Characterization of He-3 Detectors Typically Used in International Safeguards Monitoring

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ABSTRACT

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Pulse height distribution of He-3 detectors used in international safeguards monitoring vary from that of a typical He-3 neutron counter. Data taken show that between eighteen and twenty-five percent of the neutron counting efficiency is lost when using low-level discrimination of 100mV, per manufacturers recommendation. Also, the charge-coupled amplifiers of the detectors may be responsible for changing the pulse height distributions of the detectors.

Keywords: He-3 detectors, safeguards monitoring, low-level discrimination, counting efficiency

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When it comes to making my Physics education a success, three people deserve utmost honors and recognition. In reverse sort order:

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To my Father in Heaven — all I have, am, and will be comes from Thee. There are countless times that Thy Spirit has lifted and directed me. I would quote Ronald Reagan with one minor change: “There is no limit to what a man can do or where he can go if he gives God the credit.”

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Chapter 1

Introduction to He-3 Neutron Counters

1.1 Characteristics and Uses of He-3

Helium is the second element on the periodic table, and comprises twenty-three percent of the mass of the universe. Existing as a gas at room temperature, it is non-toxic and non-reactive. Helium was initially discovered in 1868 via spectroscopic analysis of the sun, and later found to exist on Earth as well. There are several isotopes of helium, but only two that are stable, namely He-3 and He-4 [1].

The most common form of helium is He-4. On Earth, 99.999863% of all naturally occurring helium is He-4. It is an inert substance, and is the first of the noble gasses. This isotope is used for making HeNe lasers, and in arc welding. It is also used in party balloons and blimps as it is lighter than air and provides buoyancy. Additionally, alpha particles, products of certain nuclear decay chains, are nothing more than He-4 nuclei.

In contrast, only 0.000137% of the helium on our planet is He-3. This isotope is most commonly used as a neutron detector in the oil and gas industry, medical fields, the Department of Energy, and the Department of Homeland Security [2]. It has been proposed that He-3 might be a possible fuel for fusion reactors in the future.

He-3 tubes are good devices for counting neutrons as they have low reaction rates with gamma rays; a problem for many other types of detectors. There is one major drawback, however—the supply of He-3 is rapidly decreasing. The isotope is rare on Earth, and the only way to manufacture it is through the production of tritium, which then decays to He-3. Production of tritium in the U.S. was halted in 1988, resulting in only a small amount of He-3 created every year from decaying nuclear stockpiles [3, 4].

Motivated by the September 11 attack in 2001, Homeland Security has drastically increased the consumption of He-3. About eighty percent of all He-3 used in the U.S. has been used by Homeland Security in monitoring for nuclear weapon threats [5]. The diminishing reserves of He-3 have caused Congress to look into the restriction of the gas stores that remain [6, 7].

Neutrons are difficult to detect, as they are a neutral particle, and thus not affected by the presence of electric or magnetic fields. Thus, instead of attempting to see the neutron directly, the byproducts of neutron reactions or their collisions must be detected. Devices used in this manner include glass, liquid, or plastic scintillators, neutron activation detectors, and gas-filled proportional counters.

1.2 He-3 Neutron Counters

Our focus is on He-3 proportional counters. Commonly called He-3 tubes, these instruments are typically cylinders made of stainless steel, ranging in length from several inches to several feet. An anode wire runs internally along the axis of the tube, and several hundred volts are applied relative to the outside of the tube. Each tube contains He-3 gas. Some also contain

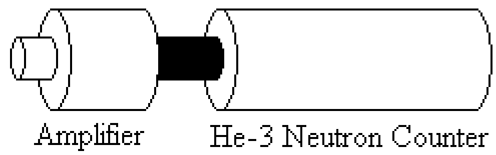

Figure 1.1 Diagram of a He-3 neutron counter. A charged-coupled amplifier is attached via a wire to the tube containing the helium and the anode.

a heavier gas to increase the pressure inside the tube.

Most He-3 tubes are used in conjunction with a charged-coupled amplifier. The purpose of the amplifier is to increase the signal pulse that comes from the detector when a neutron is captured.

