bias voltage of 2100 V and count time of 300 seconds. The results are shown in Figure 3 on the following page.

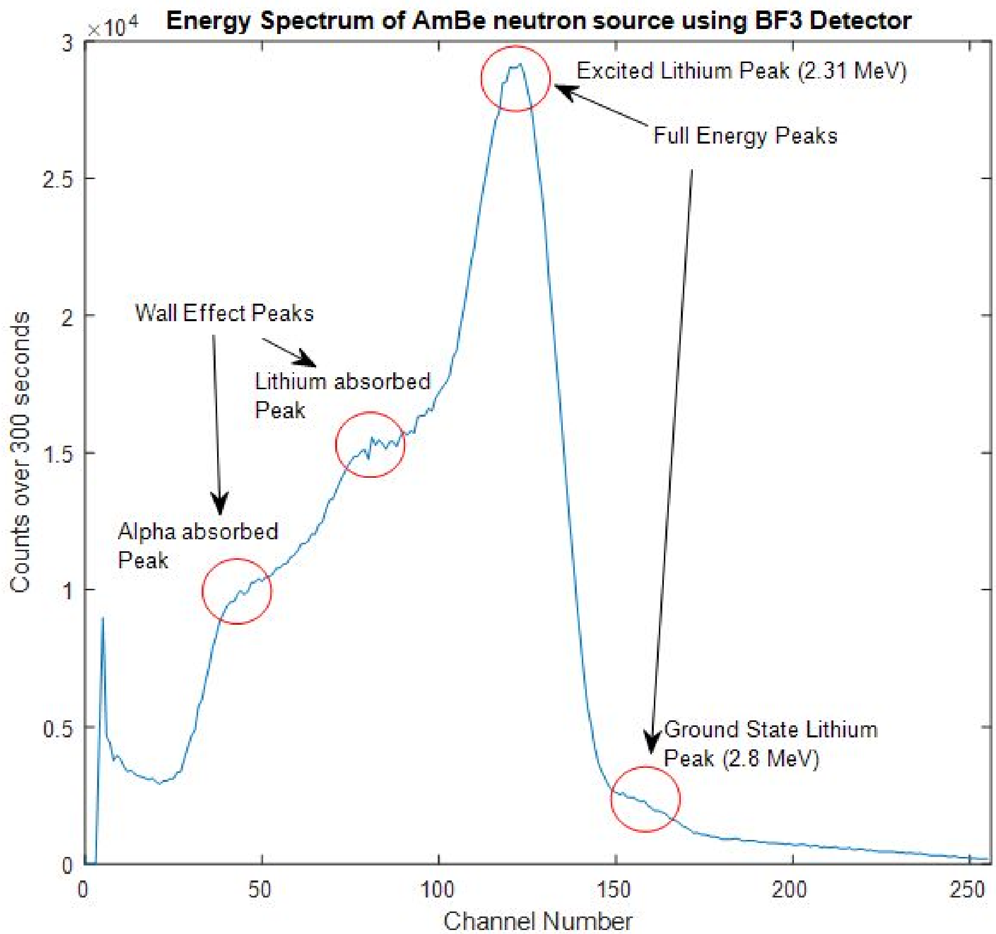

Figure 3: Energy Spectrum of the BF3 detector.

The figure shows the expected full energy peaks of the n+BF_3 at 2.31 MeV and 2.8 MeV as both the alpha particle and lithium atom energies are completely absorbed within the detector. The excited lithium peak happens 94 percent of the time, and ground state lithium peak happens 6 percent of the time. The experimental results match these percentages. Wall effect peaks can be observed depending on which particle is absorbed into the detector wall. The lithium absorption peak is at 1.47 MeV, as only the alpha particles energy is deposited and collected by the detector. This is found by subtracting the excited lithium particles kinetic energy (0.84 MeV) by the excited full energy lithium peak (2.31 MeV) to obtain the energy of this peak. Using the same method but subtracting the alpha particle kinetic energy, the alpha absorbed peak was found to be 0.84 MeV.

Finally, statistics were calculated after taking data for counts per second for a high (~600 counts/s) and low (~30 counts/s) counting rate. The table below summarizes the results.

Table 2: Statistical results of high and low count rates for the detector.

Count Rate	Mean	Experimental Standard Deviation	Expected Standard Deviation	Fraction of Observations outside 1 Standard Deviation	Standard Error in Mean
High	625.8	27.2	29.7	0.34	2.64
Low	33.1	6.16	16.3	0.32	1.53

Histograms were made to discretize each data set and plotted with gaussian and poisson distributions. These can be seen below in figures 4 and 5.

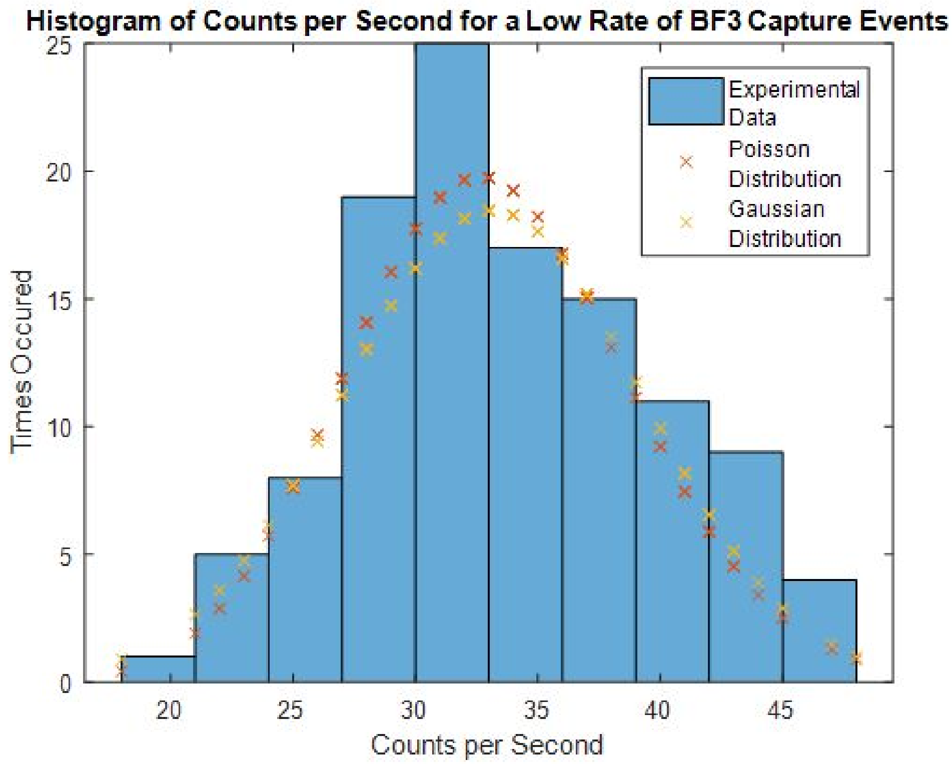

Figure 4: Distribution of counting data for low count rate.

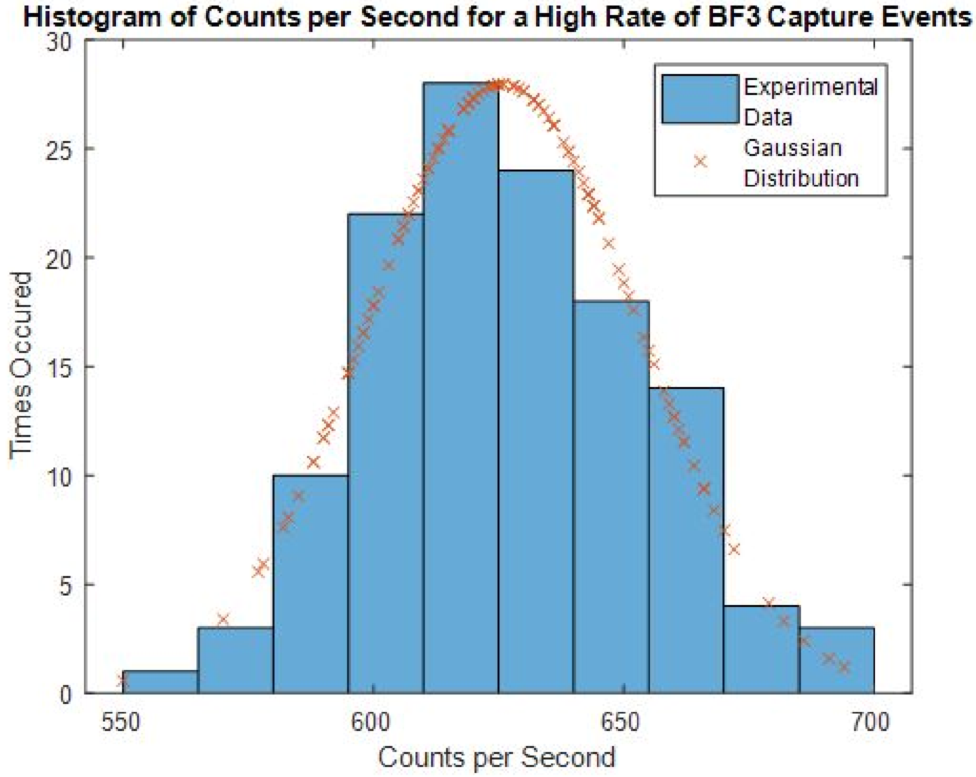

Figure 5: Distribution of counting data for high counting rate.