He-3 tubes are usually surrounded by a neutron moderator, which slows the neutron enough for it to capture in the He-3 in the tube. When the neutron captures it undergoes the following reaction:

$$^{3}He + n \rightarrow p + t$$

The reaction energy is carried away by the proton and triton, which ionize the surrounding atoms. These electrons are attracted to the anode, which produces a pulse when the electrons reach it. By registering the pulse on external instruments, we are able to detect that a neutron was captured. Because the pulse does not tell us the energy of the incident neutron, we can only count the number of events, giving rise to the term neutron counter [8].

1.3 Motivation for Research

While learning about the operation of He-3 detectors used in international safeguards monitoring, it was discovered that the pulse height distributions were not what was expected. This research was then undertaken to characterize the loss of counting efficiency when following the manufacturers recommended operating conditions.

Chapter 2

Experiments

2.1 He-3 Tube Pulse Height Distribution

When a thermal neutron captures in the He-3 it produces a proton and a triton. As these particles collide with the gas in the tube they lose energy and ionize the gas atoms. These electrons then migrate to the anode and produce the pulse that is then measured.

A He-3 tube with just helium will show a distribution with the peak energy at 764 keV. Ideally, all of the energy of the reaction products ends up deposited in the gas of the detector. More typically, the fission products collide with the wall of the tube, losing energy. The result is plateaus in the distribution. The two different particles produce these two wall effects (see Fig. 2.1).

2.2 Testing He-3 Tubes Used in Safeguards Monitoring

Data were taken for three random He-3 tubes that have been used in safeguards monitoring. For each set of data, the tube was placed in a polyethylene well and the potential on the wire was set to 1600V. Using a Cf-252 source to provide neutrons, I used a Canberra AccuSpec

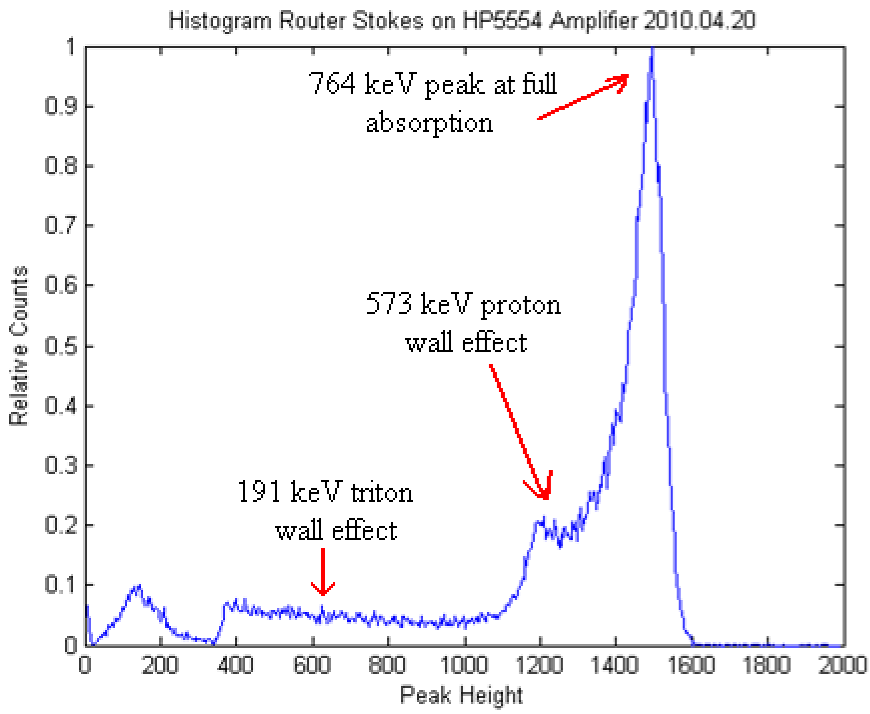

Figure 2.1 Typical He-3 tube pulse height distribution. The peak at 764 keV occurs when the fission products lose all of their energy in ionizing the surrounding gas. The stair steps occur when the products lose energy in collisions with the walls.

multi-channel analyzer (MCA) to acquire data. There was a major discrepancy between the plots of a traditional He-3 tube and the safeguards tubes, which led to the suspicion that there was distortion in the electronics being used.

A Reuter-Stokes He-3 tube pressurized to four atmospheres was used as a control. After taking test data using the AccuSpec we obtained the above plot, which shows the typical distribution with wall effects, as expected. I surmised that the AccuSpec was operating properly, but decided to pursue another course in order to be sure that the distributions of the safeguards tubes were as they appeared to be.

I ceased using the AccuSpec MCA and switched to taking data via waveform pulse digitization. This removed an amplification step from the process. A RayLink digitizer was chosen as the device to use, but the delivered program lacked desired functionality. I rewrote parts of the code to include the ability to save individual pulses. I also included functions to enable the user to choose a length of time during which the device would take data and save it out continuously.

With the RayLink program ready, I took data on the safeguards tubes over a period of ten hours each. The histogram for each tube was then generated from the data to obtain the following plots (see Figs. 2.2, 2.3, 2.4).

The RayLink data agreed with the AccuSpec. To verify that the data were accurate, the RayLink was used in conjunction with the Reuter-Stokes tube. When plotted the data came out as expected (see Fig. 2.1).

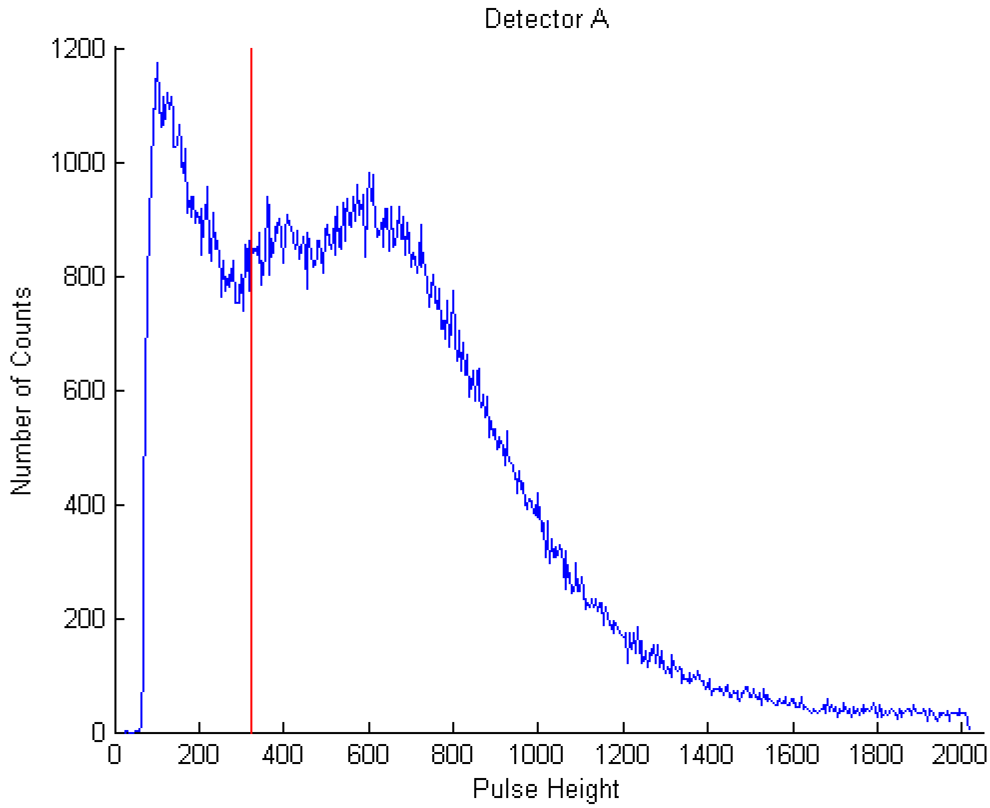

Figure 2.2 Pulse height distribution of detector A. The number of pulses before the 100mV low-level discriminator is 40,565 with 176,805 after. This results in an 18.66% loss in overall counting efficiency.