The gaussian and poisson distributions were centered around the actual mean of the data and normalized to fit the data. It can be seen that both data sets roughly follow both distributions; however they are not exact. Taking more data points would increase the similarity between experimental distribution and the theoretical distributions.

A simulation of a coin flip was performed using 500 flips and repeated 100 times. The next page has the results.

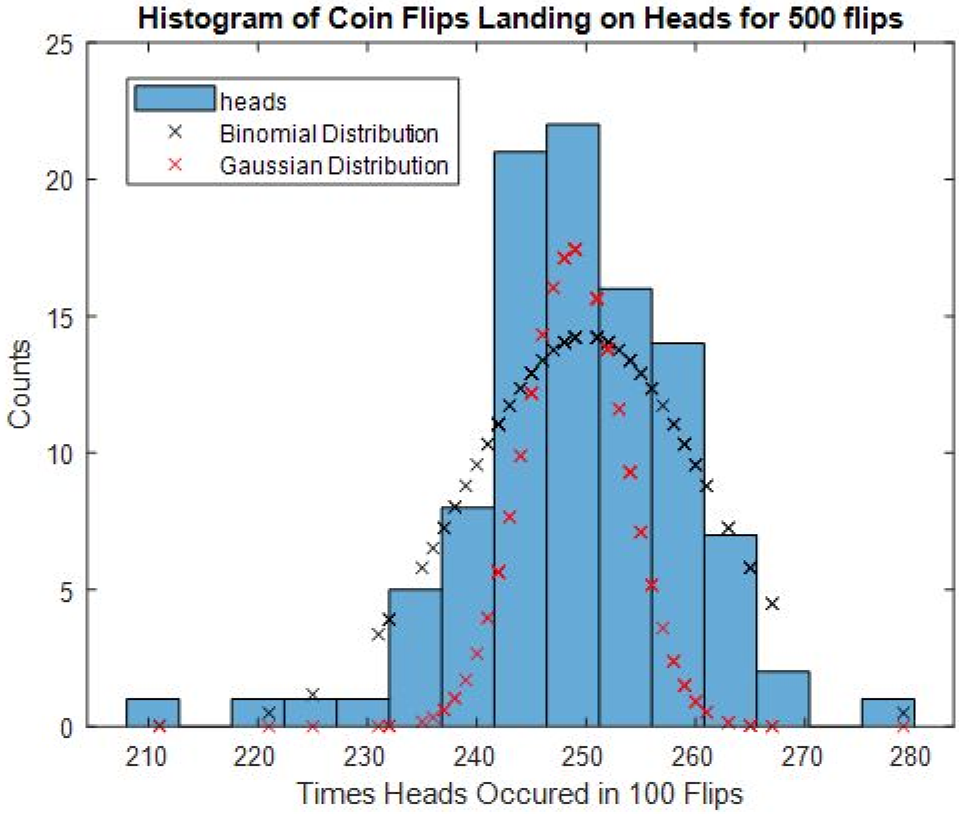

Figure 6: Simulation of coin flip experiment.

It can be seen that the coin flip follows a binomial distribution more closely than a gaussian, as the number of times the event occured is broader. The gaussian distribution predicts a narrow, large peak towards the center (250) of the graph. The program simulating this can be seen boxed in, in the MatLab code attached in Appendix B.

V. Conclusion

The detector bias voltage was found to be around 1950 V, the center of the plateau of the count rate. Obtaining an energy spectrum for the detector yielded expected results, as shown in figure 2. Full energy peaks were observed at 2.31 and 2.8 MeV, and wall effect peaks at 1.47 and 0.84 MeV. Data was taken for high and low counting rates and was analyzed statistically. Table 2 shows the statistical values for each data set. The low count rate roughly matched a poisson distribution, and high count rate a gaussian distribution. To obtain a fit closer to these distributions, more data points could be taken for each data set. The results show that proportional detectors can be used to effectively measure radiation events, but a statistical approach needs to be taken to interpret the results.