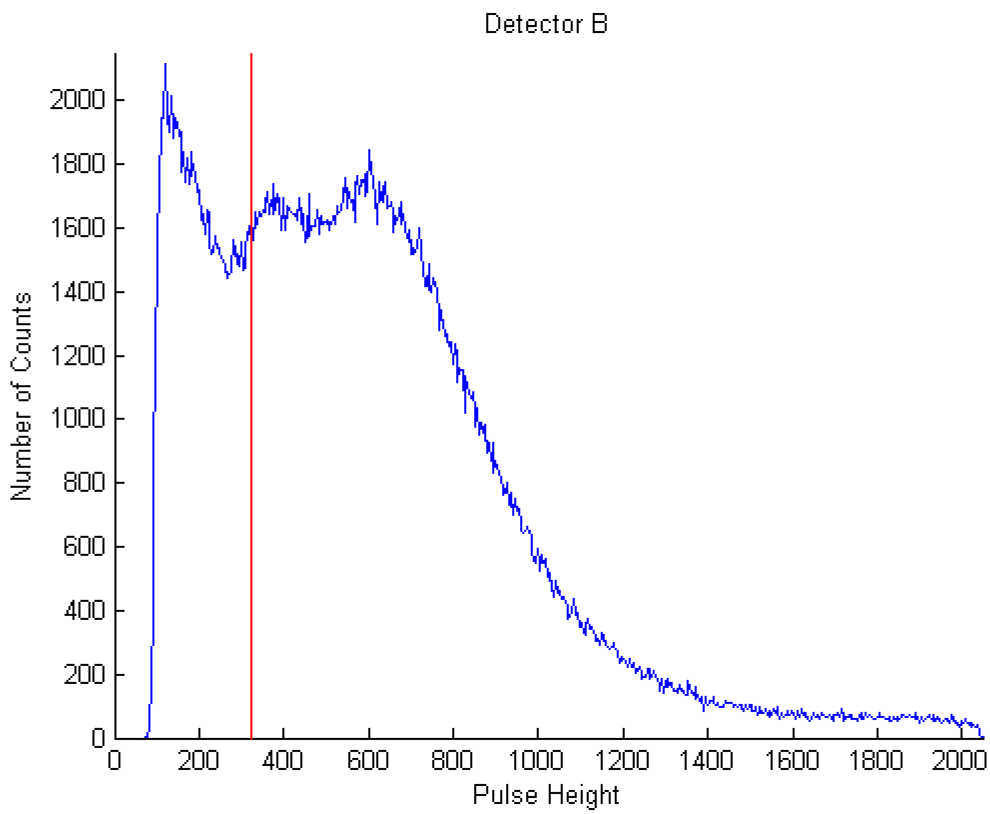

Figure 2.3 Pulse height distribution of detector B. The number of pulses before the 100mV low-level discriminator is 81,748 with 300,882 after. This results in an 21.66% loss in overall counting efficiency.