Appendix A
Raw Data

Volts	Counts per 10 Seconds
1200	0
1300	18
1400	984
1500	10233
1600	42057
1700	50996
1800	53963
1900	55012
2000	5573
2100	56131

Appendix B
MatLab Code

```
%% Lab 2 %%
% Mark Luke %

%Input voltage and counting data to determine bias voltage
volts = linspace(1200, 2100, 10); %Volts
counts = [0 18 984 10233 42057 50966 53963 55012 55773 56131]; %counts per 10
seconds

plot(volts, counts, 'x')
xlim([1100 2200])
title({'Voltage input compared to counts per 10 seconds';' of a BF3 Detector'})
xlabel('Voltage (V)')
ylabel('Counts per 10 seconds')


fit = polyfit(volts(7:10),counts(7:10),1);
fitY = polyval(polyfit(volts(7:10),counts(7:10),1),volts(7:10));

hold on
plot(volts(7:10), fitY)
hold off

%Find bias voltage (center of 1800 and 2100 volts)
bias = (volts(7)+volts(10))/2;

%% Spectrum Analysis
%Spectrum! 300s count time

plot(BF3PHA300seconds(:,1), BF3PHA300seconds(:,2))
xlim([0 256])
title('Energy Spectrum of AmBe neutron source using BF3 Detector')
xlabel('Channel Number')
ylabel('Counts over 300 seconds')
```

```
%% Heads vs Tails program
% 0 heads, 1 tails

for i = 1:100

      flip = randi([0 1], 1, 500);
      heads(i) = sum(flip==0);
end
```

```
meanHEADS = mean(heads);
actSTDHeads = (1/(500-1)*sum((heads-meanHEADS).^2))^0.5;

figure(5)
histogram(heads, 15)
title('Histogram of Coin Flips Landing on Heads for 500 flips')
xlabel('Times Heads Occured in 100 Flips')
ylabel('Counts')

hold on
biHeads = binopdf(heads,500,0.5)*400;
plot(heads, biHeads, 'xk')

gaussHeads = normpdf(heads,meanHEADS,actSTDHeads)*200;
plot(heads, gaussHeads, 'xr')
hold off

%% High and low count rates
% Counting for 1 second each, approx 100 readings
% Using 1-127 for high rate
% Using 1-114 for low rate
clf
% High Rate calcs (roughly 600 counts/s = x)
x = 600;
meanH = sum(mcshirate(1:127, 2))/127; %mean
actSTDH = (1/(127-1)*sum((mcshirate(1:127,2)-meanH).^2))^0.5; %actual standard
deviation
PxH = poisspdf(600,meanH); %poissons distribution
expSTDH = (PxH*sum((mcshirate(1:127, 2)-meanH).^2))^0.5; %expected standard
deviation
outsideSTDH = sum(mcshirate(1:127,2)>(meanH+actSTDH) |
mcshirate(1:127,2)<(meanH-actSTDH)); %number events outside 1 standard
deviation
stEH = expSTDH/(127)^0.5; %standard error in mean

figure(1)
histogram(mcshirate(1:127, 2), 10)
title('Histogram of Counts per Second for a High Rate of BF3 Capture Events')
xlabel('Counts per Second')
ylabel('Times Occured')

hold on

gaussHI = normpdf(mcshirate(1:127,2),meanH,actSTDH)*127*15;
plot(mcshirate(1:127,2), gaussHI, 'x')
hold off
```

```
% Low rate calcs (roughly 30 counts/s = x)
x = 30;
meanL = sum(mcslorate(1:114, 2))/114; %mean
actSTDL = (1/(114-1)*sum((mcslorate(1:114,2)-meanL).^2))^0.5; %actual standard
deviation
PxL = poisspdf(x,meanL); %poissons distribution
expSTDL = (PxL*sum((mcslorate(1:114, 2)-meanL).^2))^0.5; %expected standard
deviation
outsideSTDL = sum(mcslorate(1:114,2)>(meanL+actSTDL) |
mcslorate(1:114,2)<(meanL-actSTDL)); %number events outside 1 standard
deviation
stEL = expSTDL/(114)^0.5; %standard error in mean

figure(5)
histogram(mcslorate(1:114, 2), 10)
title('Histogram of Counts per Second for a Low Rate of BF3 Capture Events')
xlabel('Counts per Second')
ylabel('Times Occured')

hold on
poissonLO = poisspdf(mcslorate(1:114,2), meanL)*114*2.5;
plot(mcslorate(1:114,2), poissonLO, 'x')

gaussLO = normpdf(mcslorate(1:114,2),meanL,actSTDL)*114*2.5;
plot(mcslorate(1:114,2), gaussLO, 'x')
hold off
```