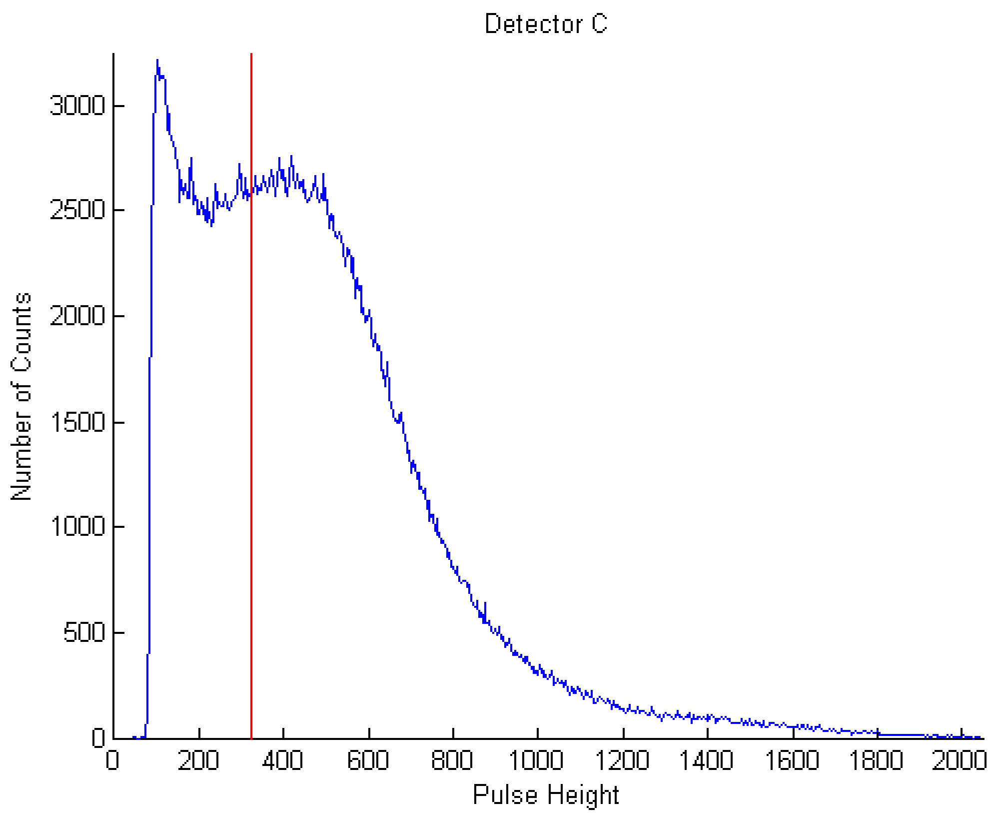

Figure 2.4 Pulse height distribution of detector C. The number of pulses before the 100mV low-level discriminator is 118,063 with 341,937 after. This results in an 25.67% loss in overall counting efficiency.

Chapter 3

Conclusions

3.1 Safeguards Amplifiers

It is easy to see from the plots that the safeguards detectors are not the same as the Reuter-Stokes tube. I formulated that the amplifiers on the detectors were distorting the distribution of the pulses, giving emphasis to the low pulses while de-emphasizing the higher ones.

3.2 Low-level Discriminator Voltages

The manufacturers of the safeguards detectors recommended that the low-level discriminator (LLD) potential should be set at 100mV. I characterized the position of a 100mV pulse for the RayLink using a pulse generator. A 100mv pulse is marked at bin 323 in MCA histograms above. When overlaying the plots with the line showing the position of 100mV, it can be seen that many of the pulses were below the 100mV LLD. The following table displays the efficiency lost in neutron counting when using 100mV as the LLD.

Table 3.1 Pulse height distribution data for the three detectors used.

	Pulses below threshold	Pulses above threshold	Efficiency lost	Efficiency remaining
Detector A	40 565	176 805	18.66%	81.34%
Detector B	81 748	300 882	21.36%	78.64%
Detector C	118 063	341 937	25.67%	74.33%

When the recommendation of the manufacturer is followed, between eighteen and twenty-five percent of the detectable neutrons will be uncounted. This results in a large loss in counting efficiency.

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Appendix A

Matlab Program plotHeights.m

Program used to plot the histograms of data taken. A line is placed at channel 323 to show the location of the 100 mV LLD. Percent counts above and below the LLD are calculated.

```
%-----------------------------------------------------------------------
% Program: plotHeights.m
% Reads timestamp and waveform data from RayLinx files
% and plots the peak pulse heights against time.
%
% This program reads *.mat format files collected in a directory.
%-----------------------------------------------------------------------

clear;
clc;
close all;

i=0;
fprintf(1,'Type the number of the file or type 0 to exit \n\n');
```

```
files = dir ('*.mat');
Nf=length(files);
index(30)=0;
ind=0;

for i=1:Nf
   if files(i).name
      fprintf(1,'%d: %s\n',i,files(i).name);
   end
end

opt2=-1;
opt2=input('\nEnter a number--> ');

if opt2>0
   filename = files(opt2).name;
   fprintf(1,'\nFor directory %s:\n',filename);
   exit=0;
else
   break;
end

data=load(filename);

[n,xout] = hist(data.data(:,2),512);
mx = max(n);
```

```
totalNum=0;
rejected=0;
kept=0;

for i=1:54
   totalNum = totalNum + n(i);
   rejected = rejected + n(i);
end

for i=55:512
   totalNum = totalNum + n(i);
   kept = kept + n(i);
end

disp('Efficiency lost: ');
rejected/totalNum
disp('Remaining efficiency: ');
kept/totalNum

hold on
plot(xout,n,'b')
axis([0 2048 0 1200])
line(323, 0:3250, 'Color', 'r');
title('Detector A')
ylabel('Number of Counts')
xlabel('Pulse Height')
hold off
```

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